Egypt. J. Food. Sci. **Vol. 53**, No.1, pp. 133-142 (2025)

Egyptian Journal of Food Science
http://ejfs.journals.ekb.eg/

Healthy Barley (*Hordeum vulgare* L.) Biscuits with Carob Powder for Diabetics

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RECENTLY, barley grains have been utilized in various food applications due to their numerous health benefits and exceptional nutritional value. Carob (*Ceratonia siliqua* L.) pods are rich in minerals, natural sugars, dietary fiber, and polyphenolic compounds. This study aimed to produce a diabetic-friendly biscuit using barley flour sweetened with carob powder, offering enhanced nutritional and functional value. The total phenol content in carob (186.97 mg GAE/100 g) and its antioxidant activity (125.5 mg TE/100 g) were significantly higher than those in barley (183.46 mg GAE/100 g; 78.17 mg TE/100 g). Barley biscuits were supplemented with 25%, 35%, and 45% carob powder. Results showed improved moisture, fiber, and ash content, with reduced fat levels compared to the control. Antioxidant capacity increased, and oxidative stability improved over a three-month storage period. Physical properties were enhanced, though color values decreased. Sensory analysis identified the 25% and 35% formulations as the most acceptable, as they balanced odor, texture, and nutrition. These findings suggest that carob powder is an effective functional ingredient for developing healthier baked products without compromising quality. This research contributes to the growing field of functional food development, aligning with consumer demand for natural, health-promoting ingredients.

Keywords: Barley grains; Carob pods; Functional food; Antioxidants; Dietary fiber; diabetics

Introduction

Incorporating alternative ingredients into traditional food recipes has become a common practice, resulting in innovative products that deliver unique sensory experiences and support balanced nutrition. Rising consumer awareness about healthy eating has fostered the development of a new market for products that offer health benefits while aligning with sustainable and circular economy practices (Nicolosi et al., 2023).

In response to these trends, the bakery industry has diversified its offerings, integrating alternative ingredients into baked goods to meet consumer preferences. For example, traditional wheat flour is partially or entirely replaced by alternatives such as seeds, legumes, vegetables, spices, and cereals. These formulations improve nutritional content and cater to consumers with specific dietary needs, including those with gluten intolerance and diabetes (Birch et al., 2019).

Barley (*Hordeum vulgare* L.) is a highly adaptable cereal crop with a rich history of cultivation dating back over 7,000 years. It is the fourth most significant cereal crop worldwide, valued for its versatility and nutritional content. Hulled barley, in particular, is prized for its high levels of dietary fiber, proteins, vitamins, and minerals. β-glucan, the primary fiber in barley, is recognized for its health benefits, including a reduced risk of coronary heart disease, diabetes, and certain cancers (Farag et al., 2022; Ozogul

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Received : 24/5/2025; Accepted : 13/8/2025
DOI: 10.21608/EJFS.2025.379933.1211

et al., 2022). These qualities position barley as a valuable ingredient for developing functional bakery products, including bread, biscuits, and muffins (Farag et al., 2022; Ozogul et al., 2022).

Another promising ingredient is carob (*Ceratonia siliqua* L.), a tree species native to the Mediterranean region cultivated in temperate areas such as Central America, Australia, and Africa. Carob powder, derived from the dried pods of the tree, has garnered attention for its nutritional and functional applications. It is rich in dietary fiber, simple sugars, vitamins, minerals, and polyphenolic compounds, which possess anti-inflammatory, antibacterial, anti-diabetic, and antioxidant properties (Tounsi et al., 2019). Its natural sweetness and low glycemic index make it an ideal sugar substitute in bakery products, catering to the growing demand for low-sugar and diet-friendly options (Mesias et al., 2024).

The biscuit industry has been at the forefront of incorporating alternative ingredients, replacing traditional recipes with innovative formulations to create healthier products. This shift has facilitated the advancement of biscuits with reduced sugar, gluten-free formulations, and enhanced fiber and mineral content, appealing to health-conscious consumers (Mesias et al., 2024). Using carob powder as a natural sweetener addresses the need for sugar reduction while enhancing the nutritional profile of baked goods (Hafez et al., 2023). The insufficiency of fiber consumption in the typical consumer's diet has established the development and manufacturing of dietary fiber-enriched cookies as a significant focus for manufacturers and researchers (Popova et al., 2020).

Therefore, this study aimed to produce barley-based biscuits sweetened with carob powder, rich in dietary fiber and designed to offer enhanced nutritional and physiological benefits, particularly for individuals with diabetes. This research evaluated the biscuits' physical, chemical, and sensory characteristics, as well as their peroxide value and overall quality. The findings aim to contribute to the development of functional foods, focusing on enhanced safety, extended shelf life, and improved consumer satisfaction in bakery products.

Materials and Methods

Materials

Carob pods (*Ceratonia siliqua* L.) were sourced from a local market, with seeds removed and ground into particles approximately 0.45 mm in size. The ground carob pods were stored in polyethylene bags in a refrigerator until they were used. Barley flour, powdered sugar, shortening, eggs, vanillin, and baking powder were purchased from local markets in Tanta, El Gharbia, Egypt.

Methods

Dough preparation

Powdered sugar and shortening were mixed using a Braun mixer equipped with a high-speed flat beater for 2 minutes. Eggs and vanillin were added, and the mixture was beaten for 5 minutes to create a uniform cream. Baking powder was gradually mixed with the flour for 2 minutes at low speed to form the dough. The dough was then sheeted to a thickness of approximately 3 mm and cut into round shapes using a 45 mm diameter cutter. The biscuits were baked at 170°C for 12 minutes. After baking, they were cooled at room temperature for 75 minutes, packed in polyethylene bags, and stored at room temperature (~25°C) for up to 3 months (Manohar et al., 1997).

Biscuits made from barley substituted with carob

The biscuit dough was prepared according to the formula outlined in Table 1, as described by ("Books in Brief," 1997). Biscuits made from barley flour were substituted with carob powder at replacement levels of 25%, 35%, and 45% of the barley flour initially used in the formula and were compared with the control biscuit made from 100% barley flour.

Chemical composition and minerals content for carob powder and barley flour

The AOAC (1997) methods were employed to analyze the moisture, crude protein, lipid, ash, and crude fiber content. Carbohydrate was calculated by difference. The mineral content was determined using an atomic absorption spectrophotometer (Model 3300, USA) according to the AOAC method (1997). The method of van Handel (1968) was implemented to quantify the total soluble sugar content.

Determination of total phenolic compounds

Maurya and Singh's method was employed to determine the total phenolic compound content, expressed as gallic acid equivalents (mg GAE/100 g) on a dry weight basis, using the Folin-Ciocalteu reagent (Maurya & Singh, 2010).

Antioxidant activity

The antioxidant properties of the compounds were determined by evaluating their free radical scavenging activity, as Miliauskas et al. (2004) outlined. The results were expressed as milligrams of Trolox equivalents (TE) per 100 grams of dried weight.

TABLE 1. The formula of Barley biscuit substituted with carob powder (g)

Ingredients / Treatments	Barley flour	Carob powder	Sugar powder	Shortening	Baking powder	Eggs	Vanillin
Control	100	-	30	30	3	15	1
BFCP 25%	75	25	17.24	30	3	15	1
BFCP 35%	65	35	12.14	30	3	15	1
BFCP 45%	55	45	7.04	30	3	15	1

Control: (100% barley flour), BFCP 25%: barley flour substituted with 25% carob powder, BFCP 35%: barley flour substituted with 35% carob powder, and BFCP 45%: barley flour substituted with 45% carob powder. The total soluble sugar in carob powder is 51.01%.

Chemical composition of biscuits

The chemical constituents of biscuit formulations made from carob powder and barley flour at varying levels were determined according to AOAC ("Books in Brief," 1997).

Physical evaluation of biscuit formulas

Baking quality tests were conducted according to the methods described in the AACC (2000) guidelines. Biscuit measurements included weight, diameter, thickness, and spread ratio. The spread ratio was calculated as the average diameter divided by the average thickness of the material.

Color analysis of biscuit formulas

Utilizing a Hunter Lab Scan XE Spectro colorimeter with the CIE Lab color scale (Hunter, Reston, VA, USA), the objective evaluation of the noodle sample color was conducted in reflection mode (Popova et al., 2020). The Hunter L*, a*, and b* parameters were measured.

Sensory evaluation of biscuit formulas

For fresh, chilled products, sensory analysis was performed, scoring based on representative quality attributes that Popova et al. (2020) identified as most suitable for evaluating barley-carob biscuit formulations. A five-point scoring system (1-5) was implemented, with each quality level precisely defined for the initial assessment of crust appearance, color, odor, flavor, texture, and overall acceptability. Evaluations were conducted by a panel of ten experienced judges from the Food Technology Research Institute, Agricultural Research Center, Giza, Egypt. Assessors were provided with a clear definition of the distinctions between scores to facilitate their differentiation.

Peroxide value of biscuit formulas during the storage period

According to Egan et al. (1981), the peroxide value was determined for different biscuit formulations over three months and calculated as milliequivalents of active oxygen peroxide per kilogram of fat. Extraction was carried out using chloroform. Afterward, distilled water was added to the mixture of the extracted fat, glacial acetic acid, and saturated potassium iodide, which was then allowed to remain in the presence of intermittent stirring for one minute. The mixture was titrated with 0.1 N sodium thiosulfate solutions in 1 mL starch solution. The peroxide value was calculated as follows:

e value (mille equivalent O_2/kg oil) $= \frac{V x N x 1000}{W}$

where: V = volume of Na_2SO_3; N = normality of Na_2SO_3; and W = weight of fat by grams.

Statistical analysis

Following Steel et al. (1960), the data were analyzed. Analysis was conducted with the SPSS program (SPSS Inc., Chicago, IL, USA). One-way analysis of variance (ANOVA) was used to analyze the data, and Duncan's multiple range test was employed to identify the means. The significance of differences was determined at a p-value of less than 0.05 (Abdel-Aal et al., 2014).

Results and Discussion

Chemical and mineral composition of barley flour and carob powder

The chemical composition and mineral content of barley flour and carob powder are summarized in Table 2. Barley flour exhibited higher moisture, protein, and fat contents (13.34%, 11.36%, and

3.22%, respectively) than carob powder (7.14%, 7.48%, and 1.12%, respectively). The moisture levels in barley landraces generally exceeded the values reported in the literature, ranging from 11.9% to 16.2% (Abdel-Aal et al., 2014). The preservation of grain vitreous stability and the prevention of microbial growth necessitate low moisture levels in barley grains. Whole cereal grains are considered good sources of minerals and trace elements compared to refined flour. The ash content varied within a narrow range (2.4%-3.9% dry weight), aligning with findings from previous studies (Holopainen et al., 2014). The mean crude fiber concentration in 42 barley landraces varied significantly (4.2%-8.1% dry weight) and was higher than the values reported by Åman et al. (985). The protein content in barley ranged from 10.8% to 14.0% on a dry weight basis, similar to values reported by Lahouar et al. (2017).

Conversely, Yousif and Alghzawi (2000) found that carob powder contained high carbohydrate levels (75.92%), moderate protein content (6.34%), and low-fat content (1.99%). Additionally, Yousif & Alghzawi (2000) reported that carob powder exhibited higher ash and crude fiber contents (4.95% and 14.62%, respectively) compared to barley flour (3.12% and 8.03%, respectively). Crude fiber is widely recognized for its health benefits, including improved digestion, enhanced satiety, and reduced risks of chronic conditions such as type 2 diabetes and cardiovascular diseases. Incorporating carob into the biscuit formulation enhances its nutritional profile, addressing public health concerns regarding insufficient fiber intake in modern diets. Moreover, carob powder contained a total soluble sugar content of 51.01%, consistent with findings by Ibrahim et al. (2015), who reported that carob powder is low in fat but rich in crude fiber, ash, total soluble sugars, and carbohydrates. Similarly, Raj et al**. (**2023**)** noted that barley is a rich source of proteins, carbohydrates (including beta-glucan), lipids, vitamins, and minerals. Beta-glucan in barley, a soluble fiber, is particularly significant due to its cholesterol-lowering properties.

Carob powder exhibited a superior mineral profile, particularly in calcium (2291.4 mg/kg) and magnesium (1633.15 mg/kg), compared to barley flour (4.24 mg/kg and 1.208 mg/kg, respectively). These minerals are essential for bone health, enzymatic functions, and cardiovascular regulation, aligning with dietary recommendations for mineral-rich foods. The data further revealed that carob powder is a rich Fe, Ca, Na, and Mg source, while Mn and Zn were present in lower concentrations (14.29 mg/kg and 8.65 mg/kg, respectively). These findings align with reports identifying barley grain as an excellent source of microelements, including Ca (0.02%) and Mg (0.08%), and trace elements such as Fe (49.9 mg/kg), Mn (13.9 mg/kg), and Zn (24.4 mg/kg), with variations depending on barley variety and environmental factors (Almendros et al.,2019). Similarly, Özcan et al**. (**2007) identified carob powder as a rich Fe, Ca, Na, K, and P source, alongside trace elements such as Cu and Mn.

Total phenol content and antioxidant activity

Table 3 presents data on antioxidant activity and total phenol content for barley flour and carob powder. The total phenol content of carob powder (186.97 mg GAE/100 g) is slightly higher than that of barley flour (183.46 mg GAE/100 g). However, the antioxidant capacity, as determined by DPPH activity, revealed a significant difference; carob powder exhibited a much higher value (125.5 mg TE/100 g) than barley flour (78.17 mg TE/100 g). This substantial disparity highlights the potential of carob powder to enhance the health benefits of biscuits, particularly in combating oxidative stress and neutralizing free radicals.

TABLE 2. Chemical composition (g/100g) and mineral content (mg/kg) of barley flour and carob powder on a dry weight basis

Ingredients / Analysis	Barley flour	Carob powder
Moisture	13.34	7.14
Ash	3.12	4.95
Protein	11.36	7.48
Crud fiber	8.03	14.62
Crud fat	3.22	1.12
Total carbohydrate	74.27	71.83
Total soluble sugar	-	51.01
Na	335.33	514.54
Mg	1.208	1633.15
Ca	4.24	2291.4
Fe	45.7	156.66
Mn	17.1	14.29
Zn	51.7	8.65

The antioxidant activity of barley grains is primarily attributed to a diverse array of phenolic compounds, including phenolic acids (Abdel-Aal et al., 2014). In barley, most of these phenolic compounds are bound to other components; consequently, liberated phenolics contribute only a minor proportion of the total phenolic compounds (Abdel-Aal et al., 2014). Barley samples exhibit antioxidant activity and total phenolic compound concentrations ranging from 59.0 to 96.0 mg TE/100 g dry weight (dw) and 117 to 284 mg GAE/100 g dw, respectively. They are approximately twice as high as those observed in wheat land-races from the Canary Islands (Rodrigues et al., 2021).

From a product development standpoint, including carob powder in formulations enhances nutritional quality and extends the shelf life of baked goods by slowing lipid oxidation. This is particularly advantageous for clean-label products that aim to avoid synthetic preservatives. Furthermore, these results align with the findings of Darwish et al. (2021), who emphasized the significant antioxidant potential of carob due to its abundant phenolic compounds. Antioxidants are crucial in neutralizing free radicals, mitigating oxidative stress, and potentially reducing the risk of chronic illnesses, including cardiovascular diseases and certain types of cancer.

Chemical composition of barley biscuits with carob powder

Table 4 presents the chemical composition of barley biscuits substituted with carob powder at 25, 35, and 45% levels. The data indicated that increasing the carob powder content in the biscuits leads to a significant reduction in moisture and a slight decrease in protein content. Moreover, the carbohydrate content gradually decreased, possibly due to the increased ash and crude fiber content, which showed an upward trend with higher carob powder incorporation.

Notably, the biscuits with 45% carob powder (BFCP 45%) have the highest crude fiber content (12.48%) compared to the control sample (6.20%). This increase is accompanied by a reduction in total carbohydrates attributed to the natural sugars present in carob powder. The enhanced fiber content offers substantial functional benefits, such as improved digestion and better glycemic control, particularly appealing to health-conscious consumers seeking high-fiber snack options (Mesias et al., 2024).

While there is a minor reduction in protein content, this is balanced by the improved fiber and mineral content, resulting in a more comprehensive nutritional profile. These changes align with the objectives of functional food development, emphasizing nutritional enhancements without compromising overall product quality.

Physical characteristics of barley biscuits supplemented with carob powder

The physical characteristics of barley biscuits and those fortified with carob powder, including diameter, thickness, spread ratio, and spread factor, are detailed in Table 5. The results showed a progressive increase in the barley biscuits supplemented with carob powder spread ratio. Notably, the thickness of fortified biscuits decreased significantly compared to the control. Biscuits with 45% carob powder (BFCP 45%) exhibited the highest spread ratio (8.02) and spread factor (109.11%), reflecting enhanced dough extensibility.

The increase in spread ratio and spread factor across all fortified biscuit types is linked to a decrease in thickness, which could be attributed to the soluble fiber content in carob. This fiber enhances water retention and affects the viscosity of the dough. These results align with the findings of Mesias et al**.** **(**2024**)**, who observed that fiber-rich ingredients alter the dough's structural and rheological properties, resulting in desirable transformations in baked products. Improved spread ability and diameter may enhance consumer perception, as larger, evenly spread biscuits are often associated with superior quality and texture.

The variety of carob used significantly influenced the physical properties of the biscuits, with all varieties yielding high values. Partial substitution of barley flour with carob powder led to the production of high-quality biscuits.

Color characteristics of barley biscuits with carob powder

The color attributes of barley biscuits, with and without carob powder, are summarized in Table 6. Across all measurements, the positive *a* values attest that the red tone is predominant over the green in all fiber-enriched dietary biscuit formulations. However, a significantly more pronounced red tone was observed in biscuits made with barley flour substituted with 45% carob powder as a fiber source.

TABLE 3. Total phenol content and antioxidant activity of barley flour and carob powder.

Ingredients / Analysis	Barley flour	Carob powder
Total phenol (mg/GAE/100g)	183.46	186.97
DPPH (mg TE /100g)	78.17	125.5

TABLE 4. Chemical composition (g/100 g dry weight) of carob barley biscuits.

Treatments / Chemical analysis	Control	BFCP 25%	BFCP 35%	BFCP 45%
Moisture	7.53[a]	7.39[a]	7.33[a]	5.81[b]
Ash	1.91[c]	3.12[b]	3.24[ab]	3.55[a]
Protein	10.94[a]	9.93[b]	9.18[b]	8.68[c]
Crud fiber	6.20[d]	8.12[c]	10.72[b]	12.48[a]
Crud fat	29.33[a]	29.19[b]	28.50[bc]	28.17[c]
Total carbohydrate	52.62	49.64	48.36	47.12

According to Duncan's multiple range test, means followed by different letters in the same row are significantly different ($p < 0.05$).

TABLE 5. Physical characteristics of barley biscuits and carob barley biscuits.

Parameters / Treatments	Diameter (mm)	Thickness (mm)	Weight (g)	Spread ratio D/T	Spread factor %
Control	39.24[b]	5.90[a]	6.51[a]	6.63[a]	100.00[b]
BFCP 25%	39.35[b]	5.60[ab]	6.58[a]	7.07[a]	103.34[bc]
BFCP 35%	39.58[ab]	5.60[ab]	6.77[a]	7.23[a]	106.7[ab]
BFCP 45%	39.78[a]	5.50[b]	6.94[a]	8.02[a]	109.11[a]

Means followed by different letters in the same column are significantly different according to Duncan's multiple range test ($p < 0.05$).

The *b* values, all significantly greater than zero, suggest that the yellow tone is more prominent than the blue tone in all fiber-enriched dietary biscuit formulations, with the yellow tone appearing more prominent than the red tone.

The intensity of the yellow tone varied depending on the measurement surface. The most pronounced yellow tone was detected in biscuits containing 45% carob powder as a fiber source.

The lowest *L* values were recorded in biscuits containing 45% carob powder as the dietary fiber source. Consequently, biscuit formulations with increasing carob powder levels exhibited significantly lower hue values, indicating a more pronounced dark tone due to the deep brown color of the carob.

Thus, increasing carob powder levels resulted in a darker biscuit coloration, as evidenced by a reduction in lightness (L) and an increase in redness (*a*). This shift in hue is often associated with whole grains and natural ingredients, potentially enhancing consumer appeal. However, effective marketing strategies are essential to educate consumers about the health benefits of carob and present the darker color in a positive light.

Carob-enriched biscuits display darker tones due to the natural pigments in carob, which are marked by decreased lightness and increased redness. While these visual changes may suggest a more natural and wholesome product, consumer education is crucial for broader acceptance. Minimal color variation was observed when substituting up to 45% of barley flour with carob powder, maintaining acceptable color levels. Similar trends were reported by Hafez et al. (2023) for cakes and bread supplemented with carob powder, where higher inclusion levels significantly influenced color characteristics.

Sensory characteristics of barley biscuits with carob powder

The results of the sensory evaluation of dietary biscuits, presented in Table 7 and Figure 1, highlight differences among the various biscuit compositions. The average sensory scores for all assessed properties varied within a relatively narrow range across the tested biscuit formulations made from barley and carob as dietary fiber sources. Fresh products were rated, on average, with an overall acceptability score of 4.3 points for biscuits made with barley flour and 25% carob powder, followed by 3.92 points for biscuits with 35% carob powder and 3.32 points for biscuits with 45% carob powder. The control biscuit, made solely from barley flour, received the highest score of 4.7 points.

However, the rankings of assessed sensory properties varied depending on the fiber source used in the production process. Biscuits made with barley flour and carob flour were rated highest in texture, aroma, and taste. In contrast, biscuits containing 45% carob powder received lower evaluations for mouthfeel, particularly in chewiness and crispness.

These findings align with those of Ibrahim et al. (2015), who reported that rice biscuits with 35% carob powder achieved high acceptance. Conversely, biscuits with 45% carob powder had lower texture and taste scores due to their denser structure and more intense flavor, resulting from the higher fiber content. (Soltan et al., 2023**)** emphasized the importance of optimizing sensory characteristics to ensure the success of functional foods. While higher carob levels enhance nutritional benefits, additional formulation adjustments are necessary to maintain sensory quality.

Potential fiber sources for cookies, such as oat and carob (Kumazawa et al., 2002), provide dietary benefits, particularly for gastrointestinal health **(**Bilgiçli et al., 2007). According to Bilgiçli et al. (2007), replacing wheat flour with 0-30% fiber from apple, lemon, or wheat does not significantly alter the nutritional profile of cookies, whereas adding wheat bran significantly reduces their nutritional properties.

Peroxide values during the storage period of barley-carob biscuit formulas

Cookies are characterized by a relatively long shelf life, making them widely available at almost any time (Seifried et al., 2007).

The peroxide values of barley biscuits supplemented with carob powder are presented in Table 8. The results indicated that peroxide values were measured from zero time to three months of storage at room temperature (25±2°C). Initially, biscuits with 45% carob powder exhibited a lower peroxide value (0.96 mequiv./kg fat) than the control (1.00 mequiv./kg fat). Over three months, all samples exhibited increased peroxide values; however, carob-supplemented biscuits remained more stable, with a BFCP of 45% reaching only 5.10 mequiv./kg fat, compared to 8.14 mequiv./kg fat for the control.

Table 6. Color values of carob barley biscuit formulations

Treatments \ Parameters	*L**	*a**	*b**
Control	70.09^{a}	1.80^{d}	31.65^{a}
BFCP 25%	52.53^{b}	6.16^{c}	21.40^{b}
BFCP 35%	42.52^{c}	7.51^{b}	13.59^{c}
BFCP 45%	33.24^{d}	8.95^{a}	13.21^{d}

Means followed by different letters in the same column are significantly different according to Duncan's multiple range test ($p < 0.05$).

TABLE 7. Sensory characteristics of carob barley biscuits.

Formulas	Crust appearance	Color	Odor	Texture	Taste	Overall acceptability
Control	4.6[a]	4.7[a]	4.9[a]	4.5[a]	4.8[a]	4.7[a]
BFCP 25%	4.2[b]	4.0[b]	4.5[b]	4.3[b]	4.5[b]	4.3[b]
BFCP 35%	3.8[c]	3.7[c]	4.0[c]	4.0[c]	4.1[c]	3.92[c]
BFCP 45%	3.2[d]	3.0[d]	3.7[d]	3.0[d]	3.7[d]	3.32[d]

Means followed by different letters in the same column are significantly different according to Duncan's multiple range test ($p < 0.05$).

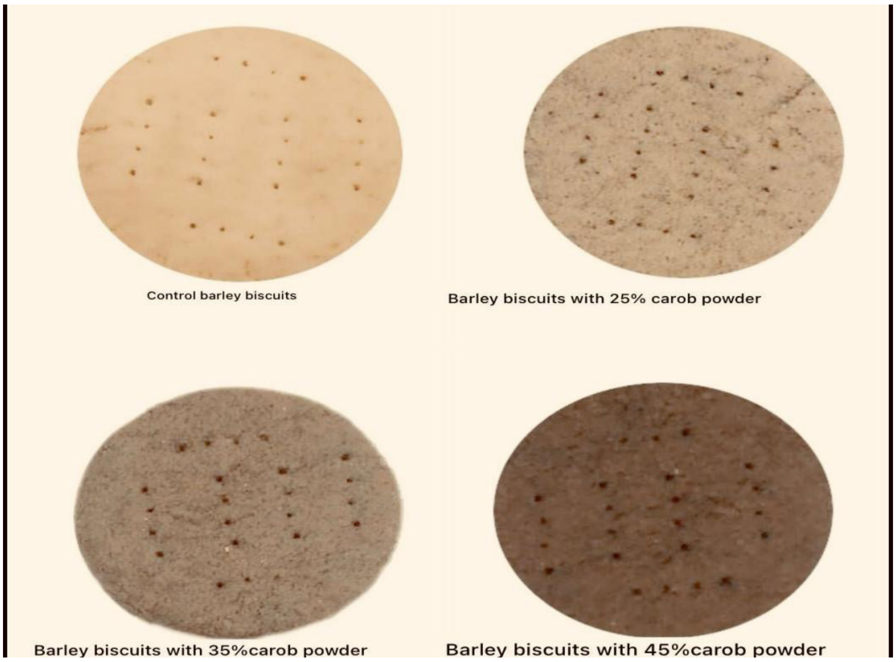

Fig. 1. Barley biscuits supplemented with carob powder at different levels.

This enhanced stability may be attributed to the antioxidant properties of carob powder (*Ceratonia siliqua*), which, when added in different amounts, contributed to a reduction in peroxide values across various formulations. These findings align with those of Seifried et al. (2007), who reported that the antioxidant capacity of carob extract is primarily due to its high levels of phenolic compounds. These compounds are well-known for their ability to scavenge free radicals, such as superoxide radicals ($O_2^{\bullet -}$), hydroxyl radicals ($OH^{\bullet}$), and other reactive oxygen species (ROS). Additionally, most natural extracts commonly show a positive correlation between phenolic content and antioxidant capacity (Chon et al., 2009).

Furthermore, this enhanced oxidative stability is attributed to the natural antioxidants in carob, which inhibit lipid oxidation and extend shelf life. Findings by Červenka et al**.** **(**2019) further support the role of plant-based antioxidants, such as those found in carob, in preserving baked goods. These results highlighted the potential of carob powder as a natural preservative, enhancing both biscuits' nutritional value and storage stability.

TABLE 8. Peroxide value of barley-carob biscuit formulas during storage at room temperature (25±2°C) for up to three months.

Formulas	Zero time	Storage period/month		
		1	2	3
Control	1.0[a]	3.00[a]	5.12[a]	8.14[a]
BFCP 25%	0.95[a]	2.54[ab]	4.45[b]	7.20[b]
BFCP 35%	0.97[a]	2.00[b]	4.11[b]	6.14[c]
BFCP 45%	0.96[a]	1.52[c]	3.12[c]	5.10[d]

*The peroxide value was calculated as mequiv. of O_2/kg oil. Means followed by different letters in the same column are significantly different according to Duncan's multiple range test ($p < 0.05$).

Conclusion

Barley grains and their derivatives are rich in natural antioxidants, providing significant health benefits when incorporated into diets from an early age. The physicochemical and functional properties of barley flour make it a valuable ingredient for functional and nutritive applications in bakery products, such as biscuits, to enhance their health appeal. Additionally, carob powder, rich in polyphenols and soluble fiber, offers remarkable benefits, including antioxidant activity that combats oxidative damage and supports cardiovascular health by reducing serum cholesterol levels. Polyphenols in carob contribute to the prevention of diseases linked to oxidative stress. Incorporating carob powder into barley-based biscuits enriches their nutritional profile, catering to health-conscious consumers and individuals with dietary restrictions. Moderate inclusion levels (25%) maintain sensory appeal while offering health benefits, whereas higher levels (45%) enhance nutritional value but may require sensory adjustments. Carob powder is a cost-effective, functional ingredient that supplies natural polyphenols and dietary fiber, thereby supporting the development of innovative, health-promoting bakery products, such as biscuits, which aligns with the growing demand for functional and healthy food formulations.

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