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PHYSICAL, THERMO MECHANICAL AND TEXTURE CHARACTERISTICS OF BISCUIT PREPARED FROM COMPOSITE FLOUR FROM WHEAT, WHITE BEAN AND CARROT

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ABSTRACT: The present study investigates the effects of fortifying wheat flour with a functional mixture of white bean protein and dried carrot powder (3:1) on the thermomechanical, chemical, physical, and sensory properties of biscuits. Functional mixtures were incorporated at 0%, 5%, 10%, 15%, and 20%. Results indicated that increasing levels of the mixture enhanced water absorption and protein content, while reducing dough stability, development time, and gluten network formation. Physically, the biscuits exhibited darker coloration, increased diameter, and higher hardness, attributed to carotenoid pigments and fiber's water-binding capacity. Sensory attributes, including appearance, taste, aroma, and overall acceptability, significantly declined with higher substitution levels due to the introduction of legume and vegetal flavors. The findings highlight the potential of enriching biscuits with plant-based proteins and fibers to improve nutritional value but also underscore the challenge of maintaining desirable sensory and physical properties. Results showed that enrichment biscuits by the functional This study provides valuable insights for optimizing functional mixtures by 5% and 10% gained the highest sensorial scores, suggesting its ability to produce healthy functional biscuits.

Key words: Biscuit, white bean, carrot, thermomechanical, texture, sensory analysis

INTRODUCTION

The evolving of modern lifestyles has brought about a rise in health issues linked to malnutrition, emphasizing the need for the development of fortified food products with enhanced nutritional profiles. Functional foods, which provide health benefits beyond basic nutrition, have gained significant attention due to their potential to address these concerns. These foods often contain bioactive compounds such as antioxidants, dietary fibers, and probiotics, which are associated with the prevention of chronic diseases, including cardiovascular disorders, cancer, and metabolic syndrome **(Das *et al.*, 2022)**. Moreover, functional foods have been shown to promote overall health and well-being, further supporting their growing demand in today's health-conscious society.

Bakery products are considered one of the most important products that are fortified with functional ingredients due to their wide consumption by consumers of all ages in all countries of the world (R**awat and Indrani, 2015**). Among bakery products, biscuits are a widely consumed snack but are often nutritionally imbalanced, being high in carbohydrates and fats while low in essential nutrients like protein and dietary fiber. This has contributed to the need for healthier alternatives. The incorporation of functional ingredients, such as protein and dietary fiber, into wheat flour presents a promising strategy for enhancing both the nutritional and structural properties of biscuits. Given the rising consumer demand for healthier snacks, the fortification of wheat flour with these ingredients not only addresses nutritional deficiencies but also aligns with the trend toward functional, health-promoting foods (**Noorfarahzilah *et al.*, 2014**).

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Wheat flour is the most commonly used base for biscuit production due to its ability to form a strong gluten network, which is crucial for achieving the desired structure and texture of biscuits. However, its relatively low protein and dietary fiber content limits the nutritional value of conventional biscuits. Protein fortification, particularly through plant-based proteins such as soy, pea, and legume proteins, has emerged as an effective way to enhance the protein content of biscuits. Increasing protein intake is associated with multiple health benefits, including muscle maintenance, improved satiety, and weight management (**Binou *et al.*, 2022**). Protein-enriched biscuits not only serve to address protein deficiencies but also meet the demand for high-protein snacks, particularly among health-conscious consumers.

Dietary fiber fortification, on the other hand, offers numerous health benefits. Naturally low in refined wheat flour, dietary fiber is a crucial component for improving the health profile of bakery products. It is known for its role in promoting digestive health, regulating blood glucose levels, and lowering the risk of chronic diseases such as diabetes and cardiovascular conditions (T**osh and Yada, 2010**). When incorporated into wheat flour, dietary fiber influences the physical properties of the dough, such as water absorption and dough viscosity, ultimately affecting the textural properties of the final product. Insoluble fibers, such as wheat bran or cellulose, contribute to improved bowel function, while soluble fibers like inulin help retain moisture and enhance the mouthfeel of biscuits (**DI CAIRANO, 2021**).

However, the fortification of wheat flour with protein and dietary fiber presents technical challenges. Protein enrichment can disrupt the gluten network, leading to changes in dough rheology, elasticity, and extensibility, which can negatively affect the texture, volume, and overall sensory quality of biscuits (**Ureta *et al.*, 2014**). Similarly, dietary fiber's high water-binding capacity can increase dough hardness and reduce the spread ability and crispness of the final product. Therefore, careful optimization of the protein and fiber levels is essential to ensure that the sensory attributes of the biscuits, such as taste, texture, and appearance, are preserved while enhancing their nutritional value.

Recent research suggests that the synergistic use of protein and fiber can yield improved functional and technological properties in bakery products. Protein-fiber interactions can enhance dough stability, reduce staling, and extend the shelf life of biscuits (**Hedayati *et al.*, 2022**). Furthermore, advancements in food processing technologies, such as extrusion, enzymatic modification, and thermal treatments, have shown potential in mitigating the negative effects of protein and fiber fortification on dough properties, enabling the production of high-quality, nutrient-rich biscuits.

Common beans (*Phaseolus vulgaris*) considered an economical and valuable source of proteins, accounting for 23%- 26% of dry matter. Thus beans have been consumed mostly in countries where protein energy malnutrition is predominant (**Siddiq *et al.*, 2022**). High carbohydrate, dietary fibre, mineral, and vitamin contents are also found in the common beans (**Almeida *et al.*, 2008**). In addition, beans are rich in phytochemical compounds, including phenolic compounds, phytosterols, and oligosaccharides (**Bai *et al.*, 2024**). These phytochemicals have been confirmed to be associated with numerous physiological and health advantages, including the prevention of cancer, diabetes mellitus, obesity, and cardiovascular disease (**Hall *et al.*, 2019**) However, besides these phytochemicals, beans also present antinutrients, such as enzyme inhibitors, phytic acids/ phytates, saponins, and lectins that negatively influence nutrient digestion and absorption (**Baral, 2022**).

Carrot (*Daucus carota*) being a good source of phytochemicals (e.g., carotenoids, phenolics, ascorbic acid, and polyacetylenes (**Ahmad *et al.*, 2019**), is associated with reducing the risk of cardiovascular disease and cancer. Carrot (*Daucus carota* L.) is a nutritious root vegetable (seasonal crop), which is not available through the year. Drying the carrot could be an efficient way to extend its shelf-life (**Giang *et al.*, 2024**). Carrots are known as a multinutritional food source and are rich in natural bioactive compounds, such as phenolics, carotenoids, polyacetylenes, and ascorbic acid (**Ahmad *et al.*, 2019**), fiber, and minerals. As a result, carrots can be used as a functional ingredient in any product to increase the biological and nutritional values (**Turturică and Bahrim, 2021**).

The aim of this study was to fortify wheat flour with white bean and carrot pomace as sources of protein and dietary fiber at varying ratios. The study evaluated the thermomechanical, physical, structural, and sensory properties of the fortified biscuits in order to optimize the formulation of the targeted functional biscuit.

MATERIALS AND METHODS

Materials

White bean (*Phaseolus vulgaris*), Carrots (*Daucus carota*) and other materials including wheat flour (72%), eggs, sugar, salt, baking powder and margarine were purchased from local market at Zagazig, Egypt. All chemicals were of analytical grade obtained from sigma Aldrich

Preparation of White Bean Powder (WBP)

White bean (*Phaseolus vulgaris*) was purchased from a local market in Zagazig, Egypt. The beans were soaked in distilled water at 25°C for 6 hours, boiled at 100°C for 15 minutes, mashed, and dried in a hot air oven at 45°C overnight. The dried mash was then pulverized, sieved (150 µm), packed in an airtight container, and stored at 6°C until use.

Preparation of Carrot Powder (CP)

Carrots (*Daucus carota*) were also purchased locally. After washing, the carrots were sliced (1 mm), steam-treated at 70°C for 10 minutes to inactivate enzymes, cooled to room temperature, and dried at 45°C overnight. The dried slices were milled into powder, sieved (150 µm), packed in an airtight container, and stored at 6°C until use.

Experimental formulations

Preliminary trials were conducted to optimize the ratio of white bean powder (WBP) to carrot pomace (CP) in developing an experimental composite (EC), as well as to determine the appropriate levels of EC incorporation into wheat flour. The final selection of experimental ratios was guided by the assessment of the physical and sensory properties of the resulting biscuits. EC consists of WBP: CP at ratio of 3:1. Biscuit formulations consist of EC: wheat flour at ratios of 0:100 (control), 5:95 (B5), 10:90 (B10), 15:85 (B15), and 20:80 (B20).

Thermo mechanical properties

Chopin Technologies' Mixolab instrument was utilized to ascertain the thermo-mechanical characteristics. During the controlled heating and cooling process of mixing, this device gauges the consistency of the dough. During the measurement, the "Chopin+" protocol was applied. A torque of 1.1 Nm with a "C1" consistency was obtained by adding enough water (**Rosell *et al.*, 2011**). The program's parameters were as follows: 8 minutes of holding at 30°C; 4 minutes of heating to 90°C; 7 minutes of holding at 90°C; 4 minutes of cooling to 50°C; and 5 minutes of holding. This operation took forty-five minutes in total. The following parameters were measured: dough development time (DT), dough stability time (ST), minimum torque produced by the dough related to protein weakening (C2 value), maximum torque during the heating stage (C3 value), minimum torque during the heating stage (C4 value), torque after cooling to 50°C (C5 value), and so on. The dough samples without carrot or white beans included are referred to as the control group.

Biscuit preparation

The production of biscuits follows the method of **Juhász *et al.* (2020)** with some modification. Experimental biscuit dough was made from a formula that contained flour (50 g/100g), butter (25 g/100g), sugar (10 g/100g), and milk (15 g/100g), with EC added in amounts of 0 g/100g, 5 g/100g, 10 g/100g , 15 g/100g and 20 g/100g of the wheat flour substitute.

Firstly, the butter and sugar/EC were mixed until light and fluffy, followed by the addition of milk. The mixture was then stirred until it became fluffy, after which a specified proportion of flour was incorporated. The dough was prepared by thoroughly mixing the ingredients in a blender under slow mixing speed for 3 min to form the dough, followed by fast mixing for 1 min to form a smooth dough. Then the dough was placed into a circular mold and baked at 185◦C for 20 min. The biscuits were removed from the oven, cooled at room temperature (25 ± 2◦C), and conditioned into polyethylene bags.

Physical Characteristics of Biscuit

Diameter (mm), thickness (mm), spread ratio and specific volume (ml/g) were determined as described in **AACC (2000)** methods.

Color measurement of biscuit

Color was measured for L* value (brightness), a* value (red green), and b* value (yellow blue) using Minolta colorimeter (Model CR-400, Konica Minolta Sensing, Inc., Osaka, Japan). Each group of 8 biscuits was measured, with 6 points measured for each biscuit.

Texture analysis

The textural properties of control biscuits and EC fortified biscuits were determined using a TA-XTplus Texture Analyzer (Stable Microsystems, Godalming, UK). The test parameters were a pre-test speed of 1.0 mm/s, a mid-test speed of 3.0 mm/s, a post test speed of 10.0 mm/s, a distance of 5 mm, and a triggering force of 50 g.

Statistical Analysis

The analytical data were analyzed using SPSS 16.0 software. Means and standard deviations were determined using descriptive statistics. Comparisons between samples were determined using analysis of one-way variance (ANOVA) and multiple range tests. Statistical significance was defined at ($P \leq 0.05$).

RESULTS AND DISCUSSION

Thermo-Mechanical Properties of the Wheat, White Bean and Carrot Composite Flour

The impact of fortifying wheat flour with EC on dough thermomechanical was studied in terms of water absorption, dough development time, stability, torque values (C1–C5), and indicators of protein weakening and starch retrogradation to provide insights into the effects of protein and fiber incorporation on dough behavior (Table 1).

Water absorption increased with higher incorporation levels of the functional mixture, rising from 55.0% in the control to 56.0% in B20 (Table 1). This increase can be attributed to the high water-binding capacity of both white bean protein and carrot fiber, as non-gluten proteins and fibers generally absorb more water than starch or gluten fractions (**Kenny *et al.*, 2012**). The competition for water between fiber, protein, and starch reduces free water availability, requiring additional water to achieve proper dough consistency.

Dough development time decreased with increasing enrichment, dropping from 4.30 minutes in the control to 3.33 minutes in B20. This reduction indicates that the functional mixture interferes with gluten network formation, as plant proteins and dietary fibers tend to disrupt gluten cross-linking by physically interacting with gluten-forming proteins and diluting their concentration **(Renzetti and Rosell, 2016; Rosell *et al.*, 2007**). As a result, the dough becomes less cohesive and requires less time to develop.

The stability time, reflecting the resistance of the dough to mechanical stress, declined significantly from 9.70 minutes in the control to 3.22 minutes in B20. The weakened stability suggests that the structural integrity of the gluten network is compromised by the introduction of non-gluten proteins and fibers. Dietary fibers, particularly insoluble fibers like those in carrot powder, reduce gluten extensibility by absorbing water and creating mechanical barriers within the matrix.

Protein weakening, measured by the difference between C1 and C2 torque, also declined with increased enrichment. The control dough exhibited the highest value (0.83 Nm), while B20 showed a reduction to 0.69 Nm. This decline further confirms that the functional mixture interferes with gluten development, leading to a weaker dough matrix.

The maximum torque (C1), representing initial dough consistency, decreased from 1.27 Nm in the control to 1.05 Nm in B20. This indicates that the enriched dough exhibits lower resistance during mixing, consistent with the dilution of gluten. A similar trend was observed for the minimum torque (C2), which reflects protein breakdown; it decreased from 0.44 Nm in the control to 0.36 Nm in B20, indicating a reduction in dough elasticity.

Table 1. Characterization of the EC-enriched biscuits

Properties	Treatments				
	C	B5	B10	B15	B20
Thermomechanical properties*					
Water absorption (%)	55.0±0.2.0d	55.0±0.3d	55.5±0.2c	55.6±0.2b	56.0±0.3a
Dough development time (min)	4.30± 0.15a	3.70 ±0.12b	3.62±0.14b	3.40±0.16c	3.33±0.11c
Stability time (min)	9.70±0.9a	8.40±0.78b	5.52±0.86c	4.60±0.92d	3.22±0.35e
Maximum torque (C1, Nm)	1.27±0.03a	1.21±0.02bc	1.17±0.02c	1.10±0.03bc	1.05±0.02b
Minimum torque (C2, Nm)	0.44±0.01a	0.42±0.02ab	0.40±0.01b	0.39±0.03b	0.36±0.02c
Peak viscosity (C3, Nm)	1.77±0.02a	1.69±0.03a	1.61±0.02a	1.54±0.04b	1.45±0.05c
Holding viscosity (C4, Nm)	1.66±0.02a	1.64±0.04a	1.57±0.03b	1.40±0.03c	1.39±0.04d
Final viscosity (C5, Nm)	2.31±0.09a	1.88±0.05b	1.88±0.06b	1.57±0.08c	1.24±0.11d
Protein weakening (C1–C2, Nm)	0.83±0.02a	0.79±0.04b	0.77±0.03b	0.71±0.02c	0.69±0.03c
Breakdown (C3–C4, Nm)	0.11±0.01a	0.05±0.02b	0.05±0.01b	0.06±0.01b	0.06±0.02b
Setback (C5–C4, Nm)	0.65±0.04a	0.24±0.06c	0.31±0.05b	0.17±0.08d	-0.05±0.0e
Proximate composition (g/100g) (wet weight basis)					
Moisture	5.42±0.16e	5.66±0.20d	5.92±0.28c	6.16±0.18 b	6.46b±0.22a
Protein	8.57±0.12e	8.88±0.16d	9.17±0.24c	9.42±0.18b	9.71±0.22a
Fat	15.35±0.25a	14.58±0.26b	14.47±0.20b	13.65±0.24c	12.73±0.28d
Ash	1.72±0.05e	1.854±0.07d	2.04±0.04c	2.25±0.06ab	2.42±0.05a
Crude fiber	0.76±0.14e	1.07±0.12d	1.46±0.16c	1.70±0.14b	2.03±0.15a
Soluble carbohydrates	68.18±0.24a	67.96±0.16b	66.94±0.24c	66.82±0.20d	66.65±0.18d
Physical properties					
L*	65.78±1.4a	61.59±1.06b	60.02±1.2c	51.91±2.5d	48.39±2.8e
a*	3.3±0.65d	6.2±0.92c	6.49±0.88c	10.65±1.6b	13.67±1.2a
b*	30.23±0.85a	28.36±1.02b	27.82±0.94bc	25.67±0.98c	24.05±0.77cd
Diameter (mm)	63.20±0.11e	63.62±0.09d	63.95±0.08c	64.05±0.12b	64.24±0.06a
Thickness (mm)	8.16±0.04b	8.16±0.03b	8.18±0.05ab	8.20±0.02a	8.22±0.04a
Spread ratio	7.48±0.04b	7.79±0.02a	7.80±0.03a	7.81±0.05a	7.82±0.02a
Specific volume (ml/g)	2.66±0.02c	2.72±0.03b	2.72±0.01b	72.74±0.01a	72.75±0.02a
Hardness (N)	89±04.14c	102.35±2.3b	103.49±1.4b	103.79±3.2b	114.65±4.3a
Adhesiveness (g·cm)	0.6±0.01a	0.6±0.02b	0.3±0.02c	0.1±0.01d	0.07±0.01e
Resilience	0.11±0.03a	0.11±0.02a	0.08±0.02b	0.04±0.001c	0.03±0.001c
Sensory evaluation					
Appearance	9.81±0.41a	9.13±0.67b	9.11±0.15b	8.54±0.44c	8.21±0.51d
Color	9.62±0.63a	9.24±0.12b	8.31±0.81c	8.12±0.04d	8.02±0.67d
Taste	9.34±0.51a	9.03±0.66b	8.34±0.85c	7.15±0.69d	6.49±0.09e
Aroma	9.48±0.91a	8.37±0.42b	7.98±0.31c	7.38±0.87d	6.75±0.70e
Overall acceptability	9.56±0.22a	8.94±0.49b	8.43±0.26b	7.79±0.53c	7.36±0.32d

*Thermomechanical properties were carried out on dough

Data are expressed as mean ± standard deviation (n = 3). Values labelled with different letter in the same raw are significantly different ($p < 0.05$).

The peak viscosity (C3), which corresponds to starch gelatinization, decreased from 1.77 Nm in the control to 1.45 Nm in B20. This suggests that the added protein and fiber components compete with starch for water, limiting starch granule swelling during gelatinization. The holding viscosity (C4), representing the stability of the starch gel under heat, also decreased, particularly in the higher enrichment levels (1.66 Nm for the control vs. 1.39 Nm for B20), indicating that the starch structure is less stable in enriched doughs.

The setback value (C5–C4), a measure of starch retrogradation during cooling, showed a marked decline with increasing functional mixture levels, dropping from 0.65 Nm in the control to -0.05 Nm in B20. The negative setback value in B20 suggests minimal or no retrogradation, which may improve the shelf life of the biscuits by reducing staling. These findings align with previous studies showing that fibers can inhibit retrogradation by interfering with starch reorganization (**Rosell *et al.*, 2011**).

The breakdown value (C3–C4), indicating the stability of the starch paste during heating, decreased slightly with enrichment but showed no statistically significant differences between samples B5, B10, B15, and B20. This suggests that the functional mixture does not severely compromise the thermal stability of the starch gel.

Proximate composition

The moisture content increased progressively from 5.42% in the control (C) to 6.46% in B20 (Table 1). This increase is likely due to the higher water-binding capacity of both white bean protein and dietary fiber from carrot powder. Dietary fibers are known for their hydrophilic nature, which allows them to retain water within the dough matrix, resulting in higher moisture content in the final product (**Kenny *et al.*, 2012**). Higher moisture retention can positively affect the softness of the biscuits but may also influence shelf life by promoting microbial growth if not properly managed.

The protein content increased significantly with the addition of the functional mixture, from 8.57% in the control to 9.71% in B20 (Table 1). This increase is attributed to the incorporation of white bean protein, which is rich in essential amino acids and serves as a plant-based protein source (**Wang *et al.*, 2020**). Protein-enriched biscuits address consumer demand for functional foods with enhanced nutritional value, particularly for individuals seeking plant-based or high-protein snacks. However, higher protein levels may also influence dough handling and texture, as non-gluten proteins can interfere with gluten network formation.

The fat content decreased with increasing levels of enrichment, from 15.35% in the control to 12.73% in B20 (Table 1). The decline in fat content is likely due to the partial replacement of wheat flour with the functional mixture, which contains lower fat levels compared to wheat-based formulations. Reducing fat content contributes to the production of healthier biscuits, aligning with dietary recommendations for reducing saturated fat intake. However, the reduction in fat may also affect the texture and mouthfeel, as fat plays a crucial role in biscuit tenderness and flavor.

The ash content, which indicates the total mineral content, increased from 1.72% in the control to 2.42% in B20 (Table 1). The higher ash content reflects the mineral contribution of the carrot powder, which is rich in calcium, potassium, and other essential minerals. Increasing mineral content enhances the nutritional profile of the biscuits, providing added value as a functional food.

The crude fiber content showed a significant increase from 0.76% in the control to 2.03% in B20 (Table 1). The rise in fiber content is attributed to the inclusion of carrot powder, which contains both soluble and insoluble dietary fibers. Increased fiber content improves digestive health and contributes to satiety, aligning with the growing demand for high-fiber products (**Meldrum and Yakubov, 2024**). However, high fiber levels can also affect dough rheology by increasing water absorption and reducing dough elasticity.

The soluble carbohydrate content decreased slightly with enrichment, from 68.18% in the control to 66.65% in B20 (Table 1). This reduction reflects the dilution of starch content due to the addition of the functional mixture, which contains higher proportions of protein and fiber. Lower carbohydrate content contributes to a healthier nutritional profile by reducing the glycemic load, which is beneficial for consumers seeking products that support better glycemic control.

Physical properties

The addition of the functional mixture led to a significant change in the color parameters of the biscuits. The lightness (L)* decreased progressively with higher levels of enrichment, dropping from 65.78 in the control (C) to 48.39 in B20. This reduction is consistent with the darker pigments introduced by the carrot powder, which contain β-carotene and other natural pigments known to impart color (Haq, Kumar, & Prasad, 2016). As the concentration of the functional mixture increases, the biscuit's overall brightness diminishes due to both the inherent color of the ingredients and the Maillard reactions promoted by the added protein during baking (Table 1).

The *redness (a)** value increased from 3.3 in the control to 13.67 in B20, indicating that the biscuits became redder with higher levels of the mixture. Carrot powder, being rich in carotenoids, is responsible for the increased reddish hue. Similarly, the *yellowness (b)** value decreased from 30.23 in the control to 24.05 in B20. While carrot powder contributes to both red and yellow tones, the increased protein content may have intensified the Maillard browning, slightly shifting the hue towards red at the expense of yellow tones (**Mercer *et al.*, 2021**) (Table 1).

The biscuit diameter increased significantly with higher levels of enrichment, rising from 63.20 mm in the control to 64.24 mm in B20 (Table 1). The addition of dietary fiber, especially from carrot pomace, influences dough viscosity, reducing resistance to flow during baking, which results in a greater spread (**Martins *et al.*, 2017**). The thickness showed a slight but significant increase, from 8.16 mm in the control to 8.22 mm in B20 (Table.1), indicating that the enriched dough retains more structure during baking, possibly due to the higher water absorption capacity of the fibers and proteins.

The spread ratio (diameter/thickness) increased slightly across the enriched samples, with the highest values recorded at B20 (7.82) compared to the control (7.48) (Table 1). The increase in spread ratio suggests that the added functional ingredients enhance the dough's ability to spread, likely due to changes in dough hydration and reduced gluten network strength caused by the added proteins and fibers (**Rosell *et al.*, 2011**).

The specific volume of the biscuits increased significantly with enrichment, rising from 2.66 ml/g in the control to 2.75 ml/g in B20 (Table 1). The increase in specific volume may be attributed to the enhanced water retention and improved gas-holding capacity provided by the added proteins and fibers. Plant proteins such as those from legumes can incorporate air during mixing, contributing to a lighter texture (**Wang *et al.*, 2020**). Additionally, the dietary fiber in carrot pomace may have helped retain moisture, preventing excessive collapse during baking, which results in higher specific volume.

Hardness refers to the force required to break or compress the biscuit, and it increased significantly with higher levels of the functional mixture, rising from 89 N in the control (C) to 114.65 N in B20 (Table 1). The increase in hardness can be attributed to the high water-absorption capacity of dietary fiber from carrot powder, which limits the availability of free water in the dough. This results in a denser structure upon baking, contributing to increased firmness (**Rathnayake *et al.*, 2018**). Additionally, the protein component from white bean may have interacted with starch, leading to the formation of a more rigid network that further enhances hardness (**Zhang *et al.*, 2021**). While increased hardness can improve product stability, it may negatively affect consumer acceptability if the biscuits become too hard to bite.

Adhesiveness, defined as the force required to overcome the attraction between the biscuit and a surface (or tongue), decreased with increasing levels of enrichment. It dropped from 0.6 g·cm in both the control (C) and B5 to 0.07 g·cm in B20 (Table 1). The reduction in adhesiveness suggests that the added fiber interferes with the formation of sticky or cohesive structures within the dough, likely by reducing moisture availability and weakening gluten development (**Rosell *et al.*, 2007; Rosell *et al.*, 2011**). As a result, the biscuits become less prone to sticking, which enhances handling and ease of consumption. However, extremely low adhesiveness may affect the mouthfeel, reducing the perception of smoothness.

Resilience, which measures the ability of the biscuit to recover its shape after compression, decreased from 0.11 in the control to 0.03 in B20 (Table 1). This decline indicates that the biscuits with higher levels of the functional mixture are less elastic and more prone to fracturing under pressure. The loss of resilience is likely related to the dilution of the gluten network by the added proteins and fibers, which weakens the dough's structural integrity. Additionally, dietary fibers create a more rigid matrix, further limiting the dough's ability to recover from deformation.

Sensory evaluation

The appearance of the biscuits showed a statistically significant decrease as the level of the functional mixture increased (Table 1). The control (C) biscuits exhibited the highest score for appearance (9.81±0.41), which progressively diminished in treatments B5, B10, B15, and B20, with B20 showing the lowest score (8.21± 0.51). This decline could be attributed to the incorporation of non-gluten proteins from white beans and carotenoid pigments from dried carrots, which altered the visual structure and surface texture of the biscuits. Studies indicate that alternative proteins often modify the visual uniformity and textural properties of baked goods, resulting in less consumer preference due to changes in surface smoothness and uniformity. Similar trends have been observed with the addition of legume proteins, which disrupt the typical gluten network, thus altering the biscuit structure. Color also showed a significant decrease with increasing substitution of the mixture. The control biscuit scored the highest (9.62± 0.63), while B20 received the lowest score (8.02±0.67). This reduction is likely due to the presence of carrot powder, which imparts an orange hue, altering the traditional golden-brown color of biscuits. Carotenoids, the pigments in carrots, are known to intensify with higher concentrations, leading to a color shift towards darker, less preferred shades as noted in previous studies evaluating vegetable powders in baked goods (sensory). Consumers generally associate darker or non-traditional biscuit colors with less desirability, leading to lower sensory scores. Taste scores exhibited a sharp decline, with the control biscuit (C) scoring the highest (9.34±0.51) and B20 the lowest (6.49±0.09). The a ddition of bean protein, known for its distinct legume flavor, likely contributed to this reduction, especially at higher concentrations. Bean proteins often impart a beany or grassy flavor, which can be unappealing in sweet baked products like biscuits(sensory). Moreover, the presenc e of carrot powder, while potentially adding a subtle sweetness, could also introduce earthy or vegetal notes that further detract from the traditional biscuit flavor profile. The drastic decline in taste acceptability from B10 (8.34± 0.85) to B20 (6.49±0.09) underscores the threshold at which the addition of functional ingredients becomes too dominant, overwhelming the preferred wheat-based flavor. Aroma followed a similar trend to taste, decreasing significantly as the level of functional mixture increased. The control (C) had the highest score (9.48± 0.91), while B20 had the lowest (6.75± 0.70). The aroma of biscuits is typically associated with the Maillard reaction, which occurs during baking and imparts desirable caramelized and toasted notes. The addition of bean protein and carrot powder likely disrupted this reaction or introduced competing aromatic compounds, such as earthy and leguminous notes from the beans and the vegetal aroma from carrots (sensory). The sensory evaluation highlights the difficulty in masking these fewer desirable aromas in high-protein, high-fiber formulations. The overall acceptability, a comprehensive measure combining all sensory attributes, also significantly decreased with increasing levels of the functional mixture. The control scored the highest (9.56±0.22), followed by B5 (8.94±0.49), B10 (8.43±0.26), B15 (7.79± 0.53), and B20 (7.36±0.32). This trend mirrors the decline in individual sensory attributes, indicating that while lower levels of the functional mixture (e.g., 5-10%) may still produce biscuits with acceptable sensory properties, higher levels (15-20%) result in products that are less appealing to consumers. Similar studies on the fortification of baked goods with legume proteins and vegetable powders have demonstrated that while moderate additions can enhance nutritional value without severely compromising sensory quality, higher concentrations often result in unacceptable products.

Conclusion

The incorporation of a functional mixture consisting of white bean protein and dried carrot powder (3:1) into wheat flour, at substitution levels ranging from 5% to 20%, had a profound effect on the thermal, mechanical, chemical, physical and sensory properties of biscuits. The addition enhanced water absorption due to the hydrophilic properties of the fiber, while reducing dough stability and gluten network formation, resulting in a weaker and less cohesive dough structure. At the chemical level, the protein and fiber content increased, improving the nutritional profile, but the fat content decreased. At the physical level, the biscuits showed a darker color and increased hardness, driven by carotenoid pigments and higher water absorption. Sensory evaluations revealed a decrease in appearance, taste and overall acceptability, especially at higher enrichment levels, where flavors derived from legumes and vegetables overshadowed the traditional sensory attributes of biscuits, but the low addition ratios of 5% and 10% were the most acceptable among the experimental biscuits suggestion its suitability for producing functional biscuit.

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الخصائص الفيزيائية والميكانيكيه الحراريه والتركيبية للبسكويت المحضر من الدقيق المركب من القمح والفاصوليا البيضاء والجزر

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تهدف الدراسة الحالية الى دراسه تأثيرات تدعيم دقيق القمح بخليط وظيفي من مسحوق بروتين الفاصوليا البيضاء ومسحوق الجزر المجفف بنسبه (1:3) على الخصائص الميكانيكيه الحراريه والكيميائية والتركيبيه والحسية للبسكويت الناتج. حيث تم دمج الخلطات الوظيفية بنسبة 0% و 5% و 10% و 15% و 20%. أشارت النتائج إلى أن زيادة مستويات المخلوط الوظيفى المضاف عززت امتصاص الماء ومحتوى البروتين، مع تقليل ثبات العجين ووقت تطور العجين وتكوين شبكة الجلوتين. ومن ناحية الخواص الفيزيائية، أظهر البسكويت تلوينًا أغمق وقطرًا متزايدًا وصلابة أعلى، ويعزى ذلك إلى صبغه الكاروتينويد وقدرة الألياف على ربط الماء. انخفضت الخواص الحسية، بما في ذلك المظهر والطعم والرائحة والقبول العام، بشكل كبير مع مستويات الاستبدال الأعلى بسبب تداخل نكهات البقول النباتيه. تسلط النتائج الضوء على إمكانية تدعيم البسكويت بالبروتينات والألياف النباتية لتحسين القيمة الغذائية ولكنها تؤكد أيضًا على تحدي الحفاظ على الخصائص الحسية والفيزيائية المرغوبة. أظهرت النتائج أن البسكويت المدعم بالمخلوط الوظيفى بنسبة 5% و 10% قد حصل على أعلى الدرجات الحسية، مما يشير إلى امكانيه استخدام هذة النسب فى إنتاج بسكويت وظيفي صحي.

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