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Fortification of Biscuits with Vitamin D and Cinnamon: Evaluation of Texture, Color, and Sensory

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ABSTRACT

This study aimed to formulate and evaluate biscuits produced from refined and whole wheat flour fortified with vitamin D and cinnamon. Four formulations were prepared using refined or whole wheat flour, with and without the addition of 0.6 g cinnamon and 666 IU vitamin D per biscuit. The vitamin D level was adjusted to compensate for an estimated 40% loss during baking. The products were analyzed for vitamin D content via LC/MS, color attributes through digital imaging, and texture by a three-point bending test. Sensory evaluation was performed by a trained panel of twelve assessors. Statistical comparisons were made using ANOVA and t-tests. Fortification with vitamin D and cinnamon resulted in a decrease in lightness (L from 71.77 in the control to 58.00 in the most enriched sample), an increase in redness (a from 6.11 to 13.11), higher yellowness (b* up to 33.66), and a significant increase in total color difference (ΔE*), indicating noticeable visual changes. Textural analysis showed a reduction in hardness from 1125.55 g to 552.83 g. Sensory assessment revealed that overall acceptability was highest in enriched samples (scores of 6.83 for refined and 6.42 for whole wheat biscuits), while the control whole wheat biscuit had the lowest acceptability (score 4.92). Vitamin D exhibited high stability (>97% retention) after 60 days of storage at room temperature. These findings suggest that fortification of biscuits with vitamin D and cinnamon can improve sensory quality while maintaining micronutrient stability, highlighting the potential of such products as functional bakery foods.

KEYWORDS: Biscuit fortification, Cinnamon, Sensory properties, Texture, Whole wheat flour, Vitamin D.

INTRODUCTION

Biscuits are among the most widely consumed baked products worldwide, valued for their palatability, convenience, and extended shelf life (Ferruzzi et al., 2014). In recent years, there has been a growing focus on enhancing the nutritional quality of biscuits by incorporating whole

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wheat flour and bioactive ingredients, both to improve health outcomes and to meet consumer demand for functional foods (Slavin, 2004; Marquart et al., 2000). Whole wheat flour, which retains the bran and germ, provides higher levels of dietary fiber, micronutrients, and phytochemicals compared to the refined flour; its regular intake has been associated with a reduced risk of cardiovascular disease, type 2 diabetes, and other chronic disorders (Kelly et al., 2017; Hu et al., 2022). Food fortification is widely recognized as a sustainable, population-level intervention to reduce the prevalence of micronutrient deficiencies. The Food and Agriculture Organization (FAO) has emphasized that successful food fortification depends on appropriate food vehicles, suitable processing technology, and effective quality control throughout production (FAO, 1995). In parallel, guidelines developed jointly by the World Health Organization (WHO) and FAO stress that food fortification is among the most cost-effective and sustainable strategies for addressing public health nutrition gaps, offering substantial economic and societal benefits in both industrialized and developing countries (Allen et al., 2006). Micronutrient fortification has therefore emerged as an integral component of national nutrition policies due to its scalability, sustainability, and positive impact on health outcomes and productivity. Accordingly, the fortification of staple foods such as wheat flour with micronutrients like vitamin D has become a priority in many countries. Vitamin D deficiency remains a major global public health problem, linked to an increased risk of bone disorders, metabolic syndromes, and a variety of chronic diseases (Holick, 2007). Extant research supports the effectiveness of vitamin D fortification in improving serum vitamin D status and reducing associated health risks (Allen et al., 2006; Holick, 2007). More recent evidence has further confirmed that vitamin D fortification of staple foods is an effective strategy for improving vitamin D status in different populations (Nyakundi et al., 2023).

Cinnamon (Cinnamomum spp.) is a culinary spice rich in polyphenols and antioxidants, displaying a range of pharmacological activities including anti-inflammatory, neuroprotective, and potential glycemic effects (Verma et al., 2022; Ranasinghe et al., 2013; Gu et al., 2022). In addition to its nutritional and functional properties, cinnamon has attracted considerable attention as a bioactive ingredient for the development of functional foods. Emerging evidence suggests possible associations between cinnamon, vitamin D status, and neurological conditions such as migraine through anti-inflammatory mechanisms and modulation of neurovascular pathways (Huang and He, 2023; Morton et al., 2025; Ghorbani et al., 2019; Nowaczewska et al., 2020; Zareie et al., 2020; Zareie et al., 2024; Rambod et al., 2018). However, these potential health effects were not investigated in the present study, which focused on the development and quality evaluation of nutritionally enhanced biscuits. Several studies have investigated the incorporation of cinnamon powder into bakery products to enhance their nutritional and health-promoting properties. Recent reviews have also highlighted cinnamon as a promising functional food ingredient because of its antioxidant properties and its ability to improve the nutritional and sensory quality of bakery products (Chakraborty and Chakraborty, 2023). For example, Ng and Wan Rosli (2014) demonstrated that replacing sucrose partially with 2–4% cinnamon powder in butter biscuits resulted in increased protein, dietary fiber, and ash content, while simultaneously lowering moisture and sucrose levels. This fortification did not significantly affect the sensory acceptability of the biscuits at moderate levels, indicating that cinnamon-enriched products can offer improved nutritional profiles without compromising consumer preference (Ng and Wan Rosli, 2014). Additionally, vitamin D fortification of foods has been addressed in previous research, focusing not only on enhancing nutritional value but also on sensory quality, cost-effectiveness, and consumer acceptance. For example, research has demonstrated that fortifying various staple foods with vitamin D could significantly improve serum vitamin D levels in the population, while maintaining acceptable organoleptic properties and having minimal impact on product cost (Calvo et al., 2004). Furthermore, consumer studies indicated that appropriate fortification strategies generally received positive public acceptance, provided that the sensory characteristics of the food were not adversely affected and the price remained reasonable. Given these considerations, and the societal demand for affordable, accessible, and nutritionally enhanced foods, the present study was conducted to formulate and evaluate biscuits prepared from refined and whole wheat flour fortified with vitamin D and cinnamon, and to assess their physicochemical, nutritional, and sensory characteristics.

MARERIALS AND METHODS:

Materials

Cinnamon powder was purchased from a reputable hypermarket in Shiraz, Iran. Vitamin D_3 (cholecalciferol; Dry Vitamin D_3 100 SD/S, Product Code: 05902880, potency: 109,210 IU/g) was obtained from DSM Nutritional Products Ltd., Basel, Switzerland. All other ingredients required for biscuit production, including commercial refined wheat flour (Star flour) and commercial whole wheat flour, both supplied by Kamran Flour Mill (Shiraz, Iran) in accordance with the relevant Iranian National Standards, as well as sugar, vegetable shortening, skimmed milk powder, eggs, salt, sodium pyrophosphate, sodium bicarbonate, invert syrup, and starch, were provided by Parastoo Biscuit Factory (Shiraz, Iran), where all biscuit formulations were prepared under commercial manufacturing conditions.

Methods

Biscuit Preparation

Four biscuit formulations were prepared to investigate the effects of flour type and fortification with cinnamon and vitamin D. Throughout this manuscript, the formulations are designated as follows: Sample A (refined wheat flour, control), Sample B (refined wheat flour fortified with cinnamon and vitamin D), Sample C (whole wheat flour, control), and Sample D (whole wheat flour fortified with cinnamon and vitamin D). These designations are used consistently throughout the manuscript .To ensure that the final concentration of vitamin D in the fortified biscuits reached 666 IU per biscuit, the vitamin D level was adjusted to compensate for thermal losses during baking. Based on preliminary trials and subsequent quantitative analysis, approximately 40% of the added vitamin D was estimated to be lost during baking. Therefore, 933 IU of vitamin D per biscuit (corresponding to 62.2 IU/g of dough) was incorporated into the fortified formulations before baking to achieve the target level after baking .For Samples B and D, cinnamon powder (0.6 g per biscuit) and vitamin D (933 IU per biscuit) were added, whereas Samples A and C served as non-fortified controls and did not contain these ingredients .In each formulation, soft shortening and sugar were first mixed for 3–4 min until a homogeneous mixture was obtained. Owing to its fat-soluble nature, vitamin D_3 was initially dispersed in the shortening before being blended with sugar (Keegan et al., 2013). Water, egg, skimmed milk powder, and salt were gradually incorporated, followed by sodium pyrophosphate, sodium bicarbonate, and invert syrup, with continued mixing using an industrial horizontal dough mixer (SM, 400 kg capacity) operating at 40 rpm. Subsequently, starch and the appropriate flour (refined wheat flour or whole wheat flour, depending on the formulation) were added. For Samples B and D, cinnamon powder (0.04 g/g of dough) and vitamin D (62.2 IU/g of dough) were incorporated at this stage, whereas these ingredients were omitted from Samples A and C. The dough was mixed until a uniform consistency was achieved, sheeted, and cut into pieces weighing approximately 15 g each. The biscuits were allowed to rest at room temperature for 10 min and were then baked at 200°C for 30 min. After cooling to room temperature, the biscuits were stored in airtight containers until further analysis.

Vitamin D Content Determination

Vitamin D content was quantified using a validated liquid chromatography–mass spectrometry (LC/MS) method adapted from Dimartino (2007) (22). Vitamin D content was quantified using a validated liquid chromatography–mass spectrometry (LC/MS) method adapted from the method described by Dimartino (2007) (22). Biscuit samples were homogenized, and approximately 5 g of ground material was subjected to saponification using 2% pyrogallol in ethanol and 25% aqueous potassium hydroxide. Following saponification, vitamin D was extracted with hexane containing 0.001% BHT. The organic phase was evaporated under reduced pressure, and the residue was reconstituted in acetonitrile, filtered through a 0.45 µm PTFE syringe filter, and injected into the LC/MS system. Chromatographic separation was achieved on a C18 reversed-phase column (4.6 × 250 mm, 5 µm) under isocratic elution with 100% methanol at a flow rate of 1.1 mL/min. Detection was performed using atmospheric pressure chemical ionization (APCI) in positive mode, with monitoring of m/z 385.2 for vitamin D_3 (cholecalciferol) and m/z 397.2 for vitamin D_2 (internal standard) in selected ion monitoring (SIM) mode. Quantification was based on the peak area ratio of vitamin D_3 to vitamin D_2 using an external calibration curve. The method exhibited high analytical performance, with recoveries of 98–105%, a limit of detection (LOD) of 1.3 ng, and a limit of quantification (LOQ) of 3 ng. All measurements were conducted in duplicate, and the results are expressed as mean ± standard deviation.

Surface Color Measurement

The surface color of biscuit samples was evaluated using digital imaging. For each formulation, three biscuits were randomly selected for color analysis. Three digital images were captured from each biscuit under identical lighting conditions, and three measurement points were analyzed on the surface of each image. The mean values of all measurements were used for statistical analysis. Images were captured inside a wooden light box under controlled illumination conditions to minimize the influence of ambient light. Prior to analysis, the acquired images were color-calibrated to ensure consistency among samples. The calibrated images were then converted to the CIE L*a*b* color space using Adobe Photoshop (Adobe Inc., San Jose, CA, USA), and the L* (lightness), a* (red–green), and b* (yellow–blue) color parameters were extracted for analysis. The total color difference (ΔE*) between each sample and the control was calculated according to the following formula:

$$\Delta E^* = \sqrt{(L^*s - L^*c)^2 + (a^*s - a^*c)^2 + (b^*s - b^*c)^2}$$

Where Ls, as, and bs are the color parameters of the sample, and Lc, ac, and bc are those of the control biscuit. A ΔE* value less than 2.15 was considered imperceptible to the human eye (Bourne, 2002; Stewart et al., 2012; Kane et al., 2003).

In addition to the CIELAB color parameters (L*, a*, and b*), the Chroma (C*), Whiteness Index (WI), and Browning Index (BI) were calculated to provide a more comprehensive evaluation of biscuit color. Chroma (C^*) was calculated as $C^* = (a^{*2} + b^{*2})^{1/2}$. The Whiteness Index (WI) was calculated using the equation $WI = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2}$. The Browning Index (BI), which reflects the degree of browning developed during baking, was calculated according to the equations $x = (a^* + 1.75L^*)/(5.645L^* + a^* - 3.012b^*)$ and $BI = [100(x - 0.31)]/0.17$.

Texture Analysis (Three-Point Bending Test)

One of the most common methods for evaluating the hardness of brittle, sheet-like products such as biscuits is the three-point bending test. This technique is widely used for food products with hard and fragile textures (Agu et al., 2010). In the present study, texture analysis was performed using a TA-XT2 texture analyzer (Stable Micro Systems, UK) equipped with a three-point bending rig. The test conditions were as follows: pre-test speed, 1 mm/s; test speed, 3 mm/s; post-test speed, 10 mm/s; trigger force, 3 g; and span length, 40 mm. Each sample was tested in triplicate, and the maximum fracture force (g) required to break the biscuit was recorded as the texture parameter. The resulting data were subjected to statistical analysis.

Sensory Evaluation

Sensory evaluation of the biscuit samples was conducted by a panel of 12 trained assessors following standard sensory evaluation procedures (Stone et al., 2016; Meilgaard et al., 2016; Destarianto et al., 2017). Four biscuit formulations (Samples A–D) were evaluated, and each assessor received all four samples in a randomized order. The biscuit samples were randomly coded using three-digit numbers to minimize presentation bias. The sensory evaluation was conducted under controlled conditions, and all panelists were instructed on the use of the 9-point hedonic scale before the assessment. Each sample was evaluated for color, aroma, texture, taste, and overall acceptability using a 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely. Water was provided between sample evaluations for palate cleansing (Stone et al., 2016). The sensory scores obtained from the panelists were subsequently used for statistical analysis (Steel and Torrie, 1960).

Statistical Analysis

Statistical analyses were performed using SPSS software version 16 (SPSS Inc., Chicago, IL, USA). Data are presented as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was used to compare the physicochemical characteristics, vitamin D content, texture, color, and sensory attributes among the four biscuit formulations. Independent-samples t-test was applied for pairwise comparisons between two independent groups, where appropriate. Paired-samples t-test was used to compare vitamin D content of the fortified biscuit samples before and after the storage period. A P-value ≤ 0.05 was considered statistically significant.

RESULTS AND DISCUSSION

Fortification Optimization and Composition

In this study, biscuits were fortified with specific amounts of vitamin D and cinnamon to achieve the intended nutritional and compositional targets for both refined wheat and whole wheat formulations. The amount of vitamin D added was determined based on the laboratory analysis and compensation for the expected baking losses. The concentration of cinnamon powder in each batch was determined empirically through gradual adjustment and preliminary sensory evaluation of the uncooked dough and baked biscuits. The final level was selected by trial and error to achieve a pleasant flavor without adversely affecting the acceptability of the product. Accordingly, all biscuit samples were prepared using the optimized levels of vitamin D and cinnamon.

Vitamin D Stability during Storage

The stability of vitamin D in biscuit samples during storage was evaluated by measuring vitamin D content on day 1 and after 60 days of storage (Table 1). Independent samples t-test showed that there was no significant difference in the initial vitamin D content between the two groups (P>0.05). Paired samples t-test revealed slight decreases in vitamin D levels in both groups after 60 days of storage (P>0.05). Although the difference observed during storage was statistically significant, the magnitude was relatively small, with a decrease of 49 IU in group B and 45 IU in group D. These findings indicate that vitamin D remained relatively stable during 60 days of storage, supporting the suitability of biscuits as an effective vehicle for vitamin D fortification. This observation is consistent with previous studies reporting minimal vitamin D degradation in baked products during storage (Itkonen et al., 2016; Tabibian et al., 2017). This observation is consistent with recent evidence indicating that vitamin D can remain relatively stable in fortified bakery products when appropriate processing and storage conditions are applied (Vieira et al., 2021). Although thermal processing inevitably causes some degradation of vitamin D, previous studies have shown that vitamin D3 is relatively stable during baking, and the remaining vitamin D retains its biological activity. However, the present study evaluated vitamin D retention rather than its bioavailability; therefore, further in vivo studies are required to determine the absorption of vitamin D from the fortified biscuits after baking.

Table 1. Changes in vitamin D content of biscuit samples.

Samples	Day 1	Day 60
B	1939.5±331.81^{aA}	1890±21.21^{aB}
D	1930±12.72^{Aa}	1885±13.43^{aB}

Sample description: Sample B: (refined wheat flour + cinnamon + vitamin D), sample D: (whole wheat flour + cinnamon + vitamin D) Values are presented as mean ± SD (n=2). Different lowercase letters in the same column indicate significant statistical differences ($P < 0.05$) between samples; different uppercase letters in the same row indicate significant statistical differences ($P < 0.05$) between storage days.

Surface Color Characteristics

Analysis of surface color parameters revealed significant effects of cinnamon and vitamin D fortification on the visual attributes of biscuit samples. The control group (A) registered the highest lightness (L*) value (71.77 ± 4.96), indicating the lightest product surface, while the addition of cinnamon and vitamin D resulted in a pronounced reduction in L* (B: 57.66 ± 8.06; D: 58.00 ± 2.59). The complete results for L*, a*, and b* values in each treatment group are summarized in Table 2 .This darkening effect was in line with the findings of Ng and Wan Rosli (2014), who attributed the decline in L* values to the natural color pigments and polyphenols present in cinnamon, which could accelerate Maillard reactions and enhance browning during baking. Similarly, the increase in redness (a) observed in the fortified samples is likely attributable to both the inherent reddish compounds of cinnamon and intensified Maillard reactions facilitated by changes in moisture and sugar content. Ng and Wan Rosli (2014) also reported that increasing cinnamon powder concentrations in biscuits resulted in a marked rise in a values, further supporting the present findings .Regarding the yellowness parameter (b), the higher values observed in wholemeal flour formulations suggest that dietary fiber and naturally occurring plant pigments contribute to the final color characteristics of the biscuits. These observations are consistent with those reported by Ng and Wan Rosli (2014), highlighting the combined influence of flour type and cinnamon incorporation on biscuit appearance .These observed trends are pertinent to several overlapping mechanisms: the increased Maillard reactions due to the higher levels of natural antioxidants and fiber in cinnamon and wholemeal flour, the effect of reduced moisture and sucrose (also reported by Ng and Wan Rosli, 2014), and pigment interactions and transformation during baking .Overall, the color modifications observed in the present study are consistent with previous findings and demonstrate that cinnamon fortification, particularly when combined with wholemeal flour, not only enhances the nutritional profile of biscuits but also produces predictable changes in product appearance. From a technological perspective, these color changes reflect the interactions among ingredient composition and baking reactions and should be considered when optimizing fortified biscuit formulations to achieve both desirable sensory quality and functional benefits (Ng and Wan Rosli, 2014).

To provide a more comprehensive evaluation of the visual characteristics of the biscuits, Chroma (C), Whiteness Index (WI), and Browning Index (BI) were also calculated from the measured L, a*, and b* values. Sample D exhibited the highest chroma value (36.12), indicating the greatest color saturation, whereas sample B showed the lowest chroma (29.24). The Whiteness Index decreased following cinnamon fortification, with sample A showing the highest WI (58.44) and sample D the lowest (44.60), confirming the darker appearance of fortified biscuits. In contrast, the Browning Index increased markedly in fortified samples, reaching its highest value in sample D (99.57), which is consistent with enhanced browning reactions during baking induced by cinnamon incorporation and whole wheat flour. The additional color indices further supported the visual changes observed in the fortified biscuits. The increase in Browning Index together with the reduction in Whiteness Index confirmed the progressive browning caused by cinnamon addition and whole wheat flour. Likewise, the higher chroma values indicated greater color intensity in fortified formulations, reflecting the contribution of natural cinnamon pigments and browning reactions during baking. These complementary indices provide a more comprehensive characterization of biscuit color than L, a, and b* values alone.

Table 2. Surface color values (L*, a*, and b*) of biscuit samples.

Sample	**L* (Lightness)**	**a* (Red-Green)**	**b* (Yellow-Blue)**	**Chroma**	**Whiteness Index (WI)**	**Browning Index (BI)**
A	71.77 ± 4.96 ^{a}	6.11 ± 0.92 ^{a}	29.88 ± 2.02 ^{a}	30.50	58.44	58.81
B	57.66 ± 8.06 ^{c}	10.11± 0.78 ^{b}	27.44 ± 2.40 ^{b}	29.24	48.54	75.81
C	65.22 ± 5.62 ^{b}	7.88 ± 0.92 ^{c}	31.66 ± 3.12 ^{ac}	32.63	52.31	73.35
D	58.00 ± 2.59 ^{c}	13.11 ± 1.05 ^{d}	33.66 ± 1.32^{c}	36.12	44.60	99.57

Sample description: sample A (refined wheat flour), sample B (refined wheat flour + cinnamon + vitamin D), sample C (whole wheat flour), and sample D (whole wheat flour + cinnamon + vitamin D). Lowercase letters indicate significant statistical differences within the column. Data are expressed as mean ± SD.

Textural Characteristics

Figure 1 presents the results of texture analysis for the different biscuit formulations, thereby providing insight into the impact of each variable on the hardness of the final product. According to the physical properties measured, sample A exhibited the highest hardness value (1125.55 g), which can be attributed to the higher gluten content of refined wheat flour, leading to increased structural strength and firmness. In contrast, sample C exhibited lower hardness (603.79 g) compared with sample A. This reduction may be related to the higher dietary fiber content of whole wheat flour, which can interfere with gluten network formation and reduce dough cohesiveness, ultimately decreasing the hardness of the final product. Similar effects of flour type on the texture of baked products have been reported in previous studies. These findings are consistent with previous studies addressing the effect of different types of flour on the texture of baked goods. Similarly, the incorporation of cinnamon and vitamin D further reduced biscuit hardness compared with the corresponding control formulations, suggesting that these ingredients contributed to a softer biscuit structure. This effect may be explained by the ability of cinnamon polyphenols to modify protein–carbohydrate interactions, thereby weakening the structural network, while vitamin D may also influence the organization of protein and carbohydrate components during baking (Dabija and Păiuș, 2016; Pauly et al., 2013; Tarancón et al., 2014). Numerous studies have evaluated the effects of flour type and additives on the physical properties of biscuits. For example, the physical, chemical, sensory, and rheological properties of biscuits prepared with whole wheat flour have been investigated in several works, as well as the effects of cinnamon on sensory and textural characteristics (Ahmadi et al., 2013). However, the extent of each parameter's influence depends on the concentration and type of ingredients used, the baking conditions, and other formulation factors. Moreover, the higher dietary fiber content of whole wheat flour increases water absorption, resulting in biscuits with relatively higher moisture content than those produced from refined wheat flour. Because the three-point bending test reflects the structural integrity of the biscuit, this higher moisture content may contribute to reduced fracture strength and, consequently, lower hardness (Agrahar-Murugkar et al., 2015).

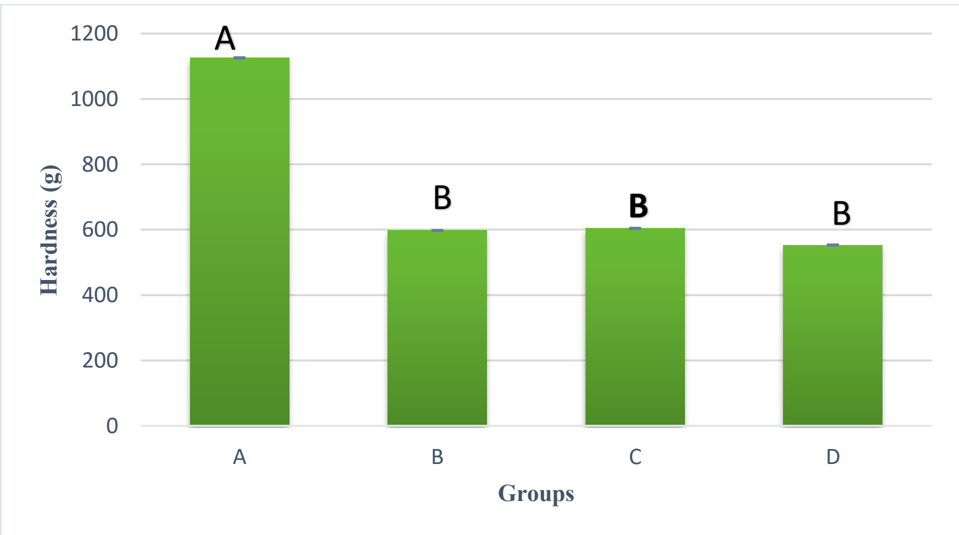

Figure 1. Textural analysis of biscuit samples (mean ± SD). **Sample description:** sample A (refined wheat flour), sample B (refined wheat flour + cinnamon + vitamin D), sample C (whole wheat flour), and sample D (whole wheat flour + cinnamon + vitamin D).

Sensory Characteristics

Sensory evaluation of color, odor, texture, taste, and overall acceptability was conducted by 12 panelists. Statistical analysis of the data was performed using one-way analysis of variance (One-Way ANOVA), and differences were considered statistically significant at $P < 0.05$ .As shown in Table 3, the highest mean score for color was recorded for sample A, while sample C exhibited the lowest mean value. However, one-way analysis of variance (ANOVA) revealed no statistically significant differences among the mean color scores of the four biscuit samples. This finding suggests that the addition of cinnamon and vitamin D, as well as the substitution of refined wheat flour with wholemeal flour, did not significantly influence the visual appearance of the biscuits as perceived by the panelists. Regarding aroma, significant differences were observed among the biscuit formulations. Sample B exhibited the highest aroma score, which can be attributed to the characteristic volatile compounds of cinnamon that enhance the aromatic quality of bakery products. The absence of a significant difference between samples B and D further suggests that the use of wholemeal flour did not adversely affect the positive aromatic contribution of cinnamon. This observation is consistent with previous findings highlighting the beneficial effect of cinnamon on the aroma of food products (Sahan et al., 2013). For texture, sensory assessment indicated that sample A had the highest mean score, while sample C had the lowest. Nevertheless, one-way ANOVA confirmed that there was no statistically significant difference among the mean texture scores of the four biscuit samples. The similarity in texture scores indicates that the formulation modifications did not adversely affect the sensory perception of texture, possibly because the standardized processing conditions maintained comparable structural characteristics among the biscuit formulations. Taste was significantly influenced by the incorporation of wholemeal flour. The characteristic flavor profile of wholemeal flour, including pronounced cereal notes and slight bitterness, may explain the lower sensory preference for this formulation (Fadel et al., 2019). In contrast, cinnamon fortification appeared to moderate these sensory limitations without negatively affecting taste perception .Overall acceptability reflected the combined influence of the individual sensory attributes. Although wholemeal flour improved the nutritional quality of the biscuits, its characteristic flavor reduced consumer acceptance. Conversely, cinnamon fortification enhanced sensory perception and helped maintain the overall acceptability of fortified biscuits at a level comparable to that of refined wheat flour biscuits. This finding agrees with previous studies reporting that cinnamon improves sensory quality, whereas wholemeal flour may reduce consumer preference because of its characteristic flavor profile (Gómez et al., 2020). Overall, the sensory evaluation demonstrated that cinnamon fortification improved aroma while maintaining the overall acceptability of the biscuits. Although wholemeal flour provides important nutritional advantages, its characteristic flavor profile may reduce consumer preference. Nevertheless, incorporating cinnamon into wholemeal biscuits partially compensated for these sensory limitations, indicating that an appropriate combination of functional ingredients can improve product acceptability while preserving the nutritional benefits of wholemeal flour.

Table 3. Sensory evaluation results for biscuit samples.

Sample	Color	Smell	Texture	Taste	General acceptability
A	7.41 ± 1.44^{A}	6.25 ± 2.09^{AB}	6.75 ± 1.66^{A}	6.16 ± 1.90^{A}	6.33 ± 1.56^{A}
B	6.58 ± 1.44^{A}	7.33 ± 1.23^{A}	6.50 ± 1.57^{A}	7.33 ± 1.78^{A}	6.83 ± 1.34^{A}
C	6.00 ± 1.76^{A}	5.16 ± 1.47^{B}	5.41 ± 1.78^{A}	4.41 ± 1.44^{B}	4.92 ± 1.56^{B}
D	6.41 ± 1.68^{A}	6.41 ± 1.98^{AB}	5.91 ± 1.73^{A}	6.41 ± 1.38^{A}	6.42 ± 1.38^{A}

Sample description: sample A (refined wheat flour), sample B (refined wheat flour + cinnamon + vitamin D), sample C (whole wheat flour), and sample D (whole wheat flour + cinnamon + vitamin D), Data are expressed as Mean ± SD.

Conclusion

This study successfully developed and characterized biscuits prepared from refined and whole wheat flour, fortified with vitamin D and enriched with cinnamon. Cinnamon contributed to the sensory characteristics of the biscuits while serving as a functional ingredient. Although cinnamon significantly influenced biscuit color and slightly affected hardness, these changes were generally acceptable. Nutritional analysis confirmed successful vitamin D fortification, with Groups B and D exhibiting the highest vitamin D content per serving and the highest overall sensory acceptability, indicating a favorable balance between fortification and product quality. These findings demonstrate the feasibility of developing nutritionally enhanced biscuits as a promising vehicle for vitamin D fortification and highlight their potential application as functional bakery products. However, further studies are required to evaluate vitamin D bioavailability, long-term stability of physicochemical and sensory attributes under different storage conditions, consumer acceptance in larger populations, and clinical efficacy before broader public health implications can be established.

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تولید بیسکویت‌های غنی‌شده با ویتامین D و دارچین: ارزیابی بافت، ویژگی‌های حسی و رنگ

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چکیده

هدف این پژوهش، فرمولاسیون و ارزیابی بیسکویت‌هایی بر پایه آرد کامل و آرد سفید، با غنی‌سازی ویتامین D و دارچین، با تأکید بر بهبود ارزش تغذیه‌ای و خصوصیات حسی، به‌ویژه برای افراد مستعد ابتلا به میگرن بود. بدین منظور، چهار گروه بیسکویت با ترکیبات متفاوت شامل آرد سفید و کامل، همراه با یا بدون دارچین (0/6 گرم در هر بیسکویت) و ویتامین D (666 واحد بین‌المللی در هر بیسکویت) تولید شد. برای جبران کاهش احتمالی ویتامین D در فرآیند پخت، دوز مصرفی آن به‌طور مناسب تنظیم گردید. آنالیزها شامل اندازه‌گیری ویتامین D به روشLC/MS ، تعیین شاخص‌های رنگ (L*, a*, b*) با تصویربرداری دیجیتال و تحلیل بافت با آزمون خمشی سه نقطه‌ای بود. ارزیابی حسی با استفاده از مقیاس هدونیک ۹ نقطه‌ای توسط ۱۲ ارزیاب آموزش‌دیده صورت گرفت و داده‌ها با آزمون‌های آماری ANOVA و t-testتحلیل شدند. نتایج نشان داد غنی‌سازی با ویتامین D و دارچین، موجب کاهش میزان روشنایی(L*) ، افزایش قرمزی (a*) و زردی (b*) بیسکویت‌ها گردید. همچنین سختی بافت در نمونه‌های غنی‌شده به‌طور معناداری کاهش یافت. از نظر پذیرش حسی، بالاترین امتیاز کلی برای بیسکویت‌های غنی‌شده (نمونه‌های آرد سفید و کامل) ثبت شد و کمترین امتیاز مربوط به نمونه شاهد آرد کامل بود. ارزیابی پایداری نشان داد بیش از ۹۷ درصد ویتامین D پس از ۶۰ روز نگهداری در شرایط محیطی، باقی مانده است. در مجموع، غنی‌سازی همزمان بیسکویت‌ها با ویتامین D و دارچین، ضمن حفظ پایداری ریزمغذی، باعث بهبود مطلوب ویژگی‌های حسی محصول شد. این راهکار می‌تواند روشی مؤثر برای تولید محصولات عملکردی غنی از نظر تغذیه‌ای و قابل پذیرش برای گروه‌های در معرض خطر کمبود ریزمغذی‌ها باشد.