Future Foods 12 (2025) 100760

Contents lists available at ScienceDirect

Future Foods

journal homepage: www.elsevier.com/locate/fufo

Substituting soft wheat flour with field bean (*Vicia faba* L. var. *minor*) flour varying in Tannin Content: assessing impacts on nutritional, physical, and sensory characteristics of cookies

Khalil Khamassi [a], Hayet Ben Haj Koubaier [b], Riccardo Primi [c,*], Pier Paolo Danieli [c], Raffaello Spina [c], Mustapha Rouissi [d], Rayda Ben Ayed [e,f], Fatma Gueddiche [a,b], Mohsen Hanana [f], Chokri Messaoud [g], Moncef Chouaibi [h]

[a] *Institut National de la Recherche Agronomique de Tunisie, Field Crop Laboratory (LR16INRAT02), University of Carthage, Rue Hédi Karray, 1004 Menzah 1, Tunis, Tunisia*
[b] *Food Technology Department, Laboratory of Innovation and Valorization for a Sustainable Food Industry, Higher School of Food Industries of Tunis, University of Carthage, Avenue Alain Savary 58, 1003 Tunis, Tunisia*
[c] *Department of Agricultural and Forest Sciences, University of Tuscia, Via S. C. de Lellis snc, 01100 Viterbo, Italy*
[d] *Institut National de la Recherche Agronomique de Tunisie, Agricultural Applied Biotechnology Laboratory (LR16INRAT06), University of Carthage, Rue Hédi Karray, 1004 Menzah 1, Tunis, Tunisia*
[e] *Department of Agronomy and Plant Biotechnology, National Institute of Agronomy of Tunisia (INAT), University of Carthage, Tunis, Tunisia*
[f] *Laboratory of Extremophile Plants, Centre of Biotechnology of Borj-Cédria, B.P. 901, 2050, Hammam Lif, University of Carthage, Tunis, Tunisia*
[g] *Laboratory of Nanobiotechnology and Valorisation of Medicinal Phytoresources, University of Carthage, National Institute of Applied Science and Technology, Tunis, Tunisia*
[h] *Food Engineering and Basic Science Department, Higher School of Food Industries, University of Carthage, 58 Av. Alain Savary El Khadra, Tunisia*

A R T I C L E I N F O

Keywords:
Field bean flour
Wheat substitution
Protein enrichment
Antioxidant properties
Sensory evaluation

A B S T R A C T

This study explores the use of field bean (*Vicia faba* L. var. *minor*) flour as a sustainable alternative to soft wheat flour in cookie production. Two Tunisian varieties—Bachaar (high tannin) and Zaher (tannin-free)—were incorporated at 40% and 100% wheat flour substitution levels to assess their effects on the nutritional, physical, and sensory properties of cookies. Substitution with field bean flour increased protein content by up to 26% (from 9.8% in wheat-based cookies to 12.3–13.7%), and antioxidant activity was enhanced significantly, particularly in high-tannin formulations (e.g., DPPH inhibition increased from 24% in control cookies to 81% in 100% Bachaar cookies). However, higher substitution levels also impacted texture, reducing crispness and altering flavor. Sensory evaluation highlighted a slight bitterness in high-tannin formulations and a mild almond-like aftertaste that intrigued panelists. Results showed that cookies with 40% substitution retained good consumer acceptance, while formulations with 100% substitution required optimization. Despite these challenges, the potential of field bean flour as a protein-rich, gluten-free ingredient is evident, offering both nutritional benefits and environmental sustainability.

1. Introduction

Pulses, long consumed worldwide, have recently gained renewed attention for their nutritional (Hall et al., 2017), health (Willett et al., 2019), and environmental benefits (Ferreira et al., 2021; Stagnari et al., 2017), as well as their potential to meet future food demand (Sim et al., 2021; Rajpurohit and Li, 2023). They help address chronic diseases such as obesity, coronary heart disease, and diabetes (Willett et al., 2019), offer gluten-free options for coeliac individuals (Foschia et al., 2016), and provide 15–30 g protein/100 g dry matter (Hall et al., 2017). Pulses also supply carbohydrates (6–62 % dry mass), mono- and poly-unsaturated fatty acids, dietary fibre, B-group vitamins, minerals, and

* Corresponding author at: Department of Agricultural and Forest Sciences, University of Tuscia, Via S. C. de Lellis snc, 01100 Viterbo, Italy.
E-mail addresses: khamassi.khalil@inrat.ucar.tn (K. Khamassi), hayet.benhajkoubaier@esiat.ucar.tn (H.B.H. Koubaier), primi@unitus.it (R. Primi), danieli@unitus.it (P.P. Danieli), raffaello.spina@unitus.it (R. Spina), mustapha_rssi@yahoo.fr (M. Rouissi), raydabenayed@yahoo.fr (R.B. Ayed), fatma.guediche@gmail.com (F. Gueddiche), mohsen.hnana@cbbc.rnrt.tn (M. Hanana), chokri.messaoud@cbbc.rnrt.tn (C. Messaoud), moncef.chouaibi@esiat.ucar.tn (M. Chouaibi).

https://doi.org/10.1016/j.fufo.2025.100760
Received 25 June 2025; Received in revised form 26 August 2025; Accepted 14 September 2025
Available online 15 September 2025

bioactive compounds with antioxidant potential (Multari et al., 2015; Hall et al., 2017; Chorężiak et al., 2025).

Among pulses, faba bean (*Vicia faba* L.) is valued for its adaptability, low production costs, and soil improvement (Sim et al., 2021; Parisi et al., 2020; Hadou el Hadj et al., 2022; Karkanis et al., 2018). In 2023, broad beans (*V. faba* var. *major*) and horse beans (*V. faba* var. *equina*) were grown in 55 countries, producing 1.6 million tonnes of green seeds and 6 million tonnes of dry seeds (FAO, 2023). The small-seeded *V. faba* var. *minor* (field bean) contains up to 33.7 g protein/100 g dry matter (Jezierny et al., 2011), moderate dietary fibre (Mayer Labba et al., 2021), minerals such as iron and zinc (Lovegrove et al., 2023), and bioactive compounds including phenolics, saponins, and l-DOPA (Martineau-Côté et al., 2022). It is mainly used for animal feed, although some varieties are also used for human consumption.

Despite its promising nutritional profile, the use of field bean in human food is limited by antinutrients such as lectins, trypsin inhibitors, saponins, phytates, raffinose-family oligosaccharides, vicine, and convicine—the latter associated with favism in susceptible individuals (Mayer Labba et al., 2021; McKay, 1992). Sensory drawbacks, including beany, earthy, bitter, or rancid notes, arise from volatile compounds, processing-related reactions, and condensed tannins (Oomah et al., 2014; Roland et al., 2017; Duc et al., 1999), which also contribute to astringency. Low-antinutrient and low-tannin cultivars have been developed to improve sensory quality (Mayer Labba et al., 2021). Moreover, field bean proteins are low in sulfur-containing amino acids (Aghababaei et al., 2025), a limitation mitigable by combining with cereal flours richer in these amino acids (Monnet et al., 2019).

The incorporation of legume flour in cereal-based bakery products has been studied as a strategy to enhance protein and fibre content, though it can affect technological and sensory properties. For example, Singh Sibian and Singh Riar (2021) reported improved protein quality and acceptable sensory scores in cookies made from wheat–kidney bean or wheat–chickpea blends, while Cappa et al. (2020) observed textural and colour changes when *Phaseolus vulgaris* flour was combined with corn starch. Simons and Hall (2018) found gluten-free cookies with 40 % raw pinto bean flour comparable in acceptability to those made with pre-treated beans. Fewer studies have examined broad bean flour, but Rababah et al. (2006) found no sensory issues with 3–12 % substitution, whereas Schmelter et al. (2021) reported increased hardness, darker colour, and variety-dependent flavour at higher substitution levels.

Cookies are an ideal model to evaluate novel flours, as they are widely consumed, simple to formulate, and less dependent on gluten (Foschia et al., 2016). From an industrial perspective, field bean flour—especially from low-tannin cultivars—aligns with market trends toward plant-based, protein- and fibre-enriched foods. However, achieving consistent sensory quality remains challenging. This study evaluates the effects of replacing soft wheat flour with increasing proportions of low- and high-tannin field bean flours in cookies, assessing impacts on nutritional composition, physical characteristics, and sensory properties. The findings aim to guide the development of pulse-enriched bakery products that meet nutritional goals, maintain consumer acceptability, and support sustainability objectives.

2. Materials and methods

2.1. Raw materials

This study examined seeds from two Tunisian varieties of field bean (*Vicia faba* L. var. *minor*): the mostly known and grown cultivar "Bachaar" (FLIP 85_52FB: XS2166), registered by INRAT/ICARDA since 2004 (Anonymous, 2004), known for its high tannin content and sensitivity to broomrape Orobanche spp. (Kharrat et al., 2010), and the new tannin-free variety "Zaher" (XAR-VF00.13–27–2–1–1–4–2–1–1–1). “Zaher” is a novel, broomrape-resistant variety (Thebti et al., 2024) developed by a collaboration between the National Agronomic Research Institute of Tunisia (INRAT) and the Field Crop regional Research Center of Béja (CCRGCBéja). Officially registered in 2019 (COV N°174, JORT N° 17 of 26/02/2019), Zaher represents a significant advancement in agricultural research in Tunisia and the Mediterranean region. Although it is not yet commercially available to farmers, efforts are underway by private seed companies and cooperatives to increase seed production and develop its supply chain. (Fig. 1)

Pure seeds were obtained from the experimental station nursery at the Jendouba Governorate during the 2019–2020 growing season. Harvesting was carried out at full seed maturity (June; grain moisture < 12 %) and dimensional characteristics (length, L, mm; width, W, mm; and thickness, T, mm) were determined on a sample of 20 natural dry seeds for each variety using a BMI 770200 caliper (0.01 mm precision, BMI, Germany). These measurements were used to determine morpho-physical properties (Joshi et al., 1993; Ferruzzi et al., 2009; Khamassi et al., 2021) (Table 1).

2.2. Flour preparation for biochemical analyses

An initial sorting process was implemented to remove any impurities and damaged seeds from the collected batches. After this sorting, a representative sample was selected from each variety for further characterization. Each of these samples was then divided into two portions, and a manual dehulling process was conducted. This process resulted in the separation of each sample into three distinct fractions: teguments (seed coat), dehulled seeds (cotyledons), and whole seeds. For clarity, we introduce the following acronyms: SWF (Commercial soft wheat flour: Ps-7), BS (Bachaar Sample) and ZS (Zaher Sample), followed by a number indicating the fraction type: 1 for whole seed, 2 for seed coat, and 3 for dehulled seed. The detailed classification is presented in S1. The grinding process was carried out on the various samples of *Vicia faba* L. using a Cyclotec mill (CT 293 Cyclotec™, Germany) equipped with a 250 µm stainless steel sieve. Subsequently, the resulting flours were carefully stored in glass jars at room temperature. The SWF was purchased from the market and is known as PS-7 wheat flour.

2.3. Composite flour mixing and gluten analysis

The cotyledons (dehulled seeds) and whole seed faba bean flour of both *Vicia faba* respective variety and cultivar ZS and BS were used to produce individual mixtures containing 10, 20, 30, 40 and 100 % replacement levels (S2). All samples were stored in airtight containers and kept at 3–4 °C until required. Faba bean (0, 10, 20, 30, 40 and 100 %) flour was added to the commercial standard wheat flour (Ps-7).

2.3.1. Extraction and determination of wet gluten and dry gluten

Gluten content was determined according to the wet gluten method described by Popovska (2023) and Bah et al. (2024), following the ISO standard procedure with slight modifications. Briefly, 33.33 g of flour were mixed with 17 mL of water and kneaded to form a sticky dough ball. The dough was then washed under running water until starch and soluble components were completely removed. The remaining gluten mass was weighed to determine the wet gluten content, expressed as a percentage of the flour mass, in accordance with ISO 21,415–1:2007.

The wet gluten content (WG, %) was calculated as:

$$WG\ (\%) = \frac{W_{db}}{E} \times 100$$

where w_{db} is the weight of the wet gluten (g), and E is the sample weight (g).

For the determination of dry gluten content, the wet gluten was dried at 120 °C until a constant weight was achieved (approx. 2 h), and the result was expressed as a percentage of the flour mass, following ISO 21,415–4:2007.

The dry gluten content (DG, %) was calculated as:

Fig. 1. Appearance of the *V. faba* L. var. *minor* seeds used in this study. Varieties A: Zaher (tannin-free) and B: Bachaar (high tannin content).

Table 1
Morpho-physical parameters of seeds considered and related calculation formulas.

Trait	Abbrev.	Formula*
Arithmetic diameter means (mm)	Ad	Ad = $(L + W + T)/3$
Geometric diameter means (mm)	Gd	Gd = $(L * W * T)^{1/3}$
Sphericity (%)	Φ	Φ = (Gd/L) * 100
Elongation	E	$E = L/W$
Degree of flattening	A	$A = W/T$
Aspect ratio (%)	Ra	Ra = (W/L) * 100
Volume (mm^3)	V	$V = (\pi/6) * Gd^3$
Surface area (mm^2)	Sa	$Sa = \pi * Gd^2$

* L = seed length; W = seed width; T = seed thickness.

$$DG\ (\%) = \frac{W_{ddb}}{E} \times\ 100$$

Where w_{ddb} is the weight of the dried gluten (g), and E is the sample weight (g)

2.4. Cookies preparation

The cookies were prepared using refined commercial white soft wheat flour (PS-7), either entirely or with partial substitution by faba bean flour, as specified in Table 2. In total, five batches of cookies (C1-C5) were prepared for each different proportion of replacement of wheat flour with faba bean fractions based on flour gluten content results.

The biscuit recipe was adopted from Vasanthakumari and Jaganmohan (2018) with minor modifications. First, 80 g of butter was mixed with 80 g of ground sugar in a stand mixer (Kenwood KMix KMX750, France) for 3 min at approximately 80 rpm. Subsequently, egg powder (13 g), baking powder (1 g), and salt (1 g) dissolved in 40 g of water were added and thoroughly mixed. The 150 g flour mixture (C1-C5) was then incorporated into the dough. After mixing, the dough was rolled out to a thickness of 4 mm and cut into circular shapes of 4 cm in diameter. The cookies were baked in an oven (Brandt FC55MUB, France) at 170 °C for 15 min, then allowed to cool for one hour, sealed in polyethylene zipper bags, and stored at room temperature until analysis.

Table 2
Cookies flour composition.

Cookie type	Mixing ratios between flours
C1	40 % whole seed Bachaar bean flour (BS1) + 60 % soft wheat flour
C2	40 % whole seed Zaher bean flour (ZS1) + 60 % soft wheat flour
C3	100 % soft wheat flour
C4	100 % whole Bachaar bean flour (BS1)
C5	100 % whole Zaher bean flour (ZS)

2.5. Physicochemical analyses of flour and cookies

Soft wheat and faba bean raw flours, as well as ground cookie powders, were analyzed for moisture (AACC, 1999a; method 44–15.02), protein (AACC, 1999b; method 46–10), fat (AACC, 1999c; method 30–25), and ash (AACC, 1999d; method 08–01). All measurements were conducted in triplicate. Additionally, the assessment of total polyphenols, flavonoids, and tannin contents was performed according to the following procedures.

2.5.1. Extract preparation

Polyphenols were extracted following the procedure of Kahlaoui et al. (2022), with minor modifications. Briefly, 1 g of flour or cookie sample was mixed with 10 mL of purified methanol (99.8 %, HPLC gradient grade; Loba Chemie Pvt. Ltd, Mumbai, India) and incubated at ~25 °C (ambient room temperature) for 24 h on a KS501 digital orbital shaker (IKA Labortechnik, Germany) operating at 60 rpm. The mixtures were then centrifuged at 2800 × g for 10 min at 4 °C using an R260 refrigerated centrifuge (MPW Med. Instruments, Poland). Supernatants were collected, filtered through 0.45 µm nylon membrane syringe filters (Captiva Premium, 25 mm diameter, Agilent, USA), and transferred into amber glass vials. Extracts (Ext_A) were stored at –18 °C until analysis. All extractions were carried out in triplicate to ensure reproducibility.

2.5.2. Total phenolic content (TPC)

The quantification was done colorimetrically using the Folin–Ciocalteu reagent following Barbosa-Pereira et al. (2018). A 100 µL aliquot of the diluted extract (Ext_A) (1:5, v/v) was added to 400 µL of 10 % Folin–Ciocalteu reagent (Sigma-Aldrich, St. Louis, MO, USA). After 5 min incubation in the dark, 500 µL of 7.5 % sodium carbonate (Sigma-Aldrich, St. Louis, MO, USA) solution was added, and the mixture was incubated for 90 min at room temperature (~25 °C) in the dark. Absorbance was measured at 765 nm using a Jenway UV–Visible Spectrophotometer (Jenway, UK). A standard curve with gallic acid (Sigma-Aldrich, St. Louis, MO, USA) (20–100 mg/mL) was used to calculate total phenolic content, expressed as mg gallic acid equivalents per gram of dry matter (mg GAE/g DM).

2.5.3. Total flavonoids content (TFC)

The determination of total flavonoid content (TFC) involved a colorimetric method with slight modifications, in line with the procedure outlined by Chaieb et al. (2011). Aliquots (500 µL) of extracts (Ext_A) were mixed with 500 µL of 2 % $AlCl_3 \cdot 6H_2O$ (Sigma-Aldrich, St. Louis, MO, USA) solution. The mixture was allowed to stand for 30 min in the dark at room temperature. Absorbance was recorded at 430 nm. TFC was determined from a standard rutin (Sigma-Aldrich, St. Louis, MO, USA) curve (0.5–10 mg/mL; $y = 0.0076x + 0.0355$) and expressed as rutin-equivalent (RE) per gram of dry weight of sample (mg RE/g DM).

2.5.4. Tannin content (TC)

The tannin content was determined following the modified method of Akkad et al. (2019). 100 µL of extracts (Ext_A) were added to 600 µL of vanillin (2 %) and 300 µL of HCl (12 M) then kept in obscurity at room temperature for 15 min. The absorbance was measured at 500 nm with a spectrophotometer (Jenway, UK). Catechin at various concentrations (0.1–1 mg/mL) was used as a standard. TC was expressed as catechin-equivalent (CE) per gram of dried sample (mg CE/g DM).

2.5.5. Antioxidant activity

Briefly, the antioxidant capacity of the flour extracts was evaluated using the DPPH and $ABTS^{•}$ radical scavenging assays, following the modified procedures described by Ben Said et al. (2025), Li et al. (2015), and Marathe et al. (2011).

The decrease in DPPH (Sigma-Aldrich, St. Louis, MO, USA) and $ABTS^{+}$ (Sigma-Aldrich, St. Louis, MO, USA) absorbances was measured at 517 and 734 nm, respectively. All assays were conducted in triplicate. The antioxidant capacity was calculated as the inhibition percentage (IP) of the DPPH and $ABTS^{+}$ radicals as follows:

$$IP(\%) = 100 \times \frac{(A_{control} - A_{sample})}{A_{control}}$$

where $A_{control}$ and A_{sample} were the absorbance of blank and sample extract at 30 min, respectively.

A standard curve of Trolox (Sigma-Aldrich, St. Louis, MO, USA) (0.5–2.5 mM; $y = 0.16x - 9.354$) was used to determine the radical-scavenging activity, and the results were expressed as milligrams equivalent of Trolox per gram of dry sample (mg $Trolox_{eq}$/g DM).

The antioxidant capacity (CA) of each extract was expressed in mg vitamin C equivalent/g of dry matter ($VitC_{\mathbf{eq}}$/g DM) by referring to the vitamin C (Sigma-Aldrich, St. Louis, MO, USA) calibration curve ($y = 1.018x + 0.546$).

2.5.6. Textural characteristics of cookies

The textural properties of cookies were evaluated using a texture analyzer (Perten TVT 6700; Perten Instruments, Hägersten, Sweden) equipped with TexCalc software. Texture was assessed by uniaxial penetration tests, generating force–distance curves for each sample. Tests were carried out with a cylindrical stainless-steel probe (model P-CY05S; diameter: 5 mm). The probe descended at a pre-test speed of 1 mm/s, followed by a penetration speed of 2 mm/s, until reaching a depth of 10 mm. A constant load of 50 g was applied during penetration. From the force–distance curves, the maximum force (Fmax) was determined and taken as the measure of cookie strength, corresponding to the hardness parameter commonly reported in cookie texture studies. Three replicate measurements were performed for each sample to ensure reproducibility. All tests were conducted under controlled laboratory conditions at room temperature (25 ± 2 °C), with cookies analyzed within 24 h of baking. For each flour preparation, samples were made in triplicate for this experiment.

2.5.7. Rheologic characteristics of flours

The dough mixing and alveographic properties of the wheat/faba bean flour blends were evaluated using a farinograph and an alveograph (Brabender, Germany). From the farinograph curves, two key parameters were determined: water absorption (WA), expressed as the percentage of water required to obtain a dough with a consistency of 500 Brabender Units BU, and dough development time (DDT), defined as the time needed to reach maximum consistency.

The alveograph provided additional parameters describing dough viscoelasticity. These included: extensibility (L), the maximum length (mm) the dough can stretch before breaking; maximum overpressure (P), the highest pressure (mm) needed to inflate the dough bubble until rupture, representing resistance to extension; and the swelling index (G), calculated as the square root of the volume of air needed to inflate the bubble until it bursts. The baking strength (W), or deformation energy, reflects the overall work needed to expand the dough and is an indicator of baking performance. Finally, the P/L ratio describes the curve configuration and indicates dough stability, serving as an index of gluten performance and dough behavior during mixing and baking.

2.5.8. Sensory characterization

A total of twenty-five trained panelists evaluated the cookies for sensory attributes, including color, odor, texture, taste, and overall quality, using a 5-point hedonic scale ranging from 1 (“dislike extremely”) to 5 (“like extremely”). The use of trained panelists in this preliminary assessment ensured consistency, reliability, and a more controlled evaluation of the samples (Djekic et al., 2021). Applying a hedonic scale with trained assessors allowed for a qualitative comparison between formulations. Nevertheless, we acknowledge that future studies should include a larger consumer panel to better capture actual consumer preferences. The sensory evaluation was conducted in accordance with the ethical standards for research involving human participants. All panelists participated voluntarily, provided informed verbal consent, and were informed about the study’s purpose and procedures. No personal data was collected or shared, and participants were free to withdraw at any time. According to current national regulations in Tunisia, where the sensory analysis was conducted, this type of research is exempt from ethical committee approval.

2.5.9. Evaluation of geometric properties of cookies

The geometric characteristics of cookies (diameter, thickness, weight, and spread ratio) were analyzed based on penetration test using a TVT 6700 texture analyzer linked to TexCalc software (Perten Instruments, Sweden) were determined according to the AACC methods 10–05.01, 10–50.05, and 10–52.01 respectively standards (AACC, 1999e,f,g).

2.6. Statistical analysis

Two-way analysis of variance (ANOVA) was performed in the R environment (R Project for Statistical Computing, version 2.0.0) using functions from the ‘*tidyverse*’ package, applied to biochemical, phytochemical, and antioxidant property datasets. Additionally, one-way ANOVA was used to evaluate the statistical significance of differences in morpho-physical seed characteristics and the percentage decrease in dry and humid gluten in various fractions following the addition of faba bean flour, using Statistix v8.0 (Analytical Software, Florida, USA). For both analyses, mean comparisons were conducted using Fisher’s LSD post hoc test, with results expressed as mean ± standard deviation.

3. Results and discussion

3.1. Morpho-physical characteristics of seeds

Table 3 summarizes the mean values of the axial dimensions of the seeds. The analysis of variance showed significant differences between the two evaluated varieties across all parameters. Specifically, seed length (L), width (W), and thickness (T) exhibited significant variations

Table 3
Morpho-physical characteristics (mean ± SD) of the Var. Bachaar (high tannin content) and Zaher (tannin free) faba bean seeds.

Traits[1]	Bachaar	Zaher
L (mm)	10.20 ± 0.95^{B}	15.00 ± 1.50^{A}
W (mm)	8.35 ± 0.98^{B}	10.15 ± 0.67^{A}
T (mm)	5.90 ± 0.71^{B}	7.05 ± 0.50^{A}
Ad (mm)	8.15 ± 0.57^{B}	10.73 ± 0.72^{A}
Gd (mm)	7.93 ± 0.56^{B}	10.22 ± 0.63^{A}
Φ (%)	68.51 ± 4.58^{B}	78.01 ± 5.00^{A}
E	1.22 ± 0.08^{B}	1.49 ± 0.19^{A}
A	1.75 ± 0.20^{B}	2.14 ± 0.29^{A}
Ra	0.68 ± 0.05^{B}	0.82 ± 0.08^{A}
V (mm^3)	264.9 ± 52.3^{B}	564.3 ± 104.4^{A}

[A, B]Different letters indicate means Least significant differences (LSD test) at $P < 0.05$.

[1] L = seed length; *W* = seed width; *T* = seed thickness; Ad = arithmetic diameter; Gd = geometric diameter; Φ = average index of sphericity; *E* = elongation; *A* = flattening; Ra = aspect ratio; *V* = seed volume.

($P < 0.05$), differing by 4.80, 1.80, and 1.15 mm, respectively. The variety Zaher exhibited higher values, with its seeds being longer, wider, and thicker compared to Bachaar. Additionally, Zaher seeds displayed greater arithmetic (Ad) and geometric (Gd) diameters than those of Bachaar.

These axial measurements allowed for the assessment of seed shape based on parameters such as flattening (A), elongation (E), the average sphericity index (Φ), and aspect ratio (Ra). The analysis of variance for these shape metrics indicated highly significant differences between the varieties ($P < 0.001$) across all parameters. Notably, the Zaher variety demonstrated a higher elongation value (+22 %) than Bachaar, alongside increased A (+22 %), Φ (+14 %), and Ra (+21 %) values. As a result, Zaher seeds tend to exhibit a more oblong shape.

The sphericity index is particularly informative regarding the tendency of faba bean seeds towards a spherical shape. Zaher seeds were more spherical, with a higher average sphericity index (78.01 %) compared to Bachaar seeds (68.51 %). Understanding sphericity is crucial for designing transportation, storage, and processing equipment for seeds. Previous studies have shown that seeds with higher sphericity tend to roll rather than slide during transport, which improves handling in industrial machinery (Karolkowski et al., 2023; Ferruzzi et al., 2009).

3.2. Biochemical analyses of bean flour

Biochemical characterization was conducted on flour from whole seeds, as well as from cotyledonary and seed coat fractions (see S1). The analysis of variance (Table S3) for these biochemical properties showed significant differences among the evaluated samples ($P < 0.001$), except for the ash content that was not significant ($P > 0.05$).

3.2.1. Moisture content

Moisture content differed significantly among samples (Table 4), with whole seeds showing higher values (10.98–11.55 %) than other seed components. This pattern is consistent with Mayer Labba et al. (2021), who reported similar differences between hulled and dehulled seeds of zero- and high-tannin faba bean cultivars, likely reflecting the higher water-holding capacity of the intact seed matrix.

Table 4
Chemical properties (mean ± SD) of different samples of faba bean flour (g/100 g DM).

Flour type[1]	Moisture	Ash	Fat	Protein
BS1	10.91 ± 0.02^{B}	2.81 ± 0.56	1.11 ± 0.01^{B}	22.74 ± 0.02^{B}
BS2	10.44 ± 0.01^{C}	2.23 ± 0.01	0.29 ± 0.01^{D}	3.86 ± 0.01^{C}
BS3	11.55 ± 0.31^{A}	2.84 ± 0.56	0.93 ± 0.02^{C}	26.02 ± 0.02^{A}
ZS1	10.69 ± 0.01^{B}	2.76 ± 0.79	1.22 ± 0.01^{B}	23.75 ± 0.01^{B}
ZS2	9.56 ± 0.09^{B}	2.22 ± 0.01	0.34 ± 0.06^{D}	3.92 ± 0.01^{C}
ZS3	10.98 ± 0.13^{B}	2.81 ± 0.79	1.45 ± 0.08^{A}	26.47 ± 0.03^{A}

[1] BS1 = Bachaar, whole seed; BS2 = Bachaar, seed coat; BS3 = Bachaar, dehulled seed (cotyledons); ZS1 = Zaher, whole seed; ZS2 = Zaher, seed coat; ZS3 = Zaher, dehulled seed (cotyledons). Different letters indicate means Least significant differences (LSD test) between flours types at $P < 0.05$.

3.2.2. Ash content

Ash content did not differ significantly between the two faba bean varieties (2.22–2.84 %; Table 4). These values align with previous reports showing comparable ash levels in seeds with and without tannins (Duc et al., 1999; Schmelter et al., 2021; Roland et al., 2017). The consistency across studies suggests that tannin presence has little influence on mineral residue content, regardless of seed form or processing.

3.2.3. Fat content

Fat content varied significantly among samples (Table 4), with teguments showing the lowest values, shelled seeds intermediate levels, and whole seeds the highest. All values remained below 1.5 %, consistent with earlier reports for faba bean (Roland et al., 2017; Duc et al., 1999), reflecting the inherently low lipid content of this species.

3.2.4. Protein content

Protein content varied significantly among samples (Table 4), with cotyledons showing the highest values, followed by whole seeds, and teguments the lowest. This confirms faba bean as a good protein source, although levels differ with variety and seed fraction. The observed range is consistent with previous findings for both tannin-free and high-tannin cultivars (Roland et al., 2017; Duc et al., 1999), highlighting that protein distribution is concentrated in the cotyledons rather than in the seed coat.

3.3. Phytochemical and antioxidant characterization of bean flour

The analysis of variance for all the phytochemical and antioxidant traits investigated revealed the existence of a highly significant difference between the different samples evaluated ($P < 0.001$) (Table S4).

3.3.1. Polyphenol, flavonoid and condensed tannin content

Phenolic composition showed a consistent pattern across all measured compounds (Table 5). Total polyphenols were markedly higher in the seed coats of the high-tannin variety (49.16 mg GAE/g DM) compared with all other fractions (1.57–3.38 mg GAE/g DM), with whole seeds and cotyledons also showing higher values than their tannin-free counterparts. Flavonoid content followed the same trend, with seed coats of the high-tannin variety reaching 10.59 mg RE/g DM—over ten times higher than in other fractions (1.55–1.87 mg RE/g DM). Condensed tannins were likewise concentrated in the seed coat (30.33 mg EC/g DM), more than 30-fold greater than in other samples, while whole seeds of the same variety contained only 0.91 mg EC/g DM. These results, consistent with previous studies (Roland et al., 2017; Voisin et al., 2014), confirm that phenolic compounds in faba bean are predominantly localized in the seed coat, explaining both its strong antioxidant potential and its contribution to bitterness and astringency. This distribution has important implications for food formulation: while high phenolic content can enhance functional properties such as antioxidant activity, it may also negatively affect sensory acceptance, particularly in baked products where bitterness and astringency are undesirable. Strategies such as using low-tannin cultivars, partial seed coat removal, or formulation adjustments could help balance nutritional benefits with consumer acceptability in cookie production.

3.3.2. Antioxidant activity

Antioxidant activity differed significantly among samples ($P < 0.001$; Table 5), as measured by DPPH and ABTS assays. Seed coats of the high-tannin variety showed the highest values (19.09 mg VitCeq/g

DM and 121.93 mg Troloxeq/g DM), followed by whole seeds and cotyledons of the same variety, while the tannin-free variety exhibited consistently lower activity across all fractions. This pattern reflects the concentration of bioactive compounds in the seed coat and agrees with previous findings using different methods, such as FRAP (Chaieb et al., 2011), and with studies on radical scavenging activity in faba bean extracts (Boukhanouf et al., 2016). The results confirm that tannin-rich seed coats are the main contributors to antioxidant potential in faba bean, supporting earlier observations that phenolic-rich legume flours, including faba bean, have higher antioxidant activity than cereal flours (Benayad et al., 2021) (Table 5).

3.4. Evaluation of gluten (dry and wet) percentage in different fractions after faba bean flour addition

The analysis of variance (Table S6) for the enrichment with faba bean and raw flour showed significant differences among the evaluated samples ($P < 0.001$) as faba bean flour significantly decreased the percentage of dry and wet gluten.

Table 6 summarizes the pairwise comparison based on the least significant difference at a 5 % p-value (LSD) for both dry and wet gluten contents. The incorporation of faba bean flour from both varieties decreased the levels of dry and wet gluten. This decrease is attributed to the absence of gluten in faba bean flours, which will cause a weakening of the gluten network. Consequently, the composite flours ZS1–10 %, ZS3–10 %, BS1–10 %, and BS3–10 % recorded higher gluten values than those of other mixtures supplemented with high doses of faba bean flours. A 40 % incorporation of faba bean flour, whether from low- or normal-tannin varieties and used as either dehulled or whole seeds, can produce natural composite bread that retains satisfactory technological and sensory quality. These findings align with those of Benayad et al. (2021), who demonstrated that a 40 % supplementation of faba bean flour produced optimal outcomes for making naturally composite bread with low gluten content, while simultaneously preserving satisfactory technological and sensory qualities. Moreover, Coda et al. (2017) reported that a substantial level (30 %) of faba bean flour substitution did not adversely impact the technological performance of faba bean sourdough bread.

3.5. Evaluation of geometric properties of cookies

Fig. 2 displays the appearance of the representative cookies, made of 40 % and 100 % of faba bean flour (with and without tannin) and the reference cookies (100 % soft wheat flour). As expected, the respective color deviation increases with the faba bean flour content. The impact of faba bean flour and tannin is more pronounced compared to wheat flour cookies reference. These results align with those reported by Schmelter et al. (2021), who evaluated the effect of using six faba bean varieties at 50 % and 100 % replacement levels in *V. faba* flour.

The analysis of variance for all the geometric properties of cookies highlighted the existence of a significant difference ($P < 0.05$) between the different samples evaluated: weight ($P = 0.0054$) and thickness ($P < 0.001$) were significantly affected, while diameter ($P = 0.5584$) was not. Table 7 summarizes these three parameters of the different cookies studied samples.

The inclusion of faba bean flour significantly influenced cookie weight and thickness, whereas diameter was unaffected (Table 7). The reference sample (C3, 100 % wheat flour) had the highest values for both parameters, reflecting the well-known baking performance of wheat flour in producing well-expanded cookies. Substituting 40 % of the wheat flour with faba bean flour led to a moderate reduction in weight and thickness, while complete replacement (C4, C5) further accentuated these decreases. These changes can be attributed to the absence of gluten in faba bean flour, which compromises dough structure and gas retention, and to its higher fibre and protein content, which

Table 6
Gluten composition of whole soft wheat flour, whole faba bean flour and their blends (%).

Flour composition	SWF %	FF %	Dry Gluten %	Humid Gluten %
SWF*	100	0	10.38 ± 0.37^{A}	28.55 ± 0.45^{A}
ZS1*	0	100	0.00^{K}	0.00°
BS1*	0	100	0.00^{K}	0.00°
ZS3	90	10	8.06 ± 0.2^{C}	22.74 ± 0.12^{D}
ZS3	80	20	6.09 ± 0.22^{E}	17.04 ± 0.66^{G}
ZS3	70	30	1.55 ± 0.22^{I}	4.25 ± 0.08^{L}
ZS3*	60	40	0.60 ± 0.40^{J}	0.41 ± 0.45°
ZS1	90	10	9.06 ± 0.22^{B}	24.76 ± 0.1^{C}
ZS1	80	20	4.20 ± 0.09^{F}	11.34 ± 0.06^{H}
ZS1	70	30	1.77 ± 0.07^{H,I}	5.10 ± 0.27^{K}
ZS1	60	40	0.69 ± 0.04^{J}	1.89 ± 0.1^{N}
BS3	90	10	9.09 ± 0.17^{B}	26.94 ± 0.14^{B}
BS3	80	20	3.03 ± 0.07^{G}	9.03 ± 0.13^{I}
BS3	70	30	1.53 ± 0.06^{I}	4.28 ± 0.09^{L}
BS3*	60	40	0.71 ± 0.11^{J}	2.08 ± 0.32^{M,N}
BS1	90	10	8.14 ± 0.16^{C}	22.09 ± 0.22^{E}
BS1	80	20	7.00 ± 0.2^{D}	18.56 ± 0.12^{F}
BS1	70	30	2.07 ± 0.06^{H}	5.98 ± 0.23^{J}
BS1	60	40	0.88 ± 0.18^{J}	2.50 ± 0.50^{M}

SWF: whole soft wheat flour (Ps-7); **FF**: whole faba bean flour. NS: not significant ($p < 0.05$) and *: significant ($p < 0.05$) according to LSD's test. 1 BS1 = Bachaar, whole seed; BS3 = Bachaar, inhulled seed (cotyledons), ZS1 = Zaher, whole seed; t, ZS3 = Zaher, inhulled seed (cotyledons). ^{A,B} $P < 0.05$ among the flour types.

[*] Flours used in making experimental cookies.

Table 5
Phytochemical contents and antioxidant properties (mean ± SD) of different flour fractions of faba bean seeds.

Flour type[1]	Total polyphenol (mg GAE/g DM)	Flavonoids (mg ER/g DM)	Tannins (mg EC/g DM)	DPPH		ABTS	
				mg VitC$_{eq}$ /g DM	PI (%)	mg Trolox$_{eq}$ /g DM	PI (%)
BS1	3.38 ± 0.40^{B}	1.87 ± 0.11^{B}	0.91 ± 0.13^{B}	1.96 ± 0.20^{B}	22.85 ± 4.13^{B}	14.90 ± 0.54^{B}	38.32 ± 1.73^{B}
BS2	49.16 ± 6.27^{A}	10.59 ± 0.23^{A}	30.33 ± 0.80^{A}	19.09 ± 0.16^{A}	97.74±0.78^{A}	121.93 ± 3.34^{A}	88.19 ± 2.67^{A}
BS3	2. 59 ± 0.71^{B}	1.56 ± 0.07^{CD}	0.76 ± 0.01^{B}	0.60 ± 0.11^{C}	12.82 ± 4.22^{C}	9.96 ± 0.34^{C}	22.53 ± 1.10^{C}
ZS1	2.58 ± 1.32^{B}	1.60 ± 0.09^{CD}	0.73 ± 0.07^{B}	0.28 ± 0.08^{D}	6.27 ± 1.71^{D}	7.99 ± 0.33^{CD}	16.21 ± 1.04^{D}
ZS2	2.85 ± 0.55^{B}	1.76 ± 0.05^{BC}	0.65 ± 0.01^{B}	0.92 ± 0.04^{B}	19.26 ± 0.90^{B}	7.22 ± 0.18^{CD}	13.75 ± 0.56^{D}
ZS3	1.57 ± 0.19^{C}	1.55 ± 0.05^{D}	0.69 ± 0.14^{B}	0.29 ± 0.05^{D}	6.38 ± 1.04^{D}	7.66 ± 0.34^{D}	15.16 ± 1.09^{D}

^{A,B}P < 0.05 among the flour types.

[1] BS1 = Bachaar, whole seed; BS2 = Bachaar, seed coat, BS3 = Bachaar, inhulled seed (cotyledons), ZS1 = Zaher, whole seed; ZS2 = Zaher, seed coat, ZS3 = Zaher, inhulled seed (cotyledons).

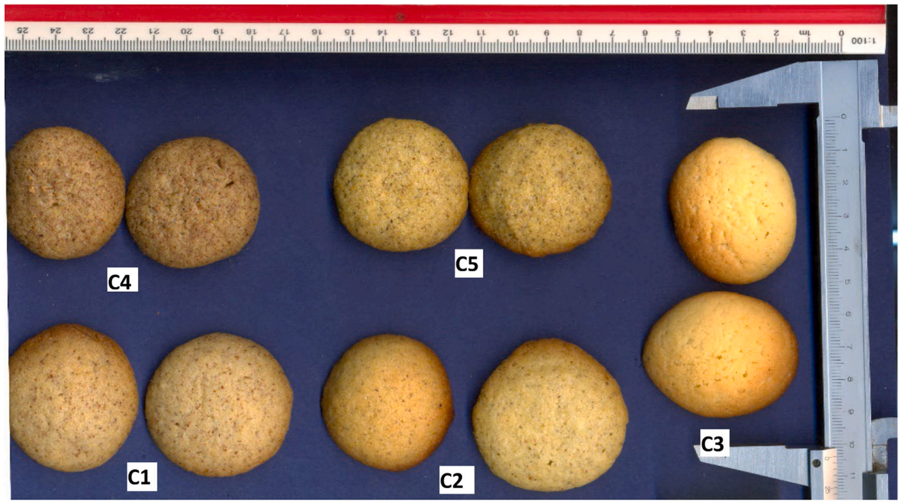

Fig. 2. Appearance of the reference cookie (left) and cookies made by replacing wheat flour as follows: C1: 40 % whole Bachaar bean flour with tannin; C2: 40 % whole Zaher bean flour without tannin + 60 % soft wheat flour; C3: 100 % soft wheat flour; C4: 100 % whole Bachaar bean flour with tannin; C5: 100 % whole Zaher bean flour without tannin.

Table 7
Physical properties (means ± SD) of different samples of cookies. Cookies sharing the same letter in a column are not significantly different at $P < 0.05$.

COOKIE TYPE[1]	WEIGHT (g)	THICKNESS (cm)	DIAMETER (cm)
C1	5.94 ± 0.40ab	1.26 ± 0.05b	4.32 ± 0.24a
C2	4.86 ± 0.94b	1.06 ± 0.09c	4.28 ± 0.54a
C3	6.94 ± 1.22a	1.54 ± 0.05a	4.18 ± 0.52a
C4	4.93 ± 0.57b	1.04 ± 0.09c	3.94 ± 0.40a
C5	5.66 ± 0.83b	1.10 ± 0.07c	4.02 ± 0.31a

[1] C1: 40 % whole Bachaar bean flour with tannins + 60 % soft wheat flour; C2: 40 % whole Zaher bean flour without tannins + 60 % soft wheat flour; C3: 100 % soft wheat flour; C4: 100 % whole Bachaar bean flour with tannin; C5: 100 % whole Zaher bean flour without tannin. a,$b = P < 0.05$ among the cookie's types.

Table 8
Textural properties of different samples of cookies.

COOKIE TYPE[1]	WEIGHT (g)	HEIGHT (cm)	STRENGHT (g)
C1	5.66 ± 0.58^{A}	12.54 ± 0.10^{B}	692.33 ± 13.87^{B}
C2	4.33 ± 0.58^{C}	11.45 ± 0.19^{D}	835.00 ± 130.77^{A,B}
C3	6.00 ± 0.00^{A}	16.1 ± 0.24^{A}	1041.7 ± 152.55^{A}
C4	6.00 ± 0.00^{A}	11.61 ± 0.15^{C,D}	414.33 ± 109.00^{C}
C5	5.00 ± 0.00^{B}	11.87 ± 0.22^{C}	644.67 ± 142.73^{B}

^{A,B} $P < 0.001$ among the cookie types.
[1] C1: 40 % whole Bachaar bean flour with tannins + 60 % soft wheat flour; C2: 40 % whole Zaher bean flour without tannins + 60 % soft wheat flour; C3: 100 % soft wheat flour; C4: 100 % whole Bachaar bean flour with tannins; C5: 100 % whole Zaher bean flour without tannins.

alter water absorption, dough viscosity, and expansion during baking. Despite differences in tannin content, the Bachaar (C1, C4) and Zaher (C2, C5) varieties exhibited similar geometric characteristics at the same substitution levels, suggesting that the extent of replacement is the primary factor influencing these physical parameters.

Some studies have demonstrated, however, that tannins can interact with gluten proteins through hydrogen bonding, altering dough microstructure and consequently influencing expansion, volume, and the overall geometry of baked products; however, the magnitude of these effects can vary depending on tannin concentration, flour type, and processing conditions (Wang et al., 2015; Nam et al., 2025).

3.6. Textural and rheological properties of cookies

3.6.1. Textural properties

Cookie formulation had a clear impact on physical and mechanical properties (Table 8). The control sample (C3, 100 % wheat flour) exhibited the greatest height ($P < 0.001$), confirming the ability of wheat gluten to retain gas and promote dough expansion during baking, which translated into higher volume and a more aerated structure. In contrast, cookies with partial or total substitution by faba bean flour (C1, C2, C4, C5) showed reduced height and, in some cases, lower weight, reflecting the weaker gluten network and the dilution effect caused by the incorporation of legume proteins and fibers.

Breaking strength was highest in the control (C3, 100 % wheat flour) and decreased progressively with the incorporation of faba bean flour, with C2 (40 % Zaher) showing intermediate strength, C1 and C5 (40 % Bachaar and 100 % Zaher, respectively) lower values, and C4 (100 % Bachaar) the lowest. This reduction in strength can be attributed to the absence of gluten in faba bean flour, which weakens the protein network and limits structural cohesion. The higher fibre and protein content of faba bean flour likely also contributed to reduced hardness by altering dough hydration and expansion during baking. These findings are consistent with the weight and thickness results, further confirming that increasing wheat flour replacement leads to less dense and mechanically weaker cookies.

3.6.2. Rheological behavior of dough

The farinograph and alveograph parameters measured are given in Table 9.

The DDT is the time required for the dough to reach maximum consistency after the first addition of water. It indicates the minimum mixing time for dough formation. The inclusion of faba bean flour showed a significant effect between 2.7 and 4.6 min, but the overall DDT was slightly raised by the increase of faba bean, in agreement with Abou-Zaid et al. (2011). The increase in DDT could be explained by the interactions between the non-wheat proteins and gluten, leading to a delay in the hydration and development of gluten in the presence of these ingredients (Dhinda et al., 2012). It was found that increasing the addition of faba bean to wheat flour increased WA from 52.18 % (control) to 65.20 % (100 % Zaher faba bean flour). Although the trend clearly pointed to higher values with increasing substitution levels, the differences among the faba bean formulations were not statistically significant, with significance ($P < 0.05$) observed only between the control and the faba bean–based samples. The rise in WA is consistent with previous findings, as the higher content of proteins, starch, and

Table 9
Rheological properties of faba bean cookies.

Sample	DDT (min)	WA (%)	P (mm)	L (mm)	G (mm)	W (10^4 J)	P/L
C1	3.8 ± 0.3^{c,b}	59.5 ± 4.9^{a}	134.0 ± 4.0^{a}	30.0 ± 4.0^{a}	15.0 ± 2.0^{a}	166.0 ± 4.0^{a}	4.5 ± 0.5^{a,b}
C2	3.7 ± 0.4d^{c}	58.3 ± 5.2^{a,b}	135.0 ± 5.0^{a}	29.0 ± 5.0^{a}	15.0 ± 3.0^{a}	164.0 ± 3.0^{a,b}	4.7 ± 0.6^{a}
C3	2.7 ± 0.6^{a}	52.2 ± 3.0^{b}	141.0 ± 6,0^{a}	33.0 ± 3.0^{a}	17.0 ± 2.0^{a}	167.0 ± 4.0^{a}	4.3 ± 0.2^{a,b}
C4	4.6 ± 0.3^{b}	63.1 ± 2.2^{a}	124.0 ± 6,0^{b}	29.0 ± 3.0^{a}	15.0 ± 2.0^{a}	158.0 ± 4.0^{b}	4.3 ± 0.2^{a,b}
C5	4.5 ± 0.4^{b,c}	65.2 ± 3.1^{a}	122.0 ± 3.0^{b}	31.0 ± 5.0^{a}	15.0 ± 3.0^{a}	162.0 ± 3.0^{a,b}	3.9 ± 0.3^{b}

Values refer to arithmetic mean ± standard deviation of $n = 3$ measurements. Mean values with a different letter in a column differ significantly by LSD test at $P < 0.05$. C1: 40 % whole Bachaar bean flour with tannin + 60 % soft wheat flour; C2: 40 % whole Zaher bean flour without tannin + 60 % soft wheat flour; C3: 100 % soft wheat flour; C4: 100 % whole Bachaar bean flour with tannin; C5: 100 % whole Zaher bean flour without tannin. DDT: represents the time required by the dough to reach maximum consistency after the first addition of water; WA: Water absorption is the amount of water needed to obtain dough of a defined consistency and is largely related to the dough yield; W: Deformation energy (J x 10^{-4}), P: over-pressure (mm), G: swelling index (mL), L: abscissa at rupture (mm) and P/L ratio.

fibers in legume flours competes with gluten proteins for water during dough development (Dhinda et al., 2012; Giménez et al., 2012). Alveographic parameters reveal the dough rheology and predict the quality of the final baked products (Mirsaeedghazi et al., 2008). The elasticity of the dough is directly related to the protein/gluten network and is more closely related to the glutenin macro polymers which, being weak, reduce the elastic property. The alveographic results showed that W value increased from 158 to 167 (+20 %). This increase could be due to the high content in fiber of faba bean flour and to the gluten's dilution. Bubble burst pressure (P), extensibility (L) and swelling index (G) decrease with the addition of the two varieties of faba bean flour. As a result of the faba bean action on both dough resistance and dough extensibility, the P/L ratio was increased in dough containing faba bean flour.

Our findings are consistent with the study of Belghith Fendri et al. (2016), which attributes this increase to the high cellulose content in fiber, promoting a strong interaction between fiber and flour proteins.

The matrix of linear correlation coefficients obtained between the different groups of cookies studied and the cookies geometric properties are given in Table 10. Height is positively correlated with maximum strength while weight is negatively correlated with maximum strength and positively correlated with height.

3.7. Antioxidant activity of cookies

The analysis of variance for the antioxidant activity evaluated by the DPPH test revealed the existence of a highly significant difference ($P < 0.05$) between the different samples evaluated. Table 11 summarizes the measurements of the antioxidant activity of the different cookies studied.

The mean LSD comparison test at the threshold of $\alpha < 5$ % divided

Table 10
Simple linear correlation coefficients obtained between the cookies geometric properties data measured for the different cookie samples.

Variable	Weight	Height	Force max **(Strength)**
Weight	1		
Height	0.536	1	
Force max (strength)	−0.134	0.749	1

Table 11
Percent Inhibition (PI) of Free Radicals DPPH and their Vitamin C Equivalent of cookies.

Cookie type	Antioxidant activity	
	PI (%)	mg VC_{eq} /g DM
C1	42.21 ± 4.79^{B,C}	0.40 ± 0.05^{C,D}
C2	37.29 ± 6.94^{C,D}	0.35 ± 0.07^{C,D,E}
C3	24.25 ± 10.06^{D}	0.22 ± 0.09^{E}
C4	80.98 ± 13.96^{A}	0.77 ± 0.13^{A}
C5	54.28 ± 14.16^{B}	0.51 ± 0.13^{B}

Values refer to arithmetic mean ± standard deviation of $n = 3$ measurements. Mean values with a different letter in a column differ significantly by LSD test at $P < 0.001$.
C1: 40 % whole Bachaar bean flour with tannin + 60 % soft wheat flour; C2: 40 % whole Zaher bean flour without tannin + 60 % soft wheat flour; C3: 100 % soft wheat flour; C4: 100 % whole Bachaar bean flour with tannin; C5: 100 % whole Zaher bean flour without tannin.

the samples into 5 significantly different classes. The antioxidant activity varied from 24.25 to 80.99 % and from 0.22 to 0.77 mg Eq vitamin C/g DW. Sample C4 has the highest value, compared to the other samples, followed by sample C5, then C1 and C2. Sample C3 showed the lowest activity. It can be concluded that the higher the amount of faba bean flour, the greater the antioxidant activity. Similarly, Voisin et al. (2013) demonstrated that pulses contain a significant amount of antioxidants, enhancing free radical scavenging activity when pulse flour is incorporated into wheat flour.

3.8. Sensory characterization of control and enriched cookies

The result of the sensory test is grouped in the form of a sensory profile and illustrated in Fig. 3.

Applying statistical analysis on the different attributes and values showed that the probabilities P of color intensity ($P = 0.0013$), out-of-mouth crispness ($P = 0.032$), in-mouth crispness ($P = 0.007$), the sweet taste ($P = 0.00025$) and the bitter taste ($P = 0.0024$) are less than 0.05 (critical threshold), from which a significant difference is observed at the level of these sensory characteristics.For the other attributessmell ($P = 0.19$), color homogeneity ($P = 0.069$), sandy mouthfeel ($P = 0.050$), salty taste ($P = 0.52$), aftertaste intensity ($P = 0.20$), and overall appreciation ($P = 0.40$)—the differences were not significant.

For smell, the most intense was contributed to sample C4 followed by samples C5, C1, C3 and C2.

Regarding the color intensity, sample C4 was judged as the most intense, which is probably due to the dark colored seed coats, followed respectively by samples C1, C2, C5 and C3 which are the lightest. On the other hand, for color homogeneity, control C3 was the most homogeneous product followed by samples C5, C4, C2 and C1. These changes in color intensity likely influenced the sensory scores for appearance. Cookies with markedly lower L* values tended to receive lower visual appeal ratings, consistent with consumer preferences for lighter, golden-brown tones in baked goods. Conversely, moderate darkening, as observed in certain formulations, may have been perceived positively, lending an artisanal or wholegrain character to the product.

When it comes to out-of-mouth texture, sample C4 is considered the softest and least gritty sample followed by sample C5, which is like C4 less gritty but a bit crispier. Samples C2, C1 and C3 are the crispiest and sandiest. The same findings were noted for the texture sensory criterion in the mouth. The hardness values showed clear differences among formulations, with higher faba bean flour incorporation generally increasing firmness, particularly in 100 % substitution cookies. This trend corresponded closely to the sensory texture scores, where cookies with extreme hardness were less favored by panelists. However, moderate increases in firmness, especially at partial substitution levels, did not substantially compromise texture acceptability, suggesting that instrumental hardness measurements can be predictive of consumer

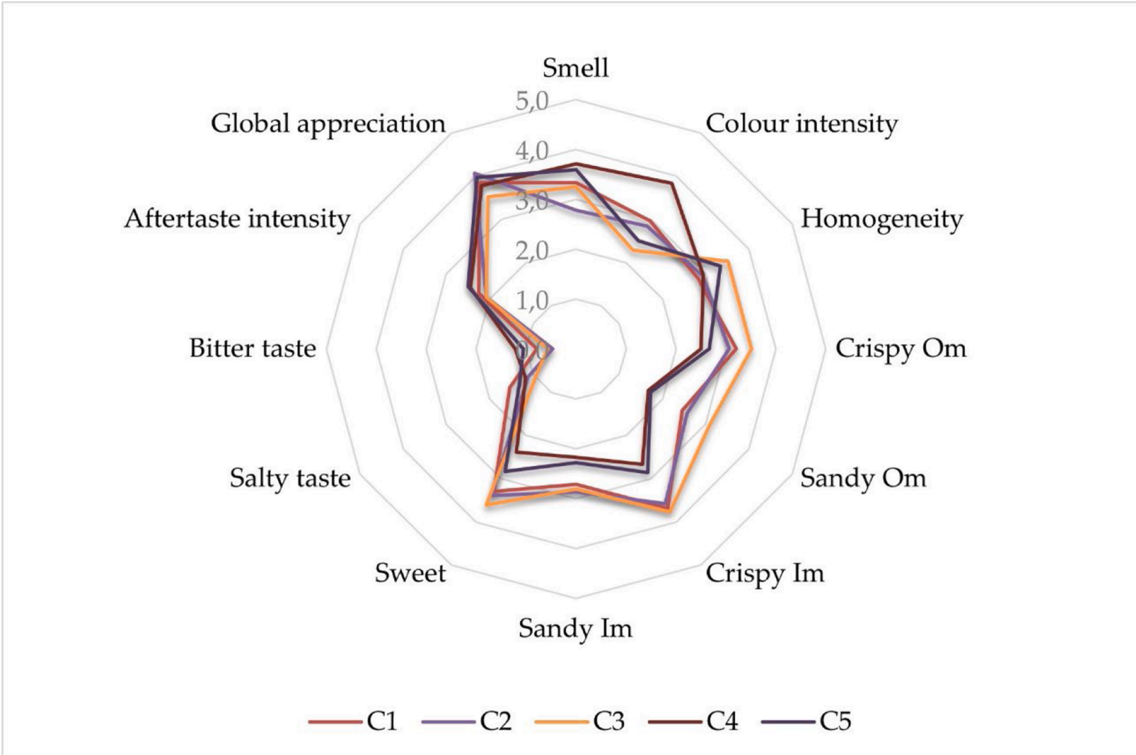

Fig. 3. Sensory evaluation of cookies prepared by the different incorporation rate of *Vicia faba* flour. C1: 40 % whole Bachaar bean flour with tannin + 60 % soft wheat flour; C2: 40 % whole Zaher bean flour without tannin + 60 % soft wheat flour; C3: 100 % soft wheat flour; C4:100 % whole Bachaar bean flour with tannin; C5: 100 % whole Zaher bean flour without tannin; Im: in mouth; Om: out the mouth (crispy on mouth, crispy out of mouth). Crispiness inside the mouth refers to the sensory perception experienced during chewing, when the cookie breaks and crumbles, releasing both textural and auditory cues as its structure disintegrates in the oral environment. Crispiness outside the mouth describes the physical texture and sound perceived when the cookie is handled or bitten, such as the initial snap or fracturability detected prior to mastication.

perception but that small deviations from the wheat flour control may still be acceptable if other sensory attributes remain favorable.

Cookies made with high-tannin faba bean flour (Bachaar variety) were consistently rated higher in bitterness and astringency compared to those made with low-tannin flour (Zaher variety), with these differences being statistically significant ($p < 0.05$). In particular, the Bachaar formulations—especially at 100 % substitution—showed a more pronounced almond-like aftertaste, which some panelists found pleasant, while others perceived it as overly intense. By contrast, the low-tannin Zaher cookies were described as milder, sweeter, and with a more neutral aftertaste, aligning more closely with conventional wheat cookies. These sensory differences translated into consumer acceptability scores, with low-tannin formulations generally receiving higher liking ratings, except in the case of certain tasters who valued the distinctive flavour complexity of high-tannin samples. This suggests that while tannins can contribute to flavour depth, their intensity needs to be carefully balanced to optimise broad consumer appeal.

In terms of overall appreciation, all samples received positive evaluations from the panelists; however, cookies formulated with faba bean flour at both 40 % and 100 % substitution levels achieved the highest scores, indicating that the inclusion of faba bean flour can enhance consumer acceptance despite the changes in composition and texture. Similar positive sensory acceptance at substitution levels around 40 % has been reported in gluten-free cookies using pinto bean flour (Simons and Hall, 2018) and in bread enriched with raw faba bean flour, which was also shown to improve iron and protein content, thereby enhancing overall nutritional quality (Benayad et al., 2021). At this substitution level, both cookies and bread can be formulated as natural composite products while preserving technological functionality and acceptable sensory attributes.

Nevertheless, other studies point to important sensory challenges. While some research confirms that faba bean flour can improve consumer acceptance under appropriate formulation conditions, issues such as bitterness, astringency, and the characteristic “beany” or earthy flavor have been highlighted as key deterrents (Katina et al., 2023). In particular, a large consumer study in Finland (Tuccillo, 2025) reported generally negative attitudes toward faba bean ingredients, especially protein concentrates and isolates, which were associated with undesirable flavor attributes. Although flour forms were perceived more positively than isolates or concentrates, bitterness and off-flavors remained significant barriers to broader consumer acceptance.

Further evidence confirms that the sensory profile of faba bean ingredients varies depending on ingredient type and processing, with bitterness and off-flavors representing critical challenges for market success (Tuccillo, 2025). Therefore, while our results support the potential of faba bean flour to enhance consumer acceptance in cookies, these must be considered alongside contrasting findings that emphasize the importance of careful ingredient selection and processing strategies to mitigate sensory drawbacks.

4. Conclusions

The valorization of faba bean flour aligns closely with the principles of sustainable development, combining environmental benefits—such as nitrogen fixation and low input requirements—with economic advantages for farmers and social gains through improved nutrition and food security. In this context, the formulation of cookies combining faba bean and cereal flours can represent a promising strategy to deliver nutritionally enriched, plant-based products that meet consumer expectations while reducing the environmental footprint of baked goods.

By addressing current limitations related to antinutritional factors and sensory quality, such products can contribute to diversifying sustainable protein sources and supporting the agri-food industry's transition toward healthier, more sustainable offerings.

This study demonstrated that partial replacement of soft wheat flour with field bean flour can enhance the nutritional and functional quality of cookies. Incorporating 40 % field bean flour, particularly from the tannin-free Zaher cultivar, increased protein content and antioxidant capacity while retaining acceptable color, texture and sensory attributes. Complete (100 %) replacement substantially increased protein and antioxidant activity but resulted in darker color, increased hardness and perceptible bitterness, particularly for the high-tannin Bachaar cultivar. Textural measurements showed that cookie hardness (Fmax) decreased in the sequence control > 40 % substitution > 100 % substitution, and sensory tests revealed that the almond-like aftertaste associated with high tannin formulations was intriguing but less liked by consumers. These findings suggest that moderate incorporation levels (around 40 %) provide a good compromise between nutritional enhancement and consumer acceptability. Future research should focus on improving the sensory quality of high-substitution formulations through processing methods (e.g., dehulling, fermentation or enzymatic treatment) and exploring complementary protein sources to balance amino-acid profiles.

Ethical statement - studies in humans and animals

This study involved a sensory evaluation with adult participants. According to Tunisian regulations, where the research was conducted, formal ethical approval is not required for this type of trial. Nevertheless, all appropriate protocols for protecting the rights and privacy of participants were strictly followed throughout the study. Participation was entirely voluntary, and no coercion was applied.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

CRediT authorship contribution statement

Khalil Khamassi: Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Hayet Ben Haj Koubaier:** Writing – original draft, Methodology, Conceptualization. **Riccardo Primi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Funding acquisition. **Pier Paolo Danieli:** Writing – original draft, Validation. **Raffaello Spina:** Writing – review & editing, Writing – original draft. **Mustapha Rouissi:** Software, Investigation. **Rayda Ben Ayed:** Investigation. **Fatma Gueddiche:** Investigation. **Mohsen Hanana:** Investigation. **Chokri Messaoud:** Writing – review & editing, Supervision, Funding acquisition. **Moncef Chouaibi:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition.

Declaration of competing interest

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

Acknowledgments

The authors wish to thank the Ministry of Agriculture, Hydraulic Resources and Maritime Fisheries (Tunisia) and the Ministry of Higher Education and Scientific Research for their financial support to this work. This study was carried out also within the Agritech National Research Center and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.fufo.2025.100760.

Data availability

Data will be made available on request.

References

AACC International, 1999a. Approved Methods of Analysis, 11th ed. Cereals & Grains Association. https://doi.org/10.1094/AACCIntMethod-10-05.01. Method 10-05.01.
AACC International, 1999b. Approved Methods of Analysis, 11th ed. Cereals & Grains Association. https://doi.org/10.1094/AACCIntMethod-10-50.05. Method 10-50.05.
AACC International, 1999c. Approved Methods of Analysis, 11th ed. Cereals & Grains Association. https://doi.org/10.1094/AACCIntMethod-10-52.01. Method 10-52.01.
AACC International, 1999d. Approved Methods of Analysis. Cereals & Grains Association Method 08-01. https://doi.org/10.1094/AACCIntMethod-08-01.
AACC International, 1999e. Approved Methods of Analysis. 11th ed. Cereals & Grains Association Method 10-05.01 doi:10.1094/AACCIntMethod-10-05.01.
AACC International, 1999f. Approved Methods of Analysis. 11th ed. Cereals & Grains Association Method 10-50.05 doi:10.1094/AACCIntMethod-10-50.05.
AACC International, 1999g. Approved Methods of Analysis. 11th ed. Cereals & Grains Association Method 10-52.01 doi:10.1094/AACCIntMethod-10-52.01.
Abou-Zaid, A.A.M., Ramadan, M., Al-Asklany, S., 2011. Utilization of faba bean and cowpea flours in gluten-free cake production. Aust. J. Basic Appl. Sci. 5, 2665–2672.
Aghababaei, F., McClements, D.J., Hadidi, M., 2025. Strategies to overcome nutritional and technological limitations of pulse proteins. Future Foods 11, 100624. https://doi.org/10.1016/j.fufo.2025.100624.
Akkad, R., Kharraz, E., Han, J., House, J.D., Curtis, J.M., 2019. Characterisation of the volatile flavour compounds in low and high tannin faba beans (Vicia faba var. minor) grown in Alberta, Canada. Food Res. Int. 120, 285–294. https://doi.org/10.1016/j.foodres.2019.02.044.
Anonymous., 2004. OGT: official Gazette of the Republic of Tunisia, 06/08/2004. N° 63 (06/08/2004): 2366-2367. http://www.iort.gov.tn/WD120AWP/WD120Awp.exe/CTX_6308-68-ezTZuLbywf/RechercheJORT/SYNC_401578402.
Bah, L., Kourouma, K., Sakho, A.M., Diallo, A., Sow, M.M., 2024. Study and formulation of composite flours based on gluten flour and local cereal flours: fonio, Millet and Sorghum. J. Agric. Chem. Environ. 13, 169–181. https://doi.org/10.4236/jacen.2024.131011.
Barbosa-Pereira, L., Guglielmetti, A., Zeppa, G., 2018. Pulsed electric field assisted extraction of bioactive compounds from cocoa bean shell and coffee silverskin. Food Bioprocess Technol 11, 818–835. https://doi.org/10.1007/s11947-017-2045-6.
Belghith Fendri, L., Chaari, F., Maaloul, M., Kallel, F., Abdelkafi, L., Ellouz Chaabouni, S., Ghribi-Aydi, D., 2016. Wheat bread enrichment by pea and broad bean pods fibers: effect on dough rheology and bread quality. LWT-Food Sci. Technol. 73, 584–591. https://doi.org/10.1016/j.lwt.2016.06.070.
Ben Said, K., Hedhili, A., Bellagha, S., Gliguem, H., Dufrechou, M., 2025. The potential of combining faba bean (*Vicia faba* L.) and pea pod (Pisum sativum L.) flours to enhance the nutritional qualities of food products. Foods 14 (13), 2167. https://doi.org/10.3390/foods14132167.
Benayad, A., Taghouti, M., Benali, A., Aboussaleh, Y., Benbrahim, N., 2021. Nutritional and technological assessment of durum wheat–faba bean enriched flours, and sensory quality of developed composite bread. Saudi J. Biol. Sci. 28, 635–642. https://doi.org/10.1016/j.sjbs.2020.10.053.
Boukhanouf, S., Louaileche, H., Perrin, D., 2016. Phytochemical content and in vitro antioxidant activity of faba bean (Vicia faba L.) as affected by maturity stage and cooking practice. Int. Food Res. J. 23, 954–961. http://www.ifrj.upm.edu.my.
Cappa, C., Kelly, J.D., Ng, P.K.W., 2020. Baking performance of 25 edible dry bean powders: correlation between cookie quality and rapid test indices. Food Chem 302, 125338. https://doi.org/10.1016/j.foodchem.2019.125338.
Chaieb, N., González, J.L., López-Mesas, M., Bouslama, M., Valiente, M., 2011. Polyphenols content and antioxidant capacity of thirteen faba bean (Vicia faba L.) genotypes cultivated in Tunisia. Food Res. Int. 44, 970–977. https://doi.org/10.1016/j.foodres.2011.02.026.
Choręziak, A., Rosiejka, D., Michałowska, J., Bogdański, P., 2025. Nutritional quality, safety and environmental benefits of alternative protein sources—An overview. Nutrients 17 (7), 1148. https://doi.org/10.3390/nu17071148.

Coda, R., Varis, J., Verni, M., Rizzello, C.G., Katina, K., 2017. Improvement of the protein quality of wheat bread through faba bean sourdough addition. LWT-Food Sci. Technol. 82, 296–302. https://doi.org/10.1016/j.lwt.2017.04.062.
Dhinda, F.A., Prakash, J., J.L, 2012. Effect of ingredients on rheological, nutritional and quality characteristics of high protein, high fibre and low carbohydrate bread. Food Bioproc. Technol. 5, 2998–3006. https://doi.org/10.1007/s11947-011-0752-y.
Djekic, I., Lorenzo, J.M., Munekata, P.E.S., Gagaoua, M., Tomasevic, I., 2021. Review on characteristics of trained sensory panels in food science. J. Texture Stud. 52 (5), 501–509. https://doi.org/10.1111/jtxs.12616.
Duc, G., Marget, P., Esnault, R., Le Guen, J., Bastianelli, D., 1999. Genetic variability for feeding value of faba bean seeds (Vicia faba): comparative chemical composition of isogenics involving zero-tannin and zero-vicine genes. J. Agric. Sci. 133, 185–196. https://doi.org/10.1017/S0021859699006905.
FAO, 2023. World Food and Agriculture – Statistical Yearbook 2023. Rome. https://doi.org/10.4060/cc8166en.
Ferreira, H., Pinto, E., Vasconcelos, M.W., 2021. Legumes as a cornerstone of the transition toward more sustainable agri-food systems and diets in Europe. Front. Sustain. Food Syst. 5, 694121. https://doi.org/10.3389/fsufs.2021.694121.
Ferruzzi, G., Pistoia, A., Balestri, G., Casarosa, L., Poli, P., 2009. Effect of different processing methods on the nutritional characteristics and tannin content of fababean seed (Vicia faba minor). Ital. J. Anim. Sci. 8, 298–300. https://doi.org/10.4081/ijas.2009.298.
Foschia, M., Horstmann, S., Arendt, E.K., Zannini, E., 2016. Nutritional therapy – Facing the gap between coeliac disease and gluten-free food. Int. J. Food Microbiol. 239, 113–124. https://doi.org/10.1016/j.ijfoodmicro.2016.06.014.
Giménez, M.A., Drago, S.R., De Greef, D., Gonzalez, R.J., Lobo, M.O., Samman, N.C., 2012. Rheological, functional and nutritional properties of wheat/broad bean (Vicia faba) flour blends for pasta formulation. Food Chem 134, 200–206. https://doi.org/10.1016/j.foodchem.2012.02.093.
Hadou el Hadj, D., Tellah, S., Goumeida, K., Aitouakli, S., Tifest, C., Ammi, N., Ratet, P., Pulvento, C., Sellami, M.H., 2022. Evaluation of adaptability of different faba bean landraces under Mediterranean field conditions of Central-Northern Algeria. Agronomy 12, 1660. https://doi.org/10.3390/agronomy12071660.
Hall, C., Hillen, C., Robinson, J.G., 2017. Composition, nutritional value, and health benefits of pulses. Cereal Chem 94, 11–31. https://doi.org/10.1094/CCHEM-03-16-0069-FI.
Jezierny, D., Mosenthin, R., Sauer, N., Roth, S., Piepho, H.P., Rademacher, M., Eklund, M., 2011. Chemical composition and standardised ileal digestibilities of crude protein and amino acids in grain legumes for growing pigs. Livest. Sci. 138, 229–243. https://doi.org/10.1016/j.livsci.2010.12.024.
Joshi, D.C., Das, S.K., Mukherjee, R.K., 1993. Physical properties of pumpkin seeds. J. Agric. Eng. Res. 54, 219–229. https://doi.org/10.1006/jaer.1993.1016.
Kahlaoui, M., Bertolino, M., Barbosa-Pereira, L., Ben Haj Kbaier, H., Bouzouita, N., Zeppa, G., 2022. Almond hull as a functional ingredient of bread: effects on physico-chemical, nutritional, and consumer acceptability properties. Foods 11, 777. https://doi.org/10.3390/foods11060777.
Karkanis, A., Ntatsi, G., Lepse, L., Fernández, J.A., Vågen, I.M., Rewald, B., Alsiņa, I., Kronberga, A., Balliu, A., Olle, M., et al., 2018. Faba bean cultivation – Revealing novel managing practices for more sustainable and competitive European cropping systems. Front. Plant Sci. 9, 1115. https://doi.org/10.3389/fpls.2018.01115.
Karolkowski, A., Gourrat, K., Bouzidi, E., Albouy, J.-F., Levavasseur, L., Briand, L., Guichard, E., Salles, C., 2023. Origins of volatile compounds and identification of odour-active compounds in air-classified fractions of faba bean (Vicia faba L. minor). Food Res. Int. 163, 112260. https://doi.org/10.1016/j.foodres.2022.112260.
Katina, K., Sandell, M., Tuccillo, F., Mäkinen, A., Lampi, A.-M., 2023. Exploring consumer perception of faba bean ingredients. In: 15th Pangborn Sensory Science Symposium - Meeting new challenges in a changing world (PSSS 2023), p. G03. Available at SSRN: https://ssrn.com/abstract=4550286.
Khamassi, K., Babay, E., Rouissi, M., Dakhlaoui, A., Ben Ayed, R., Hanana, M., 2021. Genetic variability of Tunisian faba beans (Vicia faba L.) based on seeds' morphophysical properties as assessed by statistical analysis. J. Food Qual. 2021, 1–10. https://doi.org/10.1155/2021/9493607.
Kharrat, M., Abbes, Z., Amri, M., 2010. A new faba bean small seeded variety "Najeh" tolerant to Orobanche registered in the Tunisian catalogue. Tun. J. Plant Protect. 5, 125–130.
Li, Y., Ma, D., Sun, D., Wang, C., Zhang, J., Xie, Y., Guo, T., 2015. Total phenolic, flavonoid content, and antioxidant activity of flour, noodles, and steamed bread made from different colored wheat grains by three milling methods. Crop J 3, 328–334. https://doi.org/10.1016/j.cj.2015.04.004.
Lovegrove, J.A., O'Sullivan, D.M., Tosi, P., Millan, E., Todman, L.C., Bishop, J., Chatzifragkou, A., Clegg, M.E., Hammond, J., Jackson, K.G., et al., 2023. Raising the pulse': the environmental, nutritional and health benefits of pulse-enhanced foods. Nutr. Bull. 48, 134–143. https://doi.org/10.1111/nbu.12601.
Marathe, S.A., Rajalakshmi, V., Jamdar, S.N., Sharma, A., 2011. Comparative study on antioxidant activity of different varieties of commonly consumed legumes in India. Food Chem Toxicol 49 (9), 2005–2012. https://doi.org/10.1016/j.fct.2011.04.039.
Martineau-Côté, D., Achouri, A., Karboune, S., L'Hocine, L., 2022. Faba bean: an untapped source of quality plant proteins and bioactives. Nutrients 14, 1621. https://doi.org/10.3390/nu14081541.
Mayer Labba, I.-C., Frøkiær, H., Sandberg, A.-S., 2021. Nutritional and antinutritional composition of fava bean (Vicia faba L., var. minor) cultivars. Food Res. Int. 140, 110038. https://doi.org/10.1016/j.foodres.2020.110038.
McKay, A.M., 1992. Hydrolysis of vicine and convicine from fababeans by microbial β-glucosidase enzymes. J. Appl. Bacteriol. 72, 475–478. https://doi.org/10.1111/j.1365-2672.1992.tb01861.x.
Mirsaeedghazi, H., Emam-Djomeh, Z., Mousavi, M., 2008. Rheometric measurement of dough rheological characteristics and factors affecting it. Int. J. Agric. Biol. 10. https://www.researchgate.net/publication/239805380_Rheometric_Measurement_of_Dough_Rheological_Characteristics_and_Factors_Affecting_It.
Monnet, A.-F., Laleg, K., Michon, C., Micard, V., 2019. Legume enriched cereal products: a generic approach derived from material science to predict their structuring by the process and their final properties. Trends Food Sci. Technol. 86, 131–143. https://doi.org/10.1016/j.tifs.2019.02.027.
Multari, S., Stewart, D., Russell, W.R., 2015. Potential of fava bean as a future protein supply to partially replace meat intake in the human diet. Compr. Rev. Food Sci. Food Saf. 14, 511–522. https://doi.org/10.1111/1541-4337.12146.
Nam, S., Ozturk, O.K., Lim, J., 2025. Interaction effects of tannic acid and gluten on bread-making and its starch digestion. Foods 14 (2), 233. https://doi.org/10.3390/foods14020233.
Oomah, B.D., Razafindrainibe, M., Drover, J.C., 2014. Headspace volatile components of Canadian grown low-tannin faba bean (*Vicia faba* L.) genotypes. J. Sci. Food Agric. 94, 473–481. https://doi.org/10.1002/jsfa.6272.
Parisi, G., Tulli, F., Fortina, R., Marino, R., Bani, P., Dalle Zotte, A., De Angelis, A., Piccolo, G., Pinotti, L., Schiavone, A., et al., 2020. Protein hunger of the feed sector: the alternatives offered by the plant world. Ital. J. Anim. Sci. 19, 1204–1225. https://doi.org/10.1080/1828051X.2020.1827993.
Popovska, O., 2023. Determination of some flour characteristics. EJFOOD 5 (4), 8–12. https://doi.org/10.24018/ejfood.2023.5.4.683.
Rababah, T.M., Al-Mahasneh, M.A., Ereifej, K.I., 2006. Effect of chickpea, broad bean, or isolated soy protein additions on the physicochemical and sensory properties of biscuits. J. Food Sci. 71, S438–S442. https://doi.org/10.1111/j.1750-3841.2006.00077.x.
Rajpurohit, B., Li, Y., 2023. Overview on pulse proteins for future foods: ingredient development and novel applications. J. Future Foods 3, 340–356. https://doi.org/10.1016/j.jfutfo.2023.03.005.
Roland, W.S.U., Pouvreau, L., Curran, J., Van De Velde, F., De Kok, P.M.T., 2017. Flavor aspects of pulse ingredients. Cereal Chem 94, 58–65. https://doi.org/10.1094/CCHEM-06-16-0161-FI.
Schmelter, L., Rohm, H., Struck, S., 2021. Gluten-free bakery products: cookies made from different Vicia faba bean varieties. Future Foods 4, 100038. https://doi.org/10.1016/j.fufo.2021.100038.
Sim, S.Y.J., SRV, A., Chiang, J.H., Henry, C.J., 2021. Plant proteins for future foods: a roadmap. Foods 10, 1967. https://doi.org/10.3390/foods10081967.
Simons, C.W., Hall, C., 2018. Consumer acceptability of gluten-free cookies containing raw cooked and germinated pinto bean flours. Food Sci. Nutr. 6, 77–84. https://doi.org/10.1002/fsn3.531.
Singh Sibian, M., Singh Riar, C., 2021. Optimization and evaluation of composite flour cookies prepared from germinated triticale, kidney bean, and chickpea. J. Food Process. Preserv. 45, e14996. https://doi.org/10.1111/jfpp.14996.
Stagnari, F., Maggio, A., Galieni, A., Pisante, M., 2017. Multiple benefits of legumes for agriculture sustainability: an overview. Chem. Biol. Technol. Agric. 4, 2. https://doi.org/10.1186/s40538-016-0085-1.
Thebti, S, Bouallegue, A, Rzigui, T, En-Nahli, Y, Horchani, F, Hosni, T, Kharrat, M, Amri, M, Abbes, Z, 2024. Potential physiological tolerance mechanisms in faba bean to *Orobanche* spp. parasitism. Front. Plant Sci. 15, 1497303. https://doi.org/10.3389/fpls.2024.1497303.
Tuccillo, F., 2025. On the Flavor of Faba Bean ingredients: Consumer acceptance, Sensory perception, Food application, and Identification of Potential Flavor Compounds. University of Helsinki [dissertation]ISBN 978-952-84-1311-0.
Vasanthakumari, P, Jaganmohan, R, 2018. Process development and formulation of multi-cereal and legume cookies. J. Food Process Preserv. 42, e13824. https://doi.org/10.1111/jfpp.13824.
Voisin, A.-S., Guéguen, J., Huyghe, C., Jeuffroy, M.-H., Magrini, M.-B., et al., 2013. Les légumineuses dans l'Europe du XXIè siècle: quelle place dans les systèmes agricoles et alimentaires actuels et futurs? Quels nouveaux défis pour la recherche? Innov. Agron. 30, 283–312. https://doi.org/10.17180/767p-n553.
Voisin, A.-S., Guéguen, J., Huyghe, C., Jeuffroy, M.-H., Magrini, M.-B., Meynard, J.-M., Mougel, C., Pellerin, S., Pelzer, E., 2014. Legumes for feed, food, biomaterials and bioenergy in Europe: a review. Agron. Sustain. Dev. 34, 361–380. https://doi.org/10.1007/s13593-013-0189-y.
Wang, Q., Li, Y., Sun, F., Li, X., Wang, P., Sun, J., He, G., 2015. Tannins improve dough mixing properties through affecting physicochemical and structural properties of wheat gluten proteins. Food Res. Int. 69, 64–71. https://doi.org/10.1016/j.foodres.2014.12.012.
Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., et al., 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet 393, 447–492. https://doi.org/10.1016/S0140-6736(18)31788-4.