

## Assessing the culinary qualities of a shortcrust pastry food model: Impact of the chemical and functional characteristics of legume flours

Lorène Akissoé<sup>a</sup>, Céline Brasse<sup>a</sup>, Isabelle Maitre<sup>a</sup>, Brice Guerin<sup>b</sup>, Guillaume Piva<sup>c</sup>, Ronan Symoneaux<sup>a</sup>, Marie Dufrechou<sup>a,\*</sup>

<sup>a</sup> USC 1422 GRAPPE, L'Ecole Supérieure des Agricultures, INRAE, SFR 4207 QUASAV, 55 rue Rabelais, BP 30748, 49007 Cedex 01, Angers, France

<sup>b</sup> CCI Maine-et-Loire Formation, 8 Bd du Roi René, 49006, Angers, France

<sup>c</sup> USC 1432 LEVA, L'Ecole Supérieure d'Agricultures (ESA), INRAE, SFR 4207 QUASAV, 55 rue Rabelais, 49007, Angers, France

### ARTICLE INFO

**Keywords:**

Legume flours  
Thermal treatment  
Shortcrust pastries  
Sensory and functional properties

### ABSTRACT

In Europe, legume consumption remains below recommended levels, and local production systems need to be developed to help improve human health and bolster the fight against global warming. A gastronomic approach provides an original way of showcasing legumes while also highlighting their main functional and sensory qualities. This study focused on five legumes—white beans, red beans, chickpeas, green lentils, and lupins—that were untreated or thermally treated and processed into flours. Professional chefs were asked to create a legume-based shortcrust pastry recipe, which was subsequently simplified into a food model with fewer ingredients to minimize ingredient interactions. The chemical composition and functionality of the flour were assessed, along with the dough texture and the final textural and sensory qualities of the shortcrust pastries. The flours differed significantly in chemical composition, water/oil absorption capacity, particle size, and color ( $p$ -value  $<0.05$ ). Consequently, marked variation was seen among the different legume-based shortcrust pastries. Fiber content was positively associated with both flour water absorption capacity and dough hardness, resulting in crumbly shortcrust pastries. Shortcrust pastries made with lupin flour had very different characteristics than shortcrust pastries made with the other legume flours, due to pronounced differences in fibre, protein, and lipid contents. Additionally, using flours made from thermally treated legumes significantly decreased shortcrust pastry hardness. Instrument-based textural results were confirmed through sensory analysis. The food model can help predict how the chemical characteristics of legume flours affect shortcrust pastry culinary quality. This knowledge can orient legume use in specific food applications.

### 1. Introduction

Legumes are crops that can help populations face environmental and food challenges because a transition to more plant-based diets can reduce greenhouse gas emissions (Magrini et al., 2018). Semba et al. (2021) reported that, worldwide, mean legume consumption was 21 g/person/day while mean meat consumption was 112 g/person/day, with variability in these figures depending on specific situations and global regions. Despite the growing awareness of the nutritional and environmental benefits of legumes, the main barriers to legume consumption are related to consumer perceptions. In Europe, and especially in France, the diversity of homemade legume recipes is very limited. A survey of a representative group of French consumers found that legumes suffer from an outdated image (Champ et al., 2015; Magrini et al.,

2016). Indeed, while innovative technologies have expanded the use of legumes in meat substitutes and plant-based dairy products (Boukid, 2021; Joshi and Kumar, 2015; Sethi et al., 2016), more traditional uses within households still face some challenges. Conversely, in other parts of the world (Asia, Africa), where legume-based foods are part of traditional dishes, populations prepare and consume legumes on a daily basis (Akissoé et al., 2022; Tiwari and Singh, 2012), leading to a higher consumption frequency (Akissoé et al., 2023).

Legumes are prepared using one of three main cooking methods: boiling, pressure cooking, and microwaving. Some innovative products, such as precooked mixtures of legumes and wheat as well as legume flours, have recently entered the large retail market. However, these products remain commercially positioned as an alternative to traditional starches (pasta, rice) (Magrini et al., 2016), and their functional

\* Corresponding author.

E-mail address: [m.dufrechou@groupe-esa.com](mailto:m.dufrechou@groupe-esa.com) (M. Dufrechou).

properties are not promoted. Moreover, proposing legumes as replacements for crops such as wheat represents a great opportunity to develop and introduce healthy, gluten-free foods for consumption (Han et al., 2010). Thus, diversifying legume-based recipes could be a way to increase legume consumption in French households.

Legumes have an appealing nutritional composition, given their levels of starch (38–44 %), proteins (18–22 %), and fiber (13–17 %) (Satya et al., 2010; Tiwari and Singh, 2012). When processed into flour, legumes can be used as ingredients in foods such as bread and other bakery products (Bresciani and Marti, 2019). Their specific chemical composition has a direct impact on their functional properties, including solubility, water/oil absorption capacity, and emulsifying capacity (Aguilera et al., 2009; Du et al., 2014; Gupta et al., 2018; Kaur and Singh, 2007; Mundi and Aluko, 2012), and thus on the texture and appearance of the final products. A deeper understanding of the functional properties of legume flours is necessary to utilize them more effectively. To our knowledge, there is little detailed research on legume characteristics (chemical composition, functional properties) and their impacts on the qualities (textural, sensory properties) of gastronomic-based food models.

In this study, the approach described by Maitre et al. (2024) was used: we employed gastronomic recipes to explore the impact of the functional and chemical characteristics of legume flours by significantly simplifying these recipes to create a target food model.

Indeed, simplified food models are often used to better understand the functional properties of legume flours (Foschia et al., 2017; Laleg et al., 2016, 2017, 2021; Schmidt and Oliveira, 2023). Even though such food models yield important insights, they also have some limitations. Food products are complex matrices, so it is important to consider the impact of other functional ingredients (e.g., eggs, sugars) on the qualities of the study product. To this end, we used a standardized complex food model. More specifically, we selected shortcrust pastry, which is a key component of gastronomic recipes, is widely popular, and displays versatility in both sweet and savory dishes (Patient, 1994).

The objectives were (i) to assess the suitability of flours made from untreated or thermally treated legumes as substitutes for wheat flour in shortcrust pastry recipes based on their chemical and functional properties and (ii) to evaluate how the use of legume flours can influence shortcrust pastry preparation, focusing on the culinary qualities defined by textural properties and sensory attributes.

## 2. Materials and methods

### 2.1. Sampling of raw materials and flours

Five legumes were studied: green lentils (*Lens culinaris*), chickpeas (*Cicer arietinum*), lupins (*Lupinus albus*), and both white and red beans (*Phaseolus vulgaris*). All the legumes used in the study were cultivated in northwestern France, harvested in 2021, and processed into flour by Inveja (Haute-Goulaine, France). This company produces flours using both untreated and thermally treated legumes. The treatment is applied to the legumes before the milling process. The target particle size distribution is as follows: 90 % of particles are smaller than 500 µm in the case of lupin flour and smaller than 250 µm in the case of the other legume flours.

A total of 10 flours were studied: nine flours made from untreated and thermally treated legumes and one commercial wheat flour (T55, Biocoop, France) used as a control. Only thermally treated lupin flour was used, due to processing constraints associated with producing flour from raw lupins (seed coat thickness and seed hardness). All flours were stored at room temperature in a dark and dry place.

### 2.2. Physicochemical and functional analyses of the flours

#### 2.2.1. Chemical analyses

**Dry matter** content was determined after drying all the samples in an oven at 105 °C for 24 h (AOAC, 1995). **Protein content** (Nx6.25) was determined using Kjeldahl's method (NF V03-050, AFNOR, 1970). **Lipid content** was determined using the Soxhlet method (AOAC Official Method, 2003.06). **Ash content** was determined after calcination had been performed in a furnace at 530 °C (Nabertherm, France) for 3 h (Mouquet-Rivier et al., 2008). **Starch content** was determined after enzymatic hydrolysis had been performed using the Megazyme Total Starch Hexokinase Kit (K-TSHK, 2022; Megazyme, Wicklow, Ireland) and following the manufacturer's instructions, with some modifications. This method is based on enzymatic hydrolysis that converts starch into glucose. The procedure for samples that contain D-glucose and/or maltodextrins was used for the assay. Briefly, 100 mg of each sample underwent two pretreatments: the elimination of free D-glucose using ethanol (80 % v/v; 20 mL in total) at 80 °C, and the dissolution of resistant starch in a 20-min ice-water bath using 2 mL of 2 M KOH. Then, 8 mL of 1.2 M sodium acetate buffer (pH 3.8) was added to the sample, and enzymatic hydrolysis was performed at 50 °C for 30 min using 0.1 mL of thermostable α-amylase and 0.1 mL of amyloglucosidase. The hydrolyzed sample was centrifuged at 4500 rpm for 10 min (Centrifuge Sigma 2-16 PK, Germany). The supernatant was then diluted, and phosphorylation and oxidation reactions were performed using hexokinase and glucose-6-phosphate dehydrogenase, respectively. Starch quantification was subsequently carried out by measuring absorbance at 340 nm using a UV spectrophotometer (MC2 SAFAS, Monaco). **Fiber content** was determined by a certified commercial laboratory using a standard enzymatic-gravimetric method (AOAC 985.29). **Carbohydrate content** was calculated using the following formula: 100 – (protein + lipid + fiber + ash). All analyses were carried out in triplicate except for the fiber analysis.

#### 2.2.2. Characterization of the physical and functional properties of the flours

**Particle size.** Particle size distributions were measured via laser diffraction using a Malvern 2000S particle sizer analyzer (Malvern Orsay, France). The values of D [4,3] (mean particle size) and D90 (90 % of the total volume of material in the sample smaller than D) were recorded.

**Bulk density.** Bulk density was measured using a method adapted from Kaur and Singh (2007). Briefly, 50 g of each flour was poured into a 100 mL graduated cylinder. The cylinder was gently tapped on a laboratory bench for approximately 5 min. Bulk density was the sample mass per unit of sample volume (g/mL).

**Water/Oil absorption capacity.** The water or oil absorption capacity (WAC/OAC) of each flour was determined using a flour-to-water or a flour-to-oil ratio of 1:10 (w/v) (Gupta et al., 2018; Marchini et al., 2021). Flour (2 g) was mixed with 20 mL of demineralized water (for WAC) or sunflower oil (for OAC) using a vortex. The mixture was then left at room temperature for 30 min following centrifugation at 3000g for 30 min (Centrifuge Sigma 2-16 PK, Germany). WAC and OAC were the ratios of grams of water or oil retained per initial gram of flour (dry matter basis).

**Emulsifying activity.** The emulsifying activity (EA) of flours was measured using the method described by Ghavidel and Prakash (2006), with some modifications. Flour (0.5 g) was mixed with 5 mL of demineralized water for 30 s at 9500 rpm using a homogenizer (IKA Ultra-Turrax with a S25-10G dispersing tool). Then, 5 mL of sunflower oil was added, and the mixture was homogenized at 13500 rpm for 1

min. The emulsion was transferred into a cylindrical tube and centrifuged at 1200 rpm for 5 min (Centrifuge Universal 320R, Hettich, Germany). The EA was a percentage: the height of the emulsified layer after centrifugation/height of the total content in the centrifuge tube multiplied by 100.

### 2.3. Shortcrust pastry preparation

Shortcrust pastry preparation was separated into two steps: (i) preparing the dough (the intermediate product) and (ii) baking the shortcrust pastry (the final product). Preparation was repeated twice for the 10 flours, using the same experimental conditions ( $n = 20$  samples = 2 rounds of preparation  $\times$  10 flours).

#### 2.3.1. Dough preparation

The original recipe proposed by the chefs affiliated with the Maine and Loire Chamber of Commerce and Industry contained eight ingredients: wheat flour, lentil flour, almond flour, powdered sugar, softened butter, egg, fine sea salt, and tap water. This recipe was simplified to obtain a food model in which legume flour was the main functional ingredient, along with butter (Table 1). Legume flour was used to replace the mixture of flours in the original recipe; the replacement was 100 % wheat flour in the control. Dough preparation was carried out using a blender (Stephan, UM5 Electronic, France). First, all the solid ingredients (66.4 % of flour, 33 % of softened butter, and 0.6 % fine sea salt) were mixed at 750 rpm for 2 min using a kneading blade. Second, tap water at room temperature was added (Table 2; the quantity was adjusted depending on flour type, as detailed in the formula below), and further mixing was carried out at the same speed for 1 min. For each sample, approximately 1 kg of dough was prepared. Each batch of dough was divided into portions of approximately 200 g, which were wrapped in plastic film and stored at  $-20^{\circ}\text{C}$  until their use in the textural analyses or for baking.

Preliminary experiments determined that a theoretical dry matter

content of 73 % was required to produce a laminable dough for most of flours. The chefs validated the visual appearance and texture of the food model prior to the main experiment. The quantity of tap water to add was determined using the following formula:

$$Q_{\text{Water}} = \frac{DM_{\text{flour}} * Q_{\text{flour}} + DM_{\text{Butter}} * Q_{\text{butter}} - DM_{\text{dough}} (Q_{\text{flour}} + Q_{\text{butter}})}{DM_{\text{dough}}}$$

Where.

DM: dry matter content (%)

Q: quantity (g).

Only salt was not considered in the calculation since the quantity added was negligible (<1 % of total solid quantity).

#### 2.3.2. Baking

Each 200 g dough portion was thawed for approximately 16 h in a refrigerator at  $4^{\circ}\text{C}$ , as per the method used by the chefs. The dough portions were then allowed to reach room temperature before baking. Dough lamination was performed manually, using a rolling pin equipped with 4-mm thickness rings. The laminated dough was cut into 12 pieces, each with a diameter of 60 mm, using a circular cutter. The dough portions were baked at  $160^{\circ}\text{C}$  for 15 min using the same electrical dry heat oven (UNOX ChefTop XVC-XBC) for all production rounds. The resulting shortcrust pastries were cooled and stored in a dry place at room temperature.

### 2.4. Characterization of the dough and shortcrust pastry food model

#### 2.4.1. Water activity ( $a_w$ )

The water activity of the dough portions and shortcrust pastries was measured using an aw-meter (LabMaster.aw, Novasina), which had been previously calibrated with salt solutions in the  $a_w$  range of interest (0.90 for dough and 0.75 for pastries). Measurements were performed in duplicate for each sample.

#### 2.4.2. Color

Different dimensions of color ( $L^*$ ,  $C^*$ ,  $h$ ) were measured using a Chroma Meter CR-5 (Konica Minolta) with a spot diameter of 3 mm. Measurements were taken using a standard illuminant (D65) and an observer angle of  $10^{\circ}$ . Samples were analyzed in triplicate.

#### 2.4.3. Dough hardness

To determine hardness, a single compression test was conducted on defrosted dough portions, which had been left at  $4^{\circ}\text{C}$  overnight and allowed to rest for 30 min at room temperature before analysis. Measurements were performed using the method described by Mamat and Hill (2014) for texture profile analysis, with some modifications. The assay was carried out using a universal testing machine (MTS Synergie 200H) equipped with a 1-kN load cell. A cylindrical probe with a diameter of 25.4 mm was used to apply the compression to the dough; the latter had a diameter of 60 mm and a thickness of 4 mm. The dough

**Table 1**  
Shortcrust pastry recipes created by chefs and used for food model.

	Recipe created by chefs (g/100 g)	Recipe used for food model (g/100 g)
Wheat flour	39.4	–
Legume flour	19.7	66.4
Almond flour	7.9	–
Flour		
Powdered sugar	13.1	–
Softened butter	15.7	33
Egg	3.6	–
Fine sea salt	0.6	0.6
Water	Quantity as needed	Quantity to reach a theoretical dry matter content of 73 % (Table 2)

**Table 2**  
Quantity of water added to 100 g of solid ingredients (flour, softened butter, and fine sea salt) to obtain doughs.

	Legumes /Wheat	Water added <sup>a</sup> (g)	Flour dry matter (%)	Dough dry matter (%)
Flours made from untreated legumes	White beans	19.6	88.7 $\pm$ 0.0 <sup>b</sup>	71.7 $\pm$ 1.1 <sup>a</sup>
	Red beans	20.0	89.2 $\pm$ 0.1 <sup>c</sup>	72.5 $\pm$ 0.3 <sup>ab</sup>
	Lentils	21.4	90.6 $\pm$ 0.0 <sup>e</sup>	72.0 $\pm$ 0.2 <sup>ab</sup>
	Chickpeas	21.2	90.4 $\pm$ 0.0 <sup>d</sup>	72.7 $\pm$ 0.0 <sup>ab</sup>
Flours made from thermally treated legumes	White beans	25.0	94.6 $\pm$ 0.7 <sup>h</sup>	72.8 $\pm$ 0.2 <sup>b</sup>
	Red beans	26.1	95.8 $\pm$ 0.0 <sup>i</sup>	72.5 $\pm$ 0.3 <sup>ab</sup>
	Lentils	23.7	93.2 $\pm$ 0.0 <sup>g</sup>	72.0 $\pm$ 0.1 <sup>ab</sup>
	Chickpeas	25.5	95.2 $\pm$ 0.2 <sup>j</sup>	73.1 $\pm$ 0.3 <sup>b</sup>
	Lupins	23.4	92.8 $\pm$ 0.0 <sup>f</sup>	72.9 $\pm$ 0.3 <sup>b</sup>
Control	Wheat	17.6	86.1 $\pm$ 0.1 <sup>a</sup>	74.4 $\pm$ 0.2 <sup>c</sup>

<sup>a</sup> Determined by calculation.

was compressed to 50 % at a test speed of 1 mm/s. Six repeated measurements were obtained for each dough type.

#### 2.4.4. Dough extensibility

Dough extensibility was measured using custom-designed laboratory equipment inspired by the Kieffer extensibility rig (Kieffer et al., 1981). The setup consisted of a hook (Allen wrench) fitted onto a clamping chuck and connected to a traction machine (MTS Synergie 200H). A 50-N load cell was used. Laminated portions of dough (thickness: 4 mm) were cut into strips measuring 10 mm in length and 1 mm in width. Extensibility was the distance (mm) required to break the dough strip. The test speed was 0.5 mm/s (Mamat and Hill, 2014). Ten repeated measurements were obtained per sample.

#### 2.4.5. Shortcrust pastry hardness

Shortcrust pastry hardness was measured using a three-point bending test on the MTS Synergie 200 H. The span length (i.e., distance between the supports) was 40 mm, and the test speed was 3 mm/s (Mamat and Hill, 2014). The maximum force applied was defined as shortcrust pastry hardness. Six repeated measurements were obtained per sample.

#### 2.4.6. Dimensions and bake yield of the shortcrust pastry

We measured the diameter (mm) and thickness (mm) of six shortcrust pastries using an electronic caliper. Sample mass was measured before and after baking to calculate the baking yield of each sample using the following formula:

$$\text{Bake Yield (\%)} = \left( 1 - \left( \frac{m_i - m_f}{m_i} \right) \right) * 100$$

where,

$m_i$ : mass of pastry before baking in grams

$m_f$ : mass of pastry after baking in grams.

**Table 3**

Definitions of sensory attributes used to characterize shortcrust pastry culinary quality.

Attribute	Definition
<b>In-hand evaluation</b>	
Firmness	Resistance of the food to hand pressure during breaking; the greater the force applied by the hands to break the dough in half, the firmer the product
Friability	Texture characteristic related to product cohesion and the force required to make it crumble
<b>Oral evaluation</b>	
Taste (sweetness, saltiness, bitterness)	Intensity of perceived sweetness, saltiness, bitterness
Flavor	Overall intensity of perceived flavor
Melting	A characteristic of food texture that relates to the propensity of a food to disintegrate under the influence of heat, saliva, and chewing; a product that disintegrates quickly is referred to as a melting product, and a product that does not disintegrate is referred to as a non-melting product
Stickiness	A characteristic of food texture that relates to a food's ability to adhere to the palate; requires an effort with the tongue to separate the food from the palate
Graininess	Perception of grainy particles in the product
Oily	Intensity of perceived oiliness in the mouth
Dry	A characteristic of food texture that relates to an absence of moisture within food structure
<b>After swallowing</b>	
Mouth dryness	Drying sensation on the palate after swallowing the product
Tooth packing	Amount of product packed into the teeth after mastication

#### 2.5. Sensory analysis of the shortcrust pastry

A quantitative descriptive analysis was conducted using a panel of 10 assessors, all employees from our research unit. The panel consisted of 9 women and 1 man between 20 and 60 years of age, all with experience in sensory evaluation. Initially, they attended two training sessions on separate days to identify and define the target attributes (Table 3) as well as to establish the evaluation procedure. The target attributes were firmness, friability, taste (sweetness, saltiness, and bitterness), flavor, melting, stickiness, graininess, oily, dry, mouth dryness, and tooth packing. The evaluations were performed in sensory booths, which provided a quiet and comfortable environment. The panelists assessed the target attributes for the shortcrust pastries made using the 10 flours (legumes and control) two times (on different days), resulting in a total of 20 sets of assessments; the shortcrust pastries were baked one day prior to the sensory assessment sessions. Samples were randomly coded with three-digit numbers and evaluated using a continuous scale of intensity, which ranged from 0 points (lowest intensity) to 10 points (highest intensity). Between samples, panelists cleansed their palates with yogurt or apple followed by water. Indeed, Vidal et al. (2016) found that yogurt consumption followed by a water rinse was an effective palate-cleansing technique during wine sensory evaluations and helped reduce perceived astringency. Moreover, Sharif et al. (2017) reported that apple is commonly used as a palate cleanser.

#### 2.6. Statistical analyses

Sample characteristics were compared using analysis of variance (ANOVA) accompanied by a Newman-Keuls multiple comparisons procedure; an alpha level of 0.05 was employed. A principal component analysis (PCA) was performed to explore patterns in sample profiles and characteristics. Twenty-one variables were included in the PCA: they described the flours (dry matter content, protein content, fiber content, starch content, lipid content, ash content, OAC, WAC, EA, and D90), dough portions (hardness and extensibility), and shortcrust pastries (hardness, bake yield,  $a_w$ , thickness, and five texture-related sensory attributes).

Certain variables were not included in the PCA: the color dimensions, the qualities determined via calculation (e.g., carbohydrates), and certain variables that were correlated with each other (e.g., D [4,3] was correlated with D90). The analyses were performed using Statgraphics Centurion 19 software (FranceStat, Neuilly, France).

### 3. Results and discussion

#### 3.1. Legume chemical and functional characteristics

##### 3.1.1. Chemical composition

When designing our research framework, legumes were selected based on variation in their chemical compositions (as reported in the scientific literature). More specifically, lupins were chosen because they have low levels of starch and high levels of protein compared to other legumes such as lentils, red beans, white beans, and chickpeas. Significant differences in chemical composition were observed among the legumes used in our study. The lupin flour had higher lipid content (12.5 % DM), protein content (37.9 % DM), and fiber content (38.2 % DM) than did the other four legume flours (approximate range: 0.8–6.3 % DM, 17.7–33.4 % DM, and 13.3–26.1 % DM for lipid, protein, and fiber content, respectively) (Table 4). These figures resemble those obtained in past studies (Kohajdová et al., 2011; Tiwari and Singh, 2012). The protein and fiber contents of the wheat flour control were lower than those of the legume flours (regardless of legume thermal treatment). Conversely, the starch content of the wheat flour control was quite high compared to what was seen in most of the legume flours (red bean, white bean, lentil, and chickpea); the lupin flour did not contain any starch. Indeed, lupins are known to contain little to no starch, and our results were thus consistent with the literature (Prusinski, 2017).

**Table 4**  
Physicochemical and functional properties of legume flours and wheat flour control.

	White Beans		Red Beans		Lentils		Chickpeas		Lupins		Wheat	
	UNT	T	UNT	T	UNT	T	UNT	T	UNT	T	UNT	UNT
<b>Chemical composition (g/100 g DM)</b>												
Protein	23.0 ± 0.3 <sup>d</sup>	23.8 ± 0.6 <sup>d</sup>	28.5 ± 0.8 <sup>f</sup>	26.7 ± 1.1 <sup>e</sup>	33.4 ± 0.8 <sup>g</sup>	27.0 ± 0.7 <sup>e</sup>	19.3 ± 0.4 <sup>c</sup>	17.7 ± 0.2 <sup>b</sup>	11.5 ± 0.5 <sup>a</sup>	11.5 ± 0.4 <sup>b</sup>	12.5 ± 1.7 <sup>d</sup>	0.8 ± 0.1 <sup>a</sup>
Lipid	1.4 ± 0.4 <sup>ab</sup>	3.5 ± 0.7 <sup>b</sup>	1.4 ± 0.7 <sup>ab</sup>	1.4 ± 0.2 <sup>ab</sup>	0.8 ± 0.03 <sup>a</sup>	1.7 ± 0.4 <sup>ab</sup>	6.3 ± 1.2 <sup>c</sup>	6.2 ± 1.2 <sup>c</sup>	58.6 ± 1.4	58.7 ± 1.6	7.2 ± 2.0	82.6 ± 0.3
Carbohydrate <sup>a</sup>	45.1 ± 0.3	44.7 ± 0.3	43.2 ± 1.6	47.2 ± 0.9	48.7 ± 0.9	54.1 ± 1.0	37.1 ± 1.2 <sup>b</sup>	39.8 ± 3.7 <sup>b</sup>	0.0 ± 0 <sup>b</sup>	74.2 ± 1.8 <sup>c</sup>	0.0 ± 0 <sup>b</sup>	74.2 ± 1.8 <sup>c</sup>
Starch	29.5 ± 2.0 <sup>b</sup>	34.2 ± 1.1 <sup>b</sup>	31.1 ± 2.0 <sup>b</sup>	33.4 ± 3.9 <sup>b</sup>	39.8 ± 1.7 <sup>b</sup>	38.4 ± 1.5 <sup>b</sup>	37.1 ± 1.2 <sup>b</sup>	37.1 ± 1.2 <sup>b</sup>	38.2 ± 4.0	14.1 ± 2.5	4.5 ± 1.6	4.6 ± 0.1 <sup>a</sup>
Fiber <sup>b</sup>	26.1 ± 3.4	23.6 ± 3.2	22.8 ± 3.3	20.5 ± 2.9	13.3 ± 2.5	14.4 ± 2.6	2.8 ± 0 <sup>b</sup>	3.4 ± 0 <sup>c</sup>	3.4 ± 0.0 <sup>c</sup>	3.4 ± 0.0 <sup>c</sup>	4.1 ± 0.2 <sup>e</sup>	0.6 ± 0.1 <sup>a</sup>
Ash	4.4 ± 0.04 <sup>f</sup>	4.3 ± 0.03 <sup>f</sup>	4.0 ± 0.01 <sup>e</sup>	4.2 ± 0.1 <sup>f</sup>	3.8 ± 0.1 <sup>d</sup>	2.8 ± 0 <sup>b</sup>	0.96 ± 0.1 <sup>b</sup>	1.22 ± 0.0 <sup>d</sup>	0.79 ± 0.0 <sup>b</sup>	1.29 ± 0.0 <sup>d</sup>	0.83 ± 0.0 <sup>c</sup>	0.58 ± 0.0 <sup>a</sup>
<b>Physical and Functional Properties</b>												
WAC <sup>c</sup>	1.24 ± 0.0 <sup>d</sup>	1.58 ± 0.0 <sup>e</sup>	1.59 ± 0.0 <sup>e</sup>	1.78 ± 0.0 <sup>f</sup>	1.06 ± 0.0 <sup>c</sup>	1.26 ± 0.0 <sup>d</sup>	0.84 ± 0.0 <sup>c</sup>	0.70 ± 0.0 <sup>a</sup>	0.82 ± 0.0 <sup>bc</sup>	42.5 ± 1.0 <sup>cd</sup>	41.6 ± 1.1 <sup>cd</sup>	39.3 ± 0.6 <sup>b</sup>
OAC <sup>c</sup>	0.85 ± 0.0 <sup>c</sup>	0.78 ± 0.0 <sup>b</sup>	0.79 ± 0.0 <sup>b</sup>	0.69 ± 0.0 <sup>a</sup>	44.0 ± 1.2 <sup>de</sup>	45.5 ± 1.2 <sup>ef</sup>	40.6 ± 0.9 <sup>bc</sup>	81.9 ± 0.1 <sup>a</sup>	88.9 ± 0.1 <sup>a</sup>	87.1 ± 0.5 <sup>f</sup>	85.7 ± 0.2 <sup>e</sup>	91.8 ± 0.1 <sup>i</sup>
EA (%)	43.5 ± 0.8 <sup>de</sup>	43.6 ± 1.6 <sup>de</sup>	47.0 ± 0.9 <sup>f</sup>	82.8 ± 0.1 <sup>b</sup>	83.8 ± 0.2 <sup>c</sup>	84.5 ± 0.3 <sup>d</sup>	15.3 ± 0.6 <sup>d</sup>	20.7 ± 0.4 <sup>f</sup>	22.6 ± 0.4 <sup>g</sup>	34.5 ± 0.6 <sup>b</sup>	9.9 ± 0.2 <sup>b</sup>	86.7 ± 0.2 <sup>f</sup>
L*	89.4 ± 0.0 <sup>b</sup>	89.5 ± 0.1 <sup>b</sup>	10.1 ± 0.2 <sup>b</sup>	12.4 ± 0.4 <sup>c</sup>	8.8 ± 0.0 <sup>a</sup>	74.9 ± 0.3 <sup>a</sup>	82.1 ± 0.2 <sup>b</sup>	92.1 ± 0.1 <sup>h</sup>	85.4 ± 0.1 <sup>c</sup>	87.1 ± 0.1 <sup>e</sup>	86.1 ± 0.1 <sup>e</sup>	86.7 ± 0.2 <sup>f</sup>
C*	88.4 ± 0.1 <sup>b</sup>	87.0 ± 0.0 <sup>b</sup>	0.75 ± 0.0 <sup>d</sup>	0.85 ± 0.0 <sup>b</sup>	0.75 ± 0.0 <sup>d</sup>	0.90 ± 0.0 <sup>b</sup>	0.67 ± 0.0 <sup>h</sup>	0.70 ± 0.0 <sup>b</sup>	0.70 ± 0.0 <sup>c</sup>	0.64 ± 0.0 <sup>b</sup>	0.79 ± 0.0 <sup>e</sup>	0.79 ± 0.0 <sup>e</sup>
h (°)	0.71 ± 0.01 <sup>c</sup>	0.76.1 ± 3.4 <sup>c</sup>	64.5 ± 0.2 <sup>b</sup>	55.0 ± 0.3 <sup>a</sup>	51.3 ± 0.6 <sup>a</sup>	54.3 ± 0.4 <sup>a</sup>	68.0 ± 0.6 <sup>b</sup>	46.2 ± 0.4 <sup>a</sup>	51.6 ± 0.6 <sup>a</sup>	186.1 ± 11.3 <sup>e</sup>	96.3 ± 3.2 <sup>d</sup>	193.3 ± 30.8 <sup>g</sup>
Bulk density <sup>c</sup>	D [4,3] (µm)	D90 (µm)	160.3 ± 1.2 <sup>c</sup>	216.8 ± 9.0 <sup>f</sup>	172.7 ± 0.4 <sup>cde</sup>	135.6 ± 3.4 <sup>b</sup>	169.5 ± 3.1 <sup>cd</sup>	185.8 ± 1.6 <sup>de</sup>	98.9 ± 3.0 <sup>a</sup>	140.8 ± 2.3 <sup>b</sup>	458.3 ± 458.3 ± 2.3 <sup>b</sup>	193.3 ± 0.7 <sup>c</sup>

UNT: flour made from untreated legumes, T: flour made from thermally treated legumes, DM: dry matter, WAC: water absorption capacity, OAC: oil absorption capacity, EA: emulsifying activity.

Values are means ± standard deviations.

Values within the same row with different superscript letters are significantly different ( $p < 0.05$ , the Newman-Keuls method was used for multiple comparisons).

<sup>a</sup> Carbohydrate values were obtained via calculation: 100 g – (protein + lipid + fiber + ash).

<sup>b</sup> Fiber values were obtained from a single analysis of each sample conducted by a commercial laboratory (using their own internal measures of standard deviation).

<sup>c</sup> Units are: g H<sub>2</sub>O/g DM for WAC, g oil/g DM for OAC, and g/mL for bulk density.

### 3.1.2. Functional properties

**Water absorption capacity.** The mean WAC of the legume flours ranged from 0.96 to 2.58 g/g DM, with lupin flour displaying the highest WAC (Table 4). The mean WAC of the wheat flour control (0.58 g/g DM) was lower than the mean WACs of the legume flours. The results we obtained for most of the legume flours were comparable to those obtained in other studies. For whole flours made from different varieties of beans, lentils, and chickpeas, Du et al. (2014) obtained WAC values ranging between 1.1 and 1.9 g/g. Jamalullail et al. (2022) observed a WAC range of 0.6–1.3 g/g for different cultivars of whole beans as well as soybeans. For lupins (white cultivar, *L. albus*), Mazumder et al. (2021) obtained values that varied from 1.7 to 3.3 g/g. Several factors may be responsible for legume-related differences in WAC. Indeed, legumes usually contain four protein fractions: glutelin, prolamin, albumin, and globulin. Glutelin and prolamin occur at lower levels, while albumin and globulin occur at higher levels. Focusing on the latter, various studies have shown that globulin has a higher WAC than does albumin (Ghumman et al., 2016; Mundi and Aluko, 2012). In lentils, beans, and chickpeas, the albumin-to-globulin ratio varies between 1:3 and 1:6 (Shevkani et al., 2019). In white lupins, a ratio of 1:9 was observed by Duranti et al. (2008), indicating that lupins contain a higher relative amount of globulin compared to other legumes. Additionally, fiber type (soluble vs. insoluble) and content can influence WAC (Keskin et al., 2022). In our study, the lupin flour had the highest fiber content and the highest WAC. Conversely, the wheat flour control had the lowest fiber content and the lowest WAC.

Among the legume flours, WAC was greater for flours made from thermally treated versus untreated legumes. This difference could be attributed to the protein denaturation that occurs during thermal treatment; indeed, Ghavidel and Prakash (2006) reported that WAC was enhanced by protein denaturation, which is known to induce structural unfolding (Lefèvre et al., 2022) and thus more exposure of hydrophilic compounds (Xu et al., 2017).

**Oil absorption capacity.** OAC was higher for the lupin flour than for the other legume flours (1.29 vs. 0.69–0.85 g oil/g DM, respectively) (Table 4). Siddiq et al. (2010) obtained values ranging from 1.23 to 1.52 g/g for different legume species. OAC is an important characteristic to consider when developing new foods and can affect stability during storage (mainly because of its influence on flavor binding and oxidative rancidity) (Siddiq et al., 2010). Moreover, the flours with a higher OAC might contain more lipophilic compounds, which could improve the palatability and shelf life of food products, particularly bakery products such as cookies, pancakes, and cakes (Thongram et al., 2016).

**Emulsifying activity.** The emulsifying properties of flours play a crucial role in bakery products since they contain both water and fat. Therefore, incorporating legume flour into bakery product recipes requires careful consideration (Gupta et al., 2018). In our study, we observed that legume flours had EA values ranging from 39.3 to 47.0 %, with lupin flour displaying the lowest value. The wheat flour control had a lower EA value (13.3 %) than did the legume flours (Table 4). Nawaz et al. (2021) also observed that EA values were lower for wheat flour (4.5–18.8 %) than for chickpea flour (25.5–32.7 %). Moreover, the researchers observed that the addition of chickpea flour to wheat flour led to a significant increase in EA values.

**Color.** All the legume flours had lower lightness (L\*) values (81.9–89.5) than did the wheat flour control (91.2) (Table 4). The hue angle (h) values indicated that the white bean, chickpea, and lupin flours tended to be more yellow because their values were closer to 90°, and yellow saturation (C\*) was higher for the lupin flour than for the other two flours. For the red bean flour, a lower level of yellowish-reddish saturation was observed. The C\* and h values obtained for the lentil flour described a green-yellow color.

**Bulk density.** Bulk density values varied between 0.64 and 0.90 g/mL (Table 4). Significant differences were observed among samples. Du et al. (2014) obtained values ranging from 0.54 to 0.82 g/mL for whole flours made from pinto beans, lima beans, red kidney beans, black

beans, navy beans, small red beans, black-eye beans, mung beans, lentils, and chickpeas. Differences in bulk density among legume flours can be related to mill type and setting (Ahmed et al., 2022).

**Particle size.** As stated in the methods, the local company producing the legume flours followed technical specifications with reproducible granulometric results: 90 % of particles were smaller than 500 µm for the lupin flour and smaller than 250 µm for the other legume flours. Our D90 results confirmed that these standards were respected. Here, the value for the lupin flour was 458.3 µm, and the values for the other legume flours ranged between 98.9 and 216.8 µm (Table 4). The differences observed among the flours could be linked to the physical characteristics (hardness and dimensions) of the legume seeds.

### 3.2. Comparison of dough and shortcrust pastry qualities

After dough preparation, the dry matter of all the dough portions was measured. Across all dough types, mean dry matter ( $72.6 \pm 0.8\%$ ) was nearly equivalent to expected dry matter (73 %) (Table 2). Thus, it was straightforward to compare the shortcrust pastries made with different flour types.

#### 3.2.1. Dough qualities

**Color.** L\* was lower for all the legume-based doughs than for the legume flours. Conversely, C\* and h were higher for the legume-based doughs than for the legume flours. These differences could have arisen from the addition of water and butter to the flours to make the doughs (Table 5).

**Hardness and extensibility.** Hardness was lower for the doughs made with the lentil and chickpea flours (regardless of legume thermal treatment) than for the doughs made with the red bean, white bean, or lupin flours (Table 5).

The wheat-based dough had a higher extensibility value than did any of the legume-based doughs (Table 5). This difference could be related to the presence of gluten, a major wheat protein that promotes the formation of a gluten network, which is crucial for dough extensibility. Gluten consists of gliutenins (protein aggregates with high- and low-molecular-weight subunits) and gliadins. In the presence of water, the high-molecular-weight gliutenin subunits are linked by disulfide bonds and form an elastic structure with the low-molecular-weight gliutenin subunits (Hu et al., 2023). The difference in extensibility could also be explained by the higher fiber contents of the legume flours compared to

that of the wheat flour control. Indeed, Gómez et al. (2003) showed that higher levels of fiber can negatively affect dough extensibility during bread-making.

#### 3.2.2. Shortcrust pastry qualities

**3.2.2.1. Baking and textural characteristics. Color.** Baking induced significant changes in color. For most of the shortcrust pastries, we observed a decrease in L\* and an increase in C\* (Table 5 and S1 Supplementary materials). Moreover, for most of the shortcrust pastries made with untreated legume flours, h values were lower than for the equivalent doughs. Color changes are usually related to the Maillard reaction, non-enzymatic browning that results from the interaction of reducing sugars with proteins and that produces reddish-brown hues. Color changes can also be linked to the dextrinization of starch. In doughs with very open structures, the migration of moisture to the surface occurs more slowly, allowing for a local increase in surface temperature and, consequently, more pronounced color shifts (Chevallier et al., 2000).

**Bake yield, water activity, and thickness.** A comparison of the legume-based shortcrust pastries showed that the bake yield for the shortcrust pastry made with the thermally treated lentil flour was significantly higher than that for the shortcrust pastries made with any of the other legume flours. However, no significant differences were seen in thickness or a<sub>w</sub> (Table 5).

The wheat-based shortcrust pastry had higher values for all three characteristics than did the legume-based shortcrust pastries (bake yield: wheat-based = 80.6 % vs. legume-based = 74.4–79.1 %; thickness: wheat-based = 12.8 mm vs. legume-based = 5.7–6.7 mm; and a<sub>w</sub>: wheat-based = 0.69 vs. legume-based = 0.39–0.51). The result for the wheat-based shortcrust pastry thickness could be explained by the fact that a gluten network forms in the wheat-based shortcrust pastry, allowing dough expansion during baking. For the bake yield and a<sub>w</sub>, the results could be related to the behavior of water in the doughs, where water binding might have been greater in the wheat-based dough than in the legume-based doughs.

**Hardness.** We found that shortcrust pastries made with the white bean flour were softer than shortcrust pastries made with the other legume flours, regardless of legume thermal treatment (Table 5). In contrast, shortcrust pastries made with the lentil flour were harder than shortcrust pastries made with the other legume flours. This difference

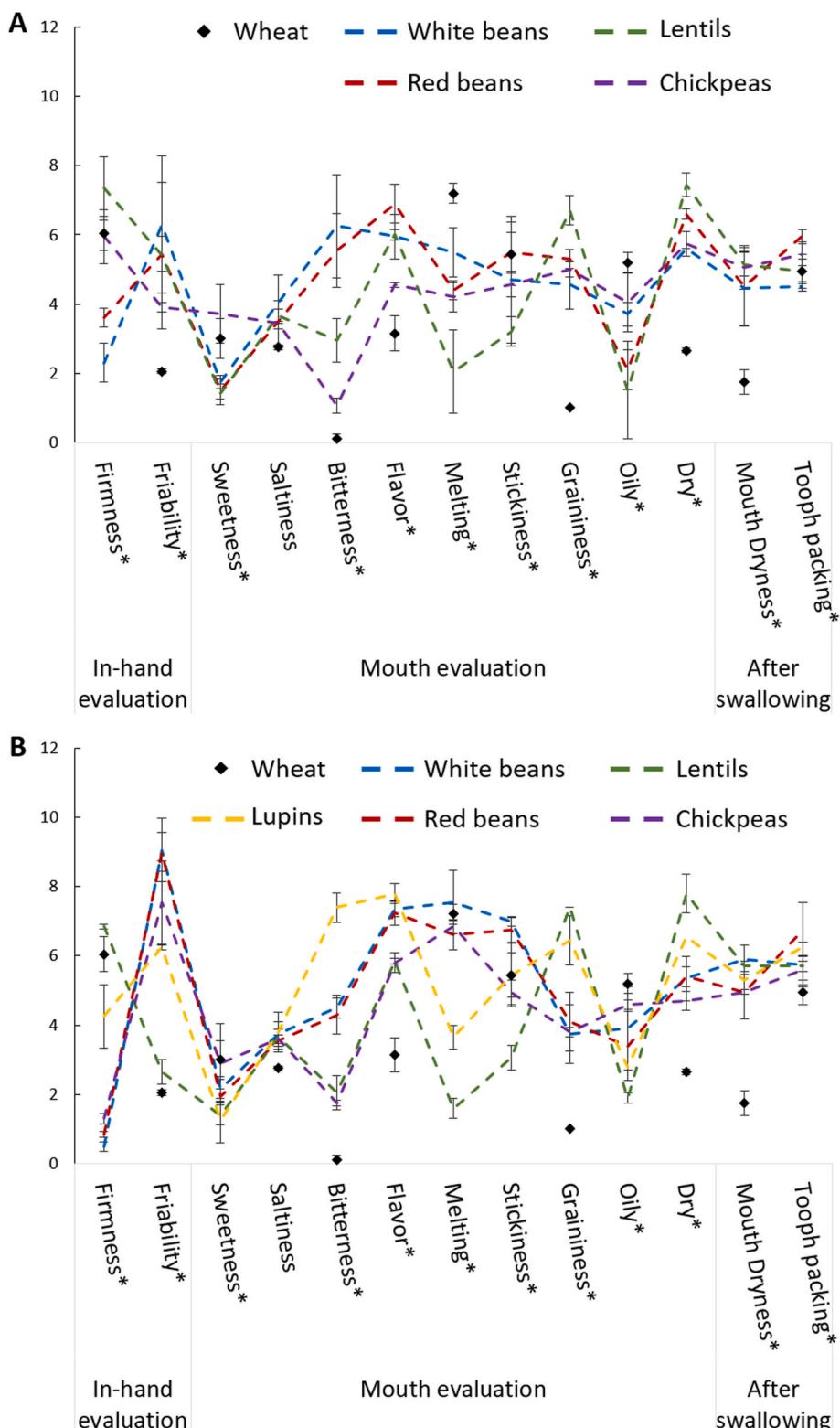
**Table 5**  
Characteristics of doughs and shortcrust pastries.

	White Beans		Red Beans		Lentils		Chickpeas		Lupins		Wheat
Doughs	UNT	T	UNT	T	UNT	T	UNT	T	UNT	T	
L*	51.6 ± 2.3 <sup>cd</sup>	57.3 ± 1.9 <sup>d</sup>	23.5 ± 4.7 <sup>a</sup>	33.6 ± 2.6 <sup>b</sup>	25.7 ± 0.2 <sup>a</sup>	25.4 ± 0.8 <sup>a</sup>	51.0 ± 2.6 <sup>cd</sup>	51.4 ± 2.0 <sup>cd</sup>	49.3 ± 1.2 <sup>c</sup>	65.8 ± 2.6 <sup>e</sup>	
C*	17.2 ± 1.1 <sup>e</sup>	25.8 ± 0.3 <sup>f</sup>	12.4 ± 0.3 <sup>b</sup>	16.2 ± 0.5 <sup>de</sup>	15.5 ± 0.4 <sup>cd</sup>	10.4 ± 0.7 <sup>a</sup>	25.9 ± 0.4 <sup>f</sup>	37.4 ± 0.4 <sup>g</sup>	43.1 ± 0.4 <sup>h</sup>	14.6 ± 0.6 <sup>c</sup>	
h (°)	85.9 ± 0.1 <sup>de</sup>	80.9 ± 0.1 <sup>bc</sup>	48.7 ± 1.9 <sup>a</sup>	60.4 ± 1.8 <sup>b</sup>	85.7 ± 1.5 <sup>de</sup>	88.0 ± 0.2 <sup>e</sup>	84.3 ± 0.4 <sup>d</sup>	80.8 ± 0.25 <sup>c</sup>	81.3 ± 0.5 <sup>c</sup>	87.6 ± 0.8 <sup>e</sup>	
Hardness (N)	59.2 ± 2.3 <sup>b</sup>	61.4 ± 6.4 <sup>b</sup>	48.2 ± 12.1 <sup>b</sup>	58.5 ± 0.6 <sup>b</sup>	20.5 ± 4.7 <sup>a</sup>	30.7 ± 9.6 <sup>a</sup>	15.9 ± 0.9 <sup>a</sup>	26.9 ± 1.7 <sup>a</sup>	53.4 ± 1.0 <sup>b</sup>	19.2 ± 3.5 <sup>a</sup>	
Extensibility (mm)	4.7 ± 0.4 <sup>a</sup>	5.3 ± 0.2 <sup>ab</sup>	6.3 ± 0.6 <sup>ab</sup>	5.9 ± 0.9 <sup>ab</sup>	12.0 ± 2.9 <sup>d</sup>	10.0 ± 0.7 <sup>bcd</sup>	11.4 ± 0.2 <sup>cd</sup>	7.8 ± 2.9 <sup>abc</sup>	5.3 ± 0.4 <sup>ab</sup>	42.7 ± 0.1 <sup>e</sup>	
Shortcrust pastries											
L*	62.3 ± 2.6 <sup>c</sup>	68.6 ± 2.3 <sup>d</sup>	41.2 ± 1.4 <sup>a</sup>	50.5 ± 1.0 <sup>b</sup>	37.9 ± 1.5 <sup>a</sup>	40.4 ± 2.7 <sup>a</sup>	58.8 ± 2.8 <sup>c</sup>	62.0 ± 2.2 <sup>c</sup>	60.1 ± 1.9 <sup>c</sup>	62.2 ± 1.2 <sup>c</sup>	
C*	33.9 ± 1.0 <sup>d</sup>	30.6 ± 1.0 <sup>c</sup>	16.6 ± 0.6 <sup>ab</sup>	17.1 ± 0.5 <sup>ab</sup>	18.6 ± 0.6 <sup>b</sup>	14.7 ± 2.4 <sup>a</sup>	35.1 ± 0.1 <sup>b</sup>	36.2 ± 1.1 <sup>d</sup>	45.4 ± 0.5 <sup>e</sup>	19.4 ± 1.9 <sup>b</sup>	
h (°)	74.1 ± 3.2 <sup>c</sup>	79.8 ± 0.9d	56.0 ± 1.8 <sup>a</sup>	69.9 ± 0.9 <sup>bc</sup>	67.0 ± 1.0 <sup>b</sup>	70.3 ± 2.1 <sup>bc</sup>	71.3 ± 2.0 <sup>bc</sup>	79.5 ± 0.5d	78.2 ± 1.0 <sup>d</sup>	87.0 ± 0.6e	
Hardness (N)	4.2 ± 2.5 <sup>ab</sup>	0.8 ± 0.2 <sup>a</sup>	6.9 ± 3.1 <sup>ab</sup>	1.2 ± 0.2 <sup>a</sup>	21.6 ± 0.3 <sup>d</sup>	18.5 ± 3.4 <sup>cd</sup>	8.9 ± 2.4 <sup>b</sup>	3.2 ± 0.7 <sup>ab</sup>	6.9 ± 1.5 <sup>ab</sup>	14.3 ± 0.3 <sup>c</sup>	
Bake yield (%)	74.8 ± 0.8 <sup>a</sup>	74.7 ± 0.6 <sup>a</sup>	76.1 ± 0.2 <sup>a</sup>	75.5 ± 0.4 <sup>a</sup>	75.9 ± 1.0 <sup>a</sup>	79.1 ± 1.3 <sup>b</sup>	76.1 ± 0.6 <sup>a</sup>	75.5 ± 0.6 <sup>a</sup>	74.4 ± 0.8 <sup>a</sup>	80.6 ± 0.3 <sup>b</sup>	
a <sub>w</sub>	0.39 ± 0.0 <sup>a</sup>	0.40 ± 0.0 <sup>a</sup>	0.45 ± 0.0 <sup>a</sup>	0.42 ± 0.0 <sup>a</sup>	0.51 ± 0.0 <sup>a</sup>	0.49 ± 0.0 <sup>a</sup>	0.47 ± 0.0 <sup>a</sup>	0.45 ± 0.0 <sup>a</sup>	0.41 ± 0.1 <sup>a</sup>	0.69 ± 0.1 <sup>b</sup>	
Thickness (mm)	5.7 ± 0.4 <sup>a</sup>	6.1 ± 0.1a	6.0 ± 0.6 <sup>a</sup>	6.3 ± 0.2 <sup>a</sup>	6.2 ± 0.4 <sup>a</sup>	6.7 ± 0.5a	6.7 ± 0.2 <sup>a</sup>	6.5 ± 0.1 <sup>a</sup>	6.1 ± 0.4 <sup>a</sup>	12.8 ± 4.4 <sup>b</sup>	

UNT: flour made from untreated legumes, T: flour made from thermally treated legumes.

Values are means ± standard deviations.

Values within the same row with different superscript letters are significantly different (p < 0.05; the Newman-Keuls method was used for the multiple comparisons).



**Fig. 1.** Comparison of sensory attributes for legume and control (wheat) shortcrust pastries. A: using flour made from untreated legumes and B: using flour made from thermally treated legumes. (\*) indicates attributes presenting significant difference ( $p < 0.05$ ) using the panel average values for the two sections. Curves are generated with the mean of the sensory rankings for each legume.

could be attributed to variation in chemical composition, particularly in fiber type (soluble or insoluble) and protein type. Both of the latter significantly affect the hydration properties of flours, thereby influencing the quality of doughs and final bakery products.

**3.2.2.2. Sensory attributes.** The one-way ANOVA testing the effects of flour type revealed significant differences ( $p < 0.05$ ) in all the sensory characteristics of the shortcrust pastries, except for saltiness (Fig. 1).

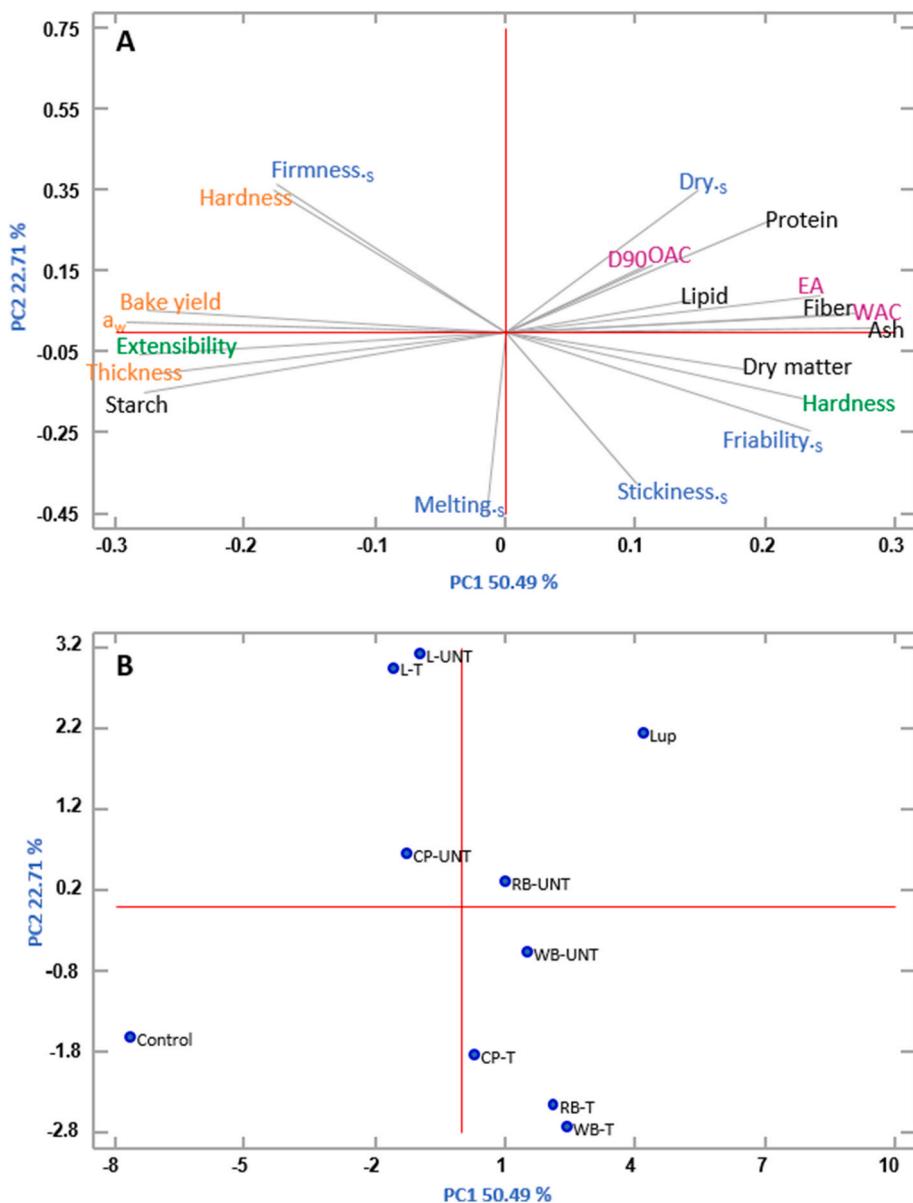
**In-hand evaluation.** We observed that the shortcrust pastry made with untreated lentil flour was firmer (mean rating:  $7.35 \pm 0.9$ ) than the

shortcrust pastries made with the other untreated legume flours (range of mean ratings: 2.30–5.95). Firmness was lower for most of the shortcrust pastries made with the thermally treated legume flours (percent reduction in ratings: 78.3 % for white bean flour, 76.4 % for red bean flour, 6.8 % for lentil flour, and 78.8 % for chickpea flour). These results concurred with the hardness values measured using laboratory instruments.

Friability was highest for the shortcrust pastries made with the thermally treated white bean and red bean flours (range of mean ratings: 9.00–9.05), with the next highest values seen for the shortcrust pastries made with the thermally treated chickpea flour (mean rating:  $7.55 \pm 1.2$ ) and lupin flour (mean rating:  $6.25 \pm 0.1$ ). The wheat-based shortcrust pastry had a lower level of friability (mean rating:  $2.05 \pm 0.1$ ) than did all of the legume-based shortcrust pastries.

**Oral evaluation.** Compared to the wheat-based shortcrust pastry, most of the legume-based shortcrust pastries exhibited lower levels of

sweetness (mean rating for wheat-based pastry:  $3.00 \pm 0.6$  versus range of mean ratings for legume-based pastries: 1.25–2.15), except in the case of the chickpea flour. Legume thermal treatment did not affect this attribute. While the wheat-based shortcrust pastry was not perceived as bitter, the legume-based shortcrust pastries were perceived as having some degree of bitterness, regardless of legume thermal treatment. The shortcrust pastries made with lupin flour had the highest level of bitterness (mean rating:  $7.4 \pm 0.4$ ). Boukid and Pasqualone (2022) reported that traditionally consumed lupins are bitter due to their high alkaloid contents, which range from 1 to 3 % of seeds dry mass. The legume-based shortcrust pastries were more flavorful, regardless of legume thermal treatment (range of mean ratings: 4.55–7.80), than the wheat-based shortcrust pastry (mean rating:  $3.15 \pm 0.5$ ). The legume-based shortcrust pastries were grainier (range of mean ratings: 3.75–6.70) than the wheat-based shortcrust pastry, which had a very low level of graininess (mean rating:  $1.00 \pm 0.0$ ). Even though the same



**Fig. 2.** Principal component analysis (PCA) showing relationship between flour, dough, and shortcrust pastry qualities. A: Variables plot, B: Samples plot. Samples code stand for: Legume abbreviation-Flour treatment abbreviation. Legume abbreviations: Lentils (L); Chickpeas (CP); White Beans (WB); Red Beans (RB); Lupins (Lup). Treatment abbreviation: flour made from untreated legumes (UNT) and flour made from thermally treated legumes (T). In black: Chemical composition, in pink: functional properties, in green: dough textural properties, in orange: shortcrust pastry qualities using laboratory instrument analyses, and in blue: shortcrust pastry qualities using sensory analyses.

amount of butter was used in all the recipes, the wheat-based shortcrust pastry was rated as oilier (mean rating:  $5.20 \pm 0.3$ ) than the legume-based shortcrust pastries (range of mean ratings: 1.50–4.60). In contrast, the legume-based shortcrust pastries were drier (range of mean ratings: 4.70–7.80) than the wheat-based shortcrust pastry (mean rating:  $2.65 \pm 0.4$ ).

**Evaluation after swallowing.** The drying sensation on the palate after swallowing (i.e., mouth dryness) was more pronounced for the legume-based shortcrust pastries (range of mean ratings: 4.45–5.90) than for the wheat-based shortcrust pastry (mean rating:  $1.75 \pm 0.4$ ). Tooth packing ratings were quite similar across all the shortcrust pastries (wheat-based mean:  $4.95 \pm 0.4$ , range of legume-based means: 4.50–6.75).

A three-level ANOVA was used to assess the effects of the two sessions, the flour types, and the panelists. It revealed that session did not influence most of the sensory attributes, with the exception of sweetness and stickiness. This finding indicates that the two rounds of production, evaluated by the panelists during the different sessions, led to consistent results (Supplementary materials Table S1).

### 3.3. Link between flour, dough, and shortcrust pastry characteristics

Fig. 2 presents the PCA results, which highlight the relationship between the chemical and functional properties of the flours, the textural properties of the doughs, and the textural and sensory properties of the shortcrust pastries. The two axes together explained 73.2 % of the variability.

When looking at the chemical and functional properties of the flours, we observed a positive correlation between WAC, fiber content, and protein content as well as between OAC and lipid content. Our results show that the wheat and lupin flours differed significantly in their culinary qualities from the lentil, chickpea, white bean, and red bean flours. This result could be partly attributed to the extreme values of protein, fiber, starch, and lipid content for the lupin and wheat flours.

For the textural properties of the doughs, extensibility was negatively correlated with fiber content and protein content. Given that gluten proteins are known to contribute to dough elasticity, the investigation of total proteins in our study did not reveal their qualitative impact on the main texture properties of doughs. Interestingly, the hardness of the doughs was not correlated with the hardness of the shortcrust pastries. This result can be attributed to the complex mechanisms occurring during baking and cooling, which are influenced by the impact of flour chemical composition on shortcrust pastry hardness. Indeed, for the shortcrust pastries, hardness was positively correlated with starch content but negatively correlated with protein content and lipid content. As a result, interactions may have occurred between partially gelatinized and retrograded starch, solidified fats, and the proteins, which resulted in the final structure. The lentil-based samples were well represented on the second axis, where firmness (sensory attribute) and hardness had higher values. Red- and white-bean-based samples displayed less appealing qualities for this food model because they had higher levels of stickiness and friability. The PCA highlighted the influence of the thermal treatment applied to the red beans, white beans, and chickpeas: greater friability and stickiness. In summary, our results suggest that the use of legume flours with higher fiber content led to increased WAC, dough hardness, and shortcrust pastry brittleness (lower hardness). A similar trend was observed by Singh et al. (2017) for cookie formulations in which sweet potato flour, rich in fiber, was added to wheat flour.

In this study, we found that the culinary qualities of the food model were influenced by both legume type and thermal treatment (except in the case of lentils). Also, it is worth noting that the sensory evaluations

highlighted some differences in terms of taste: thermally treating the legumes tended to decrease the bitterness of the legume-based shortcrust pastries (Fig. 1).

### 4. Conclusions

We collaborated with professional chefs to develop a food model where flours made from untreated or thermally treated legumes (lentils, chickpeas, red beans, white beans, and lupins) were used to make shortcrust pastries. Our study highlighted the necessity of using such food models (e.g., shortcrust pastry) to predict the impact of legume chemical characteristics on a product's culinary qualities, a process that involves both laboratory instruments and sensory attribute analyses. This work will help expand the use of legumes in specific food products.

Several aspects of this research require further exploration. Sampling approaches that include more varieties and cultural practices should be adopted in future studies to better describe the variability of legumes. Moreover, it will be important to better characterize legume composition, including the presence of different proteins (including the fractions and amino acids), starches (amylose and amylopectin), fibers (soluble and insoluble), and anti-nutritional factors. These lines of investigation will further enhance our understanding of the underlying mechanisms at play and facilitate the incorporation of legumes into food models, thereby diversifying the food applications of legumes.

### Implications for gastronomy

This study focused on enhancing the value and uses of five legumes (white beans, red beans, chickpeas, green lentils, and lupins) using a gastronomic approach. It explored multidimensional food characteristics (composition, functional properties, sensory attributes). More specifically, the originality of this study lies in the fact that legumes are valued for both their nutritional quality (high levels of starch, fiber, and protein) and their functional properties. We evaluated the culinary qualities of different legume flours using shortcrust pastry as a food model. The process employed a simplified version of the more complex legume-based shortcrust pastry recipe designed by professional chefs. This approach allowed us to link the composition and functional properties of legume flours and to determine the latter's impact on the qualities of the final food model. This research yielded useful information on the compositional, functional, and sensory qualities of legume flours, findings that can inform legume flour usage in shortcrust pastries forming part of various bakery products, including starters and desserts. High-fiber legume flours proved unsuitable because of their deleterious effects on dough handling (low extensibility) and shortcrust pastry texture (overly crumbly). The results of this study will help gastronomy professionals make more informed choices around the use of legume flours in shortcrust pastries.

### CRediT authorship contribution statement

**Lorène Akissoé:** Writing – original draft, Project administration, Methodology, Investigation, Formal analysis. **Céline Brasse:** Writing – review & editing, Validation, Supervision, Conceptualization. **Isabelle Maitre:** Writing – review & editing, Validation, Supervision, Conceptualization. **Brice Guerin:** Methodology, Conceptualization. **Guillaume Piva:** Writing – review & editing, Validation, Supervision, Conceptualization. **Ronan Symoneaux:** Writing – review & editing, Validation, Supervision, Conceptualization. **Marie Dufrechou:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization.

## Declaration of competing interest

None.

## Acknowledgments

We received financial support from Angers Loire Métropole, which allowed this work to come to fruition. We thank the company Inveja for providing the legume flours used in this study. We are grateful to Dominique Le Meurlay, Sylvain Chatonnet, Régine Struillou, and Corinne Patron for their technical assistance during this project. Moreover, we extend our appreciation to all the panelists who participated in the sensory analysis.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ijgfs.2025.101219>.

## Data availability

Data will be made available on request.

## References

- Aguilera, Y., Esteban, R.M., Benítez, V., Mollá, E., Martín-Cabrejas, M.A., 2009. Starch, functional properties, and microstructural characteristics in chickpea and lentil as affected by thermal processing. *J. Agric. Food Chem.* 57, 10682–10688. <https://doi.org/10.1021/jf902042r>.
- Ahmed, J., Mulla, M.Z., Siddiq, M., Dolan, K.D., 2022. Micromeritic, thermal, dielectric, and microstructural properties of legume ingredients: a review. *Legume Science* 4, e123. <https://doi.org/10.1002/leg3.123>.
- Akissoé, L., Hemery, Y.M., Madodé, Y.E., Icard-Vernière, C., Rochette, I., Picq, C., Houhouigan, D.J., Mouquet-Rivier, C., 2023. Current consumption of traditional cowpea-based dishes in south Benin contributes to at least 30% of the recommended intake of dietary fibre, folate, and magnesium. *Nutrients* 15, 1314. <https://doi.org/10.3390/nu15061314>.
- Akissoé, L., Icard-Vernière, C., Madodé, Y.E., Hemery, Y.M., Kpossoulande, C.E., Mouquet-Rivier, C., Houhouigan, D.J., 2022. Consumption of cowpea-based dishes in Benin: main motives and barriers, and spatial and temporal changes. *Legume Science* 1–10. <https://doi.org/10.1002/leg3.146>.
- AOAC, 1995. *Official Methods of Analysis*, sixteenth ed. Association of Official Analytical Chemists, International, Washington DC.
- Boukid, F., 2021. Plant-based meat analogues: from niche to mainstream. *Eur. Food Res. Technol.* 247, 297–308. <https://doi.org/10.1007/s00217-020-03630-9>.
- Boukid, F., Pasqualone, A., 2022. Lupine (*Lupinus* spp.) proteins: characteristics, safety and food applications. *Eur. Food Res. Technol.* 248, 345–356. <https://doi.org/10.1007/s00217-021-03909-5>.
- Bresciani, A., Marti, A., 2019. Using pulses in baked products: lights, shadows, and potential solutions. *Foods* 8, 451. <https://doi.org/10.3390/foods8100451>.
- Champ, M., Magrini, M.-B., Simon, N., Guillou, C., 2015. Les légumineuses pour l'alimentation humaine: apports nutritionnels et effets santé, usages et perspectives, p. 263.
- Chevallier, S., Colonna, P., Buléon, A., Della Valle, G., 2000. Physicochemical behaviors of sugars, lipids, and gluten in short dough and biscuit. *J. Agric. Food Chem.* 48, 1322–1326. <https://doi.org/10.1021/jf900435+>.
- Du, S., Jiang, H., Yu, X., Jane, J., 2014. Physicochemical and functional properties of whole legume flour. *Lebensm.-Wiss. Technol.* 55, 308–313. <https://doi.org/10.1016/j.lwt.2013.06.001>.
- Duranti, M., Consonni, A., Magni, C., Sessa, F., Scarafoni, A., 2008. The major proteins of lupin seed: characterisation and molecular properties for use as functional and nutraceutical ingredients. *Trends Food Sci. Technol.* 19, 624–633. <https://doi.org/10.1016/j.tifs.2008.07.002>.
- Foschia, M., Horstmann, S.W., Arendt, E.K., Zannini, E., 2017. Legumes as functional ingredients in gluten-free bakery and pasta products. *Annu. Rev. Food Sci. Technol.* 8, 75–96. <https://doi.org/10.1146/annurev-food-030216-030045>.
- Ghavidel, R.A., Prakash, J., 2006. Effect of germination and dehulling on functional properties of legume flours. *J. Sci. Food Agric.* 86, 1189–1195. <https://doi.org/10.1002/j.sfa.2460>.
- Ghumman, A., Kaur, A., Singh, N., 2016. Functionality and digestibility of albumins and globulins from lentil and horse gram and their effect on starch rheology. *Food Hydrocoll.* 61, 843–850. <https://doi.org/10.1016/j.foodhyd.2016.07.013>.
- Gómez, M., Ronda, F., Blanco, C.A., Caballero, P.A., Apesteguía, A., 2003. Effect of dietary fibre on dough rheology and bread quality. *Eur. Food Res. Technol.* 216, 51–56. <https://doi.org/10.1007/s00217-002-0632-9>.
- Gupta, S., Chhabra, G.S., Liu, C., Bakshi, J.S., Sathe, S.K., 2018. Functional properties of select dry bean seeds and flours. *J. Food Sci.* 83, 2052–2061. <https://doi.org/10.1111/1750-3841.14213>.
- Han, J., Jay, Janz, J.A.M., Gerlat, M., 2010. Development of gluten-free cracker snacks using pulse flours and fractions. *Food Res. Int.* 43, 627–633. <https://doi.org/10.1016/j.foodres.2009.07.015>.
- Hu, X., Cheng, L., Hong, Y., Li, Z., Li, C., Gu, Z., 2023. An extensive review: how starch and gluten impact dough machinability and resultant bread qualities. *Crit. Rev. Food Sci. Nutr.* 63, 1930–1941. <https://doi.org/10.1080/10408398.2021.1969535>.
- Jamalullail, N.A., Chan, Y.L., Tang, T.K., Tan, C.P., Mat Dian, N.L.H., Cheong, L.Z., Lai, O.M., 2022. Comparative study of physicochemical, nutritional and functional properties of whole and defatted legume flours. *Food Res.* 6, 280–289. [https://doi.org/10.26656/fr.2017.6\(6\).659](https://doi.org/10.26656/fr.2017.6(6).659).
- Joshi, V., Kumar, S., 2015. Meat Analogues: plant based alternatives to meat products- A review. *Inte. Jour. of Food and Ferm. Tech.* 5, 107. <https://doi.org/10.5958/2277-9396.2016.00001.5>.
- Kaur, M., Singh, N., 2007. A comparison between the properties of seed, starch, flour and protein separated from chemically hardened and normal kidney beans. *J. Sci. Food Agric.* 87, 729–737. <https://doi.org/10.1002/jsfa.2798>.
- Keskin, S.O., Ali, T.M., Ahmed, J., Shaikh, M., Siddiq, M., Uebersax, M.A., 2022. Physicochemical and functional properties of legume protein, starch, and dietary fiber—a review. *Legume Science* 4, e117. <https://doi.org/10.1002/leg3.117>.
- Kieffer, R., Garnreiter, F., Belitz, H.-D., 1981. *Beurteilung von Teigegenschaften durch Zugversuche im Mikromaßstab 2*.
- Kohajdová, Z., Karovičová, J., Schmidt, Š., 2011. Lupin composition and possible use in bakery – a review. *Czech J. Food Sci.* 29, 203–211. <https://doi.org/10.17221/252/2009-CJFS>.
- Laleg, K., Barron, C., Cordelle, S., Schlich, P., Walrand, S., Micard, V., 2017. How the structure, nutritional and sensory attributes of pasta made from legume flour is affected by the proportion of legume protein. *Lebensm.-Wiss. Technol.* 79, 471–478. <https://doi.org/10.1016/j.lwt.2017.01.069>.
- Laleg, K., Cassan, D., Abecassis, J., Micard, V., 2021. Processing a 100% legume pasta in a classical extruder without agglomeration during mixing. *J. Food Sci.* 86, 724–729. <https://doi.org/10.1111/1750-3841.15604>.
- Laleg, K., Cassan, D., Barron, C., Prabhansankar, P., Micard, V., 2016. Structural, culinary, nutritional and anti-nutritional properties of high protein, gluten free, 100% legume pasta. *PLoS One* 11, e0160721. <https://doi.org/10.1371/journal.pone.0160721>.
- Lefèvre, C., Bohuon, P., Lullien-Pellerin, V., Mestres, C., 2022. Modeling the thermal denaturation of the protein-water system in pulses (lentils, beans, and chickpeas). *J. Agric. Food Chem.* 70, 9980–9989. <https://doi.org/10.1021/acs.jafc.2c03553>.
- Magrini, M.-B., Anton, M., Chardigny, J.-M., Duc, G., Duru, M., Jeuffroy, M.-H., Meynard, J.-M., Micard, V., Walrand, S., 2018. Pulses for sustainability: breaking agriculture and food sectors out of lock-in. *Front. Sustain. Food Syst.* 2, 64. <https://doi.org/10.3389/fsufs.2018.00064>.
- Magrini, M.-B., Anton, M., Cholez, C., Corre-Hellou, G., Duc, G., Jeuffroy, M.-H., Meynard, J.-M., Pelzer, E., Voisin, A.-S., Walrand, S., 2016. Why are grain-legumes rarely present in cropping systems despite their environmental and nutritional benefits? Analyzing lock-in in the French agrofood system. *Ecol. Econ.* 126, 152–162. <https://doi.org/10.1016/j.ecolecon.2016.03.024>.
- Maitre, I., Akissoé, L., Guerin, B., Piva, G., Symoneaux, R., Dufrechou, M., Brasse, C., 2024. Simplifying a multi-sensory gastronomic experience to identify the culinary potential of legumes: a proof of concept. *Sci. Talks* 10, 100352. <https://doi.org/10.1016/j.scitalk.2024.100352>.
- Mamat, H., Hill, S.E., 2014. Effect of fat types on the structural and textural properties of dough and semi-sweet biscuit. *J. Food Sci. Technol.* 51, 1998–2005. <https://doi.org/10.1007/s13197-012-0708-x>.
- Marchini, M., Carini, E., Cataldi, N., Boukid, F., Blandino, M., Ganino, T., Vittadini, E., Pellegrini, N., 2021. The use of red lentil flour in bakery products: how do particle size and substitution level affect rheological properties of wheat bread dough? *LWT* 136, 110299. <https://doi.org/10.1016/j.lwt.2020.110299>.
- Mazumder, K., Biswas, B., Kerr, P.G., Blanchard, C., Nabila, A., Golder, M., Aziz, M.G., Farahanyak, A., 2021. Comparative assessment of nutritional, thermal, rheological and functional properties of nine Australian lupin cultivars. *Sci. Rep.* 11, 21515. <https://doi.org/10.1038/s41598-021-00838-x>.
- Mouquet-Rivier, C., Icard-Vernière, C., Guyot, J.-P., Tou, E.H., Rochette, I., Trèche, S., 2008. Consumption pattern, biochemical composition and nutritional value of fermented pearl millet gruels in Burkina Faso. *Int. J. Food Sci. Nutr.* 59, 716–729. <https://doi.org/10.1080/09637480802206389>.
- Mundi, S., Aluko, R.E., 2012. Physicochemical and functional properties of kidney bean albumin and globulin protein fractions. *Food Res. Int.* 48, 299–306. <https://doi.org/10.1016/j.foodres.2012.04.006>.
- Nawaz, H., Aslam, M., Rehman, T., Mahmood, R., 2021. Modification of Emulsifying Properties of Cereal Flours by Blending with Legume Flours. *AJDFR*. <https://doi.org/10.18805/ajfr.DR-223>.
- Patient, D., 1994. The chemistry of pastry products. *Nutr. Food Sci.* 94, 33–35. <https://doi.org/10.1108/00346659310060223>.
- Prusinski, J., 2017. White lupin (*Lupinus albus* L.) - nutritional and health values in human nutrition - a review. *Czech J. Food Sci.* 35, 95–105. <https://doi.org/10.17221/114/2016-CJFS>.
- Satya, S., Kaushik, G., Naik, S.N., 2010. Processing of food legumes: a boon to human nutrition. *Mediterr. J. Nutr. Metabol.* 3, 183–195. <https://doi.org/10.1007/s12349-010-0017-8>.
- Schmidt, H. de O., Oliveira, V.R. de, 2023. Overview of the incorporation of legumes into new food options: an approach on versatility, nutritional, technological, and sensory quality. *Foods* 12, 2586. <https://doi.org/10.3390/foods12132586>.
- Semba, R.D., Ramsing, R., Rahman, N., Kraemer, K., Bloem, M.W., 2021. Legumes as a sustainable source of protein in human diets. *Global Food Secur.* 28, 100520. <https://doi.org/10.1016/j.gfs.2021.100520>.

- Sethi, S., Tyagi, S.K., Anurag, R.K., 2016. Plant-based milk alternatives an emerging segment of functional beverages: a review. *J. Food Sci. Technol.* 53, 3408–3423. <https://doi.org/10.1007/s13197-016-2328-3>.
- Sharif, M.K., Butt, M.S., Sharif, H.R., Nasir, M., 2017. *Sensory Evaluation and Consumer Acceptability*.
- Shevkani, K., Singh, N., Chen, Y., Kaur, A., Yu, L., 2019. Pulse proteins: secondary structure, functionality and applications. *J. Food Sci. Technol.* 56, 2787–2798. <https://doi.org/10.1007/s13197-019-03723-8>.
- Siddiq, M., Ravi, R., Harte, J.B., Dolan, K.D., 2010. Physical and functional characteristics of selected dry bean (*Phaseolus vulgaris* L.) flours. *Lebensm.-Wiss. Technol.* 43, 232–237. <https://doi.org/10.1016/j.lwt.2009.07.009>.
- Singh, S., Riar, C.S., Saxena, D.C., 2017. Evaluation of the textural and sensory properties of cookies in order to improve quality. *African J. Food Sci. Res.* 5, 1–8.
- Thongram, S., Tanwar, B., Chauhan, A., Kumar, V., 2016. Physicochemical and organoleptic properties of cookies incorporated with legume flours. *Cogent Food Agric.* 2, 1172389. <https://doi.org/10.1080/23311932.2016.1172389>.
- Tiwari, B., Singh, N., 2012. *Pulse Chemistry and Technology*. Royal Society of Chemistry.
- Vidal, L., Antúnez, L., Giménez, A., Ares, G., 2016. Evaluation of palate cleansers for astringency evaluation of red wines. *J. Sensory Stud.* 31, 93–100. <https://doi.org/10.1111/joss.12194>.
- Xu, Y., Obielodan, M., Sismour, E., Arnett, A., Alzahrani, S., Zhang, B., 2017. Physicochemical, functional, thermal and structural properties of isolated Kabuli chickpea proteins as affected by processing approaches. *Int. J. Food Sci. Technol.* 52. <https://doi.org/10.1111/ijfs.13400>.