

Article

Mechanical and Sensory Properties of Pulse Gels in the Development of New Plant Based Food

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Abstract: The shift towards healthier and sustainable food consumption requires a greater variety of plant-based products. This study aimed to determine how the mechanical and sensory properties of three different pulse gels (chickpea, lentil, or red lentil flour) vary with the ingredients (flour, oil, lemon, and salt content). All pulse flours were able to form self-standing gels. Mechanical properties varied with the pulse type and with the formulation differently depending on the pulse. For all pulses, the hardness and stiffness increased with the flour content and decreased with salt. They decreased with lemon in chickpea gels and increased with oil content in the red lentil gel. The Flash Profile technique provided distinctive sensory characteristics of each pulse gel. The red lentil gels were homogeneous, creamy, and compact. The chickpea gels were also compact, but harder. Lentil flour resulted in rough and sandy gels. For the three pulses, including oil and lemon reduced pulse flavors and increased sour taste. The results of this study give insights into the suitability of pulse gels to be the basis of new solid plant-based products whose sensory properties can be modulated by varying the concentration of natural ingredients.

Keywords: plant-based; natural ingredients; vegetal protein; texture; flavour; Flash Profile



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1. Introduction

In recent years, due to consumers' awareness about health and environmental problems issued from animal-based food consumption, there is an increasing interest in plant-based food [1,2]. It was reported that about 75 million consumers around Europe purchase vegetarian or vegan food products [3]. Most plant-based products on the market are analogs that try to mimic meat or dairy products; therefore, most research is devoted to the challenge of emulating their properties [4,5]. However, an increase in the availability and variety of plant-based products is necessary to convince consumers [6,7], so other innovation strategies need to be considered when placing new products in the plant-based market. Still, it should be considered that the expected increase in the demand for plant-based products is mainly driven by flexitarians who seek to reduce their consumption of animal products without cutting them out. These consumers are less interested in "imitation" alternatives of products they already eat, and when seeking plant-based products, they may prefer other product concepts or recipes that they could enjoy and incorporate into the diet [7,8]. In addition, most plant-based products in the current market are made from soy or gluten [4,9–11], and the list of ingredients usually contains many additives (stabilizers, emulsifiers, acidifiers, salt, colorings, flavorings, and preservatives) that help overcome limitations in techno-functional properties of the plant-based ingredients [4], but it is one of the main drawbacks for consumers who perceive them as not natural or too processed.

Pulses are also a source of vegetal proteins and can be considered a good alternative to wheat and soy, taking into account their low allergenicity; therefore, they are safe for numerous consumers [2,12]. Regarding sustainability, pulses can fix atmospheric nitrogen,

thus reducing the amount of fertilizer used in crops [13,14]. Pulses have a high content of protein (17% to 30%), carbohydrates, essential vitamins, and minerals and are low in fat [15,16]. Moreover, pulse proteins provide a high content of amino acids such as lysine, among others, and they are rich in bioactive compounds. In addition, pulse proteins exhibit high digestibility, resulting in higher absorption of the macronutrient by the human body. Thus, pulse proteins could be considered as a great choice for consumers seeking dense nutrient options and rich protein products [17].

From a technological viewpoint, some pulse flours such as lentil, red lentil, and chickpea can also form strong gels that can be the basis of solid products [18–22]. Gels are mainly based on the formation of a three-dimensional network of a starch–protein matrix. Gelation properties of flours depend on the relative ratio of different constituents such as proteins, lipids, and carbohydrates [23]. Previous studies showed that the techno functional properties of pulse gels depend on flour concentration and conditions such as pH and ionic strength, as well as on the effect of heating treatment [24–27]. Most studies dealing with technological properties of pulse flours [22,28] aimed to include flours in the formulation of conventional products [29] as a way of enrich them in protein with, in general, little attention to sensory properties. However, the approach of using different pulse flours as the base for creating new products has been only scarcely explored.

To respond to the consumer's demand for more variety of plant-based products, our hypothesis is that the use of pulse flours and the inclusion of natural ingredients such as lemon juice, oil, and salt can be a successful strategy in creating different new solid plant-based products whose sensory properties can be modulated by changing the amount of ingredients. From a practical viewpoint, the knowledge on how changes in the formulation influence the properties of a product is needed in the development of products. Mechanical properties are of special relevance in the elaboration of solid-formulated products because they provide identity to the product, and they are usually quality indexes closely related to the sensations of texture that the product will provide. The mechanical properties depend largely on the structure of the product. The measurement of mechanical properties is based on evaluating the response to deformation (compression, shear, or penetration) that is adapted depending on the product and how it is consumed. Regarding sensory properties, Flash Profile is one of the rapid sensory techniques proven to be useful for describing and quantifying sensory differences among products [30,31]. Since participants generate and individually use their own attributes, it is especially useful for exploring the terms that describe characteristics of a new concept product. Since it is based on the evaluation of differences in the intensity of the attributes, it is also ideal for being used when evaluating changes in the content of ingredients [32].

The aim of this work was to determine the variations in mechanical and sensory properties of pulse gels (lentil, red lentil, or chickpea) with the content of flour, lemon juice, oil, and salt and to know how they can be modulated to develop new solid plant-based products composed of natural ingredients.

2. Materials and Methods

In this study, lentil, red lentil, and chickpea pulse flours were used. All were whole-grain flours except red lentil flour, which came from dehulled lentils. The flours were provided by Molendum Ingredientes (Zamora, Spain) and stored at 4 °C. Mineral water (Cortes, Spain), salt (Hacendado, Spain), sunflower oil (Hacendado, Spain), and lemon juice (Hacendado, Spain) were also used to prepare the gels.

2.1. Gels Composition and Preparation

The effect of varying the concentration of four ingredients (flour, oil, lemon, and salt) on the mechanical properties of pulse gels was investigated. For this, gels were prepared varying the concentration of each ingredient in the following ranges: flour (15% to 17.5%), oil (0% to 2.8%), lemon (0% to 2.8%), and salt (1% to 1.4%). The 17 formulations studied (Table 1) followed the fractional factorial design (2^4) with augmentation (addition of axial

and center points) proposed by Gacula et al. (1993) [33] to estimate both simple and quadratic effects, and binary interactions of the factors studied

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_{14}X_1X_4 + B_{24}X_2X_4 + B_{34}X_3X_4 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{44}X_4^2 + E_{\text{error}}$$

where Y is the variable studied, B_0 is the intercept (constant), B_1, B_2, B_3, B_4 are the linear coefficients, $B_{11}, B_{22}, B_{33}, B_{44}$ are the quadratic coefficients, $B_{14}, B_{24}, B_{34}, B_{44}$ the interaction effects, and X_1, X_2, X_3, X_4 are the independent variables for flour concentrations, oil, lemon, and salt, respectively.

The gels were prepared with a kitchen robot (Mambo 9090, Cecotec, Spain) in 600 g batches. The ingredients were mixed for 2 min and subsequently heated at 90 °C for 8 min while stirring, and then cooled for 6 min. The mixture was transferred to two cylindrical glass containers (height = 36 mm, diameter = 62 mm), covered with plastic film, and stored at 4 °C for 24 h. Two batches per formulation were prepared.

Table 1. Experimental design and composition of pulse gels used in the study of the mechanical properties.

| Formulation | Flour % | Oil % | Lemon % | Salt % |
|-------------|---------|-------|---------|--------|
| 1 | 15.4 | 0.4 | 0.4 | 1.2 |
| 2 | 15.4 | 2.4 | 0.4 | 0.2 |
| 3 | 15.4 | 0.4 | 2.4 | 0.2 |
| 4 | 15.4 | 2.4 | 2.4 | 1.2 |
| 5 | 17.1 | 0.4 | 0.4 | 1.2 |
| 6 | 17.1 | 2.4 | 0.4 | 0.2 |
| 7 | 17.1 | 0.4 | 2.4 | 0.2 |
| 8 | 17.1 | 2.4 | 2.4 | 1.2 |
| 9 | 16.25 | 1.4 | 1.4 | 0.7 |
| 10 | 16.25 | 1.4 | 1.4 | 0 |
| 11 | 16.25 | 1.4 | 1.4 | 1.4 |
| 12 | 16.25 | 0 | 1.4 | 0.7 |
| 13 | 16.25 | 2.8 | 1.4 | 0.7 |
| 14 | 16.25 | 1.4 | 0 | 0.7 |
| 15 | 16.25 | 1.4 | 2.8 | 0.7 |
| 16 | 15 | 1.4 | 1.4 | 0.7 |
| 17 | 17.5 | 1.4 | 1.4 | 0.7 |

2.2. Mechanical Properties of Pulse Gels

Textural measurements of gels (texture profile analysis, compression up to rupture, resistance to penetration, and cutting test) were conducted using a texture analyzer (TA/XT Plus, Stable Micro Systems Ltd., Surrey, UK).

2.2.1. Texture Profile Analysis

Texture profile analysis was performed on gel cylinders (height = 22 mm, diameter = 17 mm) using an aluminum probe with a diameter of 75 mm (SMS P/75). Force was registered while the gel cylinder was compressed twice, up to 10% of its original height and at a constant speed of 1 mm/s. From the force–time curves, mechanical parameters were obtained. Hardness was obtained as the maximum force achieved during the first compression cycle. Cohesiveness was obtained as the relative resistance to deformation between the 2 cycles of compression (Area 2/Area 1), excluding the areas under the decompression portion. Gumminess was obtained as the product of hardness and cohesiveness. Measurements were conducted twice, and eight cylinders of two batches were analyzed.

2.2.2. Compression up to Rupture

Gel cylinders (height = 22 mm, diameter = 17 mm) were compressed at 1 mm/s up to 75% of their original height with a 75 mm diameter flat aluminum disk (SMS P/75).

Measurements were conducted twice, and eight cylinders from two batches were analyzed. The force and distance at rupture were obtained from the force–time curves to calculate Young’s modulus (N/mm^2) using the following formula:

$$\text{Young Modulus} = \frac{F(h_0 - \Delta h)}{A_0 h_0 (\ln h_0 - \ln(h_0 - \Delta h))}$$

where F is the rupture force, h_0 and A_0 are the original height and the surface of the sample, respectively, and Δh is the distance at rupture [34].

2.2.3. Resistance to Penetration

The penetration test was conducted using a 10 mm diameter cylindrical probe. The force was recorded when the sample gel contained in the cylindrical container (height = 62 mm, diameter = 36 mm) was penetrated to 5 mm at 1 mm/s. The value of the area under the curve was obtained to show the resistance to penetration. Measurements were conducted twice, and two cylinders per batch were measured.

2.2.4. Cutting Test

Gel cylinders (height = 62 mm, diameter = 36 mm) were cut transversally at 100% at a constant speed of 1 mm/s using a butter/wire cutter (A/BC). From the force–time curves, the cutting force expressed as the maximum force required to cut the sample at 100% was obtained. Measurements were conducted twice and two cylinders per batch were measured.

2.3. Sensory Evaluation

2.3.1. Composition and Preparation of Gels

For each pulse flour (Lentil: LF, Chickpea: CF, Red Lentil, RF), six formulations were considered that varied in the amount of flour (low or high) and in the presence of the other two ingredients, oil (O) or oil and lemon (O + L). The salt concentration used (0.7%) was kept constant across samples and evaluations.

The gels for sensory evaluation were prepared as described in Section 2.2, transferred to a plastic container (length = 150 mm, width = 105 mm, height = 20 mm), covered with plastic film and stored at 4 °C for 24 h. Before sensory evaluation, the gels were cut into cubes (length = 2.5 cm, width = 0.8 cm, height = 1.5 cm), labeled with three-digit random codes, and served at 20 °C.

2.3.2. Procedure

Nineteen participants (fourteen women and five men) with previous experience in sensory evaluation evaluated the pulse gels. The Flash Profile method was used to evaluate the sensory differences among pulse gels.

A first session was used to generate the list of terms of each participant through an individual interview. Each participant was asked to indicate the terms that described the differences and similarities among the three pairs of gel samples. The individual list of attributes (appearance, texture, and flavor) was collected for each assessor.

The sensory evaluation of the gels was conducted over four different sessions. In three separate sessions (one per pulse flour), the sensory differences among the six gels produced with the same pulse flour but different formulation (flour, oil, and lemon content; Table 2) were evaluated. In a fourth session, gels of different pulses were compared using two gels of each pulse. The formulation of the two gels included a high amount of flour (17.4%), one without oil and lemon and the other one with both ingredients (Table 2).

In each session, participants evaluated sensory differences using ranking tests using their own list of attributes. Six samples were presented simultaneously to the participants, who were asked to rank the samples from low to high intensity for each attribute (ties were allowed). Water was provided to the participants to rinse their mouths.

The procedure was approved by the Ethics Committee of CSIC (resolution number 199/2020). Participants gave their informed consent before participating in the study.

Table 2. Formulation of pulse flour gels included in the different sensory evaluation sessions.

| Sample Code | | | Composition | | |
|--------------------------|----------------------------|------------------------------|-------------|---------|-----------|
| Lentil Flour (Session 1) | Chickpea Flour (Session 2) | Red Lentil Flour (Session 3) | Flour (%) | Oil (%) | Lemon (%) |
| LF-Low | CF-Low | RF-Low | 15.1 | 0 | 0 |
| LF-Low + O | CF-Low + O | RF-Low + O | 15.1 | 2.8 | 0 |
| LF-low + O + L | CF-Low + O + L | RF-Low + O + L | 15.1 | 2.8 | 2.8 |
| LF-High * | CF-High * | RF-High * | 17.4 | 0 | 0 |
| LF-High + O | CF-High + O | RF-High + O | 17.4 | 2.8 | 0 |
| LF-High + O + L * | CF-High + O + L * | RF-High + O + L * | 17.4 | 2.8 | 2.8 |

* Samples included in the session 4.

2.4. Data Analysis

Analysis of variance (ANOVA) of two factors (flour type and formulation) with interaction was applied to the data of the mechanical parameters of gels (hardness, gumminess, Young's modulus, area of penetration, and cutting force). For each mechanical property, the model explaining its variation with the formulation (flour, lemon, oil, and salt) was established using a nonlinear stepwise regression (probability for entry and removal equal to 0.05). Response surface plots were used to visualize the variation of mechanical properties with the formulation in those models that were complex.

Generalized Procrustes Analysis (GPA) was performed on the Flash Profile ranking data to generate the factorial map representing sensory differences among samples. The analyses were performed using XLSTAT version 2020.4.1 software (Addinsoft, New York, NY, USA). The response surface plots were performed using MATLAB version 2023.02 (Mathworks, Natick, CA, USA).

3. Results and Discussion

3.1. Mechanical Properties of Pulse Gels

Pulse flour dispersions in water subjected to heating created self-standing gels in all the formulations studied. The mechanical properties of the gels were characterized under different deformations: compression (hardness, gumminess, and Young's modulus), shear (cutting force), and penetration (penetration area). Figure 1 shows the average values of each mechanical property for each pulse and formulation.

ANOVA showed that the three parameters obtained from the compression tests varied depending on the type of flour ($p < 0.001$), the formulation ($p < 0.001$), and its interaction ($p = 0.021$ for hardness, $p = 0.025$ for gumminess, and $p < 0.001$ for Young's modulus). Hardness and gumminess values were higher for red lentil gels and lower for chickpea gels. Young's modulus, which indicates the stiffness of the gel, was higher for red lentil gels and lower for lentil ones. However, as indicated by the interaction effect observed for the three parameters, the differences among pulses depended on the formulation, indicating that variations in the composition (lemon, oil, salt, and flour contents) affected the three pulses differently.

Like the compression parameters, the values of the penetration area and cutting force varied depending on the type of flour ($p < 0.001$), the formulation ($p < 0.001$), and the interaction ($p < 0.001$). For the penetration area, which indicates the resistance of gels to penetration [35], the values were higher for red lentil and lower for chickpea—7.32–13.67 and 4.92–10.86 N/s, respectively. Furthermore, the cutting force revealed that the differences among pulses were lower and highly dependent on the formulation.

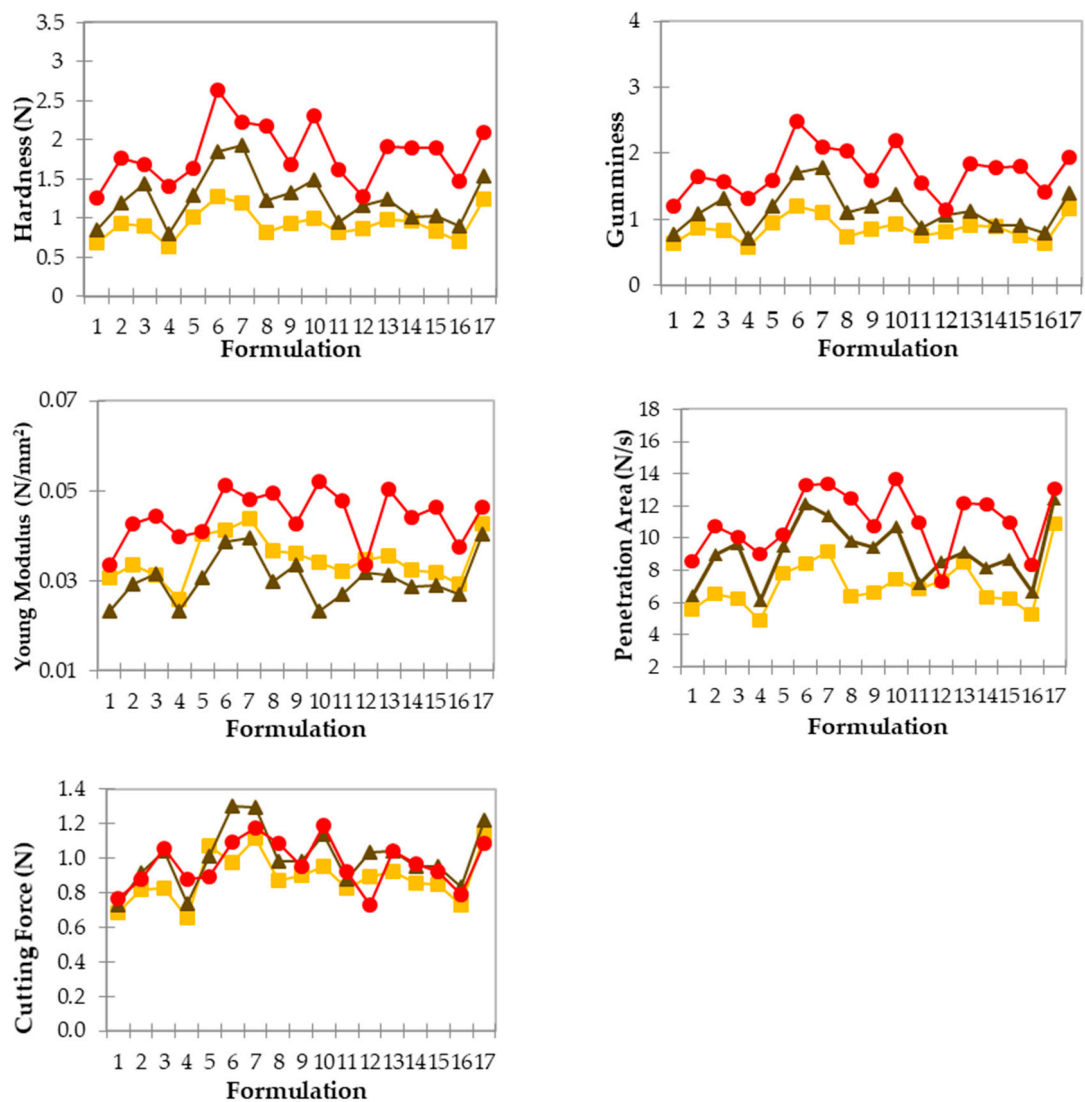


Figure 1. Mechanical parameters of pulse gels made from flours of lentil (\blacktriangle), red lentil (\bullet), and chickpea (\blacksquare) obtained from the 17 formulations as shown in Table 1.

The effect of each ingredient (flour, oil, lemon, and salt) and their interactions on the mechanical properties of pulse gels was studied by regression analysis. Table 3 shows for each pulse the equation of the regression model relating each mechanical parameter with the formulation variables. Equations included the terms that significantly affected the values of the mechanical parameter ($p < 0.05$). The terms included in the model were different among pulses, which confirms that variations on formulation affected the mechanical properties of gels differently. For hardness and gumminess, the models included the same terms, indicating that they presented a similar variation with formulation. For lentil, the equations included a positive quadratic relation with flour and a negative linear relationship with salt, so hardness and gumminess increased when the flour concentration increased (from 15% to 17.5%) and decreased as the salt increased (0% to 1.4%).

Table 3. Regression models of the mechanical parameters of pulse gels as a function of the composition according to equation in Section 2.1.

| Parameter | Flour Type | R ² | Model |
|------------------|------------|----------------|---|
| Hardness | Lentil | 0.864 | $-0.711 - 0.503\text{Salt} + 0.0087\text{Flour}^2$ |
| | Red lentil | 0.939 | $-0.85 + 0.419\text{Salt}^2 - 0.095\text{Oil}^2 + 0.010\text{Flour}^2 - 0.0649\text{Salt} \times \text{Flour} + 0.0271\text{Oil} \times \text{Flour}$ |
| | Chickpea | 0.929 | $-0.465 - 0.017\text{Lemon}^2 + 0.006\text{Flour}^2 - 0.015\text{Salt} \times \text{Flour}$ |
| Gumminess | Lentil | 0.857 | $-0.690 - 0.473\text{Salt} + 0.00816\text{Flour}^2$ |
| | Red lentil | 0.927 | $-3.331 + 0.424\text{Salt}^2 - 0.096\text{Oil}^2 + 0.315\text{Flour} - 0.0631\text{Salt} \times \text{Flour} + 0.0272\text{Oil} \times \text{Flour}$ |
| | Chickpea | 0.918 | $-0.469 - 0.018\text{Lemon}^2 + 0.006\text{Flour}^2 - 0.014\text{Salt} \times \text{Flour}$ |
| Young modulus | Lentil | 0.673 | $-0.00737 - 0.0036\text{Salt}^2 + 0.00015\text{Flour}^2$ |
| | Red lentil | 0.765 | $-0.0148 - 0.019\text{Salt} + 0.0037\text{Flour} + 0.0105\text{Salt}^2 + 0.0002\text{Oil} \times \text{Flour}$ |
| | Chickpea | 0.885 | $-0.010 + 0.000178\text{Flour}^2 - 0.0017\text{Salt} \times \text{Lemon}$ |
| Penetration area | Lentil | 0.934 | $-4.939 - 2.552\text{Salt} + 0.059\text{Flour}^2$ |
| | Red lentil | 0.759 | $-16.77 + 1.715\text{Flour} - 0.1130\text{Salt} \times \text{Flour} + 0.0522\text{Oil} \times \text{Flour}$ |
| | Chickpea | 0.735 | $-5.572 - 0.769\text{Salt}^2 + 0.049\text{Flour}^2$ |
| Cutting force | Lentil | 0.946 | $-0.258 + 0.0054\text{Flour}^2 - 0.015\text{Salt} \times \text{Flour}$ |
| | Red lentil | 0.827 | $-0.562 - 0.606\text{Salt} + 0.106\text{Flour} + 0.238\text{Salt}^2 + 0.0791\text{Salt} \times \text{Oil}$ |
| | Chickpea | 0.872 | $-0.339 + 0.005\text{Flour}^2 - 0.052\text{Salt} \times \text{Oil}$ |

Note: In the model equations, the superscript “2” indicates the quadratic effect of the factor and the “×” indicates the interaction between the two factors.

With red lentil, the equations were more complex and included quadratic effects of flour and salt (positive) and oil (negative) and the interaction effects between salt and flour (negative) and between oil and flour (positive). As observed in Supplementary Figure S1, hardness and gumminess increased with the flour content, but the increase was greater at low levels of salt and at high levels of oil. The values increased with increasing oil content to a maximum point of 2% oil, from which they started to decrease slightly. The values decreased with salt content until a minimum value at 1% salt from which they increased slightly. Therefore, the maximum values of hardness and gumminess using red lentil can be obtained using low levels of salt (approximately 0%), intermediate levels of oil (1.4%), and high levels of flour (17.5%). For chickpea, hardness and gumminess were affected by flour (positive), lemon (negative), and the salt and flour interaction (negative) as shown in Supplementary Figure S2. Values increased with the flour content and decreased slightly with the lemon content. The effect of flour depended on the salt concentration, as reflected by the negative interaction between salt and flour. At higher levels of salt, the increase in hardness and gumminess with flour concentration was slightly lower. The maximum values of hardness and gumminess in chickpea gels are obtained using low levels of salt and lemon and high levels of flour.

Young’s modulus of all pulse gels increased with flour concentration. For lentil, Young’s modulus also depended on salt and decreased as salt decreased. For the red lentil, the Young’s modulus equation included the linear effects of flour (positive) and salt (negative), the quadratic effect of salt (positive), and the effect of the oil and flour interaction (positive). Young’s modulus values increased with flour and this effect was slightly enhanced by the oil content. The values decreased as the salt increased to a point of 0.9% addition, at which it started to increase slightly. Young’s modulus of chickpea gels depended on the flour content but also on salt and lemon, which indicated the negative interaction effect. As shown in Supplementary Figure S3, the values were high and stable in the range of salt addition studied (from 0% to 1.4%), when salt was used without

lemon. The same happened with lemon (from 0% to 2.8%), when it was used without salt, but when they were used together at high levels, the values of the Young's modulus decreased drastically.

The penetration area of lentil and chickpea was positively related to flour and negatively to salt. For red lentil, the effect of flour content varied with the salt and oil contents, as showed by the significant interaction effects. The increase in the penetration area with flour content was lower when the levels of salt were high. However, the effect of flour was higher at high levels of oil.

The cutting force increased as the flour content increased for all pulses. For lentil, it was also negatively affected by the interaction of salt and flour, because the increase in cutting force with the flour content was lower at higher levels of salt. For the red lentil, the cutting force was also negatively related to salt and positively related to oil. It decreased as the salt increased from a limit to 0.9% in which it started to increase slightly. It increased with oil, and this increase was greater at high levels of salt. In chickpea gels, the cutting force was also negatively affected by the salt and oil interaction, because when they were used together at high levels, the cutting force decreased substantially.

The mechanical properties of all pulse gels, regardless of the type of pulse, were affected by the flour and salt content. Hardness, gumminess, Young's modulus, and resistance to penetration and cut decreased with salt within the studied range (0% to 1.4%) and increased with flour (15% to 17.5%).

The effect of ingredients on the mechanical parameters of pulse gels may be explained by the interaction among ingredients and flour components that leads to changes in the conformed structure of the product [28]. In this case, starches and proteins are the main components that contribute to the structure. Kaur and Singh (2005) [20] reported that the gelation of pulse flours involves the formation of a polysaccharide–protein matrix. Starch granules swell during heating and after cooling to become more ordered and form a network [36]. However, proteins can also form a network due to their aggregation resulting from denaturation during heating [37]. Johansson et al. (2022) [38] stated that proteins were the main contributors in the structure of gel formed by a mixture of starch, proteins, and fibers. According to Sharma et al. (2023) [5], heating proteins promote hydrophobic interactions and disulfide bonds, therefore molecular unfolding and network conformation. For all the three pulses, flour content highly affected mechanical properties of gels. The increase in hardness, stiffness, and resistance of gels with flour content can be attributed to the greater amount of starch and proteins that leads to strengthening the structure of the formed network due to the presence of more solutes retaining water [39,40]. Furthermore, a higher concentration of proteins and starch enhances the binding interactions among components, thus further strengthening the network.

The salt content also had a significant effect on the mechanical properties of all pulses. Increasing the salt content resulted in gels with lower hardness, gumminess, stiffness, and resistance to cutting and penetration. This effect could be attributed to the effect of salt on starches and protein solubility. According to Torres et al. (2014) [41], considering that the presence of salts lowers water activity, it could result in delaying and limiting starch gelatinization, thus decreasing the strength of the protein–starch network. However, Langton et al. (2020) [42] reported that protein solubility depends on the presence of salt and its amount. A higher amount of salt increases protein solubility, thus limiting their aggregation and precipitation, hence decreasing the strength of the gel network [27,43,44]. Langton et al. (2020) and Johansson et al. (2023) [38,42] studied the effect of different concentrations of NaCl on the gelation of different pulse proteins. The authors reported that the great repulsion between proteins results in higher solubility and thus in a more fine-stranded gel network.

The oil content affected the mechanical properties of the gels only in the case of red lentil. Increasing the oil content increased the hardness, gumminess, stiffness, and resistance of the red lentil gels. According to this, fat globules reinforce the structure of the starch–protein network. This effect could be explained by the higher emulsion capacity of

red lentil flour compared to lentil and chickpea [25]. The emulsion particles aggregate due to protein denaturation after heating and lead to a stiffer gel [5]. The lemon juice content affected the mechanical properties of chickpea. Increasing the lemon content slightly reduced the hardness, gumminess, stiffness, and resistance of chickpea gels. These changes with lemon juice can be attributed to the effect of pH on starch and protein. Starch molecules can be hydrolyzed by the effect of acids, resulting in shorter amylose and amylopectin chains and decreasing the strength of gels [45,46]. On the other side, the pH affects protein solubility depending on their isoelectric point [24,43]. At pH far from the isoelectric point, protein solubility decreases, and results in their aggregation and a harder texture. The isoelectric point of chickpea proteins is stated to be ranging between 4 and 5 [19]. In this study, chickpea gels with a higher content of lemon juice had values of pH (5.2 to 5.3) closer to isoelectric point than those without lemon (6.3 to 6.4). Thus, the lowest rigidity of chickpea gels could be explained by the hydrolysis of starch molecules due to the acidity and the greater solubility of proteins since the pH of the formulation was slightly close from their isoelectric point, resulting in more fine-stranded gels. Lemon juice content also decreased the pH of lentil (5.5) and red lentil gels (5.5), but it did not significantly affect their mechanical properties. This indicated that not only the pH but also the type of proteins and starch of the pulse are relevant.

Red lentil flour forms gels that are harder, gummier, stiffer, and more resistant to cutting than lentil and chickpea gels. Chickpea gels form soft and less gummy gels that are less resistant to cutting but are stiffer than lentil gels. These differences seem to be attributed to different compositions of flours determined in a previous paper [18]. Lentil and red lentil gels with high protein content (25.9% and 24.0%, respectively) were harder, gummier, and more resistant than chickpea gels (16.9% protein). The higher fiber content for lentil flour (16.4%) appeared to help make the gels less rigid than chickpea (14.0% fiber) and were less rigid than for red lentil (9.8% fiber).

3.2. Sensory Properties of Pulse Gels

To describe the differences among pulse gels, participants generated between 12 and 23 attributes (16 on average). A total of 114 different terms were collected (46 for appearance, 35 for texture, and 33 for flavor). Appearance terms included those related to color (dark/light, yellow, white, and gray), brightness (bright), and homogeneity (uniform, smooth, and heterogeneous). To describe the texture of gels, participants used mainly terms related to mechanical properties (hard/soft, compact, melting in mouth, pasty, and gummy) but also related to surface properties (sandy, smooth, fibrous, rugous, and lumpy) and some others related to composition (wet and dry). Flavor attributes included those related to pulse flavor (pulse, lentil, and chickpea flavor), other ingredients (lemon flavor), basic tastes (sour, salty, and bitter), terms indicating flavor intensity (bland, mild, and intense flavor), and strange flavor.

Figure 2 shows the first two-dimensional plot resulting from the GPA of the sensory evaluation of lentil flour gels. In this plot, the attributes correlated with each factor (correlation > 0.6) are summarized in the box located at the corresponding extreme of the factor. The first factor (39.9% of total variability) differentiated lentil gels according to the flour content, but also the oil. The lentil gel with a low amount of flour (LF–Low) is separated on the left side of the plot, as it was perceived to have a lighter color and a fine, light texture that melts in the mouth. On the other extreme (right side), the two gels with a high amount of flour and oil (LF–High + O and LF–High + O + L) were perceived to have a harder, more compact and sandy texture and a more intense flavor. According to the position of the samples along the first factor, both the increase of the amount of flour and the addition of oil increased the hardness, compactness, sandiness, and flavor intensity of the lentil gels. The second factor (28.1% of variability) separates the samples according to the presence of lemon. Lentil gels with lemon (LF–Low + O + L and LF–High + O + L) are differentiated (on the bottom) with higher sourness, saltiness, and lemon flavor than the rest of the gels (on the top) that were perceived as having a darker color and with more

lentil, pulse, and chickpea flavor, especially for those that have a high amount of flour (LF–High and LF–High-O). The differences in lentil gels depended on flour concentration and lemon and were perceived as having harder texture and intense and acid flavor at high amount of flour and presence of lemon.

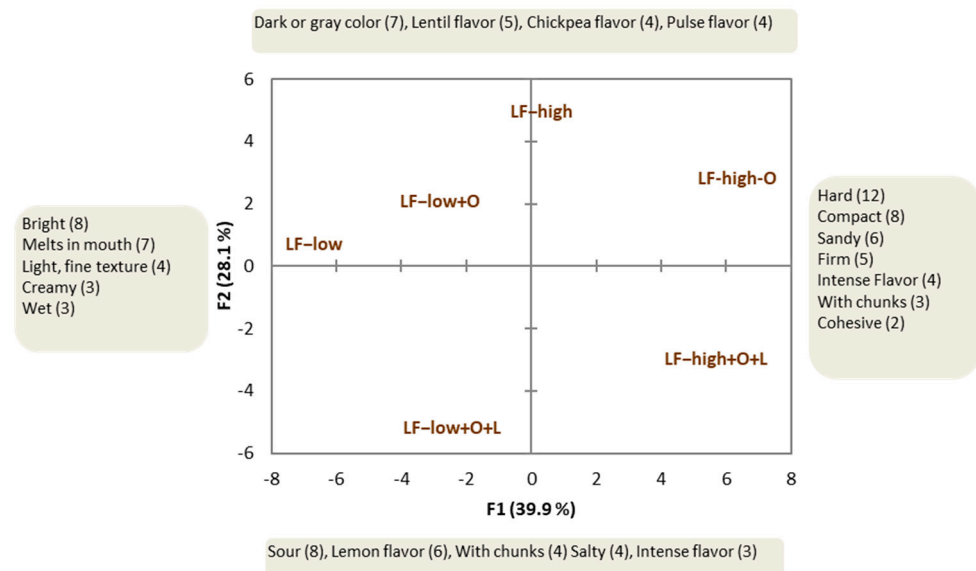


Figure 2. Sensory map (first two dimensions of the GPA) representing the differences in lentil gels when varying the amount of flour (low and high) and adding sunflower oil (O) and lemon juice (L). The complete formulation of the products is shown in Table 2. In the box are included the attributes correlated with each dimension ($r > 0.6$), and in brackets the number of times each one is correlated is indicated.

Figure 3 shows the two-factor GPA plot for the red lentil flour gels. The first factor (47.0% of total variability) differentiated red lentil gels according to the presence of oil and lemon. On the left side, the red lentil gels prepared without oil and lemon (RF–low and RF–high) were perceived to have a lighter texture that melts in the mouth and a darker color. On the right, gels prepared with oil (RF–low + O and RF–high + O,) and gels prepared with oil and lemon (RF–low + O + L and RF–high + O + L) were perceived as having a hard, compact, and sandy texture with a sour and intense flavor. According to the position of the samples along the first factor, the addition of oil and lemon increased the hardness, compactness, and intensity of the sour flavor of red lentil gels.

The second factor (25.8% of variability) separates the samples according to the amount of flour. On the bottom, the red lentil gels appeared with a high amount of flour (RF–high, RF–high + O, and RF–high + O + L) and were perceived as having darker and intense pink color. At the top of the plot appeared red lentil gels with low amount of flour (RF–low, RF–low + O, and RF–low + O + L) with more intense pulse flavor and with particles.

Figure 4 shows the two-factor GPA plot for chickpea flour gels. The first factor (43.8% of total variability) differentiated chickpea gels according to the amount of flour. On the left side, the three chickpea gels with low amounts of flour (CF–Low, CF–Low + O, and CF–Low + O + L) were perceived to have an intense chickpea and pulse flavor with a light texture that melts in the mouth. On the other extreme (right side), the gels with high amounts of flour (CF–High, CF–High + O, and CF–High + O + L) were perceived as having a harder and more compact texture. Therefore, increasing the amount of flour increases the hardness and compactness and reduces the taste of chickpea and the pulse of chickpea gels.

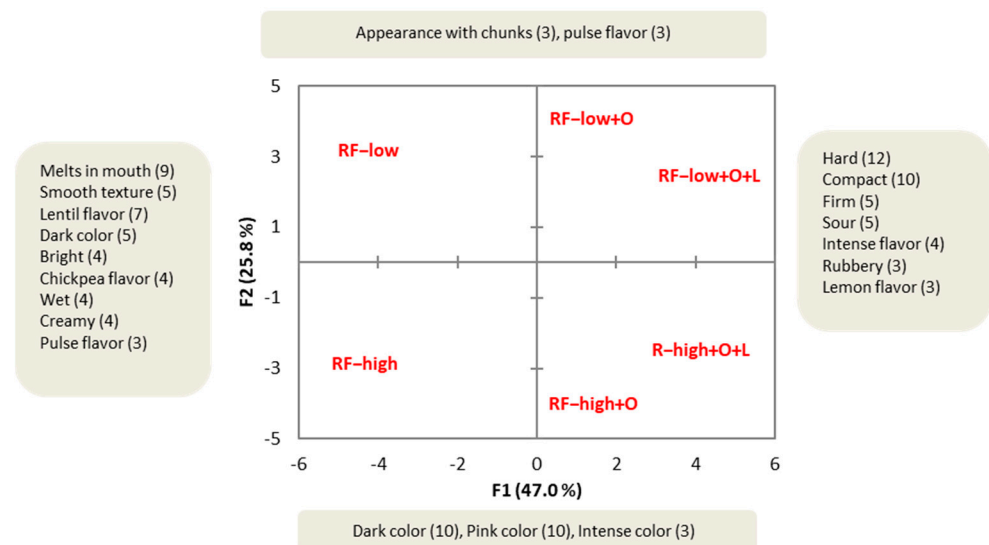


Figure 3. Sensory map (first two dimensions of the GPA) representing the differences in red lentil gels when varying flour amount (low and high) and adding sunflower oil (O) and lemon juice (L). The complete formulation of the products is shown in Table 2. In the box are included the attributes correlated with each dimension ($r > 0.6$), and in brackets the number of times each one is correlated is indicated.

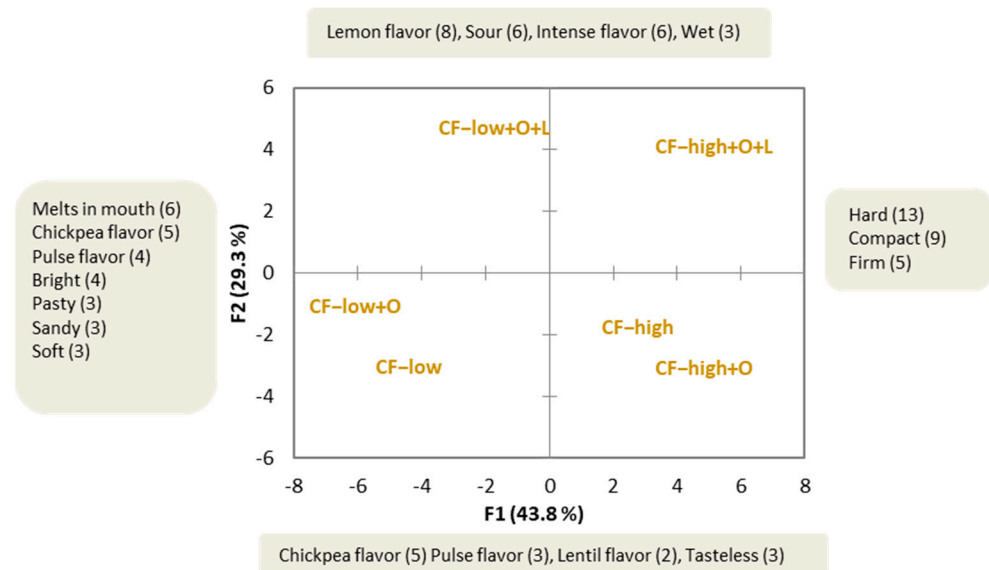


Figure 4. Sensory map (first two dimensions of the GPA) representing the differences in chickpea gels when varying the amount of flour (low and high) and adding sunflower oil (O) and lemon juice (L). The complete formulation of the products is shown in Table 2. In the box are included the attributes correlated with each dimension ($r > 0.6$), and in brackets the number of times each one is correlated is indicated.

The second factor (29.3% of variability) separates the samples according to the presence of lemon. Lentil gels without lemon (LF–Low, LF–Low + O, LF–High, and LF–High + O) are differentiated (on the bottom) for having more pulse, chickpea, and lentil flavor. Gels with lemon (CF–low + O + L and CF–High + O + L) were perceived as sour, with an intense lemon flavor. According to the position of the samples along this factor, the presence of lemon reduces the flavor of the pulse and chickpea and enhances the sour taste and the flavor of the lemon.

The flour content affected mainly texture and flavor attributes in lentil and chickpea gels, whereas it affected mainly the appearance in red lentil gels. The lentil and chickpea gels were harder, firmer, and more compact when increasing the flour content. However, the sandiness sensation increased with the flour content of the lentil and decreased for the chickpea. Likewise, the intensity of the pulse (and lentil) flavor in lentil gels increased with flour content, whereas in chickpea gels pulse (and chickpea) flavor decreased with flour content. For all three pulses, including oil and lemon, the flavor of gels was affected with a reduction in the intensity of pulse, chickpea, or lentil flavors and an increase in sour taste and lemon flavor.

For the comparison of sensory differences among the different pulse types, a sensory evaluation of the three pulse gels used in this study was assessed. The two first factors plot resulting from the GPA of sensory evaluation are represented in Figure 5. For each factor, attributes showing a positive correlation (>0.6) or a negative correlation (<0.6) are listed at the corresponding extreme of the factor. The first factor (53.2% of total variability) separated chickpea and red lentil gels from lentil gels. On the right side, lentil gels were perceived as having a darker color, particles, sandy texture, and a more intense lentil and pulse flavor. On the left side, the chickpea and red lentil gels were perceived as compact, homogeneous, and with more yellow color and chickpea flavor. The second factor (23.9% of variability) separates red lentil from the chickpea gels. The red lentil gels were characterized by a pink color, being homogeneous, and melting in the mouth. In the bottom, the chickpea gels were perceived to have a harder, compact, and sandy texture.

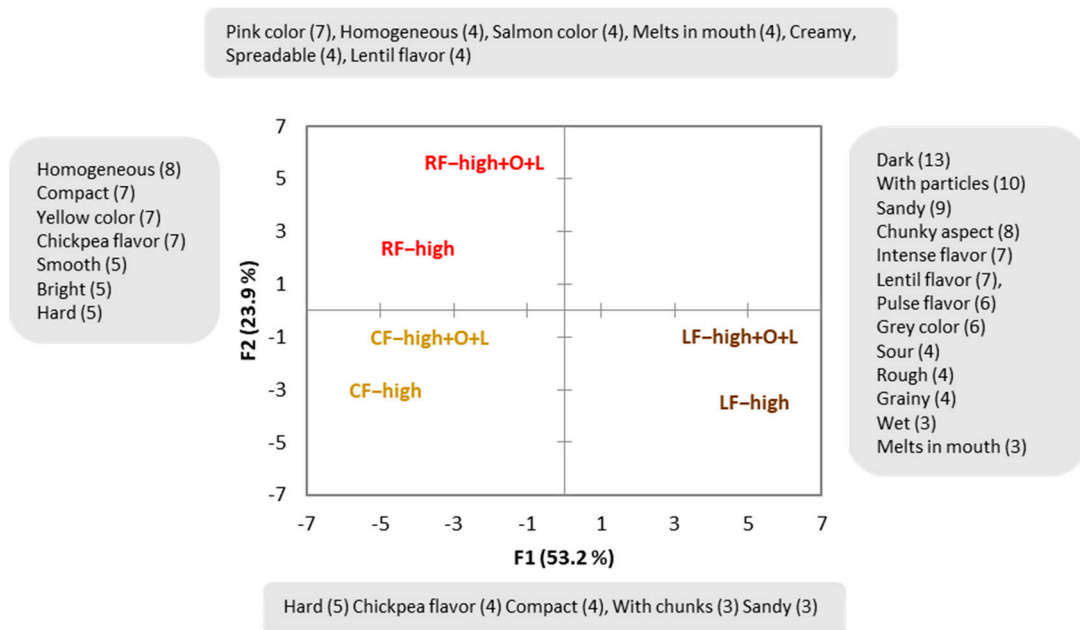


Figure 5. Sensory map (first two dimensions of the GPA) representing differences in products made with different pulse types (LF: Lentil flour, RF: Red lentil flour, CF: Chickpea flour) for formulations with high amounts of flour (high) and when including sunflower oil and lemon juice (O + L). In the box are included the attributes correlated with each dimension ($r > 0.6$), and in brackets the number of times each one is correlated is indicated.

In summary, each of the three pulses provide gels with distinctive sensory characteristics, which can be applied in the development of different types of solid plant-based products. The red lentil produces pink products with a homogeneous, creamy, and compact texture that melt in the mouth, which make it appropriate for the development of hard and soft plant-based cheeses. Chickpea also produces compact products that are harder and have more chickpea flavor, which make it appropriate for the development of sliceable or cold cuts such as products. Lentil gels have a sandy texture and are more intense in pulse

and lentil flavor, making them suitable for the elaboration of spreadable products such as pate.

Furthermore, the sensory properties of the pulse products can be modulated by varying the flour, oil, and lemon juice concentrations, which can be used to optimize products according to the acceptability of consumers.

4. Conclusions

Solid products (self-standing gels) can be obtained from heated dispersions of pulse flour (lentil, red lentil, and chickpea) at 15% to 17.5% inclusion, whose mechanical properties varied mainly depending on the type and content of the pulse flour. Red lentils provide harder, gummier, stiffer, and more resistant gels compared to chickpea and lentil gels. Chickpea gels form soft and less gummy gels that are less resistant to cutting but are stiffer than lentil gels. For the three pulses, the hardness, stiffness, and resistance of the gels increased with the flour content but decreased with the salt content.

The different pulse gels displayed distinctive sensory properties, making them suitable for developing different types of solid plant-based products. Red lentil can be the base of soft or hard cheese-like products. Chickpea gels are more suitable for developing solid products that can be sliceable such as cold-cut products. Lentil gels are suitable for the elaboration of spreadable products such as pate.

Therefore, the results of this research give insight into the suitability of these gels for the food industry, thus enhancing the variability and availability of plant-based food for attracting consumers that are seeking less processed, healthier, and sustainable food.

However, more studies are required for the optimization of these products and that consider consumer opinions and preferences to direct the design of products with sensory properties that maximize consumer acceptance. Moreover, further studies considering the sustainability of the process, regarding the efficiency, waste, and the nutritional impact ratio of the product would be interesting for future investigations.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su15129407/s1>, Figure S1: Response surface plots showing functional relationship between hardness of red lentil gels as a function of flour, salt, and oil concentrations. Model equation is shown in Table 3. The plot on the left side was generated considering a fixed concentration of oil at 1.4%. The plot on the right side was generated considering a fixed concentration of salt at 0.7%; Figure S2: Response surface plots showing functional relationship between hardness of chickpea gels as a function of flour, salt, and lemon concentrations. Model equation is shown in Table 3. The plot on the left side was generated considering a fixed concentration of salt at 0.7%. The plot on the right side was generated considering a fixed concentration of lemon at 1.4%; Figure S3: Response surface plots showing functional relationship between Young's modulus of chickpea gels as a function of flour, lemon, and oil concentrations. Model equation is shown in Table 3. In this case, the plot was generated considering a fixed concentration of flour at 16.25%.

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