*applied sciences*

MDPI

*Article*

# Effect of Flax Cake and Lupine Flour Addition on the Physicochemical, Sensory Properties, and Composition of Wheat Bread

**Agnieszka Makowska [1], Magdalena Zielińska-Dawidziak [2,*], Katarzyna Waszkowiak [3] and Kamila Myszka [4]**

1 Department of Food Technology of Plant Origin, Poznań University of Life Sciences, 60-624 Poznań, Poland; agnieszka.makowska@up.poznan.pl
2 Department of Food Biochemistry and Analysis, Poznań University of Life Sciences, 60-623 Poznań, Poland
3 Department of Gastronomy Science and Functional Foods, Poznań University of Life Sciences, 60-624 Poznań, Poland; katarzyna.waszkowiak@up.poznan.pl
4 Department of Biotechnology and Food Microbiology, Poznań University of Life Sciences, 60-627 Poznań, Poland; kamila.myszka@up.poznan.pl
* Correspondence: magdalena.zielinska-dawidziak@up.poznan.pl

**Featured Application: Wheat bread with the addition of fermented flax cake and lupine flour may be applied as a product for diabetic patients due to the high content of fiber, protein, and reduced content of starch.**

**Abstract:** Bread is consumed by people all over the world. Its quality may be modified by the application of other raw materials or changes in production technology. The addition of flax cake (FC) and lupine flour (LF) was proposed as a modification of the nutritional value of wheat bread. Bread with non-fermented and fermented FC and LF was prepared, and its physicochemical, sensory properties and composition were compared to wheat bread. A higher than 5% addition of these components reduced the bread volume and increased their hardness, gumminess, and chewiness. To reduce the negative impact of these additives on the physical and sensory properties of bread, these raw materials were fermented by selected starter cultures. The addition of FC and LF fermented by *Lactobacillus plantarum* lowered the undesirable changes in the physicochemical properties of the bread. It also slightly increased the overall acceptability of the products. Propionic fermentation lowered sensory assessment rates considerably. The following changes in the composition of bread prepared with the addition of fermented by *L. plantarum* FC and LF were noted: increase in protein (by ~30%), ash (by ~100%), both soluble and insoluble fiber (by ~500%) content. The starch content was reduced by about 18–20%. The modifications increased the nutritional value of the obtained bread, preserving its physicochemical properties and sensory acceptability.

**Keywords:** enriched wheat bread; flax cake; lupine flour; *Lactobacillus plantarum*; crumb texture; bread quality



**Citation:** Makowska, A.; Zielińska-Dawidziak, M.; Waszkowiak, K.; Myszka, K. Effect of Flax Cake and Lupine Flour Addition on the Physicochemical, Sensory Properties, and Composition of Wheat Bread. *Appl. Sci.* **2023**, *13*, 7840. https://doi.org/10.3390/app13137840

Academic Editor: Jinsong Bao

Received: 25 May 2023
Revised: 30 June 2023
Accepted: 30 June 2023
Published: 4 July 2023



## 1. Introduction

Bread is a staple food consumed by people across the world. According to World Health Organization (WHO) data, the per capita consumption of bread is estimated at about 250 g per day [1]. It is consumed at a higher ratio, especially in the cereal-based diet of societies in developing countries. Its nutritional value depends on the raw material composition and production technology. Bread is mainly a source of carbohydrates (70–80% d.m.), although it also contains proteins (10–14% d.m.), minerals (0.5–0.8% d.m.), and fats (0.7–1.35% d. m.). The dietary fiber content in bread is rather low, around 2–3% [2]. Due to its universal character and volume of consumption, it is possible to increase the nutritional value of bread through the use of appropriate additives for its production, including non-traditional raw materials.

Flax cake is a waste product after oil pressing, and similarly to lupine seeds, it is usually used as a feed component. However, these materials may become valuable food ingredients. First of all, the chemical composition of both raw materials is interesting. They are characterized by a low content of digestible carbohydrates, high content of protein, and dietary fiber [3–5]. The nutritional composition of these raw materials makes them a valuable addition that can modify traditional wheat bread, changing the glycemic load and increasing the content of protein and dietary fiber.

Flax cake contains ~35% d.m. of protein, ~33% d. m. of dietary fiber, and still linen oil (~12% d.m.), while the content of available sugar (~8% d.m.) is lower in comparison to wheat [3]. Apart from interesting macronutrients, it contains various antioxidants and lignans, not extracted together with linseed oil. These compounds are effective against diabetes, cancer, and cardiovascular disease, and they are also recommended for peri-menopausal women [3,6].

Lupine seeds are rich in protein (up to 39% d.m.), with a protein content four times higher than in wheat grains. They also have one of the highest fiber concentrations (32% d.m.) and contain a very small content of starch. Lupine does not contain cholesterol or gluten, or gastric irritants; modern sweet varieties are free of alkaloids. Corresponding to its low starch and high dietary fiber contents, it has a very low glycemic index (GI) and is recommended as an element of diet for diabetics or people who want to lose weight, lower the level of cholesterol and triglycerides in the blood and regulate blood pressure [7–9].

Unfortunately, these additives may change the physicochemical properties of bread. They may interfere with the formation of the gluten network in bread dough. This effect can be eliminated by the fermentation process, which improves the functional properties of protein and dietary fiber fractions [10].

Currently, in the market of bakery products, a trend of limiting the consumption of bread and simultaneously the growing interest of consumers in bread with increased pro-healthy values is observed. Due to the constantly recorded increase in the incidence of civilization diseases, the application of raw materials with proven anti-diabetic and hypertension-lowering properties will increase bread attractiveness and desirability. The innovativeness of the conducted research relies on the use of non-traditional raw materials such as flax cake (instead of whole flax seeds) and lupine flour (not used in baking) as an addition to bread production. In order to minimize the negative impact of flax cake and lupine flour on the characteristics of bread, it is intended to ferment them. This process should positively affect not only the physicochemical quality of the bread but also increase the bioavailability of the nutrients from these additives.

Therefore, the aim of the presented study was to produce bread with modified nutrition quality by the addition of non-fermented and fermented flax cake and lupine flour. The physicochemical features and nutrient composition of the bread prepared were examined in order to indicate the possibility of obtaining bread with increased nutritional value and with quality characteristics desired by the consumer.

## 2. Materials and Methods

### *2.1. Materials*

#### 2.1.1. Raw Materials

Raw materials for the experiment were wheat flour 680 type (GoodMills Polska Sp. z o.o., Stradunia, Poland), flax cake purchased from an oil producer (Semco Sp. Z o.o. Sp.k., Szamotuły, Poland), and flour obtained from narrow leaf lupine seeds (Jowisz var.), purchased from Plant Breeding Station Przebędowo, Poland.

#### 2.1.2. Starters

Commercial starter cultures were used for flax cake and lupine flour fermentation: LV1; LV2 (Lesaffre, Marcq-en-Barœul, France), *Lactobacillus plantarum* (Biochem s.r.l, Roma, Italy), and *Propionibacterium* (Chr. Hansen, Inc., Milwaukee, WI, USA).

### *2.2. Methods*

#### 2.2.1. Fermented Flax Cake and Lupine Flour Preparation

The starters (1 g) were mixed with water (400 mL) containing sucrose (6 g) and were put in a fermentation chamber for 2 h (37 °C). The 200 g of ground flax cake or lupine flour was mixed with previously prepared starter culture suspension, covered, and put in a fermentation chamber for 24 h (37 °C). Obtained fermented doughs were freeze-dried, ground, and stored in plastic bags. Ground fermented powders were used as the additive for wheat bread production.

#### 2.2.2. Bread Preparation

1st Experiment

The recipe for reference (control) bread was as follows: 500 g wheat flour, 15 g yeast, 7.5 g salt, and 300 mL water. In the test samples, wheat flour was replaced by grounded flax cake or native lupine flour in three different quantities of 5%, 10%, and 15%. The amounts of other components were unchanged.

The dough was prepared using a straight dough method. All of the compounds were mixed together with the KitchenAid mixer (model 5KPM5EWH, Ariston, Fabriano, Italy) for 5 min. Next, the dough was removed from the bowl and placed in the fermentation chamber for 60 min (temperature 37 °C; RH 85%). In the middle of the time, the dough was punched. Then, it was divided into pieces of equal weight (400 g), removed into molds, and placed in a fermentation chamber for proofing (~20 min). The bread was baked in a baker's oven (MIWE Michael Wenz GmbH, Amstein, Germany) at 210 °C for 30 min. Afterward, the obtained pieces of bread were left at room temperature for 2 h to cool down before weighing and packing in polypropylene pouches.

2nd Experiment

In the second experiment, bread, with the addition of fermented by different starters flax cake or lupine flour, were prepared. In the recipe, 15% of wheat flour was replaced with those additives. Reference samples were bread with the addition of native flax cake and native lupine flour (15%). The bread was prepared as in the 1st experiment.

3rd Experiment

In the last experiment, three bread samples with the addition of fermented by *L. plantarum* bacteria starter additives were prepared: (1) bread containing 15% of fermented flax cake, (2) bread containing 15% of fermented lupine flour, and (3) bread containing 10% of fermented flax cake and 10% fermented lupine flour. The samples were prepared in the same way as in the 1st and 2nd experiments.

#### 2.2.3. Bread Analysis

Bread Specific Volume

A rape seed displacement method was used for the volume determination of loaves according to AACC Method 10-05 [11]. On the basis of bread volume and weight, specific volume was determined by their ratio (Equation (1)):

$$\text{Specific Volume} = (\text{loaf weight})/(\text{loaf volume}) \tag{1}$$

Bread Crumb Color

The Conica Minolta CR-410 instrument (Konica Minolta Sensing Inc., Tokyo, Japan) was used for the color determination of bread crumbs. Results were expressed in CIE

L*a*b* scale, where L* is brightness/darkness, a* is redness/greenness, and b* is yellowness/blueness indices [12]. The color distance was calculated according to Equation (2):

$$\Delta E = \sqrt{(L^*{}_0 - L^*{}_1)^2 + (a^*{}_0 - a^*{}_1)^2 + (b^*{}_0 - b^*{}_1)^2} \quad (2)$$

where $L^*_0$, $a^*_0$, and $b^*_0$ are color determinants for control samples, and $L^*_1$, $a^*_1$, and $b^*_1$ are color determinants for bread with additions.

Bread Crumb Texture

Texture profile analysis of bread was carried out with a TA.XTplus texture analyzer (Stable Micro System Co., Ltd., Surrey, UK) equipped with a 5-kg load cell. Each sample (25 mm thick slide) was compressed twice with a cylindrical plunger probe of a 36 mm diameter. The instrument test parameters were set as follows: pre-test speed: 7.0 mm/s; test speed: 5.0 mm/s; post-test speed: 5.0 mm/s; strain 40%. The rest between compression was 5 s. The following texture parameters were measured: hardness, springiness, cohesiveness, chewiness, and resilience. The analysis was replicated 5 times.

Sensory Evaluation

The group of panelists consisted of six women and four men of 28–49 age. The sensitivity of sensory assessors selected from laboratory staff was tested according to the norm ISO 8586-1:1993. The laboratory of sensory analysis met all the basic criteria regarding equipment and application of suitable environmental conditions, according to the norm ISO 8589:2010.

Control and experimental pieces of bread were evaluated by a trained panel of ten judges for color, taste, flavor, texture, and overall acceptability using a nine-point hedonic rating scale ranging from 9 = like extremely, 5 = neither like nor dislike; 1 = dislike extremely for each sensory characteristic [13].

The samples with an approximate mass of 30 g were coded with numbers, and the serving order of samples was random. Unsweetened black tea (temp. ~45 °C) was used as a taste neutralizer between the samples.

Composition Analysis

Measurement of moisture content was performed according to AACC Method 44-19 [14]. The total nitrogen (by the Kjeldahl method) was determined according to ISO 20483 [15]. A conversion factor of 5.7 was used to calculate the protein content in the studied samples. The ash content was determined according to AACC Method 08-01 [16], the total fat content was determined according to AACC Method 30-25 [17], the starch content was determined by AACC Method 76-13.01 [18], and the dietary fiber (soluble—SDF and insoluble-IDF fractions) was measured by the enzymatic AACC Method 32-07 [19].

Bread Crumb Microstructure

The photos of the bread crumbs' microstructure were taken using the Q Imaging-Go3 camera.

2.2.4. Statistical Analysis

All the evaluations were performed in triplicate at least, and data are reported as mean values.

Compositional data were subjected to ANOVA (Statistica 13.3, TIBCO Software Inc., Palo Alto, CA, USA), followed by Tukey's HSD test at $p \leq 0.05$ of significance.

## 3. Results

### *3.1. The Effect of Native Flax Cake and Lupine Flour on Wheat Bread Properties*

The purpose of the first experiment was to determine the highest acceptable level of the native additive flax cake and lupine flour to wheat bread and to evaluate the quality of the bread prepared. Wheat bread, with the addition of 5–20% of native flax cake and lupine flour, was prepared. The appearance loaves of bread are shown in Figures 1 and 2.


**Figure 1.** Wheat bread with addition of native flax cake (1—control wheat bread not-containing flax cake; 2–5—experimental bread with addition of native flax cake in the amount: 5—5%, 4—10%, 3—15%, 2—20%).

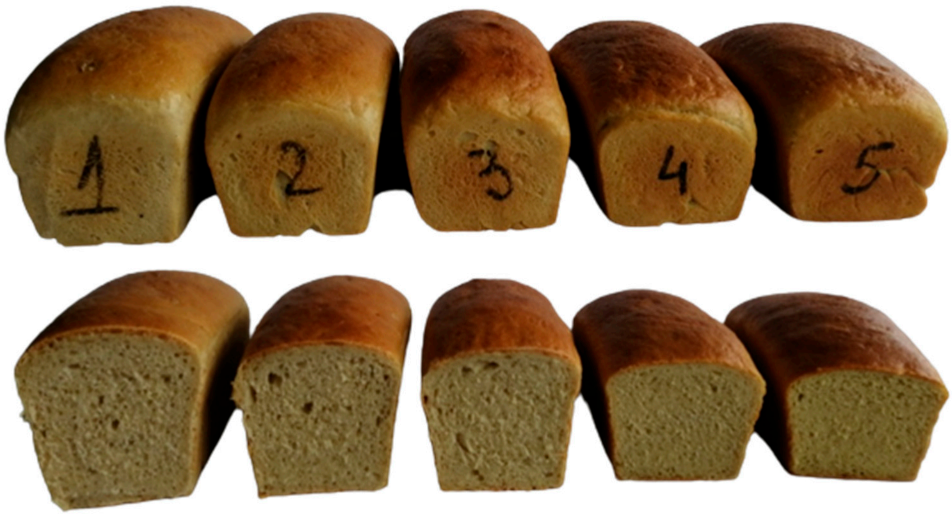


**Figure 2.** Wheat bread with addition of native lupine flour (1—control wheat bread not-containing lupine flour; 2–5—experimental bread with addition of native lupine flour in the amount: 2—5%, 3—10%, 4—15%, 5—20%).

The obtained loaves of bread were evaluated in terms of their physical properties as well as sensory features (Tables 1 and 2).

The quality of bread depends on the chemical composition of the flour, the dough mixing process, its fermentation, and baking conditions. One of the distinguishing features of bread quality is the loaf volume. The loaves with high volume are usually more attractive to consumers. It was found that the increased share of flax cake and lupine flour resulted in a decrease in bread-specific volume (Tables 1 and 2). For the smallest addition, up to 5%, these differences were not statistically significant ($p \geq 0.05$), but with a 10% substitution of wheat flour with flax cake and lupine flour, the bread had a significantly smaller volume ($p = 0.038$ and $p = 0.043$, respectively). With the addition of 20% flax cake, the specific volume decreased by 22%. Slightly smaller differences were noted (18%) when lupine flour was added. The effect of flax flour and flax cake addition on the volume of bread was also studied by Wirkijowska et al. [3]. They found a significant decrease in the volume of bread with flax cake addition compared to the control bread. It was related to the amount of the added flaxseed component rather than to its form (flour vs. cake). In the research of Koca and Anil, no difference in the volume of bread with the addition of flax meal was observed, even though the addition was 20% [20]. Boukid et al. [21] analyzed the effect of the addition of flour from the selected legume, and they showed that the addition of lupine flour in the amount of 5% does not affect the volume of wheat bread, but the increased addition causes its reduction. In the experiment by Plustea et al. [7], the addition of lupine flour at the level of 10% did not significantly reduce the bread volume, but with larger addition, such a phenomenon was observed.

**Table 1.** Characteristics of bread with addition of native flax cake.

| | **Wheat Bread Supplemented by Native Flax Cake** | | | | |
|---|---|---|---|---|---|
| | **0%** | **5%** | **10%** | **15%** | **20%** |
| Specific Volume ($cm^3/g$) | $2.51^{a*} \pm 0.15$ | $2.38^{ab} \pm 0.21$ | $2.15^{bc} \pm 0.08$ | $2.08^{c} \pm 0.10$ | $1.95^{c} \pm 0.14$ |
| | | | Color characteristics | | |
| Lightness | $68.8^{a} \pm 0.2$ | $60.4^{b} \pm 0.8$ | $55.9^{c} \pm 0.1$ | $48.1^{d} \pm 0.57$ | $49.1^{d} \pm 0.72$ |
| a * | $0.8^{e} \pm 0.07$ | $3.8^{d} \pm 0.10$ | $5.3^{c} \pm 0.04$ | $6.1^{b} \pm 0.02$ | $6.8^{a} \pm 0.02$ |
| b * | $19.2^{a} \pm 0.08$ | $10.9^{bc} \pm 0.93$ | $10.0^{bc} \pm 0.18$ | $9.2^{b} \pm 0.21$ | $9.3^{b} \pm 0.17$ |
| ΔE | - | 12.1 | 16.4 | 23.6 | 22.8 |
| | | | Texture characteristics | | |
| Hardness (N) | $23.51^{a} \pm 1.81$ | $27.02^{a} \pm 2.85$ | $35.38^{b} \pm 2.76$ | $40.70^{b} \pm 9.37$ | $57.35^{c} \pm 9.33$ |
| Springiness (-) | $0.886^{a} \pm 0.145$ | $0.954^{a} \pm 0.007$ | $0.941^{a} \pm 0.012$ | $0.922^{a} \pm 0.018$ | $0.896^{a} \pm 0.029$ |
| Cohesiveness (-) | $0.753^{a} \pm 0.019$ | $0.754^{a} \pm 0.046$ | $0.742^{a} \pm 0.034$ | $0.717^{a} \pm 0.054$ | $0.716^{a} \pm 0.053$ |
| Gumminess (-) | $17.66^{a} \pm 1.00$ | $20.28^{a} \pm 0.87$ | $30.92^{b} \pm 0.75$ | $40.07^{c} \pm 3.55$ | $42.24^{d} \pm 4.24$ |
| Chewiness (N) | $15.75^{a} \pm 3.29$ | $19.35^{a} \pm 0.91$ | $29.49^{b} \pm 0.38$ | $36.19 \pm 3.30$ | $45.63^{d} \pm 4.45$ |
| Resilience (-) | $0.374^{a} \pm 0.052$ | $0.369^{a} \pm 0.022$ | $0.355^{a} \pm 0.009$ | $0.313^{a} \pm 0.022$ | $0.306^{a} \pm 0.022$ |
| | | | Sensory evaluation | | |
| Color | $8.4^{a} \pm 0.3$ | $8.1^{a} \pm 0.5$ | $7.1^{ab} \pm 0.7$ | $7.5^{ab} \pm 0.6$ | $6.1^{b} \pm 0.8$ |
| Taste | $7.1^{ab} \pm 0.4$ | $7.6^{ab} \pm 0.4$ | $7.9^{a} \pm 0.4$ | $7.0^{ab} \pm 0.8$ | $6.4^{ab} \pm 0.6$ |
| Flavor | $7.8^{a} \pm 0.4$ | $7.2^{ab} \pm 0.6$ | $8.1^{a} \pm 0.9$ | $7.1^{ab} \pm 0.6$ | $5.1^{b} \pm 0.8$ |
| Texture | $8.5^{a} \pm 0.3$ | $8.0^{a} \pm 0.4$ | $7.7^{a} \pm 0.8$ | $7.2^{a} \pm 1.0$ | $4.8^{b} \pm 1.3$ |
| Overall acceptability | $8.0^{a} \pm 0.4$ | $8.2^{a} \pm 0.8$ | $8.0^{a} \pm 0.7$ | $7.6^{ab} \pm 0.9$ | $5.5^{b} \pm 1.1$ |

* Letters in a row $^{(a–d)}$ show statistically significant differences at $p < 0.05$.

The volume and structure of the bread crumb depend on the quality and quantity of gluten, which is the main structural factor of wheat bread. The gluten matrix formed during the kneading of the dough traps carbon dioxide bubbles in the dough during fermentation and baking. Replacing part of the wheat flour with another raw material that does not contain gluten proteins and contains a lot of other proteins and mucilage impedes the creation of a gluten network [22]. Flax cake and lupine flour are characterized by high water absorption because of their fiber content [3,7,8,23]. During the dough formation process, absorbed water surrounds protein molecules, which makes it difficult for gliadins and glutenins to bond. Furthermore, in the case of flaxseed enrichment, a fungistatic activity has been reported [24], which could hinder the growth rate of yeast and reduce carbon dioxide production and dough expansion.

The addition of flax cake and lupine flour influenced the color of the bread. In the case of flax cake, the change was more significant than with lupine flour. Bread containing 5% of lupine flour was almost the same color as the control sample (ΔE = 2.1), whereas the color of bread with 5% of flax cake differed from the control sample (ΔE = 12.1). Increasing the addition of flax cake caused a decrease in lightness and yellowness with a simultaneous increase in redness, as it was suggested before [20,25]. The addition of lupine flour increased yellowness, but it had no influence on the redness parameter. Lupine contains large amounts of beta-carotene, zeaxanthin, and lutein, which are characterized by an intensively yellow color [26], while flax cake consists of a brown-colored flaxseed coat, which is the main component of flax cake [27].

**Table 2.** Characteristics and sensory evaluation of bread with addition of native lupine flour.

| | Wheat Bread Containing Native Lupine Flour | | | | |
|---|---|---|---|---|---|
| | 0% | 5% | 10% | 15% | 20% |
| Specific Volume ($cm^3$/g) | 2.48 $^{a*}$ ± 0.11 | 2.38 $^{a}$ ± 0.05 | 2.22 $^{b}$ ± 0.12 | 2.11 $^{b}$ ± 0.10 | 2.08 $^{b}$ ± 0.08 |
| Color characteristics | | | | | |
| L * | 67.7 $^{b}$ ± 0.0.2 | 68.2 $^{ab}$ ± 0.4 | 69.6 $^{a}$ ± 0.4 | 69.8 $^{a}$ ± 0.3 | 70.4 $^{a}$ ± 0.6 |
| a * | 1.9 $^{a}$ ± 0.1 | 1.8 $^{a}$ ± 0.2 | 1.7 $^{a}$ ± 0.3 | 1.9 $^{a}$ ± 0.3 | 2.2 $^{a}$ ± 0.4 |
| B * | 19.3 $^{d}$ ± 0.2 | 21.4 $^{c}$ ± 0.5 | 23.5 $^{bc}$ ± 0.6 | 25.1 $^{b}$ ± 0.4 | 28.2 $^{a}$ ± 0.6 |
| ΔE | - | 2.1 | 4.6 | 6.2 | 9.3 |
| Texture characteristics | | | | | |
| Hardness (N) | 21.82 $^{b}$ ± 2.52 | 23.66 $^{ab}$ ± 1.85 | 27.19 $^{ab}$ ± 2.05 | 36.77 $^{a}$ ± 2.21 | 37.15 $^{a}$ ± 2.480 |
| Springiness (-) | 0.969 $^{a}$ ± 0.033 | 0.965 $^{a}$ ± 0.045 | 0.956 $^{a}$ ± 0.022 | 0.943 $^{a}$ ± 0.026 | 0.938 $^{a}$ ± 0.031 |
| Cohesiveness (-) | 0.841 $^{a}$ ± 0.018 | 0.828 $^{a}$ ± 0.045 | 0.826 $^{a}$ ± 0.042 | 0.811 $^{a}$ ± 0.038 | 0.809 $^{a}$ ± 0.028 |
| Gumminess (-) | 18.33 $^{b}$ ± 2.00 | 19.60 $^{b}$ ± 1.63 | 22.42 $^{ab}$ ± 4.17 | 29.77 $^{a}$ ± 3.80 | 29.94 $^{a}$ ± 2.81 |
| Chewiness (N) | 17.77 $^{b}$ ± 2.49 | 18.92 $^{b}$ ± 1.95 | 21.44 $^{ab}$ ± 3.34 | 28.10 $^{a}$ ± 2.03 | 28.09 $^{a}$ ± 1.64 |
| Resilience (-) | 0.415 $^{a}$ ± 0.033 | 0.471 $^{a}$ ± 0.024 | 0.421 $^{a}$ ± 0.018 | 0.435 $^{a}$ ± 0.044 | 0.447 $^{a}$ ± 0.026 |
| Sensory evaluation | | | | | |
| Color | 8.5 $^{a}$ ± 0.5 | 8.8 $^{a}$ ± 0.8 | 8.0 $^{a}$ ± 0.6 | 7.4 $^{a}$ ± 0.8 | 7.1 $^{a}$ ± 0.4 |
| Taste | 8.2 $^{a}$ ± 0.4 | 7.9 $^{ab}$ ± 0.9 | 7.0 $^{ab}$ ± 1.1 | 6.3 $^{ab}$ ± 0.6 | 5.2 $^{b}$ ± 0.9 |
| Flavor | 8.0 $^{a}$ ± 0.8 | 8.4 $^{a}$ ± 0.9 | 7.2 $^{ab}$ ± 0.7 | 6.1 $^{b}$ ± 0.5 | 5.6 $^{b}$ ± 0.4 |
| Texture | 8.2 $^{a}$ ± 0.4 | 8.1 $^{a}$ ± 0.8 | 7.1 $^{ab}$ ± 1.0 | 7.0 $^{ab}$ ± 0.6 | 6.8 $^{a}$ ± 0.5 |
| Overall acceptability | 8.4 $^{a}$ ± 0.4 | 7.9 $^{a}$ ± 0.8 | 8.1 $^{a}$ ± 0.9 | 7.4 $^{ab}$ ± 0.6 | 6.1 $^{b}$ ± 0.8 |

* Letters in a row $^{(a–d)}$ show statistically significant differences at $p < 0.05$.

The applied additives also modified the bread texture. Significant differences were found in the hardness, gumminess, and chewiness of bread crumbs ($p > 0.05$). The differences were more spectacular when flax cake was used, in comparison to lupine flour. If the amount of flax cake was 10% or more, the values of texture parameters increased. When the addition was 20%, these parameters were even more than twice as high in comparison to wheat bread. Conforti and Davis [25] reported a 40% increase in crumb hardness for white bread enriched with ground flaxseed at the 15% level [25]. They attributed the increased hardness of the flaxseed-enriched white bread to its lower loaf volume and denser texture. In the case of lupine flour addition, significant differences were noted when the addition was 15% or more. These changes in texture parameters are mainly caused by the chemical reduction of gluten proteins and a large amount of dietary fiber, including arabinoxylans, characterized by high water absorption. These factors affect the higher hardness, as well as gumminess (defined as the energy required to disintegrate a semisolid food until it is ready to swallow) and chewiness (understood as the energy required to chew a solid product). The increase in the last two parameters could be connected with a high concentration of mucilage (a large part of pentosanes) in flax cake. Some studies indicate fiber and protein content as reasons for the increased hardness of the crumb [28,29]. It was stated that the addition of raspberry and strawberry cakes (which are rich in dietary fiber) caused an increase in bread crumb hardness and chewiness and a decrease in bread crumb springiness and resilience [2]. The observation, i.e., changes in springiness and resilience, was not confirmed in our experiment.

The last analysis at this stage of the presented study was the sensory analysis of bread. The highest amount of flax cake, as well as lupine flour, that did not deteriorate the overall acceptability scores of the bread was 15%. An addition above this level caused deterioration of the sensory quality of the bread in terms of texture, overall acceptability (for flax cake addition), taste, smell, and overall acceptability (for lupine flour addition). The results confirmed the studies by Klupsaite et al. and Taglieri et al. [10,30]. Previous research found that the acceptable amount of lupine or other pulses flour was indicated as 10–15% [7,21,31].

The acceptable level of flax cake addition to wheat bread, according to the literature, ranges from 5% [30] to 20% [20], but it is usually not higher than 15% [24]. Taglieri et al. [30] stated that it also depends on the kind of fermentation used during bread preparation; in sourdough bread, the acceptable addition of flax cake to wheat bread was 7.5%, while in the case of yeast bread, only 5% [7].

*3.2. The Effect of Flax Cake and Lupine Flour Fermentation on Wheat Bread Properties*

In order to improve the properties of bread enriched in flax cake or lupine flour, these raw materials were submitted to fermentation. There are many scientific reports proving that fermentation increases the nutritional value of raw materials [10,32–35]. Stodolak et al. [34] stated that the fermentation period increases the content of phenolic compounds (13–85%) and doubles the radical scavenging activity of flax cake. Lupine flour fermentation also improves its nutritional features [10], increasing the content of soluble protein and favorably modifying its functional properties. In our study, four different kinds of starter cultures were used for the fermentation of both additives. Next, the fermented raw materials were applied to replace part of the wheat flour (15%) in the bread recipe. Bread with the addition of native raw material was the control sample. The photos of the bread obtained in this experiment are shown in Figures 3 and 4.


**Figure 3.** Wheat bread supplemented with 15% of fermented flax cake (1—control bread with native flax cake, 2—flax cake fermented with LV1 starter; 3—flax cake fermented with LV2 starter; 4—flax cake fermented with *L. plantarum* starter; 5—flax cake fermented with *Propionibacterium* starter).

A larger volume of all bread obtained with the addition of fermented flax cake in comparison to the control sample was noted. In the case of fermented lupine flour, the same effect was achieved when *L. plantarum* or *Propionibacterium* starters were used (bread 4 and 5). This observation confirms the results of physical properties measurement (presented in Tables 3 and 4). The specific volume of bread with the addition of fermented flax cake was significantly higher. The fermentation changed the color of the bread in a narrow range ($\Delta E$ ranges 0.3–2.9). The yellowness of the crumb was higher in the case of bread containing flax cake fermented by *Propionibacterium* and *Lactobacillus plantarum*. The crumb of the last sample was also brighter than the control one. In the case of bread with fermented lupine flour addition, smaller differences were observed in bread volumes. The yellowness of bread with the addition of fermented lupine flour was lower than that of bread with native flour. It possibly resulted from variations in flour components mediated by both endogenous enzymatic activities and microbial conversion. The decrease in lutein content in doughs could take place because of higher lipid oxidation involving the endogenous lipoxygenase (LOX)/linoleate system. The level of this degradation depends on the bacteria strain used [36].

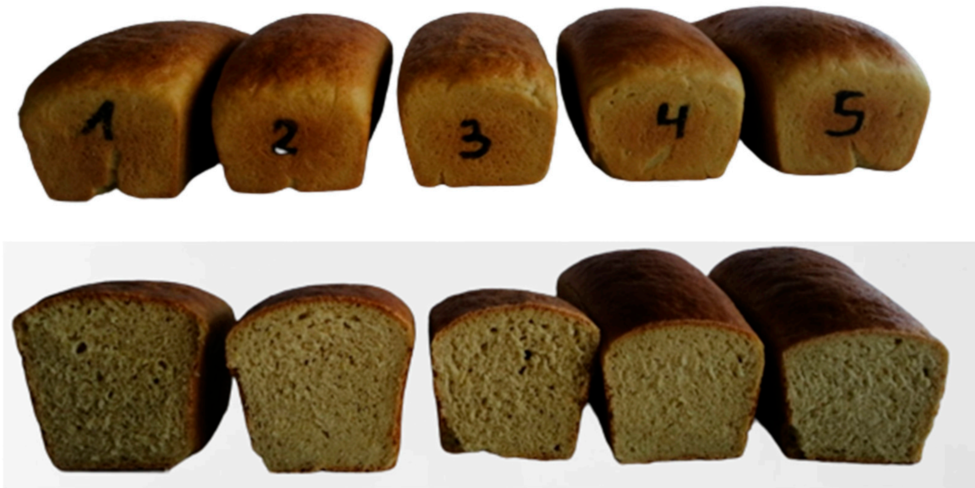


**Figure 4.** Wheat bread supplemented with 15% of fermented lupine flour (1—control bread native lupine flour, 2—lupine flour fermented with LV1 starter; 3—lupine flour fermented with LV2 starter; 4—lupine flour fermented with *L. plantarum* starter; 5—lupine flour fermented with *Propionibacterium* starter).

**Table 3.** Characteristics and sensory evaluation of wheat bread supplemented with fermented flax cake.

| | **Wheat Bread Supplemented with 15% of Fermented Flax Cake** | | | | |
|---|---|---|---|---|---|
| | **Native** | **LV1** | **LV2** | ***L. plantarum*** | ***Propioni bacterium*** |
| Specific Volume ($cm^3/g$) | $2.06^{b*} \pm 0.12$ | $2.23^{a} \pm 0.06$ | $2.36^{a} \pm 0.08$ | $2.48^{a} \pm 0.22$ | $2.44^{a} \pm 0.20$ |
| | | | Color characteristics | | |
| L * | $47.8^{b} \pm 0.1$ | $47.5^{b} \pm 0.1$ | $47.8^{b} \pm 0.1$ | $50.3^{a} \pm 0.2$ | $48.7^{b} \pm 0.3$ |
| A * | $5.8^{a} \pm 0.1$ | $5.9^{a} \pm 0.0$ | $6.0^{a} \pm 0.1$ | $5.6^{a} \pm 0.1$ | $6.1^{a} \pm 0.2$ |
| B * | $8.9^{b} \pm 0.2$ | $9.1^{b} \pm 0.2$ | $9.2^{b} \pm 0.2$ | $10.5^{a} \pm 0.3$ | $9.8^{a} \pm 0.3$ |
| ΔE | - | 0.4 | 0.3 | 2.9 | 1.3 |
| | | | Texture characteristics | | |
| Hardness (N) | $39.01^{a} \pm 3.23$ | $27.60^{ab} \pm 2.84$ | $24.81^{a} \pm 3.82$ | $20.34^{b} \pm 3.36$ | $22.88^{b} \pm 2.63$ |
| Springiness (-) | $0.955^{a} \pm 0.100$ | $0.961^{a} \pm 0.011$ | $0.973^{a} \pm 0.220$ | $0.966^{a} \pm 0.009$ | $0.961^{a} \pm 0.007$ |
| Cohesiveness (-) | $0.792^{a} \pm 0.031$ | $0.774^{a} \pm 0.043$ | $0.793^{a} \pm 0.585$ | $0.802^{a} \pm 0.046$ | $0.800^{a} \pm 0.050$ |
| Gumminess (-) | $31.72^{a} \pm 1.68$ | $23.54^{a} \pm 1.48$ | $21.64^{a} \pm 2.65$ | $22.02^{a} \pm 16.40$ | $22.45^{a} \pm 2.57$ |
| Chewiness (N) | $29.88^{a} \pm 2.53$ | $23.03^{a} \pm 0.59$ | $21.35^{a} \pm 0.83$ | $21.98^{a} \pm 1.54$ | $22.00^{a} \pm 2.47$ |
| Resilience (-) | $0.441^{a} \pm 0.020$ | $0.410^{a} \pm 0.026$ | $0.434^{a} \pm 0.046$ | $0.444^{a} \pm 0.028$ | $0.436^{a} \pm 0.042$ |
| | | | Sensory evaluation | | |
| Color | $8.1^{a} \pm 0.8$ | $8.8^{a} \pm 0.6$ | $8.0^{a} \pm 0.7$ | $8.4^{a} \pm 0.7$ | $7.7^{a} \pm 0.8$ |
| Taste | $7.1^{bc} \pm 0.9$ | $7.3^{ab} \pm 0.7$ | $7.7^{ab} \pm 0.8$ | $7.9^{a} \pm 1.0$ | $6.2^{c} \pm 1.4$ |
| Flavor | $6.6^{cd} \pm 1.0$ | $7.1^{c} \pm 0.7$ | $7.7^{bc} \pm 0.6$ | $8.2^{a} \pm 0.9$ | $5.6^{d} \pm 1.0$ |
| Texture | $7.1^{b} \pm 0.4$ | $7.7^{ab} \pm 0.9$ | $8.4^{a} \pm 0.8$ | $8.2^{a} \pm 0.6$ | $8.0^{a} \pm 0.9$ |
| Overall acceptability | $7.2^{b} \pm 0.7$ | $7.0^{b} \pm 1.0$ | $7.5^{ab} \pm 0.8$ | $8.2^{a} \pm 0.6$ | $7.1^{b} \pm 0.8$ |

* Letters in a row $^{(a–d)}$ show statistically significant differences at $p < 0.05$.

A positive effect of fermentation of these additives on the texture features of bread crumbs was found. Loaves of bread containing fermented flax cake were characterized by lower hardness (22–48%), gumminess (26–32%), and chewiness (23–29%), but the differences were significant only in the case of hardness. No differences in springiness, cohesiveness, or resilience were shown. LV1 starter proved to have the lowest impact on the bread texture. Other starters improved the bread texture significantly. Loaves of bread with the addition of fermented lupine flour were characterized by lower gumminess (17–36%) and chewiness (32–37%) compared with a sample with native flour. The measured values of hardness were also lower (15–23%), but the differences were not significant ($p > 0.05$). Klupsaite et al. [10] found out that the supplementation of wheat flour with 3% of fermented lupine flour decreased bread hardness and chewiness on average by 46%, resilience by 21%, and slightly increased springiness (by 5%), but a higher amount of this flour had no significant influence on bread texture.

Partial hydrolysis of mucilage during fermentation delivers a source of energy for bacteria growing and causes changes in bread texture. At the same time, the produced lactic acid acidifies the environment, and the acidic hydrolysis of large fiber molecules takes place. This process lowers the viscosity of their solutions, which in turn decreases the viscosity of the bread, gumminess, and chewiness of the crumb. This effect was also observed during sourdough fermentation in rye bread production [22].

In order to select the best culture starter for additives fermentation, a sensory analysis of bread samples was carried out. Loaves of bread with the addition of flax cake fermented by LV2 and *L. plantarum* were rated high for taste, flavor, and texture. Bread fermented by Propionibacterium obtained high scores for texture; unfortunately, the scores collected for taste and flavor were low. The overall acceptability of bread with *L. plantarum* bacteria had the best scores, so this sample was selected for the last part of our experiment.

**Table 4.** Characteristics and sensory evaluation of wheat bread supplemented with fermented lupine flour.

| | **Wheat Bread Supplemented with 15% of Fermented Lupine Flour** | | | | |
|---|---|---|---|---|---|
| | **Native** | **LV1** | **LV2** | ***L. plantarum*** | ***Propioni bacterium*** |
| Specific Volume ($cm^3/g$) | 2.05 $^{a*}$ ± 0.18 | 1.97 $^{a}$ ± 0.08 | 1.90 $^{a}$ ± 0.12 | 2.16 $^{a}$ ± 0.22 | 2.13 $^{a}$ ± 0.16 |
| Color characteristics | | | | | |
| L * | 67.1 $^{b}$ ± 0.3 | 68.7 $^{ab}$ ± 0.4 | 68.9 $^{ab}$ ± 0.6 | 69.4 $^{a}$ ± 0.3 | 69.7 $^{a}$ ± 0.4 |
| a * | 2.4 $^{a}$ ± 0.2 | 2.1 $^{ab}$ ± 0.1 | 1.9 $^{b}$ ± 0.2 | 2.1 $^{ab}$ ± 0.2 | 1.8 $^{b}$ ± 0.2 |
| b * | 26.3 $^{a}$ ± 0.3 | 25.3 $^{ab}$ ± 0.2 | 25.3 $^{ab}$ ± 0.4 | 24.9 $^{b}$ ± 0.2 | 24.9 $^{b}$ ± 0.3 |
| ΔE | - | 1.89 | 2.0 | 2.7 | 3.0 |
| Texture characteristics | | | | | |
| Hardness (N) | 32.66 $^{a}$ ± 2.53 | 33.20 $^{a}$ ± 3.30 | 37.44 $^{a}$ ± 3.65 | 33.43 $^{a}$ ± 2.94 | 35.97 $^{a}$ ± 4.00 |
| Springiness (-) | 0.952 $^{a}$ ± 0.059 | 0.937 $^{a}$ ± 0.044 | 0.895 $^{a}$ ± 0.036 | 0.944 $^{a}$ ± 0.042 | 0.940 $^{a}$ ± 0.064 |
| Cohesiveness (-) | 0.815 $^{a}$ ± 0.022 | 0.845 $^{a}$ ± 0.036 | 0.810 $^{a}$ ± 0.024 | 0.828 $^{a}$ ± 0.048 | 0.834 $^{a}$ ± 0.050 |
| Gumminess (-) | 43.39 $^{a}$ ± 3.81 | 27.95 $^{b}$ ± 3.55 | 3639 $^{ab}$ ± 470 | 27.71 $^{b}$ ± 2.62 | 29.90 $^{ab}$ ± 2.03 |
| Chewiness (N) | 41.31 $^{a}$ ± 2.50 | 26.17 $^{b}$ ± 3.30 | 27.08 $^{b}$ ± 4.20 | 26.22 $^{b}$ ± 3.90 | 28.11 $^{b}$ ± 3.19 |
| Resilience (-) | 0.486 $^{a}$ ± 0.028 | 0.483 $^{a}$ ± 0.048 | 0.458 $^{a}$ ± 0.062 | 0.432 $^{a}$ ± 0.066 | 0.427 $^{a}$ ± 0.037 |
| Sensory evaluation | | | | | |
| Color | 8.5 $^{a}$ ± 0.8 | 8.8 $^{a}$ ± 0.4 | 8.4 $^{a}$ ± 0.5 | 8.0 $^{a}$ ± 0.4 | 8.1 $^{a}$ ± 0.6 |
| Taste | 6.5 $^{a}$ ± 1.2 | 7.9 $^{a}$ ± 0.9 | 7.3 $^{a}$ ± 1.0 | 7.0 $^{a}$ ± 0.6 | 6.2 $^{a}$ ± 1.2 |
| Flavor | 8.0 $^{a}$ ± 1.0 | 8.4 $^{a}$ ± 0.8 | 8.2 $^{a}$ ± 1.1 | 8.1 $^{a}$ ± 1.0 | 5.6 $^{b}$ ± 0.7 |
| Texture | 6.8 $^{a}$ ± 0.9 | 8.1 $^{a}$ ± 1.0 | 7.1 $^{a}$ ± 0.9 | 7.4 $^{a}$ ± 0.8 | 7.5 $^{a}$ ± 1.1 |
| Overall acceptability | 7.4 $^{ab}$ ± 0.6 | 8.0 $^{a}$ ± 0.8 | 7.6 $^{ab}$ ± 0.9 | 7.8 $^{ab}$ ± 1.1 | 6.3 $^{b}$ ± 1.3 |

* Letters in a row $^{(a–b)}$ show statistically significant differences at $p < 0.05$.

Fermentation also improves the sensory features of bread enriched in lupine flour but to a lesser extent than with fermented flax cake. Flavor, taste, and texture were evaluated higher than in bread containing native lupine flour. The bread with flour fermented by LV1 starters obtained the highest scores in terms of overall acceptability. On the other hand, propionic fermentation again negatively affected the taste of the bread and reduced its overall acceptability.

### 3.3. The Effect of the Additives on the Microstructure of Bread Crumb

Figure 5 presents photos of the crumb microstructure of prepared bread. The loaves of bread differed in porosity. A 15% addition of not fermented flax cake and lupine flour (15% FC and 15% LF) deteriorated the structure of the crumb. The pores were smaller, which influenced the texture characteristics presented in Tables 1 and 2 (hardness, chewiness, springiness, and resilience). The porosity of wheat bread with the addition of fermented additives (15% FFC and 15% FLF) was improved, especially in the case of fermented flax cake, which was also reflected in the texture characteristics presented in Tables 3 and 4. To obtain better porosity and simultaneously increase the content of additives in the wheat bread, the 10% addition of both fermented raw materials was applied, i.e., wheat bread with the addition of 10% FCF and 10% of FLF was produced. Finally, the bread obtained was characterized by porosity similar to that of wheat bread. At the same time, such a significantly high addition of FFC and FLF must have had a significant influence on its chemical composition.

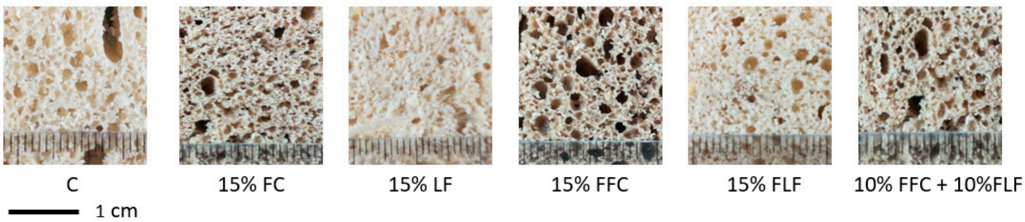


**Figure 5.** Structure of crumb of prepared bread: C—wheat bread; 15% FC—wheat bread supplemented with 15% of native flax cake; 15% LF—wheat bread supplemented with 15% of lupine flour; 15% FFC—wheat bread supplemented with 15% flax cake fermented with *L. plantarum* starter; 15% FLF—wheat bread supplemented with 15% lupine flour fermented with *L. plantarum* starter; 10% FFC + 10% FLF—wheat bread supplemented with fermented by *L. plantarum* additives, 10%—fermented flax cake and 10% of fermented lupine flour.

### 3.4. The Effect of Additives Fermented by L. plantarum on Bread Composition

Loaves of bread selected at the previous stage, with the addition of different mass ratios of fermented flax cake and lupine flour, were prepared. Table 5 presents their chemical composition.

**Table 5.** Chemical composition of wheat bread with fermented flax cake (FFC) and lupine (FLF) flour. SDF—the soluble dietary fiber, IDF—insoluble dietary fiber.

| | Bread Composition [% d.m.] | | | | | |
|---|---|---|---|---|---|---|
| **Bread Sample** | **Starch** | **Fat** | **Protein** | **Ash** | **SDF** | **IDF** |
| Wheat bread | 82.11 $^{a*}$ ± 1.22 | 0.96 $^{a}$ ± 0.21 | 11.8 $^{b}$ ± 0.2 | 0.72 $^{c}$ ± 0.04 | 0.55 $^{b}$ ± 0.05 | 2.05 $^{b}$ ± 0.12 |
| Wheat bread +15% FLF | 66.97 $^{b}$ ± 0.61 | 1.01 $^{ab}$ ± 0.26 | 15.3 $^{a}$ ± 0.3 | 1.22 $^{b}$ ± 0.12 | 2.99 $^{a}$ ± 0.28 | 10.77 $^{a}$ ± 0.97 |
| Wheat bread +15% FFC | 67.58 $^{b}$ ± 1.15 | 1.15 $^{a}$ ± 0.19 | 15.7 $^{a}$± 0.1 | 1.96 $^{a}$ ± 0.18 | 3.56 $^{a}$ ± 0.19 | 10.63 $^{a}$ ± 0.77 |
| Wheat bread +10% FLF + 10% FFC | 65.67 $^{b}$ ± 1.60 | 1.35 $^{a}$ ± 0.22 | 15.5 $^{a}$ ± 0.6 | 1.72 $^{a}$ ±0.16 | 3.05 $^{a}$ ± 0.52 | 10.99 $^{a}$ ± 0.84 |

* Letters in a row $^{(a–c)}$ show statistically significant differences at $p < 0.05$.

The addition of fermented raw materials significantly reduced the content of starch in bread (18–20%). It increased the content of all other components: protein by about 30%, ash by about 100%, and dietary fiber by more than 500%. The amount of soluble dietary fiber SDF and insoluble dietary increased both at least five times. A slight increase in fat content was also observed; however, due to the composition of raw material lipids, it should not decrease the nutritional value of the prepared bread. The application of both fermented additives made it possible to improve the chemical composition of the bread while maintaining consumer acceptability. It meets market demands for healthier bread and reduction of food waste.

The composition analysis of the bread prepared in the 1st and 2nd experiments is presented in Supplementary Materials (Table S1).

## 4. Conclusions

In the production of wheat bread with the addition of flax cake and lupine flour, the amount of additives to the bread acceptable by consumers is up to 15%, even if the amount higher than 5% reduced bread volume (14–22% in case of flax cake and 10–16% in case of lupine flour addition) and deteriorated bread texture characteristics (hardness, gumminess, and chewiness). The fermentation of both additives by *L. plantarum* had a beneficial effect on leveling these changes. The loaves of bread containing fermented flax cake are characterized by lower hardness (22–48%), gumminess (26–32%), and chewiness (23–29%). The bread with the addition of fermented lupine flour was characterized by lower gumminess (17–36%), chewiness (32–37%), and hardness (15–23%). This probably resulted from improving the functional properties of flax cake, lupine proteins, and dietary fiber during lactic acid fermentation. The bread with additives fermented by *L. plantarum* bacteria had the highest overall acceptability. However, propionic fermentation significantly reduced the consumer acceptability of the produced bread.

The finally obtained bread had a higher content of protein (by about 30%), ash (by about 100%), and both soluble and insoluble fiber (by about 500%), while the starch content was reduced by about 18–20%. However, a further increase in the content of the fermented constituents does not seem possible due to the deterioration of bread quality.

Wheat bread with the addition of fermented flax cake and lupine flour may be applied as a product for diabetic patients due to the high content of fiber, protein, and reduced content of starch. Moreover, the obtained bread also meets consumer expectations looking for healthier food products. The application of flax cake and lupine flour may also reduce food loss and waste along the agri-food value chain.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app13137840/s1, Table S1: Chemical composition of breads with variable content of flax cake and lupine flour (not fermented).

**Author Contributions:** Conceptualization, A.M.; M.Z.-D. and K.W.; methodology, A.M., M.Z.-D., K.W. and K.M.; formal analysis, A.M., M.Z.-D., K.W. and K.M.; data curation, A.M., M.Z.-D., K.W. and K.M.; writing—original draft preparation, A.M. and M.Z.-D.; writing—review and editing, A.M. and M.Z.-D.; visualization, A.M. and M.Z.-D.; project administration, A.M.; funding acquisition, A.M., M.Z.-D., K.W. and K.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was co-financed from the funds for science under the non-competition project "Support for scientific research management and commercialization of R&D results in scientific units and enterprises", implemented under the Smart Growth Operational Program 2014–2020, "Innovation Incubator 4.0" project.

**Institutional Review Board Statement:** The study was carried out in accordance with The Code of Ethics of the World Medical Association (consent No. 757/13).

**Informed Consent Statement:** Informed consent was obtained from all volunteers involved in the sensory study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data is not publicly available due to an ongoing patent process.

**Acknowledgments:** We thank Chr. Hansen Poland Sp. z o.o., (Częstków Mazowiecki, Czosnów, Poland) for providing a starter culture of *Propionibacterium* bacteria.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Mollakhalili-Meybodi, N.; Hassan Ehrampoush, M.; Hajimohammadi, B.; Hassan Mosaddeg, M. Formulation optimization of functional wheat bread with low glycemic index from technological and nutritional perspective. *Food Sci. Nutr.* **2023**, *11*, 284–294. [CrossRef] [PubMed]
2. Kowalczewski, P.Ł.; Walkowiak, K.; Masewicz, Ł.; Duda, A.; Poliszko, N.; Różańska, M.B.; Jeżowski, P.; Tomkowiak, A.; Mildner-Szkudlarz, S.; Baranowska, H.M. Wheat bread enriched with raspberry and strawberry oilcakes: Effects on proximate composition, texture and water properties. *Eur. Food Res. Technol.* **2019**, *245*, 2591–2600. [CrossRef]
3. Wirkijowska, A.; Zarzycki, P.; Sobota, A.; Nawrocka, A.; Blicharz-Kania, A.; Andrejko, D. The possibility of using by-products from the flaxseed industry for functional bread production. *LWT* **2020**, *118*, 108860. [CrossRef]
4. Zielińska-Dawidziak, M.; Tomczak, A.; Burzyńska, M.; Rokosik, E.; Dwiecki, K.; Piasecka-Kwiatkowska, D. Comparison of *Lupinus angustifolius* protein digestibility in dependence on protein, amino acids, trypsin inhibitors and polyphenolic compounds content. *Int. J. Food Sci. Technol.* **2020**, *55*, 2029–2040. [CrossRef]
5. Tomczak, A.; Zielińska-Dawidziak, M.; Piasecka-Kwiatkowska, D.; Lampart-Szczapa, E. Blue lupine seeds protein content and amino acids composition. *Plant Soil Environ.* **2018**, *64*, 147–155. [CrossRef]
6. Zhang, L.; Taal, M.A.; Boom, R.M.; Chen, X.D.; Schutyser, M.A.I. Effect of baking conditions and storage on the viability of Lactobacillus plantarum supplemented to bread. *LWT* **2018**, *87*, 318–325. [CrossRef]
7. Plustea, L.; Negrea, M.; Cocan, I.; Radulov, I.; Tulcan, C.; Berbecea, A.; Popescu, I.; Obistioiu, D.; Hotea, I.; Suster, G.; et al. Lupin (*Lupinus* spp.)-Fortified Bread: A Sustainable, Nutritionally, Functionally, and Technologically Valuable Solution for Bakery. *Foods* **2022**, *11*, 2067. [CrossRef]
8. Ahmed, H. Effect of Fortification Pan Bread with Lupine Flour on the Chemical, Rheological and Nutritional Properties. *J. Food Dairy Sci.* **2013**, *4*, 65–75. [CrossRef]
9. Doxastakis, G.; Zafiriadis, I.; Irakli, M.; Marlani, H.; Tananaki, C. Lupin, soya and triticale addition to wheat flour doughs and their effect on rheological properties. *Food Chem.* **2002**, *77*, 219–227. [CrossRef]
10. Klupsaite, D.; Juodeikiene, G.; Zadeike, D.; Bartkiene, E.; Maknickiene, Z.; Liutkute, G. The influence of lactic acid fermentation on functional properties of narrow-leaved lupine protein as functional additive for higher value wheat bread. *LWT* **2017**, *75*, 180–186. [CrossRef]
11. AACC. *AACC Method 10-05.01 Specific Volume*; AACC: Washington, DC, USA, 2010.
12. Makowska, A.; Majcher, M.; Mildner-Szkudlarz, S.; Jedrusek-Golinska, A.; Przygoński, K. Triticale crisp bread enriched with selected bioactive additives: Volatile profile, physical characteristics, sensory and nutritional properties. *J. Food Sci. Technol.* **2017**, *54*, 3092–3101. [CrossRef] [PubMed]
13. Barylko-Pikielna, N.; Matuszewska, I.; Jeruszka, M.; Kozlowska, K.; Brzozowska, A.; Roszkowski, W. Discriminability and appropriateness of category scaling versus ranking methods to study sensory preferences in elderly. *Food Qual. Prefer.* **2004**, *15*, 167–175. [CrossRef]
14. AACC. *AACC Method 44-19.01.: Moisture—Air-Oven Method, Drying at 135*; AACC: Washington, DC, USA, 2010; p. 2010.
15. ISO. *Food and Feed Products—General Guidelines for the Determination of Nitrogen by the Kjeldahl Method*; ISO: Geneve, Switzerland, 2009.
16. AACC. AACC Method 08-01: Ash—Basic Method. In *AACC International "Approved Methods of Analysis"*, 11th ed.; Contact Cereals & Grains Association: St. Paul, MN, USA, 2010.
17. AACC. *AACC Approved Methods of Analysis*, 11th ed.; Method 30-25.01: Crude Fat in Wheat, Corn, and Soy Flour, Feeds, and Mixed Feeds; Contact Cereals & Grains Association: St. Paul, MN, USA, 2010.
18. AACC. AACC Method 76-13: Total Starch Assay Procedure (Megazyme Amyloglucosidase/α—Amylase Method). In *AACC International "Approved Methods of Analysis"*, 11th ed.; Contact Cereals & Grains Association: St. Paul, MN, USA, 2010.
19. AACC. *AACC Method 32-07—Soluble, Insoluble, and Total Dietary Fiber in Foods and Food Products*; AACC: Washington, DC, USA, 1999; pp. 1–9.
20. Koca, A.F.; Anil, M. Effect of flaxseed and wheat flour blends on dough rheology and bread quality. *J. Sci. Food Agric.* **2007**, *87*, 1172–1175. [CrossRef]
21. Boukid, F.; Zannini, E.; Carini, E.; Vittadini, E. Pulses for bread fortification: A necessity or a choice? *Trends Food Sci. Technol.* **2019**, *88*, 416–428. [CrossRef]
22. Buksa, K.; Nowotna, A.; Praznik, W.; Gambuś, H.; Ziobro, R.; Krawontka, J. The role of pentosans and starch in baking of wholemeal rye bread. *Food Res. Int.* **2010**, *43*, 2045–2051. [CrossRef]
23. Koneva, S.I.; Egorova, Y.U.; Kozubaeva, L.A.; Kuzmina, S.S.; Zakharova, A.S. Influence of Flaxseed Flour on Dough Rheology from Wheat-Flaxseed Meal. *Adv. Eng. Res.* **2018**, *151*, 370–377.

24. Mercier, S.; Villeneuve, S.; Moresoli, C.; Mondor, M.; Marcos, B.; Power, K.A. Flaxseed-enriched cereal-based products: A review of the impact of processing conditions. *Compr. Rev. Food Sci. Food Saf.* **2014**, *13*, 400–412. [CrossRef]
25. Conforti, F.D.; Davis, S.F. The effect of soya flour and flaxseed as a partial replacement for bread flour in yeast bread. *Int. J. Food Sci. Technol.* **2006**, *41*, 95–101. [CrossRef]
26. Wang, S.; Errington, S.; Yap, H.H. Studies on Carotenoids from Lupin Seeds. In Proceedings of the 12th International Lupin Conference, Fremantle, Australia, 14–18 September 2008; pp. 198–202.
27. Sanmartin, C.; Taglieri, I.; Venturi, F.; Macaluso, M.; Zinnai, A.; Tavarini, S.; Botto, A.; Serra, A.; Conte, G.; Flamini, G.; et al. Flaxseed cake as a tool for the improvement of nutraceutical and sensorial features of sourdough bread. *Foods* **2020**, *9*, 204. [CrossRef]
28. Bourne, M.C. *Food Texture and Viscosity: Concept and Measurement*; Elsevier Science & Technology Books: Amsterdam, The Netherlands, 2002; ISBN 9780124171275.
29. Kaack, K.; Pedersen, L.; Laerke, H.N.; Meyer, A. New potato fibre for improvement of texture and colour of wheat bread. *Eur. Food Res. Technol.* **2006**, *224*, 199–207. [CrossRef]
30. Taglieri, I.; Bedini, S.; Zinnai, A.; Sanmartin, C.; Conti, B.; Farina, P.; Chiriboga Ortega, R.D.; De Leo, M.; Braca, A.; Tavarini, S.; et al. Effects of flaxseed cake fortification on bread shelf life, and its possible use as feed for *Tenebrio molitor* larvae in a circular economy: Preliminary results. *J. Sci. Food Agric.* **2022**, *102*, 1736–1743. [CrossRef] [PubMed]
31. Previtali, M.A.; Mastromatteo, M.; De Vita, P.; Ficco, D.B.M.; Conte, A.; Del Nobile, M.A. Effect of the lentil flour and hydrocolloids on baking characteristics of wholemeal durum wheat bread. *Int. J. Food Sci. Technol.* **2014**, *49*, 2382–2390. [CrossRef]
32. Bartkiene, E.; Juodeikiene, G.; Vidmantiene, D. Nutritional quality of fermented defatted soya and flaxseed flours and their effect on texture and sensory characteristics of wheat sourdough bread. *Int. J. Food Sci. Nutr.* **2012**, *63*, 722–729. [CrossRef] [PubMed]
33. Rosell, C.M. *Trends in Science of Doughs and Bread Quality*, 2nd ed.; Elsevier Inc.: Amsterdam, The Netherlands, 2019; ISBN 9780128146392.
34. Stodolak, B.; Starzyńska-Janiszewska, A.; Wywrocka-Gurgul, A.; Wikiera, A. Solid-State Fermented Flaxseed Oil Cake of Improved Antioxidant Capacity as Potential Food Additive. *J. Food Process. Preserv.* **2017**, *41*, e12855. [CrossRef]
35. Syah, I.T.; Irundu, D.; Bahmid, N.A.; Indrastuti; Karim, I. Changes in functional properties during fermentation of *Amorphophallus paeoniifolius* (Dennst.) Nicolson yam using *Lactobacillus plantarum*. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *978*, 012015. [CrossRef]
36. Antognoni, F.; Mandrioli, R.; Potente, G.; Saa, D.L.R.; Gianotti, A. Changes in carotenoids, phenolic acids and antioxidant capacity in bread wheat doughs fermente. *Food Chem.* **2019**, *292*, 211–216. [CrossRef]