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# Influence of Selected Plant-Derived Essential Oils on the Physicochemical, Sensory, and Oxidative Stability of Fava Bean-Based Spread During Refrigerated Storage

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## Abstract

Fava bean (*Vicia faba* L.) is a nutritionally valuable and sustainable legume with strong potential for plant-based food applications. However, similar to other lipid-containing food systems, fava bean-based spreads are susceptible to lipid oxidation during storage, leading to quality deterioration and reduced shelf life. This study evaluated the effect of basil (*Ocimum basilicum* L.), winter savory (*Satureja montana* L.), and cumin (*Cuminum cyminum* L.) essential oils (EOs) (0.1 µL/g) on the physicochemical properties and oxidative stability of fava bean-based spreads during 90 days of storage at 4 °C. Four treatments were prepared: control spread without essential oil (B-CO), basil essential oil-enriched spread (B-BA), winter savory essential oil-enriched spread (B-WS), and cumin essential oil-enriched spread (B-CU). Water activity and pH remained stable in all samples throughout storage. Color changes were most pronounced in the control, while B-WS exhibited the highest color stability (ΔE = 1.81 vs. 6.07 in B-CO). Winter savory and cumin significantly reduced peroxide value and thiobarbituric acid reactive substance (TBARS) formation and improved oxidative stability (Rancimat: 9.11 and 9.10 h vs. 7.73 h in B-CO), whereas basil showed no protective effect. Cumin was characterized by the highest flavonoid and phenolic acid contents, while winter savory exhibited the highest total polyphenols. Sensory evaluation revealed that EOs significantly influenced consumer acceptance, particularly taste and aroma. Although the control sample achieved the highest overall scores, cumin-containing formulations provided the most favorable balance between oxidative stability and sensory quality, whereas winter savory negatively affected overall acceptability. Taken together, winter savory and cumin EOs effectively enhanced oxidative stability, highlighting their potential as natural antioxidants in the development of plant-based spreads.

**Keywords:** fava bean; plant-based spread; essential oils; lipid oxidation; protein oxidation; natural antioxidants

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## 1. Introduction

The growing global demand for sustainable, nutritious, and minimally processed food products has accelerated interest in plant-based protein sources as alternatives to animal-derived ingredients [1–3]. Among these, legumes play a central role due to their high protein content, dietary fiber, bioactive compounds, and low environmental footprint [4–6]. Among the underutilized legumes with considerable food application potential, fava bean (*Vicia faba* L.) stands out due to its high protein content (20–35% dry weight basis), favorable amino acid profile, rich phytochemical composition [4,5,7,8]. Furthermore, fava bean is well adapted to temperate European climates, fixes atmospheric nitrogen, and requires limited agrochemical inputs, making it an ecologically and economically attractive crop for sustainable food systems [6,9,10].

From a production perspective, fava bean demonstrates competitive yield performance under European conditions, with reported water-limited yields of approximately 5.2 Mg ha$^{-1}$, exceeding soybean yields in comparable environments (~3.1 Mg ha$^{-1}$) [11]. In addition, fava bean is generally not classified among major allergenic food sources, increasing its suitability for hypoallergenic formulations [2,3]. Although antinutritional compounds such as vicine and convicine are present, their impact is limited to genetically susceptible individuals and can be reduced through breeding and processing strategies [4,5,8,12,13]. Collectively, these characteristics position fava bean as a promising and locally relevant protein source, while also supporting its economic potential for value-added food applications. In particular, its conversion into processed products such as spreads may increase economic returns compared to its traditional use as feed or bulk commodity [4,5]. In Serbia, fava bean has a long cultivation history but remains largely absent from commercial food product portfolios, representing an untapped opportunity for value-added processing [14]. It has been identified as an underutilized crop within the Horizon Europe project CROPDIVA.

The market for plant-based spreads and dips has expanded considerably in recent years, driven by consumer preferences for convenient, nutritious, and clean-label products [15]. Chickpea-based hummus remains the dominant product in this category, but there is increasing interest in diversifying the legume base to include other species [15–18]. Fava bean offers a number of technological advantages as a spread ingredient, including high water-binding capacity, emulsification potential, and the ability to form smooth, stable pastes upon cooking and homogenization [5,12,13]. However, its application in ready-to-eat spread formulations has received limited scientific attention, and systematic studies on formulation optimization and shelf-life stability are scarce [12,15].

In the formulation of plant-based spreadable products, the selection of the lipid phase plays a crucial role in determining both nutritional quality and oxidative stability. In line with current trends, cold-pressed vegetable oils rich in unsaturated fatty acids are increasingly used as functional ingredients [19]. High-oleic sunflower oil is characterized by a high content of monounsaturated fatty acids, particularly oleic acid, and a lower proportion of polyunsaturated fatty acids compared to conventional sunflower oil. This fatty acid profile contributes to improved oxidative and thermal stability, reduced susceptibility to lipid degradation, and lower formation of secondary oxidation products during processing and storage. Due to these properties, high-oleic sunflower oil is increasingly applied in the development of functional and shelf-stable food products. In addition, cold-pressed oils are valued for retaining naturally occurring bioactive compounds, such as tocopherols, phenolics, sterols, and carotenoids, which may further contribute to nutritional quality and oxidative stability. In addition to enhanced oxidative stability, the high monounsaturated fatty acid content of high-oleic sunflower oil is considered nutritionally favorable for the development of functional food products [20–23]. However, despite these advantages, the

presence of unsaturated fatty acids makes vegetable oils inherently susceptible to oxidative degradation, particularly in complex systems such as emulsified spreads [20,24].

A principal challenge in the development of legume-based spreads is oxidative deterioration of the lipid fraction during storage. Lipid oxidation generates peroxides, aldehydes, and malondialdehyde as primary and secondary reaction products, leading to off-flavor development, color changes, and nutritional losses that compromise product quality and consumer acceptability [25,26]. In addition, lipid oxidation may lead to the formation of reactive and potentially toxic compounds, such as aldehydes and oxysterols, which have been associated with adverse health effects and chronic diseases [27]. In emulsified food systems such as spreads, the lipid fraction is particularly susceptible to oxidation due to the large interfacial area created during homogenization, which facilitates contact between lipids and pro-oxidant species [28,29]. The simultaneous oxidation of proteins, reflected in the loss of free thiol groups, is often promoted by lipid oxidation products, which can accelerate the formation of protein aggregates and cross-links, thereby contributing to quality deterioration, textural changes, and reduced nutritional value [30,31]. Furthermore, oxidized proteins may impair protein digestibility and amino acid bioavailability, while prolonged exposure to dietary protein oxidation products has been associated with oxidative stress, inflammation, aging processes, and chronic diseases [32].

The use of natural antioxidants derived from aromatic plants represents a promising and consumer-accepted strategy for controlling oxidative deterioration in food products [21,22]. EOs, as concentrated sources of bioactive volatile compounds (e.g., terpenes, phenolics), have demonstrated antioxidant activity in a wide range of food matrices including meat products, fish, and edible oils [33–38]. Among the EOs of interest for food preservation, basil (*Ocimum basilicum* L.), winter savory (*Satureja montana* L.), and cumin (*Cuminum cyminum* L.) have each been reported to possess significant free radical scavenging capacity and lipid oxidation inhibition activity [34,37,39–42]. Basil and winter savory are aromatic plant species widely cultivated and traditionally used in the Balkan region and Serbia, while cumin essential oil is recognized for its distinctive volatile composition and documented antioxidant potential in food systems. In addition, these essential oils differ considerably in their dominant bioactive constituents, allowing the comparison of different antioxidant profiles in stabilizing fava bean-based spreads. At low concentrations, EOs can contribute to the development of desirable aroma profiles in food systems, including emulsion-based and legume-derived spread products [24,43,44]. Despite this body of evidence, the application of these EOs as antioxidant additives in legume-based spreads has not been systematically investigated.

The hypothesis of this study was that essential oils differing in their volatile composition would exert different effects on the oxidative stability and sensory properties of fava bean-based spreads during refrigerated storage.

The present study investigated the influence of selected plant-derived essential oils on the physicochemical properties, oxidative stability, and bioactive profile of a fava bean-based spread during refrigerated storage. The findings contribute to the development of functional plant-based spreads formulated with natural antioxidants and support clean-label product innovation.

## 2. Materials and Methods

### *2.1. Raw Materials and Preparation of Fava Bean Fraction*

Fava bean (*Vicia faba* L.) seeds used in this study were obtained from local growers in the Sokobanja region, Serbia (43.64° N, 21.87° E), and subsequently included in the seed collection of the Institute of Field and Vegetable Crops, Novi Sad, Serbia. The technological procedure for fava bean processing involved mechanical dehulling followed by

air classification. Dehulling and air classification were performed at the Pilot plant for feed technology, Institute of Food Technology in Novi Sad, Serbia. Seeds were dehulled using a laboratory bran finisher (Bühler, Uzwil, Switzerland) to separate the seed coat from the cotyledons [45]. The obtained material was further fractionated using a laboratory-scale cascade gravitational air classifier (model 1–40 MZM, Hosokawa Alpine, Augsburg, Germany), enabling separation of fractions differing in particle size [46,47].

Cold-pressed high-oleic sunflower oil (Bački Dukat, Odžaci, Serbia) was used as the lipid phase. The oil was characterized by a high content of monounsaturated fatty acids (82.9%), predominantly oleic acid (82.7%), confirming its high-oleic nature and enhanced oxidative stability compared to conventional sunflower oil. Linoleic acid (8.6%) and palmitic acid (4.3%) were the next most abundant fatty acids, while saturated and polyunsaturated fatty acids accounted for 8.1% and 9.0%, respectively. The detailed fatty acid composition is provided in Table 1.

**Table 1.** Fatty acid composition of cold-pressed high-oleic sunflower oil.

| Fatty Acid | Content (g per 100 g Oil) |
|---|---|
| C16:0 | 4.3 ± 0.43 |
| C16:1 | 0.1 ± 0.01 |
| C18:0 | 2.4 ± 0.24 |
| C18:1n-9 | 82.7 ± 8.27 |
| C18:2n-6 | 8.6 ± 0.86 |
| C20:0 | 0.2 ± 0.02 |
| C22:0 | 0.8 ± 0.08 |
| C24:0 | 0.3 ± 0.03 |
| ∑ SFA | 8.1 ± 0.81 |
| ∑ MUFA | 82.9 ± 8.29 |
| ∑ PUFA | 9.0 ± 0.90 |

Commercially available food-grade essential oils were used in the study: basil (*Ocimum basilicum* L.) essential oil (Terra Co, Novi Sad, Serbia), winter savory (*Satureja montana* L.) essential oil (Zemljoradnička zadruga Meli, Knjaževac, Serbia), and cumin (*Cuminum cyminum* L.) essential oil (BEWIT FRANCHISE, s.r.o., Ostrava, Czech Republic). The essential oils were characterized by different dominant volatile compounds, with estragole prevailing in basil EO, cumin aldehyde in cumin EO, and γ-terpinene and carvacrol in winter savory EO (Table 2).

**Table 2.** Major volatile constituents of the essential oils used in the study.

| Essential Oil | Major Compound | Relative Content (%) |
|---|---|---|
| Basil EO (*Ocimum basilicum* L.) | Estragole | 77.09 ± 0.02 |
| | Linalool | 19.55 ± 0.06 |
| | α-trans-Bergamotene | 0.60 ± 0.01 |
| Cumin EO (*Cuminum cyminum* L.) | Cumin aldehyde | 36.36 ± 0.02 |
| | p-Cymene | 21.10 ± 0.09 |
| | γ-Terpinene | 15.62 ± 0.09 |
| Winter savory EO (*Satureja montana* L.) | γ-Terpinene | 36.28 ± 0.14 |
| | Carvacrol | 35.48 ± 0.10 |
| | o-Cymene + limonene | 14.62 ± 0.06 |

### 2.2. Preliminary Tests and Formulation Optimization

Preliminary tests were conducted prior to the final experimental phase to define appropriate formulation ranges and ensure the technological feasibility of fava bean-based spreads. During these trials, different proportions of fava bean, oil, and water were

evaluated with the aim of obtaining a product with acceptable texture, spreadability, and overall stability.

#### 2.2.1. Experimental Design

A mixture design approach was applied to investigate the effect of the main formulation components on the properties of fava bean-based spreads. A D-optimal mixture design was generated using XLSTAT 2025.1 (Lumivero, Denver, CO, USA). The formulation consisted of three independent variables: fava bean (X1), oil (X2), and water (X3), whose proportions varied within the following ranges: fava bean 40–85%, oil 8–15%, and water 10–35%. These three components accounted for 91% of the total formulation, while the remaining 9% was kept constant and consisted of tahini, garlic, white pepper, citric acid, and salt. The constraints for each component were established based on preliminary trials, literature reports, and analysis of commercially available spread formulations, in order to ensure technological feasibility and acceptable sensory properties. The D-optimal design enabled evaluation of both individual component effects and their interactions [48].

#### 2.2.2. Preparation of Fava Bean Spreads

Cleaned seeds were soaked in water at a seed-to-water ratio of 1:3 ($w/v$) and kept at room temperature for 12 h to ensure adequate hydration. After soaking, the water was discarded and the seeds were rinsed with tap water. The soaked beans were cooked in a pot in tap water at a bean-to-water ratio of 1:4 ($w/v$) at 100 °C under boiling conditions until a soft texture was obtained. After cooking, excess surface moisture was removed using paper towels and the mass of the treated samples was recorded using a precision analytical balance [49].

Spreads were prepared in the pilot plant facility of the Institute of Food Technology in Novi Sad, Serbia, using a Thermomix TM5 (Vorwerk SE & Co. KG, Wuppertal, Germany). The processed fava bean material was homogenized at 40 °C until a uniform paste-like consistency was obtained. During homogenization, the lipid phase consisting of cold-pressed high-oleic sunflower seed oil (Bački Dukat, Odžaci, Serbia) was gradually incorporated into the mixture. The remaining ingredients were added stepwise under continuous mixing to obtain a homogeneous emulsion system with the desired spread consistency.

The obtained mass was filled into 100 mL glass jars and sealed with metal lids. Thermal treatment was carried out in a vertical autoclave (CFS-75V, TERRA Food-Tech, Barcelona, Spain) until the temperature at the geometric center of the sample reached 72 °C, where it was maintained for 10 min [50]. After thermal processing, the samples were cooled in cold water and stored at 4 °C until further analysis.

#### 2.2.3. Texture Characterization

Textural properties of fava bean spreads were evaluated by penetration test using a texture analyzer (TA.XT Plus, Stable Micro Systems, Godalming, UK). A cylindrical Delrin probe (P/0.5; 5 mm diameter) was used in distance mode with a penetration distance of 8 mm and a strain of 10%. Instrument settings were as follows: pre-test speed 1.50 mm/s, test speed 1.50 mm/s, post-test speed 10.00 mm/s, and trigger force 10 g [51,52]. Each sample was measured in five replicates and force-distance curves were recorded to determine firmness (N).

#### 2.2.4. Sensory Evaluation of Preliminary Formulations

Sensory characterization of the sixteen fava bean spread formulations was performed using the projective mapping (Napping) method as a rapid sensory profiling tool to identify similarities and differences among samples and to select the most promising formulation for further development [53].

The evaluation was conducted by a panel of twelve semi-trained assessors (7 females and 5 males, aged 25–60 years), participants who received targeted training regarding the sensory attributes, scaling procedure, and sample evaluation prior to the study, but who did not undergo the extensive calibration and performance validation required for a fully trained expert panel, according to ISO 8586:2023 [54]. Assessors were instructed to place samples on a two-dimensional space according to perceived sensory similarities and differences, positioning similar samples closer together and dissimilar samples further apart. In addition to sample positioning, panelists were asked to provide spontaneous descriptive terms for the samples or groups of samples and explained the rationale behind their positioning, in accordance with the Ultra Flash Profiling approach [55]. One hour prior to testing, samples were equilibrated to room temperature (20–22 °C) and were presented simultaneously in randomized order in closed, odourless, transparent plastic containers, coded with three-digit random numbers. Water and plain crackers were provided for palate cleansing between evaluations. The evaluation was carried out under controlled sensory laboratory conditions, including individual booths, controlled lighting, and standardized serving conditions (according to ISO 8589:2007 [56]).

Following the projective mapping task, assessors evaluated overall liking of each sample using a 9-point hedonic scale (1 = dislike extremely; 9 = like extremely). Data from projective mapping were analyzed using Multiple Factor Analysis, while frequency analysis was applied to descriptive terms to support interpretation of sensory differences among samples [57].

### 2.3. Final Formulation and Experimental Setup

Based on the results of the preliminary phase, the optimal formulation was selected for the subsequent experimental phase. All ingredient proportions were expressed as weight percentages relative to the total formulation (Table 3). The final formulation consisted of cooked fava beans (53.0%), sunflower oil (13.0%, Bački Dukat, Odžaci, Serbia), water (25.0%), tahini (7.4%, BioLand, Beograd, Serbia), garlic (0.5%, Aleva d.o.o., Novi Kneževac, Serbia), white pepper (0.2%, Nestle Adriatic S, Beograd, Serbia), citric acid (0.2%, Alimenta, Novi Sad, Serbia), and salt (0.7%, Solana Tuzla, Tuzla, Bosnia and Herzegovina). These ingredients were selected based on their technological and sensory roles in hummus-type spread formulations, where tahini contributes to structure and mouthfeel, garlic and white pepper enhance flavor, citric acid improves pH stability, and salt ensures taste balance.

**Table 3.** Formulation of fava bean spreads (% *w*/*w*).

| Ingredient | Control | BA | WS | CU |
|---|---|---|---|---|
| Cooked fava beans | 53.0 | 53.0 | 53.0 | 53.0 |
| Sunflower oil | 13.0 | 13.0 | 13.0 | 13.0 |
| Water | 25.0 | 25.0 | 25.0 | 25.0 |
| Tahini | 7.40 | 7.40 | 7.40 | 7.40 |
| Garlic | 0.50 | 0.50 | 0.50 | 0.50 |
| White pepper | 0.20 | 0.20 | 0.20 | 0.20 |
| Citric acid | 0.20 | 0.20 | 0.20 | 0.20 |
| Salt | 0.70 | 0.70 | 0.70 | 0.70 |
| Basil essential oil | – | 0.10 µL/g | – | – |
| Winter savory essential oil | – | – | 0.10 µL/g | – |
| Cumin essential oil | – | – | – | 0.10 µL/g |

In addition, three plant EOs were incorporated as natural antioxidants: basil (*Ocimum basilicum* L.), winter savory (*Satureja montana* L.), and cumin (*Cuminum cyminum* L.). Four formulations were prepared (Table 3): a control sample without EO (B-CO) and three samples containing basil (B-BA), winter savory (B-WS), or cumin (B-CU) EO, each at a concentration of 0.100 μL/g. The concentration of essential oils (0.100 μL/g) was selected based on previous studies evaluating the application of plant-derived essential oils in food systems, particularly the studies of Šojić et al. [35,58], in which concentrations of 0.075 and 0.150 μL/g were investigated. The selected concentration represented an intermediate level intended to provide antioxidant protection while minimizing potential adverse effects on sensory properties. EOs were added during the homogenization step to ensure uniform distribution within the spread matrix. Samples were prepared, thermally processed, and stored as described in Section 2.2.2.

### *2.4. Physicochemical and Oxidative Stability Analyses*

pH values were measured using a digital pH meter (Testo 205, Testo SE & Co. KGaA, Titisee-Neustadt, Germany) equipped with a combined penetration electrode and temperature probe [59].

Water activity ($a_w$) was determined using a LabSwift-aw instrument (Novasina AG, Lachen, Switzerland) at room temperature according to the manufacturer's instructions [59].

Both parameters were measured at days 0, 18, 36, 54, 72, and 90 of storage (days).

Color parameters were determined using a portable colorimeter (CR-400, Konica Minolta, Tokyo, Japan) fitted with a light protection tube (CR-A33b), using illuminant D65 and a pulsed xenon lamp as the light source [60]. The instrument was calibrated prior to each measurement session using the manufacturer's standard white tile. Color values were expressed in the CIELab color system as $L^*$ (lightness), $a^*$ (red–green axis), and $b^*$ (yellow–blue axis). Five measurements were recorded per sample at representative, visually homogeneous points. Total color difference (ΔE) was calculated relative to day 0 values for each treatment, using the following formula [58]:

$$\Delta E = \left[ (L^*{}_T - L^*{}_C)^2 + (a^*{}_T - a^*{}_C)^2 + (b^*{}_T - b^*{}_C)^2 \right]^{\frac{1}{2}} \quad (1)$$

where $L^*_T$ and $L^*_C$ represent the lightness values of the treated (T) and control (C) samples, respectively; $a^*_T$ and $a^*_C$ represent the chromaticity values on the red–green axis; and $b^*_T$ and $b^*_C$ represent the chromaticity values on the yellow–blue axis for the treated and control samples, respectively.

Peroxide value (PV) was determined to quantify primary lipid oxidation products. Lipids were extracted using the cold two-phase method of Bligh and Dyer [61], adapted for high-moisture samples. PV was determined by iodometric titration according to ISO 3960:2017 [62], with results expressed as milliequivalents of oxygen per kilogram of fat (meq $O_2$/kg).

Secondary lipid oxidation was assessed by the thiobarbituric acid reactive substance (TBARS) assay according to Šojić et al. [60], with results expressed as mg malondialdehyde per kg of sample (mg MDA/kg).

Protein oxidation was evaluated by quantifying free thiol groups according to the method of Jongberg et al. [63]. Results are expressed as nanomoles of thiol per milligram of protein (nmol SH/mg protein). All oxidative stability parameters were measured at days 0, 18, 36, 54, 72, and 90 of storage. For each treatment group, three samples were analyzed in duplicate.

### 2.5. Antioxidant and Bioactive Compound Analyses

For extraction, 0.5 g of the sample was extracted with 10 mL of 80% ethanol for 2 h. After centrifugation at 4000× *g* (Rotofix 32 A, Hettich, Vlotho, Germany) for 10 min, the supernatant was used for all subsequent determinations.

Antioxidant activity was determined by the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging method according to Sánchés-Moreno et al. [64]. Briefly, 4 mL of DPPH solution (0.025 g/100 mL ethanol) was added to 1 mL of sample extract and absorbance was measured at 515 nm using a Jenway spectrophotometer (6405 UV/Vis, Nottingham, UK). Results are expressed as mg Trolox equivalent antioxidant capacity per gram of sample (mg TEAC/g), using a Trolox calibration curve (10–100 mg/L).

Total polyphenol content (TPC) was determined spectrophotometrically using the Folin–Ciocalteu method as described by Singleton and Rossi [65]. A volume of 0.1 mL of sample extract was mixed with 0.1 mL Folin–Ciocalteu reagent, 1 mL of 20% sodium carbonate solution, and 8.8 mL of distilled water. After 30 min in darkness, absorbance was measured at 700 nm. Results are expressed as mg gallic acid equivalent per gram of sample (mg GAE/g).

Total flavonoid content (TFC) was determined using the aluminium chloride colorimetric method as described by Willett [66]. A volume of 0.5 mL of sample extract was mixed with 0.1 mL of 10% ethanolic aluminium chloride, 0.1 mL of 1 M potassium acetate, and 4.3 mL of distilled water. After 30 min in darkness, absorbance was measured at 415 nm. Results are expressed as mg quercetin equivalent per gram of sample (mg QE/g).

Total phenolic acid content (TPAC) was determined according to Jain et al. [67]. A volume of 0.5 mL of sample extract was mixed with 0.5 mL of 0.5 M hydrochloric acid, 0.5 mL of Arnova reagent (10% $NaNO_2$ + 10% $Na_2MoO_4$), 0.5 mL of 1 M sodium hydroxide, and 0.5 mL of distilled water. Absorbance was measured at 490 nm. Results are expressed as mg caffeic acid equivalent per gram of sample (mg CAE/g).

Oxidative stability was determined using a Rancimat apparatus (892 Rancimat, Metrohm, Herisau, Switzerland) according to ISO 6886:2016 [68]. A sample of 0.5 g was subjected to accelerated oxidation at 120 °C with an airflow of 20 L/h. Induction times were determined using the instrument software with a precision of 0.005 h. Antioxidant and bioactive compound analyses were performed on freshly prepared samples at day 0 of storage.

### 2.6. Microbiological Analysis

Microbiological analyses were performed according to standard ISO methods. Total aerobic bacteria were enumerated according to ISO 4833-1:2013 [69], coliform bacteria according to ISO 21528-2:2017 [70], and yeasts and moulds according to ISO 21527-1/2:2008 [71]. The detection of Listeria monocytogenes was carried out according to ISO 11290-1:2017 [72].

### 2.7. Sensory Evaluation of Final Formulations

Sensory evaluation of the developed fava bean spreads was conducted to assess liking of color, taste, aroma, texture, and overall liking. The study protocol was approved by the Ethics Committee of Institute of Food Technology in Novi Sad (Ref. No. 24-70-3, 4 September 2025).

A panel consisting of 18 semi-trained panelists (10 females and 8 males, aged 25–60 years), recruited among students and staff familiar with sensory evaluation of food products, but without extensive calibration and performance validation required for a fully trained expert panel. All participants provided informed consent prior to participation. The sensory analysis was performed in individual booths under controlled conditions.

Samples were evaluated at six storage periods (0, 18, 36, 54, 72, and 90 days). Prior to evaluation, samples were equilibrated to room temperature (20–22 °C), presented in closed, odourless, transparent plastic containers coded with random three-digit numbers. Samples were presented in randomized order to minimize bias. Panelists were instructed to rinse their mouths with water between samples.

Panelists evaluated the samples using a 9-point hedonic scale, where 1 corresponded to "dislike extremely" and 9 to "like extremely", for color, aroma, taste, texture, and overall liking [73].

### 2.8. GC–MS Analysis of Essential Oils

The volatile composition of the essential oils was analyzed using a gas chromatograph (7890A, Agilent Technologies, Santa Clara, CA, USA) coupled with a mass selective detector (5975C, Agilent Technologies, Santa Clara, CA, USA). Separation was performed on an HP-5MS UI capillary column (30 m × 0.25 mm i.d., film thickness 0.25 µm; Agilent Technologies, Santa Clara, CA, USA). Prior to analysis, essential oil samples were dissolved and appropriately diluted in hexane. An aliquot of 1 µL was injected into the GC system using an autosampler (7683B, Agilent Technologies, Santa Clara, CA, USA). Helium (purity > 99.9997%) was used as the carrier gas at a constant flow rate of 2 mL/min. The oven temperature program was as follows: initial temperature 60 °C; heating from 60 to 150 °C at 3 °C/min; subsequent heating to 250 °C at 20 °C/min; followed by a final isothermal step at 250 °C for 5 min. The injector temperature was maintained at 250 °C. Compound identification was performed by comparing the obtained mass spectra with the NIST mass spectral library and literature data [74]. In addition, linear retention indices (LRI) were calculated for the detected compounds and compared with literature values for further confirmation. The composition of essential oils was expressed as relative percentage (%) of the identified compounds (mean ± standard deviation).

### 2.9. Fatty Acid Profile Analysis

Total lipids were isolated from the samples using the cold extraction procedure described by Folch et al. [75]. Briefly, lipids were extracted with a chloroform solution (2:1, *v*/*v*) for 2.5 h. After extraction, the mixtures were filtered, and the solvents were removed under reduced pressure using a vacuum dryer (Binder VD 115, Tuttlingen, Germany). To minimize oxidative changes, the extracted lipid fraction was flushed with nitrogen prior to further analysis. Fatty acid methyl esters (FAMEs) were prepared immediately after lipid extraction according to ISO 12966-2:2017 [76]. The analysis of FAMEs was performed on a gas chromatograph (7890A, Agilent Technologies, Santa Clara, CA, USA) equipped with a flame ionization detector (FID). Separation was achieved using an SP-2560 fused silica capillary column (100 m × 0.25 mm i.d., film thickness 0.20 µm; Supelco, Bellefonte, PA, USA). The injector and detector temperatures were maintained at 250 °C. Helium was used as the carrier gas, while 1 µL of sample was injected in split mode (1:30). The oven temperature program consisted of an initial temperature of 140 °C held for 3 min, followed by heating to 220 °C at 3 °C/min with a 5 min hold, and a final increase to 240 °C at 2 °C/min with a final hold of 10 min. Individual fatty acids were identified by comparing retention times with those of a commercial reference standard mixture (Supelco 37 Component FAME Mix, Sigma-Aldrich, St. Louis, MI, USA). Quantitative results were calculated from peak areas and expressed as g fatty acids/100 g sample.

### 2.10. Statistical Analysis

All data are presented as mean ± standard deviation. The effects of formulation, storage duration, and their interaction on physicochemical and oxidative stability parameters were evaluated using two-way analysis of variance (two-way ANOVA). One-way

ANOVA was applied to oxidative stability, antioxidant parameters and content of bioactive compounds determined at a single time point. Post hoc comparison of means was performed using Tukey's HSD test at a significance level of $p \leq 0.05$. Statistical analyses were performed using Statistica v.14.0.0.15 [77].

## 3. Results and Discussion

### 3.1. Raw Materials and Sample Preparation

Prior to hydration and thermal treatment, fava bean (*Vicia faba* L.) seeds were subjected to mechanical dehulling and air classification. Dehulling enabled the removal of the seed coat, which can act as a physical barrier to water penetration and reduce hydration efficiency. In addition, the seed coat contains phenolic compounds and tannins that may negatively affect protein digestibility and overall nutritional quality [78–80]. Therefore, its removal contributes to improved technological performance and product quality.

Air classification allowed separation of fractions differing in particle size and composition, facilitating the production of a more homogeneous raw material suitable for spread formulation [45–47].

The soaking and cooking behavior observed for fava bean in the present study aligns well with known hydration patterns of other legumes, while also highlighting the unique characteristics of this underutilized crop. The initial mass of dry fava bean seeds (2.4 kg) increased to 5.8 kg after 12 h of soaking (seed-to-water ratio 1:3, $w/v$), corresponding to a water uptake of approximately 142%. Subsequent cooking (bean-to-water ratio 1:4, 100 °C, 120 min) further increased the mass to 6.2 kg, indicating a high water absorption capacity and facilitating paste formation, thereby contributing to desirable texture of the spreads. Comparable studies on other legumes have reported water uptake ranging from 80.87% for red lentils to 104.40% for chickpeas during soaking, with further increases during boiling [49]. The soaking process not only promoted pronounced swelling and softening of the seeds, facilitating paste formation, but also contributed to the reduction in antinutritional factors such as phytates, tannins, and α-galactoside oligosaccharides, which are known to impair protein digestibility and cause digestive discomfort [13,81,82]. The observed water absorption and texture changes are consistent with known legume hydration behavior, where seed size, coat permeability, and processing conditions affect both water uptake and antinutrient leaching [83–85]. Efficient hydration combined with antinutrient reduction is essential for achieving the desired consistency, nutritional quality, and emulsion stability in fava bean-based spreads.

### 3.2. Optimization of Fava Bean Spread Formulation

The resulting experimental matrix included 16 different formulations varying in fava bean, oil, and water content (Table 4), allowing the evaluation of the effects of formulation variables on texture, spreadability, and overall stability. All formulations were subjected to instrumental texture analysis and sensory evaluation using the projective mapping technique.

Firmness, a key quality attribute affecting spreadability and consumer acceptability [86], was measured for the 16 experimental formulations using a texture analyzer. Values ranged from 0.53 N to 3.64 N reflecting the effects of protein (X1), water (X3), and oil (X2) content (Figure 1).

Firmness increased with higher fava bean content (X1) and lower water content (X3), resulting in firmer and more cohesive spreads [51]. This increase in firmness can be attributed to the greater contribution of proteins to network formation during heating, which enhances structural integrity and resistance to deformation. Similar behavior has been

reported in plant protein-based emulsion systems, where increasing protein concentration leads to higher stiffness and gel strength [87].

**Table 4.** Experimental design of three components in fava bean spread formulation.

| Run Order | $X_1$: % Fava Bean | $X_2$: % Oil | $X_3$: % Water |
|---|---|---|---|
| S1 | 48.0 | 9.00 | 34.0 |
| S2 | 54.0 | 8.00 | 29.0 |
| S3 | 57.0 | 10.0 | 24.0 |
| S4 | 61.0 | 8.00 | 22.0 |
| S5 | 66.0 | 15.0 | 10.0 |
| S6 | 53.0 | 13.0 | 25.0 |
| S7 | 42.0 | 15.0 | 34.0 |
| S8 | 55.0 | 10.0 | 26.0 |
| S9 | 55.0 | 9.00 | 27.0 |
| S10 | 62.0 | 15.0 | 14.0 |
| S11 | 71.0 | 8.00 | 12.0 |
| S12 | 68.0 | 10.0 | 13.0 |
| S13 | 63.0 | 8.00 | 20.0 |
| S14 | 61.0 | 13.0 | 17.0 |
| S15 | 48.0 | 9.00 | 34.0 |
| S16 | 57.0 | 10.0 | 24.0 |

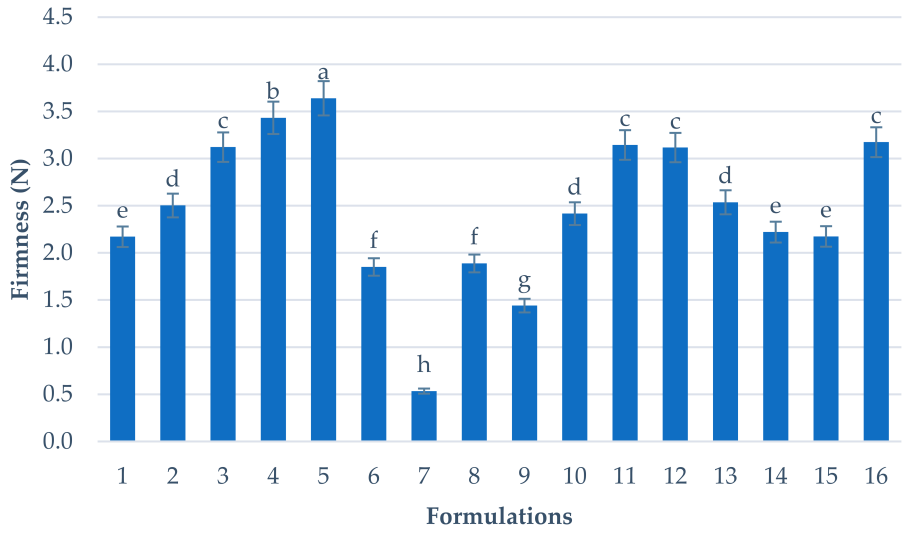



**Figure 1.** Firmness values of the 16 preliminary formulations determined by penetration test. Different letters above the bars indicate significant differences ($p \leq 0.05$).

Sensory Properties of Preliminary Formulation

Projective mapping combined with multivariate analysis resulted in a sensory map where the first two dimensions explained 40.69% of the total variability (F1 = 22.58%, F2 = 18.11%), indicating a moderate but meaningful differentiation among the samples based on sensory perception (Figure 2).

The first dimension (F1) primarily separated samples according to texture and flavour intensity. Samples positioned on the right side of the map were associated with attributes such as graininess, dryness, bitterness, low spreadability, garlic flavour, roughness, and

gritty texture. In contrast, samples located on the left side of the map were characterized by creamy texture, smoothness, high spreadability, whiteness, watery and soft texture, pleasant odour, and milky flavour notes. Therefore, F1 can be interpreted as a dimension describing the transition from creamy, smooth and mild samples to dry, grainy, rough and more intense flavoured samples.

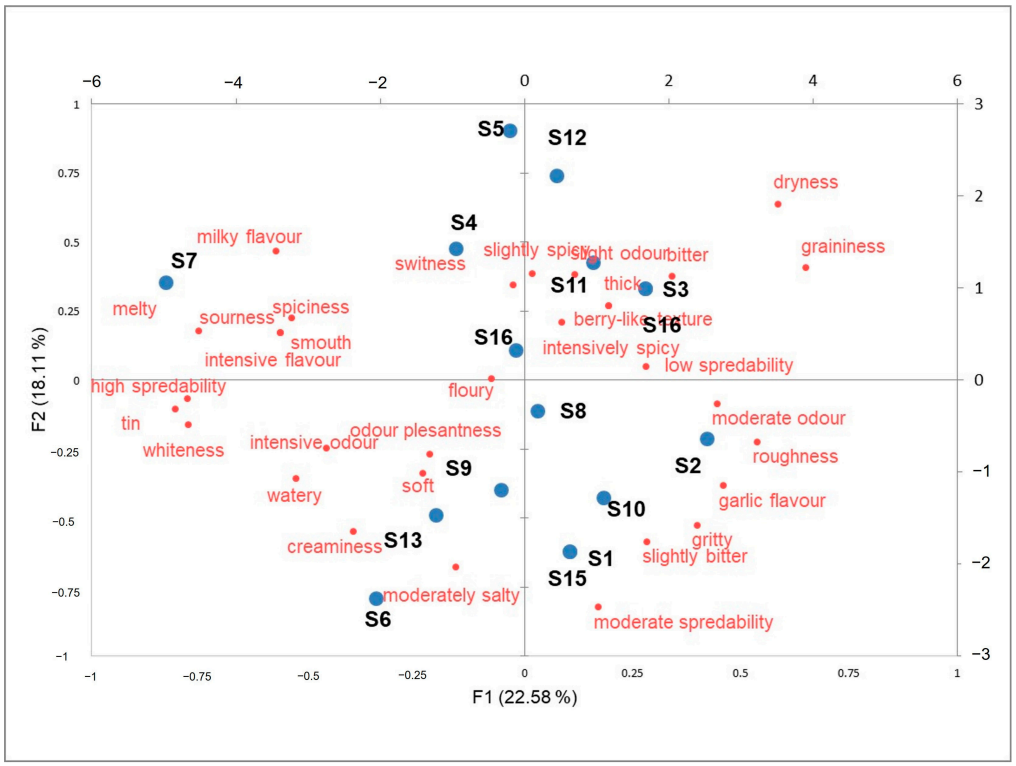



**Figure 2.** PCA bi-plot of the 16 experimental formulations.

The second dimension (F2) appeared to differentiate samples mainly based on flavour profile and odour characteristics. Samples positioned in the upper part of the map were associated with slightly spicy odour, sweetness, thickness, bitterness and berry-like texture, while samples in the lower part were related to garlic flavour, roughness, grittiness, moderate spreadability and saltiness. This dimension therefore reflects differences in flavour profile and overall sensory balance.

Based on the observation plot, several sample groups can be identified. Samples S3, S11, S12 and S16 were positioned on the right side of the map, indicating association with grainy texture, dryness, bitterness and lower spreadability. Samples S6, S7 and partially S13 were located on the left side of the map, indicating smoother texture, higher spreadability, creaminess and milder flavour profile. Samples S1, S10 and S15 were positioned in the lower right quadrant and were associated with garlic flavour, roughness and gritty texture, suggesting a stronger and less smooth sensory profile.

Samples located near the centre of the map (e.g., S8, S14) showed more balanced sensory characteristics without strongly pronounced attributes.

The results of the overall liking evaluation showed relatively high acceptance scores for most samples, with mean values ranging from 6.25 to 7.63 on the 9-point hedonic scale, indicating generally good acceptance of the developed faba bean spreads.

Among all evaluated samples, sample S6 achieved the highest overall liking score (7.63), followed by S9 (7.38), S1 and S15 (7.25). On the other hand, the lowest liking scores were recorded for S2 and S5 (6.25), although even these values indicate moderate acceptance rather than rejection.

The high overall liking score of S6 can be explained by its sensory profile observed in the projective mapping analysis. According to the sensory map, samples located in the region associated with creaminess, smooth texture, higher spreadability, pleasant odour, and milder flavour profile were generally perceived as more acceptable [51,88,89]. Samples positioned closer to attributes such as graininess, dryness, bitterness, roughness and garlic flavour were less preferred [90].

These findings suggest that S6 represents the most promising formulation for further product optimization and development, as it combines favourable sensory characteristics with the highest overall liking.

Overall, the projective mapping results demonstrated clear sensory differentiation among the faba bean spread samples, primarily driven by differences in texture properties (creaminess vs. graininess), spreadability, and flavour intensity. Texture-related attributes appeared to be the main drivers of sample positioning on the sensory map, while flavour attributes contributed to secondary differentiation. These results were used as a basis for selecting samples with the most promising sensory profile for further product optimization.

The highest overall liking score of S6 suggests that this sample likely combined favourable texture properties (creaminess, smoothness, good spreadability) with balanced flavour and absence of pronounced bitterness, dryness or graininess, which are attributes typically associated with lower consumer acceptance in spreadable products.

### 3.3. Physicochemical Stability

Water activity ($a_w$) is a key factor influencing microbial stability, texture, and shelf-life of high-moisture foods. In all treatments, $a_w$ values remained relatively stable during 90 days of storage, ranging between 0.94 and 0.95 (Table 5). These values are consistent with those reported for hummus and similar plant-based spreads, typically exceeding 0.95, and indicate conditions favorable for microbial growth [17,91,92]. Two-way ANOVA revealed significant effects of storage duration, formulation, and their interaction on aw ($p \leq 0.05$), although the observed differences were minor in practical terms. The narrow range of aw values suggests that the emulsion matrix effectively retained water, contributing to the stability of product structure and texture during storage. However, due to the relatively high aw values, refrigerated conditions are required to ensure microbiological safety [93,94].

pH values ranged from 5.32 to 5.56 across all formulations and storage periods (Table 5), reflecting a mildly acidic system consistent with the presence of citric acid. Storage duration, treatment, and their interaction had significant effects on pH ($p \leq 0.05$). A transient increase in pH was observed at day 54, reaching maximum values of 5.50–5.56, followed by a return toward initial values by day 90. This behavior may be associated with temporary buffering effects and the formation of low-molecular compounds during storage, as previously described in complex food systems [94]. Despite statistical significance ($p \leq 0.05$), the magnitude of changes was small, and all samples remained within a narrow pH range. The addition of EOs did not cause substantial deviations from the control, indicating that their incorporation did not disrupt the acid–base balance of the treatment [95]. Similar pH values have been reported for hummus and related plant-based spreads [16,17,91,92,96]. However, given the relatively high pH, refrigerated storage is required to ensure microbiological safety [43,93,97].

Color is a critical quality attribute influencing consumer acceptance and perceived freshness [98]. In the present study, lightness ($L^*$) values decreased progressively during storage in all treatments, indicating gradual darkening. The most pronounced decline was observed in the control sample (B-CO), where $L^*$ decreased significantly during storage ($p \leq 0.05$), from 81.73 at day 0 to 75.93 at day 90 (Table 6). In contrast, samples containing essential oils, particularly winter savory (B-WS), exhibited greater color stability, maintain-

ing $L^*$ values above 80 throughout storage. Two-way ANOVA confirmed significant effects of storage duration, treatment, and their interaction on $L^*$ ($p \leq 0.05$), indicating that both time and EO type influenced lightness changes. The observed darkening is likely associated with lipid and protein oxidation processes, which lead to the formation of chromophoric compounds and surface browning in legume-based systems [98,99]. The improved stability in essential oil-containing samples suggests a protective role of their bioactive constituents against oxidative discoloration, primarily through inhibition of lipid oxidation and radical scavenging activity [38,95].

**Table 5.** $a_w$ and pH of spread samples during 90-day storage period.

| | | | | **$a_w$** | | |
|---|---|---|---|---|---|---|
| | | | | **Storage day** | | |
| Treatment | 0 | 18 | 36 | 54 | 72 | 90 |
| B-CO | $0.95 \pm 0.003^{aA}$ | $0.95 \pm 0.001^{aA}$ | $0.95 \pm 0.001^{aA}$ | $0.94 \pm 0.002^{bB}$ | $0.95 \pm 0.001^{aA}$ | $0.95 \pm 0.001^{aA}$ |
| B-BA | $0.95 \pm 0.002^{aA}$ | $0.94 \pm 0.001^{bB}$ | $0.95 \pm 0.001^{aA}$ | $0.94 \pm 0.001^{bB}$ | $0.95 \pm 0.001^{aA}$ | $0.95 \pm 0.001^{aA}$ |
| B-WS | $0.94 \pm 0.005^{bB}$ | $0.94 \pm 0.001^{bB}$ | $0.94 \pm 0.002^{bB}$ | $0.94 \pm 0.001^{bB}$ | $0.95 \pm 0.002^{aA}$ | $0.95 \pm 0.000^{aA}$ |
| B-CU | $0.95 \pm 0.003^{aA}$ | $0.94 \pm 0.001^{bB}$ | $0.95 \pm 0.001^{aA}$ | $0.94 \pm 0.002^{bB}$ | $0.95 \pm 0.001^{aA}$ | $0.95 \pm 0.001^{aA}$ |
| | | | | **pH** | | |
| | | | | **Storage day** | | |
| Formulation | 0 | 18 | 36 | 54 | 72 | 90 |
| B-CO | $5.41 \pm 0.00^{cCB}$ | $5.32 \pm 0.00^{cD}$ | $5.40 \pm 0.01^{bC}$ | $5.55 \pm 0.00^{abA}$ | $5.44 \pm 0.02^{cB}$ | $5.43 \pm 0.02^{abCB}$ |
| B-BA | $5.43 \pm 0.00^{bCB}$ | $5.36 \pm 0.01^{bD}$ | $5.40 \pm 0.01^{bC}$ | $5.56 \pm 0.04^{aA}$ | $5.46 \pm 0.01^{bB}$ | $5.41 \pm 0.02^{abC}$ |
| B-WS | $5.46 \pm 0.00^{aB}$ | $5.40 \pm 0.01^{aC}$ | $5.46 \pm 0.00^{aB}$ | $5.56 \pm 0.02^{aA}$ | $5.45 \pm 0.00^{cbB}$ | $5.40 \pm 0.01^{bC}$ |
| B-CU | $5.43 \pm 0.00^{bC}$ | $5.39 \pm 0.00^{aD}$ | $5.44 \pm 0.01^{aC}$ | $5.50 \pm 0.00^{bB}$ | $5.54 \pm 0.02^{aA}$ | $5.44 \pm 0.02^{aC}$ |
| | | | | ***F* statistic values of two-way ANOVA** | | |
| Parameter | Storage duration | | Treatment | | Treatment × Storage duration | |
| pH | 168.27 * | | 15.55 * | | 10.50 * | |
| $a_w$ | 18.70 * | | 10.83 * | | 3.50 * | |

B—Fava bean; CO—control; BA—basil EO; WS—winter savory EO; CU—cumin EO. Different lowercase letters indicate significant differences among treatments within the same storage day, while uppercase letters indicate significant differences among storage times within the same treatment ($p \leq 0.05$). * indicates significant effect according to two-way ANOVA ($p \leq 0.05$).

The $a^*$ (red–green) parameter showed only minor variations across treatments, remaining within the negative (green) region (−1.25 to −0.98). Although the interaction between formulation and storage duration was significant ($p \leq 0.05$), the main effect of treatment was not ($p \geq 0.05$), indicating that EOs did not systematically affect the red–green balance. Changes in $a^*$ values were primarily time-dependent and may reflect minor oxidative or structural changes in the matrix rather than consistent formulation effects [43].

In contrast, the $b^*$ (yellow–blue) parameter increased during storage in all samples, with the most pronounced rise observed in the control (from 16.05 to 17.84), indicating progressive yellowing. Two-way ANOVA revealed significant effects of storage duration, treatment, and their interaction ($p \leq 0.05$). This increase in $b^*$ values is commonly associated with lipid oxidation and the formation of secondary oxidation products, as well as Maillard-type reactions [26,98]. B-WS exhibited the lowest and most stable $b^*$ values (15.42–15.84), while B-BA and B-CU showed intermediate behavior.

Total color difference (ΔE) increased throughout storage in all formulations, confirming progressive color changes. The control sample reached a ΔE of 6.07 at day 90, corresponding

to a clearly perceptible color difference, while B-WS showed a ΔE of only 1.81, remaining below the threshold of noticeable visual change [100]. B-BA and B-CU exhibited intermediate ΔE values (4.30 and 4.82, respectively). These results are consistent with previous findings in hummus-type products, where storage leads to decreased $L^*$ and increased $b^*$ values due to oxidative and structural changes in the matrix [16]. Representative images are available in the Supplementary Materials.

**Table 6.** Color ($L^*$, $a^*$, $b^*$, $\Delta E$) of spread samples during 90-day storage period.

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | ***L**** | | | |
| | | | **Storage day** | | | |
| Formulation | 0 | 18 | 36 | 54 | 72 | 90 |
| B-CO | $81.73 \pm 0.12^{bA}$ | $80.86 \pm 0.022^{bB}$ | $80.28 \pm 0.05^{bC}$ | $80.20 \pm 0.52^{aCD}$ | $80.09 \pm 0.08^{bD}$ | $75.93 \pm 0.07^{dE}$ |
| B-BA | $82.52 \pm 0.04^{aA}$ | $81.62 \pm 0.15^{aB}$ | $80.95 \pm 0.05^{aBC}$ | $80.70 \pm 0.67^{aC}$ | $80.48 \pm 0.80^{abC}$ | $78.27 \pm 0.69^{bD}$ |
| B-WS | $82.45 \pm 0.12^{aA}$ | $81.65 \pm 0.08^{aB}$ | $80.94 \pm 0.36^{aC}$ | $80.18 \pm 0.62^{aE}$ | $80.73 \pm 0.28^{aC}$ | $80.69 \pm 0.04^{aC}$ |
| B-CU | $82.44 \pm 0.05^{aA}$ | $81.60 \pm 0.08^{aB}$ | $81.17 \pm 0.05^{aD}$ | $80.45 \pm 0.18^{aC}$ | $81.09 \pm 0.31^{aD}$ | $77.75 \pm 0.08^{cE}$ |
| | | | ***a**** | | | |
| | | | **Storage day** | | | |
| Formulation | 0 | 18 | 36 | 54 | 72 | 90 |
| B-CO | $-1.22 \pm 0.02^{aD}$ | $-1.03 \pm 0.02^{aA}$ | $-1.21 \pm 0.01^{abD}$ | $-1.13 \pm 0.03^{bB}$ | $-1.22 \pm 0.02^{aD}$ | $-1.17 \pm 0.01^{bC}$ |
| B-BA | $-1.25 \pm 0.02^{aB}$ | $-1.20 \pm 0.05^{cB}$ | $-1.19 \pm 0.03^{aAB}$ | $-1.07 \pm 0.10^{abA}$ | $-1.18 \pm 0.12^{aAB}$ | $-1.08 \pm 0.12^{aA}$ |
| B-WS | $-1.23 \pm 0.05^{aBC}$ | $-1.19 \pm 0.03^{cBC}$ | $-1.24 \pm 0.04^{bBC}$ | $-0.98 \pm 0.09^{aA}$ | $-1.25 \pm 0.04^{aC}$ | $-1.17 \pm 0.02^{bB}$ |
| B-CU | $-1.25 \pm 0.05^{aB}$ | $-1.12 \pm 0.03^{bA}$ | $-1.24 \pm 0.03^{bB}$ | $-1.07 \pm 0.04^{abA}$ | $-1.23 \pm 0.06^{aB}$ | $-1.07 \pm 0.03^{aA}$ |
| | | | ***b**** | | | |
| | | | **Storage day** | | | |
| Formulation | 0 | 18 | 36 | 54 | 72 | 90 |
| B-CO | $16.05 \pm 0.13^{aC}$ | $16.23 \pm 0.27^{aBC}$ | $16.08 \pm 0.05^{aC}$ | $16.12 \pm 0.20^{aBC}$ | $16.31 \pm 0.12^{aB}$ | $17.84 \pm 0.03^{aA}$ |
| B-BA | $15.56 \pm 0.03^{bBC}$ | $15.44 \pm 0.06^{bC}$ | $15.68 \pm 0.05^{bB}$ | $15.28 \pm 0.12^{cD}$ | $15.56 \pm 0.23^{bBC}$ | $16.21 \pm 0.04^{cA}$ |
| B-WS | $15.42 \pm 0.08^{cB}$ | $15.48 \pm 0.07^{bB}$ | $15.50 \pm 0.16^{cB}$ | $15.42 \pm 0.18^{cB}$ | $15.51 \pm 0.11^{bB}$ | $15.84 \pm 0.03^{dA}$ |
| B-CU | $15.65 \pm 0.06^{bC}$ | $15.15 \pm 0.08^{cE}$ | $15.57 \pm 0.06^{bcC}$ | $15.80 \pm 0.07^{bB}$ | $15.45 \pm 0.13^{bD}$ | $16.76 \pm 0.02^{bA}$ |
| | | | **ΔE** | | | |
| | | | **Storage day** | | | |
| Formulation | 0 | 18 | 36 | 54 | 72 | 90 |
| B-CO | - | 0.91 | 1.45 | 1.54 | 1.66 | 6.07 |
| B-BA | - | 0.91 | 1.58 | 1.85 | 2.04 | 4.30 |
| B-WS | - | 0.80 | 1.51 | 2.28 | 1.72 | 1.81 |
| B-CU | - | 0.98 | 1.27 | 2.00 | 1.36 | 4.82 |
| | | | ***F* statistic values of two-way ANOVA** | | | |
| Parameter | Storage duration | | Treatment | | Treatment × Storage duration | |
| $L^*$ | 374.23 * | | 84.81 * | | 27.26 * | |
| $a^*$ | 32.23 * | | $0.47^{ns}$ | | 5.11 * | |
| $b^*$ | 265.17 * | | 404.36 * | | 30.75 * | |

B—Fava bean; CO—control; BA—basil EO; WS—winter savory EO; CU—cumin EO. Different lowercase letters indicate significant differences among treatments within the same storage day, while uppercase letters indicate significant differences among storage times within the same treatment ($p \leq 0.05$). * indicates significant effect according to two-way ANOVA ($p \leq 0.05$). $^{ns}$ indicates not significant effect according to two-way ANOVA ($p \geq 0.05$).

Overall, treatments containing essential oils, particularly winter savory, demonstrated superior color stability compared to the control. This effect can be attributed to the presence of phenolic compounds such as thymol and carvacrol, which inhibit oxidative reactions and

pigment degradation through radical scavenging and stabilization of lipid fractions [95], highlighting the potential of EOs as natural additives for preserving quality in plant-based spreads.

### 3.4. Lipid and Protein Oxidation Markers

#### 3.4.1. Lipid Oxidation

Peroxide value (PV), reflecting primary lipid oxidation [25,101], increased significantly in all formulations during storage ($p \leq 0.05$) (Table 7). Initial PVs were similar (1.09–1.16 meq $O_2$/kg), indicating uniform oxidative status after processing. After 90 days, the control (B-CO) reached 2.68 meq $O_2$/kg, while B-BA exhibited the highest value (2.78 meq $O_2$/kg), suggesting limited or potential pro-oxidant behavior of basil EO under the applied conditions. In contrast, B-WS (2.04 meq $O_2$/kg) and B-CU (1.97 meq $O_2$/kg) maintained consistently lower PV values, indicating their inhibitory effect on primary lipid oxidation. These results are consistent with the reported antioxidant activity of winter savory and cumin EOs in lipid-containing systems [41,42,102–104]. The stronger antioxidant performance of winter savory EO may be attributed to its high content of carvacrol and γ-terpinene, compounds previously reported to act as chain-breaking antioxidants by hydrogen donation and radical scavenging activity [38,41]. Carvacrol, as a phenolic monoterpene, is particularly effective in stabilizing lipid radicals and interrupting propagation reactions in lipid oxidation systems [38]. Similarly, the antioxidant activity of cumin EO may be related to cuminaldehyde, γ-terpinene, and p-cymene, which contribute to radical scavenging and stabilization of lipid oxidation intermediates [42,102,105]. In contrast, basil EO, dominated by estragole and linalool, generally exhibits lower antioxidant potential due to the absence of phenolic hydroxyl groups, which may explain its weaker protective effect in B-BA samples [39,40]. In addition to radical scavenging, phenolic EO constituents may delay lipid oxidation through metal-chelating activity and stabilization of hydroperoxides, thereby limiting secondary oxidation reactions [38,99].

All samples remained well below the maximum PV limit of 7.5 mmol $O_2$/kg defined by the Serbian Rulebook [106], indicating satisfactory oxidative stability. This stability can be partially attributed to the use of cold-pressed high-oleic sunflower oil, which is characterized by a high content of monounsaturated fatty acids (oleic acid) and consequently improved resistance to oxidation compared to conventional sunflower oil, which is richer in polyunsaturated fatty acids and therefore more susceptible to oxidation [20–23].

TBARS values, indicating secondary lipid oxidation, remained below 1 mg MDA/kg in all formulations, confirming low levels of lipid degradation. Although no established TBARS limits exist for hummus [16], reference values are available for other food systems [33,99,107–109]. TBARS values for the control formulation (B-CO) remained stable, ranging from 0.54 to 0.35 mg MDA/kg over 90 days of storage, which may be attributed to the intrinsic antioxidant potential of fava bean, particularly its polyphenolic composition [110–112]. Basil (B-BA) led to a gradual increase from 0.56 to 0.97 mg MDA/kg, which is consistent with the highest observed increase in peroxide values (PV) for the B-BA, indicating a potential pro-oxidative behavior of basil EO under the given conditions. Similar pro-oxidative behavior of EOs has also been reported by other authors [113].

B-WS showed the initially highest TBARS value (0.75 mg MDA/kg), which may be attributed to the possible interaction of phenolic constituents of winter savory EO with the TBA reagent, rather than to actual oxidative deterioration of the lipid fraction [36]. From day 18 onward, however, B-WS maintained low and stable TBARS values (0.37–0.46 mg MDA/kg), consistent with previous studies [34–36]. B-CU showed a notable reduction in TBARS by day 18 (0.13 mg MDA/kg) relative to day 0 (0.55 mg MDA/kg), suggesting effective radical scavenging activity and inhibition of secondary oxidation

processes, consistent with the reported free radical scavenging activity of cumin EO constituents [37,105]. The reduced formation of secondary oxidation products in B-WS and B-CU may have also contributed to lower protein oxidation, since reactive aldehydes generated during lipid oxidation are known to interact with amino acid side chains and sulfhydryl groups, promoting protein cross-linking and thiol loss [29–31]. Therefore, inhibition of lipid oxidation by EO phenolic compounds may indirectly contribute to improved protein stability in the developed spreads.

**Table 7.** Peroxide value, TBARS and Thiol group contents of spread samples during 90-day storage period.

| **Peroxide value (meq $O_2$/kg)** | | | | | | |
|---|---|---|---|---|---|---|
| | **Storage day** | | | | | |
| Formulation | **0** | **18** | **36** | **54** | **72** | **90** |
| B-CO | $1.13 \pm 0.03^{abF}$ | $1.34 \pm 0.02^{bE}$ | $1.54 \pm 0.01^{bD}$ | $1.78 \pm 0.00^{bC}$ | $2.39 \pm 0.02^{aB}$ | $2.68 \pm 0.01^{bA}$ |
| B-BA | $1.16 \pm 0.02^{aE}$ | $1.38 \pm 0.02^{aD}$ | $2.19 \pm 0.01^{aC}$ | $2.28 \pm 0.02^{aB}$ | $2.31 \pm 0.01^{bB}$ | $2.78 \pm 0.01^{aA}$ |
| B-WS | $1.10 \pm 0.04^{bD}$ | $1.14 \pm 0.01^{dD}$ | $1.22 \pm 0.04^{dC}$ | $1.81 \pm 0.04^{bB}$ | $1.82 \pm 0.02^{dB}$ | $2.04 \pm 0.02^{cA}$ |
| B-CU | $1.09 \pm 0.01^{bF}$ | $1.25 \pm 0.03^{cE}$ | $1.39 \pm 0.01^{cD}$ | $1.50 \pm 0.01^{cC}$ | $1.87 \pm 0.01^{cB}$ | $1.97 \pm 0.03^{dA}$ |
| **TBARS (mg malondialdehyde/kg)** | | | | | | |
| | **Storage day** | | | | | |
| Formulation | **0** | **18** | **36** | **54** | **72** | **90** |
| B-CO | $0.54 \pm 0.00^{bA}$ | $0.34 \pm 0.00^{bB}$ | $0.34 \pm 0.02^{cB}$ | $0.34 \pm 0.01^{cB}$ | $0.35 \pm 0.01^{cB}$ | $0.34 \pm 0.02^{bB}$ |
| B-BA | $0.56 \pm 0.02^{bC}$ | $0.67 \pm 0.04^{aBC}$ | $0.67 \pm 0.02^{aBC}$ | $0.69 \pm 0.00^{aBC}$ | $0.74 \pm 0.05^{aB}$ | $0.97 \pm 0.19^{aA}$ |
| B-WS | $0.75 \pm 0.01^{aA}$ | $0.37 \pm 0.02^{bE}$ | $0.46 \pm 0.01^{bB}$ | $0.42 \pm 0.01^{bCD}$ | $0.44 \pm 0.01^{bBC}$ | $0.40 \pm 0.02^{bD}$ |
| B-CU | $0.55 \pm 0.04^{bA}$ | $0.13 \pm 0.02^{cC}$ | $0.30 \pm 0.01^{dB}$ | $0.33 \pm 0.04^{cB}$ | $0.34 \pm 0.00^{cB}$ | $0.57 \pm 0.22^{bA}$ |
| **Thiol group contents (nmol/mg proteins)** | | | | | | |
| | **Storage day** | | | | | |
| Formulation | **0** | **18** | **36** | **54** | **72** | **90** |
| B-CO | $2.33 \pm 0.07^{dA}$ | $0.42 \pm 0.01^{aB}$ | $0.32 \pm 0.02^{aC}$ | $0.42 \pm 0.01^{aB}$ | $0.32 \pm 0.02^{abC}$ | $0.32 \pm 0.02^{abC}$ |
| B-BA | $7.13 \pm 0.73^{aA}$ | $0.37 \pm 0.02^{bB}$ | $0.28 \pm 0.03^{abB}$ | $0.40 \pm 0.03^{abB}$ | $0.29 \pm 0.02^{bcB}$ | $0.29 \pm 0.02^{bB}$ |
| B-WS | $4.88 \pm 0.29^{bA}$ | $0.37 \pm 0.03^{bB}$ | $0.25 \pm 0.02^{bB}$ | $0.36 \pm 0.02^{bB}$ | $0.34 \pm 0.02^{aB}$ | $0.34 \pm 0.02^{aB}$ |
| B-CU | $3.17 \pm 0.34^{cA}$ | $0.30 \pm 0.02^{cB}$ | $0.28 \pm 0.01^{abB}$ | $0.38 \pm 0.02^{bB}$ | $0.27 \pm 0.02^{cB}$ | $0.29 \pm 0.01^{bB}$ |
| ***F* statistic values of two-way ANOVA** | | | | | | |
| Parameter | Storage duration | | Treatment | | Treatment × Storage duration | |
| Peroxide value | 2400.78 * | | 911.86 * | | 107.73 * | |
| TBARS | 22.67 * | | 123.47 * | | 11.37 * | |
| Thiol groups | 1052.64 * | | 70.31 * | | 72.71 * | |

B—Fava bean; CO—control; BA—basil essential oil; WS—winter savory essential oil; CU—cumin essential oil. Different lowercase letters indicate significant differences among treatments within the same storage day, while uppercase letters indicate significant differences among storage times within the same treatment ($p \leq 0.05$). * indicates significant effect according to two-way ANOVA ($p \leq 0.05$).

Overall, the low TBARS values observed in this study confirm that hummus formulations can achieve high oxidative stability, with values remaining within the range associated with fresh and acceptable products in other food matrices [33,99,107–109]. However, the obtained results indicate that further optimization in terms of the selection and concentrations of EOs is necessary.

3.4.2. Protein Oxidation

Protein oxidation in food systems involves multiple reactive pathways leading to modifications of amino acid side chains, particularly cysteine thiols, resulting in disulfide bond formation and loss of protein functionality [31]. In the present study, thiol group content significantly decreased ($p \leq 0.05$) in all formulations during storage, indicating pronounced protein oxidation. Sulfhydryl groups are highly susceptible to oxidative reactions, and their depletion is commonly associated with disulfide bond formation, protein aggregation, and other oxidative post-translational modifications [30,114].

A sharp and significant ($p \leq 0.05$) decline in thiol group content was observed within the first 18 days of storage. The control formulation (B-CO) decreased from 2.33 to 0.42 nmol/mg protein, while B-BA, B-WS, and B-CU decreased from 7.13 to 0.37, 4.88 to 0.37, and 3.17 to 0.30 nmol/mg protein, respectively. After this initial significant decrease ($p \leq 0.05$), thiol levels remained relatively stable at low values throughout the remaining storage period, suggesting that most reactive sulfhydryl groups were rapidly oxidized during early storage.

These observations align with previous studies in both meat and plant protein systems. Šojić et al. (2020) reported that thiol contents in ground pork patties decreased significantly during storage due to direct reactive oxygen species attacks on cysteine residues, forming sulfenic, sulfinic/sulfonic acids and thiosulfinates, while phenolic-rich extracts could mitigate protein oxidation [115]. Similarly, Mujović et al. (2024) demonstrated that lipid oxidation and metal ions initiate protein oxidation in minced meat, producing reactive species that reduce thiol content, with natural bioactive compounds (e.g., terpene structures like limonene and carvone) preserving thiol groups in certain treatments [113]. In fish products, Šojić et al. (2026) confirmed that protein thiol loss occurs in parallel with lipid oxidation, and that basil EO and leaf extracts effectively slowed thiol depletion, highlighting the interconnectedness of lipid and protein oxidation [58].

The high protein content of fava bean (*Vicia faba* L.), predominantly composed of globulins with smaller contributions from albumin and glutelin fractions, may contribute to this behavior, as the structural characteristics of these fractions (e.g., exposure of reactive amino acid residues) influence their susceptibility to oxidative modifications [116]. The structural characteristics of these fractions, particularly the availability of reactive cysteine residues, influence their susceptibility to thiol oxidation. Similar trends have been reported in plant protein systems where processing conditions such as heat, comminution, and mechanical stress accelerate protein oxidation and aggregation [117]. In addition, thiol-based oxidative post-translational modifications represent a key mechanism affecting the structure and functionality of plant proteins [114]. This suggests that protein oxidation may have contributed to structural modifications within the spread matrix, potentially affecting textural properties, water-binding capacity, and emulsion stability during storage. Protein oxidation may also contribute to minor physicochemical changes observed in the system during storage, particularly color alterations and slight pH variations. The formation of protein oxidation products and interactions with lipid-derived compounds can promote pigment modification and matrix restructuring, which may indirectly influence product appearance and stability [30,31,118].

Although EOs exhibited antioxidant activity in terms of lipid oxidation, their protective effect against protein oxidation was limited, indicating that their antioxidant action was primarily associated with the lipid phase rather than protein protection. This is consistent with the observations of Šojić et al. (2020, 2026) and Mujović et al. (2024), who reported that phenolic-rich extracts or EOs may selectively protect lipids or proteins depending on their chemical properties and solubility, emphasizing the importance of matrix interactions in determining antioxidant efficacy [58,113,115].

### 3.5. Antioxidant Properties and Bioactive Profile

Antioxidant activity determined by the DPPH assay did not differ significantly among formulations ($p \geq 0.05$), with values ranging from 0.32 to 0.37 mg TEAC/g (Table 5). The highest activity was observed in the control sample, likely due to the intrinsic composition of fava bean, rich in polyphenols and protein-derived peptides with radical scavenging properties [110,112]. The addition of EOs did not markedly enhance DPPH activity, likely due to their lipophilic nature, which may limit their interaction with the polar DPPH radical, as well as matrix effects in the fava bean emulsion [38,119,120].

These results indicate that the overall radical scavenging capacity of the spread was not substantially altered by EOs at the concentrations used, while differences observed in oxidative stability (Rancimat) may reflect preferential protection of the lipid phase rather than a uniform increase in antioxidant capacity, consistent with previous reports on plant extracts and EOs in lipid systems [24,104].

Total polyphenol content (TPC) differed significantly among formulations ($p \leq 0.05$), ranging from 0.18 to 0.22 mg GAE/g (Table 5). The highest TPC was observed in B-WS (0.22 mg GAE/g), followed by B-BA (0.19 mg GAE/g), whereas B-CO and B-CU showed the lowest values (0.18 mg GAE/g). The elevated TPC in B-WS is consistent with the richness of winter savory in phenolic compounds, including rosmarinic acid and related hydroxycinnamic acid derivatives [40,121].

Cumin EO did not increase TPC relative to the control, suggesting that its antioxidant effect is mainly mediated by non-phenolic volatile constituents [42,122,123]. Matrix interactions and the hydrophobic nature of EOs may also limit the extractability of phenolic compounds during analysis.

Total flavonoid content (TFC) varied significantly among formulations ($p \leq 0.05$), ranging from 0.02 to 0.34 mg QE/g (Table 5). The highest TFC was observed in B-CU (0.34 mg QE/g), followed by B-BA (0.12 mg QE/g) and B-WS (0.05 mg QE/g), while the control (B-CO) had the lowest value (0.02 mg QE/g). The elevated TFC in B-CU is attributed to flavonoid compounds such as luteolin and apigenin derivatives [105,123]. The relationship between TFC, TPC, and the observed oxidative stability suggests that flavonoid constituents may contribute to selective lipid protection in the spreads, although their activity in the aqueous phase may be limited.

Total phenolic acid content (TPAC) differed significantly among formulations ($p \leq 0.05$), ranging from 0.04 mg CAE/g in B-CO to 0.09 mg CAE/g in B-CU (Table 5). B-BA and B-WS showed intermediate values (0.07 and 0.04 mg CAE/g, respectively). Cumin EO contributed the highest levels of phenolic acids, while basil and winter savory provided moderate contributions consistent with their reported phenolic acid profiles [41,121]. The control reflected mainly basal phenolic acids naturally present in fava bean [110–112].

Combined with the high TFC in B-CU, these results indicate the presence of specific bioactive constituents that likely contribute to antioxidant functionality, particularly in the lipid phase of the emulsion.

### 3.6. Oxidative Stability (Rancimat Analysis)

The oxidative stability of the fava bean-based spreads, expressed as induction time determined by the Rancimat method, differed significantly among treatments ($p \leq 0.05$) (Table 8). The control (B-CO) exhibited the shortest induction time (7.73 h), whereas essential oil-enriched samples showed prolonged stability: B-BA 8.14 h, B-WS 9.11 h, and B-CU 9.10 h. The superior performance of B-WS and B-CU confirms that winter savory and cumin EOs effectively enhance the resistance of the lipid fraction to accelerated oxidative stress.

This improvement is likely attributable to the hydrophobic antioxidant components of the essential oils, which preferentially interact with the lipid phase. In winter savory, principal bioactive constituents such as thymol and carvacrol contribute to radical scavenging and lipid protection, while in cumin, compounds including cuminaldehyde and γ-terpinene provide similar effects [34–37,105,117,121]. These findings suggest that the observed differences in induction time are primarily associated with enhanced protection of the lipid fraction, rather than a uniform increase in the overall antioxidant capacity of the system [24,38].

**Table 8.** Oxidative stability, antioxidant activity, total polyphenol, flavonoid and phenolic acid content of spread samples during 90-day storage period.

| **Oxidative stability determination** | | | |
|---|---|---|---|
| Sample | Induction time (h) | F | *p* |
| B-CO | 7.73 ± 0.40 $^{c}$ | 73.02 | ≤0.05 |
| B-BA | 8.14 ± 0.01 $^{b}$ | | |
| B-WS | 9.11 ± 0.02 $^{a}$ | | |
| B-CU | 9.10 ± 0.02 $^{a}$ | | |
| **Antioxidant activity determination** | | | |
| Sample | mg TEAC/g | F | *p* |
| B-CO | 0.37 ± 0.003 $^{a}$ | 3.29 | ns |
| B-BA | 0.35 ± 0.006 $^{ab}$ | | |
| B-WS | 0.32 ± 0.015 $^{b}$ | | |
| B-CU | 0.34 ± 0.050 $^{ab}$ | | |
| **Total polyphenol content (TPC)** | | | |
| Sample | mg GAE/g | F | *p* |
| B-CO | 0.18 ± 0.008 $^{c}$ | 24.42 | ≤0.05 |
| B-BA | 0.19 ± 0.008 $^{b}$ | | |
| B-WS | 0.22 ± 0.008 $^{a}$ | | |
| B-CU | 0.18 ± 0.008 $^{c}$ | | |
| **Total flavonoid content (TFC)** | | | |
| Sample | mg QE/g | F | *p* |
| B-CO | 0.03 ± 0.003 $^{d}$ | 810.83 | ≤0.05 |
| B-BA | 0.11 ± 0.024 $^{b}$ | | |
| B-WS | 0.06 ± 0.003 $^{c}$ | | |
| B-CU | 0.34 ± 0.007 $^{a}$ | | |
| **Total phenolic acid content (TPAC)** | | | |
| Sample | mg CAE/g | F | *p* |
| B-CO | 0.04 ± 0.008 $^{c}$ | 157.04 | ≤0.05 |
| B-BA | 0.07 ± 0.001 $^{b}$ | | |
| B-WS | 0.04 ± 0.001 $^{c}$ | | |
| B-CU | 0.09 ± 0.004 $^{a}$ | | |

B—Fava bean; CO—control; BA—basil EO; WS—winter savory EO; CU—cumin EO; Trolox equivalent antioxidant capacity per g of dry matter (mg TEAC/g); GAE—gallic acid equivalent; QE—quercetin equivalent; CAE—caffeic acid equivalent; Different letters in a column denote mean values that statistically differ one from another; ns = not significant; h—hours.

The high content of polyphenols, flavonoids, and phenolic acids in essential oil-enriched formulations, particularly B-WS and B-CU, correlated with enhanced oxidative stability of the lipid fraction and low TBARS values. This relationship confirms the effectiveness of these bioactive compounds in limiting lipid oxidation within the spread matrix.

### 3.7. Microbiological Analysis

The microbiological quality of the developed fava bean-based spreads is presented in Table 9. Coliform bacteria were not detected in any sample, while *Listeria monocytogenes* was absent, confirming adequate raw material quality and appropriate hygienic processing conditions, as well as the microbiological safety of the final products, in accordance with Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs [124].

**Table 9.** Influence of selected EOs on microbiological profile (log cfu/g) in fava bean-based spread.

| | Log CFU/g | | | |
|---|---|---|---|---|
| **Sample** | **Koliforms Bacteria** | **Total Count of Bacteria** | **Fungi and Yeasts** | ***Listeria monocytogenes*** |
| B-CO | 0 | 1.78 | 2.18 | not detected |
| B-BA | 0 | 2.17 | 2.25 | not detected |
| B-WS | 0 | 2.31 | 2.06 | not detected |
| B-CU | 0 | 2.17 | 2.24 | not detected |

B—Fava bean; CO—control; BA—basil essential oil; WS—winter savory essential oil; CU—cumin essential oil.

Relatively low total viable counts and fungal/yeast counts observed across all formulations suggest good initial microbiological quality. Minor differences among treatments may be associated with the incorporation of plant-derived EOs, which are known to exhibit antimicrobial activity depending on their chemical composition [95]. In particular, winter savory EO may exert stronger antimicrobial effects due to the presence of carvacrol and thymol, which are well-documented for their ability to disrupt microbial cell membranes, increase permeability, and cause leakage of intracellular constituents [34,35,95]. Cumin EO may contribute to microbial inhibition primarily through cuminaldehyde and related monoterpenes [95,125], while basil EO may exert comparatively weaker but still relevant antimicrobial effects due to the presence of compounds such as eugenol and linalool [95,126].

Overall, the results confirm that incorporation of selected EOs can contribute to improving the microbiological quality of plant-based spreads at the point of production. However, further studies are required to evaluate their effectiveness during refrigerated storage and to assess long-term antimicrobial stability under real consumption conditions.

### 3.8. Sensory Properties of Final Formulations

Sensory attributes of the developed fava bean spreads, including color, taste, aroma, texture, and overall liking, were evaluated during 90 days of storage (Figure 3).

Color scores remained high and unchanged across samples (7.69–8.31), with no significant effects of treatment or storage time ($p \geq 0.05$) (Table 10). Although instrumental analysis showed increasing ΔE values over time (most pronounced in the control and minimal in winter savory), these changes were not meaningfully perceived by panelists, indicating that visual differences remained close to or below the sensory detection threshold. This confirms effective color stability of the emulsion system during storage, consistent with previous findings in hummus-type products [16].

Taste and aroma were strongly driven by treatment ($p \leq 0.05$), with a smaller but significant effect of storage time ($p \leq 0.05$). The control sample consistently achieved the highest scores, while EO incorporation reduced acceptability, most notably in the winter savory formulation. This effect is attributed to the intrinsic intensity and persistence of EO volatiles, which dominate flavor perception in complex matrices [127]. EOs are characterized by a wide range of aroma-active compounds, including monoterpenes and phenolic

volatiles, which define their sensory profiles and consumer perception [44,127]. The lower acceptability of winter savory is consistent with previous studies in food systems where strong essential oil-derived flavors reduce palatability despite functional benefits [34,103]. A slight decline in scores during storage likely reflects perceptual adaptation rather than the development of oxidation-related off-flavors.

**Table 10.** F statistic values of two-way ANOVA of Sensory Evaluation.

| Parameter | Storage Duration | Treatment | Treatment × Storage Duration |
|---|---|---|---|
| Color | 1.97 $^{ns}$ | 0.81 $^{ns}$ | 0.59 $^{ns}$ |
| Taste | 11.74 * | 123.75 * | 0.79 $^{ns}$ |
| Aroma | 6.88 * | 254.33 * | 0.47 $^{ns}$ |
| Texture | 9.02 * | 2.14 $^{ns}$ | 1.07 $^{ns}$ |
| Overall liking | 3.48 * | 172.59 * | 0.93 $^{ns}$ |

* indicates significant effect according to two-way ANOVA ($p \leq 0.05$). $^{ns}$ indicates not significant effect according to two-way ANOVA ($p \geq 0.05$).




**Figure 3.** *Cont.*

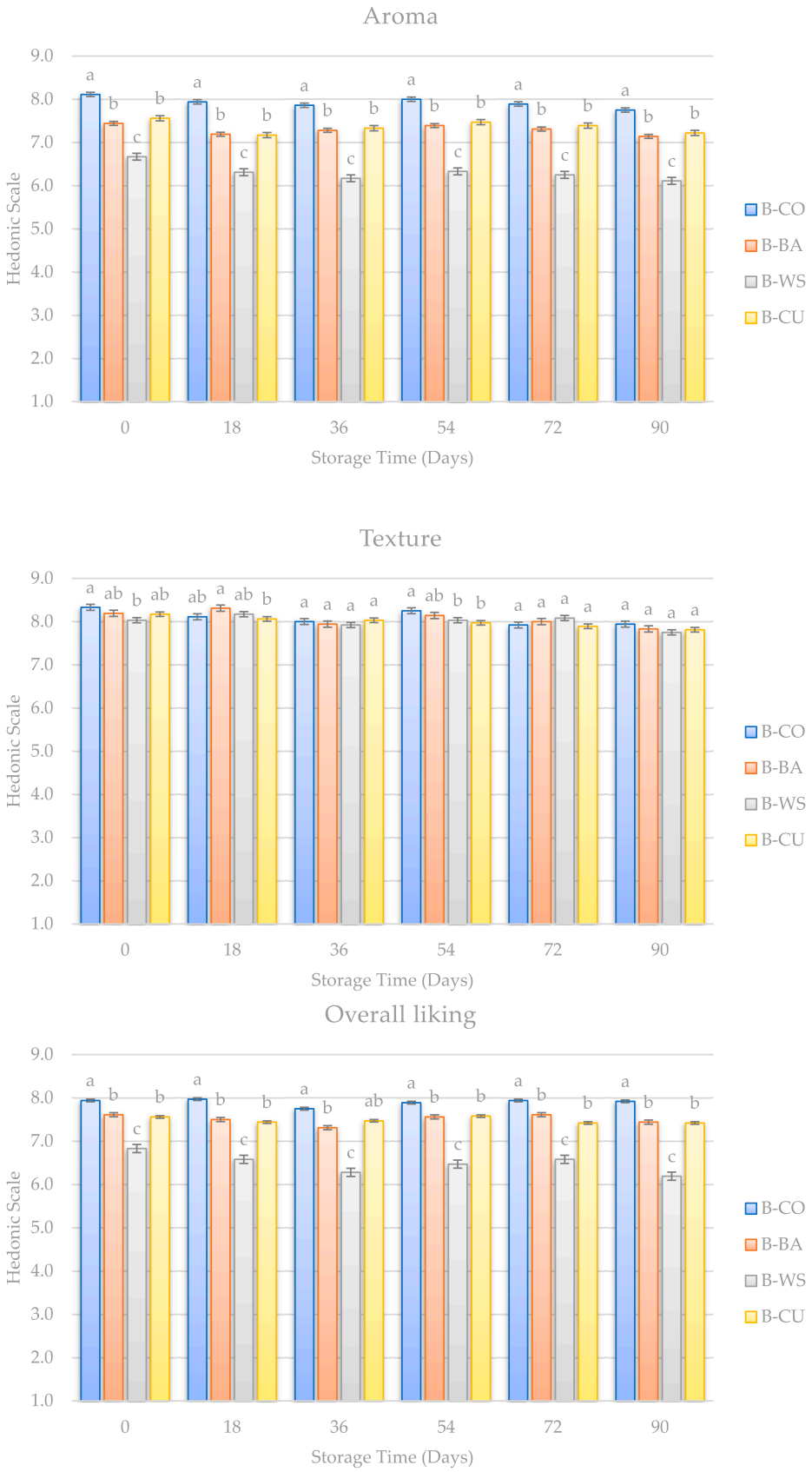



**Figure 3.** Sensory Evaluation of Final Samples (Color, Taste, Aroma, Texture and Overall Liking). B—Fava bean; CO—control; BA—basil EO; WS—winter savory EO; CU—cumin EO. Different letters above the bars indicate significant differences ($p \leq 0.05$).

Texture remained highly acceptable across all samples (7.75–8.33), with no effect of treatment ($p \geq 0.05$), confirming that EOs did not disrupt the structural integrity of the spread. A minor but significant effect of storage time ($p \leq 0.05$) suggests limited structural evolution without practical relevance to sensory quality.

Overall liking was primarily determined by treatment ($p \leq 0.05$), following the trend control $\geq$ cumin $\approx$ basil $\geq$ winter savory, while storage effects were secondary ($p \leq 0.05$). These results clearly indicate that flavor is the dominant driver of consumer acceptance, whereas color and texture play a supporting role.

In conclusion, sensory quality was governed predominantly by EO type rather than storage-related changes. Among enriched formulations, cumin achieved the most favorable balance between functionality and acceptability, whereas winter savory, despite its technological advantages, imposed a sensory penalty. These findings align with previous reports highlighting that the application of EOs in foods requires careful optimization due to their strong and composition-dependent sensory impact [34,44,127].

## 4. Conclusions

This study demonstrated that the incorporation of plant-derived essential oils significantly influenced the oxidative stability and sensory properties of fava bean-based spreads during refrigerated storage. Winter savory and cumin essential oils showed the most effective inhibition of lipid oxidation, while basil exhibited comparatively lower antioxidant performance. Among the tested formulations, cumin provided the best overall balance between oxidative stability and sensory acceptability.

These findings confirm the suitability of fava bean as a functional base for plant-based spreads enriched with natural antioxidants and highlight the importance of selecting essential oils that ensure both technological functionality and sensory acceptance.

The study is limited by its laboratory-scale design and the use of a single essential oil concentration. Future research should focus on optimizing essential oil levels, exploring synergistic antioxidant combinations, and assessing scale-up feasibility and performance in other food systems, along with safety studies to support industrial application.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/pr14111724/s1, Figure S1: Visual appearance of fava bean-based spreads during refrigerated storage (4 °C). Representative images of control (B-CO) and essential oil-enriched samples (B-BA: basil, B-WS: winter savory, B-CU: cumin) obtained at 0, 18, 36, 54, 72 and 90 days of storage.

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