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Safety of Commercial Fruit Yogurts Beyond the Stated Expiration Date: Physicochemical, Textural, Microbiological, and Sensory Evaluation

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Abstract

Consumers believe that expired products are unsafe, and, in most cases, misinterpreting the information on food labels often leads to large amounts of food waste. Yogurt is among the most widely eaten dairy products that can still be consumed after its expiration date, even though most consumers throw it away the very day it expires. The aim of this study was to determine whether commercial yogurts currently available on the market remain safe for consumption after their expiration date, with a view to reducing the amount of food waste generated in households. Therefore, the quality, stability, and edible safety of 10 commercial yogurts (two plain with 2% and 4% fat and the others with fruit, such as apricots, strawberries, bananas, blueberries, berries and strawberries, blackberries and raspberries, and cherries) stored at 4 °C before and at the expiration date were investigated. Physicochemical, textural, microbiological, and sensory analyses were performed to evaluate changes in functionality, safety, and acceptability of these yogurts. The results showed that, prior to their expiration date, certain yogurt samples (with apricots, strawberries, and blueberries, as well as plain yogurt with 4% fat) tested positive for total coliform bacteria, with values ranging from 20 to 50 CFU/g, suggesting substandard hygiene practices and insufficient sanitary conditions during and following the production process. No *Escherichia coli*, *Listeria*, *Salmonella*, *Enterobacter* spp., or *Enterococcus* spp. were detected in any of the yogurt samples that were within their expiration date. Blueberry, berry, and strawberry yogurts change their physical and chemical properties less than other types of yogurts analyzed after expiration. Yogurts containing berries and strawberries, blackberries, and raspberries remain safe at the expiration date, as they do not show the presence of harmful microorganisms such as *coliform* bacteria, *Escherichia coli*, *Enterobacter* spp., *Enterococcus* spp., *Listeria*, or *Salmonella*. Yogurt with berries and strawberries appears to be the most suitable from a microbiological point of view at expiration, as it has a low total mesophilic bacteria count and lactic acid bacteria exceeding 1×10^6 CFU/g. At the time of expiration, this fruit yogurt type (with berries and strawberries) had a total solids content of 21.29%, 5.22% protein, 2.11% fat, 13.19% carbohydrates, 4.07 pH, 26.79% syneresis, 73.21% water retention capacity, 64.78% total phenolic content, and 10.55% DPPH (inhibition percentage). Nevertheless, at the time of expiration, from a sensory perspective (only appearance and consistency, odor, and color, without taste), the yogurt samples that were most appreciated contained blackberries and raspberries. The obtained results indicate that only certain types of fruit yogurts stored unopened at 4 °C may remain safe and edible after the expiration date, but further studies are needed to help the dairy industry and policymakers promote the reduction in food waste in households.

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Keywords: food safety; food waste; fruit yogurt; physicochemical analysis; sensory evaluation; shelf life; texture properties

1. Introduction

Food waste has become a major environmental concern, given that roughly one-third of all food produced globally is wasted annually [1,2]. In 2023, in the EU alone, approximately 58 million tons of food waste were generated, with an average of 130 kg per capita, and more than half of this was generated by households [3]. In the EU, approximately 20% of dairy products are wasted annually, with nearly 6.5 million tons of yogurt being discarded (up to 17% of total yogurt production) [4]. Overbuying, improper storage, and misunderstanding expiration dates are among the primary drivers of household food waste [5]. Food expiration date labels have a significant impact on consumer behavior and influence the generation of food waste [2,6]. Some consumers will not consume yogurt if the expiration date (products labeled "best before" date) is close because they associate consumption with health problems and consider the product to be of poor quality and unappetizing [7,8]. Therefore, consumers will throw away expired yogurt instead of checking whether it is still edible [7]. According to Kechagias et al. [4], approximately 80% of yogurt waste in the EU results from products being discarded after their expiration date, despite remaining potentially safe for consumption. Some researchers believe that if foods (juices, grain-based products, and dairy products) are stored properly, they remain safe and can be consumed even after their expiration date, which may indicate reduced product quality rather than imminent health risks [9]. According to Nasralla et al. [10], accurately determining the shelf life of dairy products remains challenging. The determination of the period during which the product is stable, i.e., safe for consumption and free from organoleptic and sensory defects, can only be estimated through tests on specific spoilage organisms and not calculated with precision, as processing, transport, and storage conditions also exert a significant influence [10,11]. The "best before" label indicates the period during which the product is stable and retains its characteristics under any storage conditions, but after this period, the product may still be suitable for consumption [11]. Yogurt spoilage occurs mainly due to the development of yeast and mold, and fruit added to yogurt favor spoilage by yeasts, as they represent additional sources of contamination and fermentable substrates [12]. According to Tirloni et al. [13], yogurt spoilage becomes evident when the yeast population reaches levels of 5 to 6 $\log_{10}$ CFU/g. Meanwhile, yogurt must contain at least 10^6–10^7 CFU/mL lactic acid bacteria at the time of consumption in order to have beneficial effects on health [14].

Globally, the production of fruit yogurt has increased significantly due to the high demand for healthier products rich in biologically active compounds [15]. Fruit such as apricots, bananas, berries, strawberries, blueberries, raspberries, blackberries, and cherries can enhance the nutritional and functional characteristics of yogurt. Apricots are abundant in carbohydrates, essential nutrients, and dietary fiber [16], and they also contain bioactive compounds such as polyphenols and carotenoids, with total polyphenol levels reaching up to 160.0 mg per 100 g of edible portion and β-carotene content up to 16 mg per 100 g of fresh weight [17]. Bananas provide a notable source of protein and amino acids, they are high in dietary fiber, and they contain carotenoids (including lutein, α-carotene, and β-carotene), as well as phenolic compounds such as gallic acid, catechin, epicatechin, tannins, and anthocyanins [18,19]. In banana pulp, phenolic compound levels range from 11.8 to 90.4 mg GAE per 100 g of fresh weight, while total carotenoid content varies between 7760 and 10,633 μg per 100 g of fresh weight [18]. Berries, including strawberries, blueber-

ries, raspberries, and blackberries, are rich in anthocyanins and exhibit red, blue, or purple pigmentation [20]. Strawberries are high in vitamin C (58.8 mg/100 g), and contain fructose, dietary fiber, and phytochemicals such as anthocyanins, which are responsible for their red color (total anthocyanin content ranges from 150 to 600 mg/kg fresh weight) [21,22]. Blueberries have a high dietary fiber content (3–3.5% of the fruit's weight), and they are rich in bioactive compounds (the total polyphenol content varies between 48 and 304 mg/100 g of fresh fruit weight) [23]. Raspberries contain flavonoids, anthocyanins, ascorbic acid, and phenolic compounds, and they have a total phenolic content of between 179.41 and 391.15 mg GAE/100 g of fresh weight [24]. Blackberries contain approximately 5.3 g of dietary fiber per 100 g and are particularly rich in ascorbic acid (21 mg per 100 g) and K vitamin (19.79 mg per 100 g), as well as phenolic compounds, ranging from 200 to over 600 mg GAE per 100 g of fresh weight [25,26]. Cherries contain carbohydrates (12–17%), dietary fiber (1.3–2.1%), vitamin C (7–10 mg/100 g fresh weight), as well as anthocyanins (54.5–171.4 mg/100 g fresh weight) and phenols (174.9–254.1 mg GAE/100 g fresh weight) [27].

The bioactive compounds present in fruit are incorporated into yogurt along with the fruit and interact with proteins and fats, influencing the properties (physicochemical, textural, and sensory) of yogurt, as well as its stability (shelf life). The acidity of yogurt will be influenced by the organic acids and sugars present in fruit, affecting the consistency and texture of the yogurt. Polyphenols interact with proteins and fats in yogurt, leading to weakening or strengthening of the yogurt matrix, influencing the shelf life and nutritional characteristics of yogurt. Fruit fibers influence the structure of yogurt and the growth of lactic bacteria, while pigments (carotenoids and anthocyanins) influence the color and stability of yogurts [28,29].

Assessing the quality and safety of commercial fruit yogurt immediately after the expiration date can provide useful information for consumer education and, implicitly, reduce food waste both at home and in supermarkets. Therefore, this study aims to examine the physicochemical and textural properties, organoleptic aspects, and microbial attributes of various commercial fruit yogurt products before and after the expiration date.

2. Materials and Methods

2.1. Samples

In this study, 10 commercial yogurt samples purchased from retail markets were analyzed. The yogurt samples were selected based on the varieties currently available on the market, which are also the most widely consumed. Fruit-added yogurt samples were selected based on the type of fruit added and the quantity of fruit used. The yogurt samples were divided into two main categories: yogurt samples with fruit (FY: apricot yogurt (FY1), strawberry yogurt (FY2), banana yogurt (FY3), blueberry yogurt (FY4), berry and strawberry yogurt (FY5), blackberry and strawberry yogurt (FY6), raspberry yogurt (FY7), and sour cherry yogurt (FY8)) and plain yogurt samples (PY: with a fat content of 2% and 4% (PY9 and PY10, respectively)).

To ensure the homogeneity of the samples, 8 units from the same production lot x 3 replications were taken, resulting in 24 samples before expiration and 24 samples after expiration, with a total of (48 × 10 types of yogurts) 480 yogurt samples. The net weight of the yogurt units ranged between 100 and 160 g.

The samples were kept in the refrigerator after purchase, and they were divided into two sets of 240 samples each. The first set of samples was analyzed after 24 h to obtain the results before the yogurt samples expired, and the second set was kept in the refrigerator for approximately 18 days until expiration (the expiration dates of the yogurts were different depending on the type of yogurt, as the yogurts were produced by

different companies) and analyzed immediately after expiration. All samples were stored at refrigerated temperatures between 2 and 4 °C in their original sealed containers. The characteristics of the yogurt samples (as indicated on the product labels) are presented in Table 1, while Figure 1 illustrates the yogurt samples. The physicochemical analyses, as well as other analyses, were conducted in the laboratories of the Faculty of Food Engineering specifically to assess the quality of the yogurts available on the market, the differences between them, and whether they can be consumed after the expiration date to help prevent waste generation in households.

Table 1. Labeled composition of the investigated yogurt samples, as provided by the manufacturers.

Sample	Type of Fruit	Fruit Preparation Content * (%)	Ingredients
FY1	Apricots	14	Pasteurized whole cow's milk, lactic ferments.
FY2	Strawberries	11.2	Pasteurized cow's milk, cream, sugar, milk proteins, lactic ferments
FY3	Bananas	4.3	Pasteurized skimmed milk, pasteurized concentrated skimmed milk, cream, and yogurt starter cultures.
FY4	Blueberries	20	Pasteurized skimmed cow's milk, pasteurized condensed skimmed cow's milk, milk proteins, and lactic cultures.
FY5	Berries and strawberries	5.3	Pasteurized cow's milk, cream, milk proteins, and lactic ferments.
FY6	Blackberries and raspberries	23	Milk and yogurt-specific starter cultures.
FY7	Raspberries	2	Pasteurized partially skimmed milk, sugar, milk proteins, and selected yogurt starter cultures.
FY8	Sour cherries	18	Pasteurized cow's milk and sugar.
PY9	-	0	Pasteurized skimmed cow's milk and selected yogurt starter cultures.
PY10	-	0	Pasteurized skimmed cow's milk, cream, and selected yogurt starter cultures.

PY, plain yogurt; FY, fruit yogurt. * Indicates fruit preparation, including fruit, fruit concentrate, sugars, thickeners, colorants, stabilizers, and an acidity regulator.



Figure 1. Plain and fruit yogurt samples.

2.2. Physicochemical Analysis

2.2.1. Total Solids, Fat and Protein Contents, Titratable Acidity, pH, and Color

The total solids content of the yogurt was determined by oven-drying the samples at 102 ± 2 °C to constant weight (ISO 13580) [30], fat content was measured using the Gerber acid-butyrometric method (ISO 11870) [31], and total protein content was quantified

via the Kjeldahl method, with protein calculated from nitrogen using a conversion factor of 6.25 [32]. All results were reported as mass percentages (% w/w). Prior to analysis, yogurt samples were homogenized and conditioned to 20 ± 2 °C [33]. The ash content of yogurt samples was determined through calcination at 550 °C following [34], while total carbohydrate content was calculated by difference, as the residual fraction remaining after subtracting moisture, protein, fat, and ash [35]. Titratable acidity was determined according to ISO 11869 [36] using an automatic titrator (TITROLINE® easy, SI Analytics GmbH, Mainz, Germany) with 0.1 M NaOH to a final pH of 8.3, while the pH was evaluated with a Mettler Toledo pH meter (Mettler Toledo GmbH, Greifensee, Switzerland). Color measurements of homogenized yogurt were performed with a CR-400 Chroma Meter (Konica Minolta, Tokyo, Japan) with illuminant C and a 2° standard observer. The color parameters, L*, a*, and b*, corresponding to lightness, red–green, and yellow–blue components, respectively, were measured in accordance with the CIE Lab* color system (Commission Internationale de l'Eclairage). The hue angle (h°), whiteness index (WI), chroma (C*), yellowness index (YI), and total color difference (ΔE*) were computed using the following equations [37]:

$$h^\circ = \tan^{-1}\left(\frac{b^*}{a^*}\right), \quad (1)$$

$$WI = 100 - \sqrt{\left(100 - L^*\right)^2 + a^{*2} + b^{*2}}, \quad (2)$$

$$C^* = \sqrt{a^{*2} + b^{*2}}, \quad (3)$$

$$YI = 142.86 \times \frac{b^*}{L^*}, \quad (4)$$

$$\Delta E^* = \left[\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2\right]^{1/2}, \quad (5)$$

2.2.2. Syneresis and Water-Holding Capacity of Yogurt Samples

Syneresis of homogenized yogurt samples was assessed following the method of Farnsworth et al. [38] with minor modifications, by transferring 20 g of yogurt into centrifuge tubes and centrifuging at 640× g for 20 min at 4 °C using an OHAUS Frontier™ 5718R centrifuge (OHAUS Corporation, Greifensee, Switzerland). Following separation, the supernatant was collected and weighed, and syneresis was quantified as the proportion of the supernatant weight relative to the total weight of the yogurt sample [38].

$$\text{Syneresis } (\%) = 100 \times \frac{\text{Weight of supernatant (g)}}{\text{Weight of yogurt sample (g)}}, \quad (6)$$

Water-holding capacity (WHC) was calculated as the percentage of the centrifuged precipitate mass (m_1) relative to the initial yogurt sample mass (m_2), [39].

$$WHC\ (\%) = 100 \times \frac{m_1}{m_2}, \quad (7)$$

2.2.3. Antioxidant Properties

Extract Preparation: For extraction, 20 g of yogurt samples were thoroughly homogenized with 20 mL of 60% ethyl alcohol at ambient temperature and stirred for 30 min, after which the mixture was centrifuged at 4000 rpm for 20 min (OHAUS Frontier™ 5718R, Greifensee, Switzerland) and the supernatant was collected [33,40]. To enhance clarity, the supernatant underwent a second centrifugation process under the same conditions, and

then it was filtered through a 0.45 µm membrane before further analysis. The resulting filtrate was stored at 2–6 °C, and it was used for all subsequent analyses [41].

DPPH Radical Scavenging Assay: Antioxidant activity was determined using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay, in which 0.2 mL of yogurt extract was added to 5.8 mL of 0.1 mM ethanolic DPPH, vortexed for 1 min, and incubated in the dark at room temperature for 60 min [42]. Absorbance at 517 nm was recorded (Ocean Optics HR4000, Dunedin, FL, USA), and radical scavenging activity was calculated as:

$$\text{DPPH Scavenging } (\%) = 100 \times \left(1 - \frac{A_1}{A_0}\right), \quad (8)$$

where A_1 and A_0 are the absorbances of the sample and the blank, respectively.

Total phenolic content (TPC) was determined using the Folin–Ciocalteu method, in which 1.2 mL of yogurt extract was mixed with 6 mL of 0.2 N Folin–Ciocalteu reagent, which was followed by the addition of 4.8 mL of 0.7 N Na_2CO_3 after 5 min; the mixture was then incubated at room temperature for 2 h, and absorbance was measured at 765 nm. TPC was expressed as micrograms of gallic acid equivalents per gram of yogurt (µg GAE/g) [33,43].

2.3. Texture Evaluation

Homogenized yogurt samples were analyzed for textural properties using a Mark-10 ESM 301 texture analyzer (Mark-10 Corporation, Copiague, NY, USA) with a 10 N load cell and 50 mm disk probe, applying texture profile analysis (TPA) at 150 mm/min and a 12 mm compression distance on yogurt samples (30 mm height, 70 mm diameter) [33]. TPA curves were recorded using the MESUREgauge (Mark 10 Corporation, Copiague, NY, USA) software at a data acquisition rate of 15 points per second (pps). Texture parameters—including hardness, adhesiveness, cohesiveness, springiness, gumminess, chewiness, and viscosity—were derived from the force–distance curves [44].

2.4. Sensory Evaluation

Sensory evaluation was conducted by 17 trained student panelists (male and female) aged 22–28 years, in accordance with [45–47]. All participants signed a consent form prior to the analysis. Approximately 20 g of each yogurt sample was served in 40 mL single-use plastic cups coded with random three-digit numbers. The samples were stored in their original containers at 2–4 °C and removed from the refrigerator before the evaluation to equilibrate to the serving temperature (12 ± 2 °C). The samples were presented simultaneously under controlled conditions. Panelists independently assessed appearance and consistency, odor, taste, and color using a 5-point hedonic scale (1 = extremely dislike; 5 = extremely like). Expired yogurt samples were not evaluated in terms of taste. Water (25 ± 5 °C) and cracker biscuits were provided for palate cleansing between samples to minimize sensory carryover effects [48,49].

2.5. Microbiological Analysis

For the analysis, 10 g of yogurt samples were homogenized with 90 mL of sterile diluent (10^{-1} g/mL) using a stomacher (BagMixer, Interscience, Arpents, Saint Nom la Bretèche, France), followed by serial decimal dilutions. The total number of mesophilic bacteria (TNMB) was determined according to [50] by plating 1 mL of the appropriate dilution on the Compact Dry Total Count medium (Carl Roth, Karlsruhe, Germany), incubating at 35 ± 2 °C for 24 h, while lactic acid bacteria (LAB) were enumerated following [51] using Petrifilm LAB Count Plates incubated at 35 °C for 48–72 h, with only plates containing 30–300 CFU having been considered for enumeration. Total coliforms and *Escherichia coli*

counts were assessed according to [52] using Compact Dry Coliform and Compact Dry *E. coli* Count Plates (Carl Roth, Karlsruhe, Germany), incubated at 35 ± 2 °C for 24 h. *Enterobacter* spp. were determined following [53] on Petrifilm Count Plates incubated at 37 ± 1 °C for 24 ± 2 h (clear-side-up, stacks ≤ 20 plates), while *Enterococcus* spp. were enumerated according to [54] using Compact Dry ETC Count Plates (Carl Roth, Karlsruhe, Germany), incubated at 37 ± 1 °C for 24 ± 2 h. *Listeria* spp. were determined in accordance with [55]: 0.1 mL of the initial suspension and 0.1 mL of subsequent decimal dilutions were dispensed, each being inoculated onto the surface of a small (90 mm) Listeria agar plate; the Listeria agar plates were incubated at 37 °C for 24 ± 2 h, and the blue-green colonies, with or without an opaque halo, were counted. *Salmonella* species were determined according to the [56] standard, using the Brilliant Green Agar (BGA) medium (Merck, Darmstadt, Germany). The culture media used to identify microorganisms in yogurt samples have been validated and have been shown to be at least equivalent to the reference methods. The colonies were counted using a ColonyStar system (Funke Gerber, Berlin, Germany). The results were expressed as mean log CFU/g ± standard deviation (SD).

2.6. Statistical Analysis

All experiments were conducted in triplicate, with results expressed as mean ± standard error, and they were statistically analyzed using Minitab version 17 (State College, PA, USA) and JASP 0.96.0 (University of Amsterdam, Amsterdam, The Netherlands). The differences among groups were assessed using one-way analysis of variance (ANOVA) followed by Tukey's post hoc test for pairwise comparisons ($p < 0.05$), while principal component analysis (PCA) was employed to explore the relationships among the measured variables, and Pearson's correlation was used to evaluate the strength and direction of linear relationships between them.

3. Results and Discussion

3.1. Physicochemical Properties of Commercial Yogurts

The total solids content (%) of commercial yogurts before and after the expiration date (ED) is illustrated in Figure 2. This content ranged from 10.81 ± 0.11 (PY9—plain yogurt without fruit, 2% fat) to 23.97 ± 0.13% (FY5—yogurt with berries and strawberries) (before the ED) and between 9.91 ± 0.35 (PY9) and 22.57 ± 0.50% (FY4—yogurt with blueberries) (after the ED). The total solids content decreased during storage, with the largest decrease observed in samples FY1 (12.67%), FY5 (11.18%), and FY8 (10.36%), and the smallest decrease recorded in strawberry yogurt, FY2 (0.87%).

Yogurts with berries and strawberries (FY5), blueberries (FY4), and blackberries and raspberries (FY6) had the highest total solids content of all yogurt samples before expiration. After expiration, the samples of yogurt with blueberries (FY4), blackberries and raspberries (FY6), and strawberries (FY2) had the highest total solids content, probably due to the high concentration of added fruit preparations [57], while natural yogurts without fruit had a much lower total solids content than yogurts with fruit.

The total solids (TS) content of the banana yogurt in this study (below 20%) was lower than the over 25% reported by Roy et al. [58], whereas Cinbas and Yazici [59] reported TS content for yogurt with 25% blueberry ranging from 14.97 to 20.42%, lower than the values obtained in the present study, highlighting the role of added sugar in increasing yogurt's total solids content. Karaca et al. [60] obtained between 13.60% and 13.83% dry matter from yogurt supplemented with 1% and 2% apricot fiber, while Jaster et al. [15] reported a total solids content between 18.39% and 20.07% from commercial yogurt with strawberry pulp. Şengül et al. [61] obtained a total solids content of 21.25%, 20.55%, and 19.58% for yogurt samples with 8%, 12%, and 16% sour cherry pulp and 8% added sugar. Adding

fruit pulp (rich in fiber), fiber, and sugar to yogurt can help increase the total solids content in yogurt samples. Commercial yogurts may also contain additives and ingredients such as carboxymethylcellulose, modified starch, whole milk powder, and whey, which typically increase the total solids content [15]. Yogurts with a high total solids content may be more appealing to consumers due to their improved sensory properties [62].

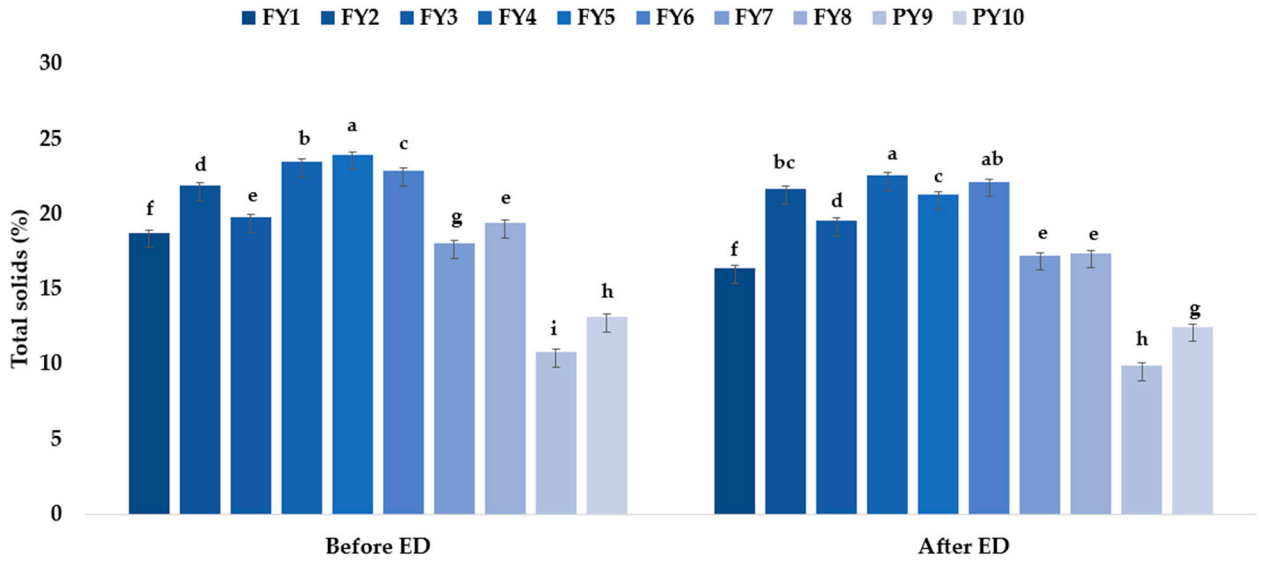

Figure 2. Total solids (%) of commercial yogurts before and after the expiration date (ED). Means labeled with different lowercase letters (a–i) denote significant differences ($p < 0.05$) among the samples.

Prior to the expiration date, the protein content ranged from 3.38 ± 0.02% (FY3) to 6.60 ± 0.03% (FY4), while after the expiration date, it varied between 2.82 ± 0.27% (FY1) and 6.02 ± 0.04% (FY4) (Figure 3). A decline in protein content was observed in the yogurt samples during storage, with the most pronounced reductions occurring in FY1 (38.27%), FY8 (16.86%), FY2 (13.77%), and FY5 (10.92%), while the remaining samples exhibited decreases of less than 10%. Samples FY4 and FY5 (with blueberries, berries, and strawberries) had the highest protein content both before and after the expiration of the yogurt samples. Before the samples expired, it was observed that samples FY6 and FY8 (blackberries and raspberries and sour cherries) had similar protein content (being statistically grouped in the same group), as did samples FY7 and PY9 (raspberries and natural yogurt 2% fat). Following the expiration date, no significant differences were observed in protein content among samples FY6, FY7, and FY9 or among samples FY3, FY8, and FY10.

The banana yogurt in this study exhibited a protein content of 3.38% with a fruit content of 4.3%, whereas Roy et al. [58] reported protein levels ranging from 3.68 to 3.76% in yogurt supplemented with 5–15% banana pulp. Blueberry yogurt with a 20% fruit content contained over 6% protein, whereas Cinbas and Yazici [59] reported a protein content of 3.76% in yogurt containing 25% blueberries. Karaca et al. [60] reported protein contents ranging from 4.18 to 5.64% in yogurt containing 1–2% apricot fiber, whereas Şengül et al. [63] observed protein levels of 2.62–2.76% in yogurt with 8–16% strawberry pulp and 8% sugar, indicating a decrease in protein content with the addition of strawberry pulp. Also, adding sour cherries lowered the protein content in yogurt from an initial 3.27% to 2.58% (for the yogurt sample with 16% sour cherry pulp) [61]. In this study, the protein content of sour cherry yogurt (3.83%) was higher than the values reported by Şengül et al. [61].

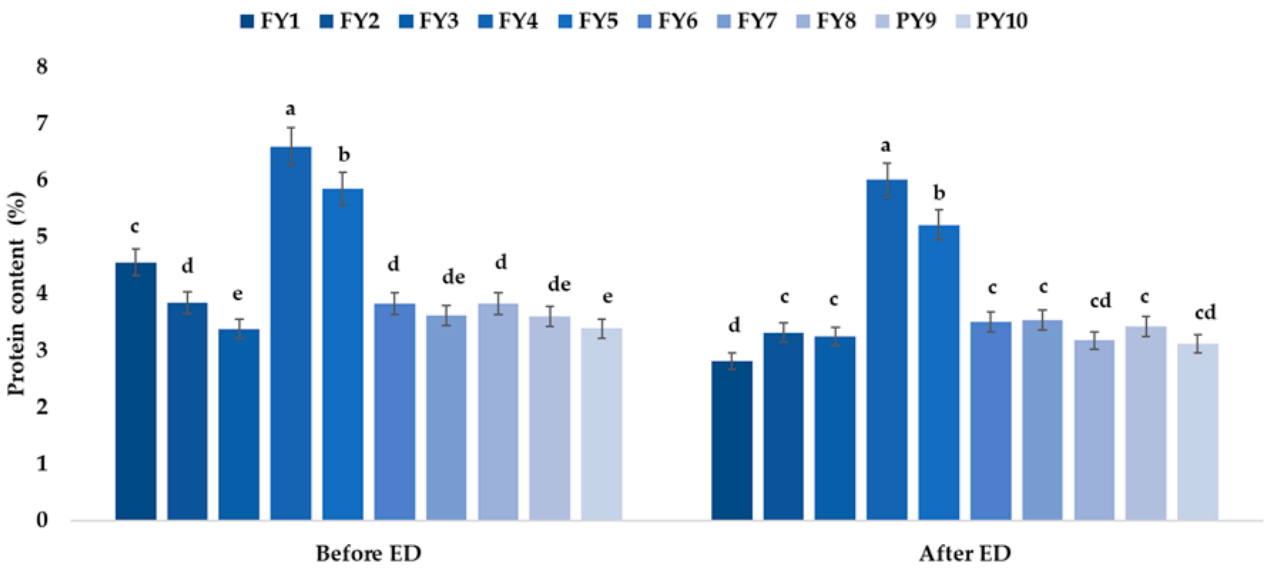

Figure 3. Protein content (%) of commercial yogurts before and after the expiration date (ED). Means labeled with different lowercase letters (a–e) denote significant differences ($p < 0.05$) among the samples.

The fat content of the yogurt samples investigated before and after the expiration date is illustrated in Figure 4. The highest fat content was obtained both before and after the expiration date in the PY10 yogurt samples (4% fat yogurt) (4.97 ± 0.07 and 4.67 ± 0.01, respectively) and FY6 (blackberries and raspberries) samples (4.22 ± 0.08 and 4.18 ± 0.05, respectively), while the lowest fat content was determined for the FY7 sample (1.60 ± 0.03% and 1.19 ± 0.03%, respectively). The largest decrease was observed in samples FY5 (28%), FY7 and FY8 (25% each), FY9 (19%), and FY4 (11%), while other samples recorded decreases of less than 10% in fat content.

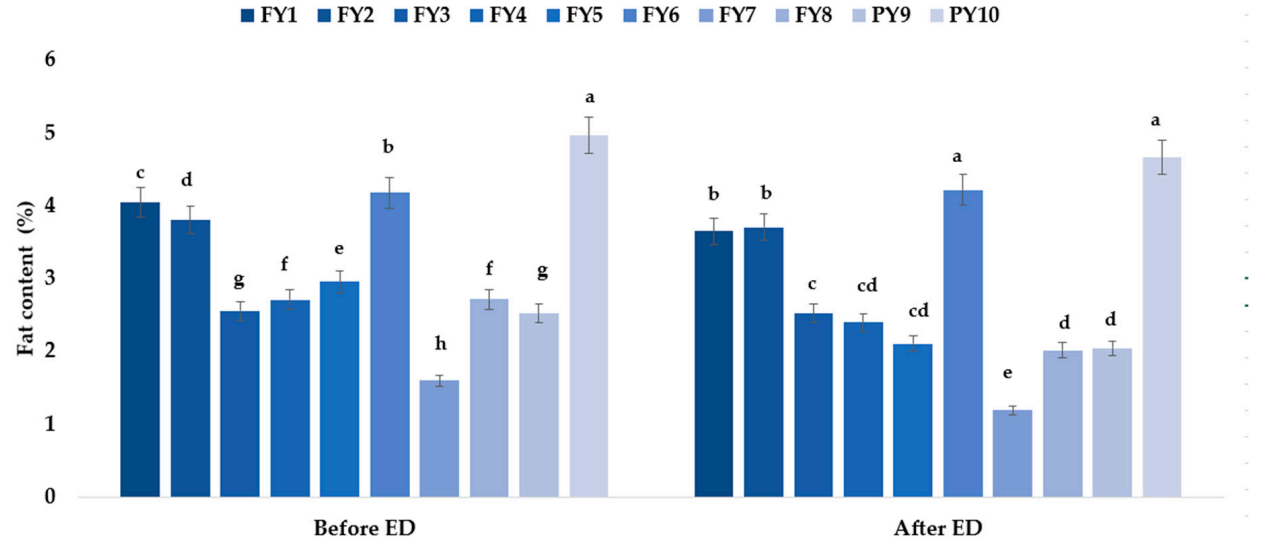

Figure 4. Fat content (%) of commercial yogurts before and after the expiration date (ED). Means labeled with different lowercase letters (a–h) denote significant differences ($p < 0.05$) among the samples.

The carbohydrate content ranged between 4.01 ± 0.11 (sample PY9) and 14.40 ± 0.12% (sample FY5) before the expiration of the yogurt samples and between 3.75 ± 0.38 (sample PY9) and 13.70 ± 0.29% (sample FY6) after the expiration of the yogurt samples (Figure 5).

The carbohydrate content decreased during storage, with the largest decrease observed for sample FY5 (8.4%) and the smallest for sample FY4 (0.24%). After the expiration of the yogurt samples, depending on the carbohydrate content, no statistically significant differences were observed between samples FY2, FY3, FY4, FY5, and FY6, between samples FY7 and FY8, or samples PY9 and PY10.

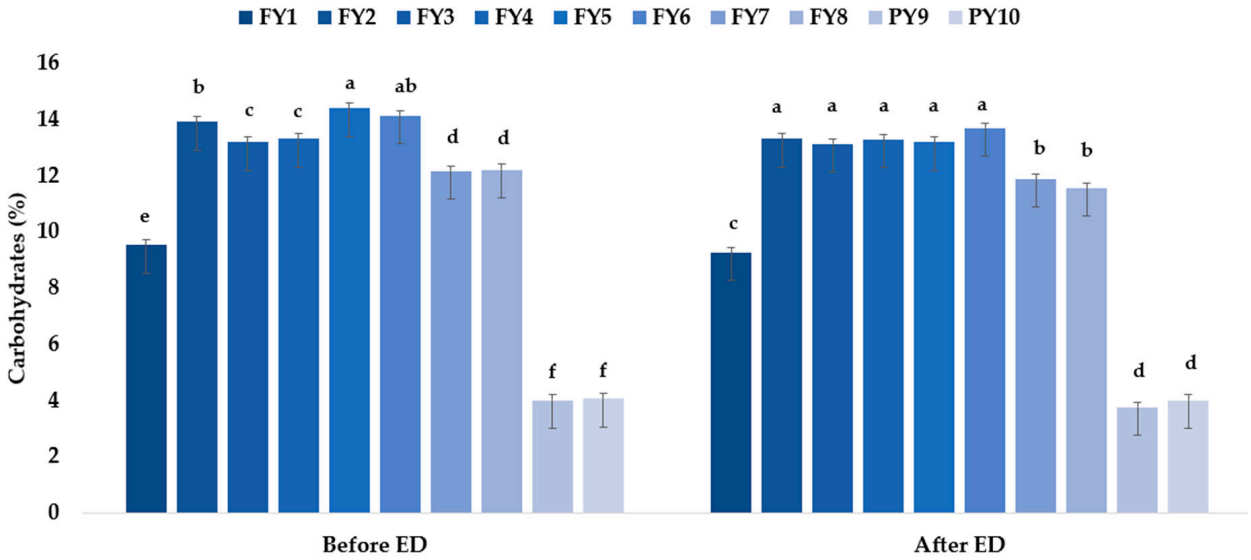

Figure 5. Carbohydrate content (%) of commercial yogurts before and after the expiration date (ED). Means labeled with different lowercase letters (a–f) denote significant differences ($p < 0.05$) among the samples.

Titratable acidity and pH were determined for all yogurt samples both before and after the expiration date, with the results presented in Table 2. The commercial yogurt samples FY5 and FY4 had the highest titratable acidity values both before (105.13 ± 1.61 °T and 95.86 ± 0.89 °T) and after the expiration date (123.17 ± 1.48 °T and 116.68 ± 1.18 °T, respectively), while the lowest titratable acidity values were recorded in samples FY1 and FY7 before expiration and in samples PY9 and FY1 after expiration (Table 2). Titratable acidity values increased over time (by 5 to over 100%), with higher values recorded at the product expiration date by over 100% for the FY7 yogurt sample, around 50% for sample FY6, between 10 and 28% for samples FY5, FY3, FY8, and FY4, and below 10% for samples PY10, FY2, FY1, and PY9. The increase in yogurt acidity may be due to the fermentation of lactose, which produces acid in yogurt, according to Çakmakçi et al. [64]. Added milk and sugar provide fermentable substances such as lactose and sucrose, which are used by starter cultures, while stabilizers do not affect lactic acid accumulation [9]. Güler-Akın et al. [65] and Karaca et al. [60] stated that the titratable acidity of fruit yogurt usually increases during storage. Organic acid production continues during yogurt storage and can influence color stability and sensory properties of yogurt [66].

The pH values ranged between 4.08 (FY5) and 4.47 (FY4) before expiration and between 4.07 (FY5) and 4.44 (FY4) after expiration of the yogurt samples (Table 2). A slight decline in pH was observed over time, with the greatest reductions occurring in samples FY1 (3%) and FY2 (2%). Karaca et al. [60] also reported a substantial decline in pH values during storage. The greater decrease in pH for berry yogurts may be due to microorganisms that are more active in the presence of berries [67].

Table 2. Titratable acidity and pH of commercial yogurts before and after the expiration date.

Sample	Titratable Acidity (°T)		pH	
	Before ED	After ED	Before ED	After ED
	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM
FY1	57.98 ± 1.52 ^{f}	62.36 ± 0.32 ^{f}	4.45 ± 0.02 ^{a}	4.29 ± 0.01 ^{d}
FY2	82.27 ± 2.38 ^{c}	88.80 ± 3.05 ^{d}	4.28 ± 0.10 ^{b}	4.19 ± 0.00 ^{f}
FY3	76.92 ± 1.07 ^{cd}	90.33 ± 0.30 ^{d}	4.15 ± 0.00 ^{c}	4.11 ± 0.00 ^{g}
FY4	95.86 ± 0.89 ^{b}	123.17 ± 1.48 ^{a}	4.47 ± 0.00 ^{a}	4.44 ± 0.00 ^{a}
FY5	105.13 ± 1.61 ^{a}	116.68 ± 1.18 ^{b}	4.08 ± 0.00 ^{c}	4.07 ± 0.01 ^{h}
FY6	66.33 ± 2.10 ^{e}	98.79 ± 0.73 ^{c}	4.11 ± 0.00 ^{c}	4.10 ± 0.00 ^{g}
FY7	34.14 ± 0.85 ^{g}	69.69 ± 0.33 ^{e}	4.42 ± 0.00 ^{a}	4.37 ± 0.00 ^{c}
FY8	74.79 ± 1.84 ^{d}	90.66 ± 1.14 ^{d}	4.28 ± 0.00 ^{b}	4.22 ± 0.00 ^{e}
PY9	65.86 ± 1.49 ^{e}	69.21 ± 0.27 ^{e}	4.43 ± 0.00 ^{a}	4.41 ± 0.00 ^{b}
PY10	65.51 ± 3.68 ^{e}	71.98 ± 0.92 ^{e}	4.41 ± 0.02 ^{a}	4.35 ± 0.00 ^{c}

ED—expiration date; SEM—standard error of the mean. Different lowercase letters within columns indicate significant differences in mean values ($p < 0.05$).

Consumers prefer fermented products with a pH between 4.2 and 4.4 according to Benedetti et al. [68] and Jaster et al. [15]. However, commercial yogurts may have even lower values than these [15]. The pH values of fruit yogurt are influenced by fruit concentration. Şengül et al. [63] and Roy et al. [58] observed that pH values decrease with increasing fruit concentration, suggesting that fruit contributes to yogurt acidity due to its natural acidity. The pH value of the banana yogurt samples (4.15) observed in this study is lower than the values reported by Roy et al. [58] (4.56–4.46). In contrast, Kamber and Harmankaya [28] reported a pH of 4.32 for banana yogurt on the first day of storage, which decreased to 3.89 after 7 days of storage. In the present study, the pH of banana yogurt at the end of the storage period (i.e., after the expiration date) was recorded at 4.11. Kamber and Harmankaya [28] likewise reported pH values of 3.95 for strawberry yogurt and 3.98 for peach yogurt after 7 days of storage, which are considerably lower than the values obtained in the present study (Table 2). Karaca et al. [60] reported pH values between 4.70 and 4.87 for apricot yogurt samples, while Jaster et al. [15] obtained values between 3.3 and 3.5 for commercial strawberry pulp yogurt. Gunenc et al. [67] determined a pH of 5.10–25 for strawberry yogurt and between 5.10 and 5.12 for raspberry yogurt after 28 days of storage. Şengül et al. [61] reported pH values for sour cherry yogurts between 3.9 and 4.2, close to the values obtained in the present study. These differences in total solids, protein, fat, titratable acidity, and pH content of commercial fruit yogurts may occur due to the composition of the raw milk, the type of fruit, the use of pulp or whole fruit, the sugar content, and the composition of the plain yogurt used in the manufacture of fruit yogurt [63]. Tables 3 and 4 present the results obtained for the analysis of the color parameters of commercial yogurts before and after the expiration date. Before the expiration date, samples PY10, FY3, and PY9 (L* between 87.11 ± 0.95 and 89.46 ± 0.28) were the lightest in color, while samples FY7 (L* = 71.41 ± 0.48) and FY6 (L* = 63.57 ± 4.69) were the lightest of all the samples investigated. After the expiration date of the products, changes in the L* color parameter were observed, with values decreasing for samples FY4 and FY3 by approximately 10% and 0.7%, respectively, while for the other samples, they increased. After the expiration date of the yogurt products, the samples lightest in color were natural yogurts without fruit (PY10 and PY9), and the samples darkest in color were FY6 (with blackberries and raspberries) and FY4 (with blueberries) (Table 4). For the FY3, PY9, and PY10 yogurt samples, the values of the parameter a* were negative, indicating a

greenish hue, whereas the remaining samples exhibited positive a* values, corresponding to a reddish coloration.

Table 3. Results of ANOVA analysis on the color of commercial yogurts before their expiration date.

Yogurt Samples	L*	a*	b*	C*	YI	WI	h°
	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM
FY1	74.27 ± 0.05^{bc}	1.68 ± 0.02^{d}	11.39 ± 0.03^{b}	11.52 ± 0.03^{cd}	21.92 ± 0.07^{a}	71.81 ± 0.06^{bc}	81.63 ± 0.07^{e}
FY2	72.00 ± 0.30^{bc}	10.14 ± 0.05^{c}	4.15 ± 0.00^{e}	10.96 ± 0.04^{d}	8.24 ± 8.24^{fg}	69.93 ± 0.26^{c}	22.27 ± 0.07^{g}
FY3	89.39 ± 0.76^{a}	-2.08 ± 0.03^{e}	12.77 ± 0.16^{a}	12.94 ± 0.15^{bc}	20.42 ± 0.39^{b}	83.26 ± 0.57^{a}	99.24 ± 0.21^{d}
FY4	73.93 ± 1.95^{bc}	11.74 ± 0.64^{b}	-1.23 ± 0.26^{h}	11.80 ± 0.66^{bcd}	-2.39 ± 0.57^{i}	71.38 ± 2.00^{bc}	354.05 ± 1.08^{a}
FY5	77.60 ± 0.52^{b}	9.25 ± 0.05^{c}	5.36 ± 0.02^{d}	10.70 ± 0.03^{d}	9.87 ± 0.03^{d}	75.18 ± 0.48^{b}	30.10 ± 0.24^{f}
FY6	63.57 ± 4.69^{d}	15.77 ± 1.38^{a}	3.38 ± 0.40^{f}	16.14 ± 1.41^{a}	7.58 ± 0.34^{g}	60.05 ± 3.87^{d}	12.11 ± 1.00^{i}
FY7	71.41 ± 0.48^{c}	12.35 ± 0.09^{b}	0.55 ± 0.02^{g}	12.36 ± 0.09^{bcd}	1.09 ± 0.03^{h}	68.85 ± 0.40^{c}	2.53 ± 0.06^{j}
FY8	72.13 ± 3.89^{bc}	12.61 ± 0.67^{b}	4.40 ± 0.32^{e}	13.36 ± 0.73^{b}	8.71 ± 0.28^{ef}	69.01 ± 3.24^{c}	19.22 ± 0.56^{h}
PY9	87.11 ± 0.95^{a}	-3.13 ± 0.04^{e}	5.99 ± 0.16^{d}	6.76 ± 0.15^{f}	9.82 ± 0.19^{de}	85.44 ± 0.78^{a}	117.61 ± 0.65^{b}
PY10	89.46 ± 0.28^{a}	-3.34 ± 0.23^{e}	8.00 ± 0.55^{c}	8.67 ± 0.59^{e}	12.77 ± 0.89^{c}	86.35 ± 0.50^{a}	112.67 ± 0.20^{c}
p-value	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
F-value	53.25	577.60	840.05	58.91	1112.69	69.14	106,846.20

Different lowercase letters within columns indicate significant differences in mean values ($p < 0.05$). L*—brightness, a*—red/green, b*—yellow/blue, C*—chroma, h°—tone, YI—yellowness index, WI—whiteness index, SEM—standard error of the mean.

Table 4. Results of ANOVA on the color of commercial yogurts after their expiration date.

Yogurt Samples	L*	a*	b*	C*	YI	WI	h°
	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM
FY1	79.27 ± 0.48^{cd}	1.17 ± 0.01^{e}	18.16 ± 0.04^{a}	18.20 ± 0.04^{a}	32.74 ± 0.26^{a}	72.41 ± 0.38^{d}	86.31 ± 0.03^{e}
FY2	82.06 ± 1.03^{c}	7.78 ± 0.32^{c}	8.52 ± 0.76^{c}	11.54 ± 0.77^{de}	14.82 ± 1.15^{c}	78.64 ± 0.52^{bc}	47.50 ± 1.47^{g}
FY3	88.68 ± 1.23^{b}	-1.54 ± 0.26^{f}	15.05 ± 0.46^{b}	15.13 ± 0.48^{b}	24.24 ± 0.64^{b}	81.07 ± 0.65^{b}	95.81 ± 0.85^{d}
FY4	66.36 ± 1.36^{f}	13.41 ± 0.16^{a}	-0.66 ± 0.15^{g}	13.43 ± 0.16^{c}	-1.43 ± 0.34^{f}	63.78 ± 1.25^{e}	357.17 ± 0.61^{a}
FY5	81.32 ± 1.18^{c}	6.60 ± 0.43^{d}	8.79 ± 0.81^{c}	10.99 ± 0.90^{e}	15.44 ± 1.30^{c}	78.29 ± 0.90^{c}	53.07 ± 0.88^{f}
FY6	69.43 ± 1.08^{f}	13.05 ± 0.37^{a}	5.82 ± 0.22^{e}	14.29 ± 0.39^{bc}	11.98 ± 0.27^{d}	66.25 ± 0.89^{e}	24.05 ± 0.71^{i}
FY7	77.15 ± 0.53^{de}	12.58 ± 0.84^{ab}	2.79 ± 0.92^{f}	12.90 ± 1.03^{cd}	5.17 ± 1.73^{e}	73.75 ± 0.92^{d}	12.25 ± 3.01^{j}
FY8	75.70 ± 1.49^{e}	11.62 ± 0.16^{b}	6.54 ± 0.21^{de}	13.34 ± 0.23^{c}	12.35 ± 0.18^{d}	72.26 ± 1.21^{d}	29.38 ± 0.54^{h}
PY9	91.83 ± 1.71^{b}	-3.14 ± 0.12^{g}	7.01 ± 0.50^{de}	7.68 ± 0.46^{f}	10.90 ± 0.66^{d}	88.70 ± 1.09^{a}	114.20 ± 1.61^{b}
PY10	95.22 ± 0.46^{a}	-2.57 ± 0.03^{g}	7.44 ± 0.08^{cd}	7.87 ± 0.08^{f}	11.16 ± 0.13^{d}	90.78 ± 0.26^{a}	109.06 ± 0.06^{c}
p-value	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
F-value	200.87	1105.65	333.71	97.67	372.22	305.22	18,101.87

Different lowercase letters within columns indicate significant differences in mean values ($p < 0.05$). L*—brightness, a*—red/green, b*—yellow/blue, C*—chroma, h°—tone, YI—yellowness index, WI—whiteness index, SEM—standard error of the mean.

On the expiration date, it was observed that the color parameter a* changed for all samples; thus, for samples FY3, FY4, FY7, and PY10, increases in the value of this parameter were observed, while for other samples, decreases were observed. Before the expiration date, the samples had a b* color parameter with values ranging from -1.23 ± 0.26 (FY4), a bluish color, to 12.77 ± 0.16 (FY3), a yellowish color, and after expiration, the values ranged between -0.66 ± 0.15 (FY4) and 18.16 ± 0.04 (FY1). All commercial yogurt samples, except for sample FY4 (the blueberry sample), had yellowish color because the b* parameter values are positive. Significant differences were observed in the b* parameter values before and after the expiration date of the commercial yogurt samples, indicating that the color of the samples changed during storage. The chroma values calculated for fruit yogurt samples differed significantly, from a statistical standpoint, from those recorded for plain yogurt samples. The higher values for chroma were obtained for samples FY6 and FY8 before the expiration date and for samples FY1 and FY3 after the expiration date. The chroma

values increased during yogurt samples' storage for almost all samples, with the exception of samples FY6, FY8, and PY10.

Before the expiration date, the WI parameter values ranged between 60.05 ± 3.87 (FY6) and 86.35 ± 0.50 (PY10), and after the expiration of the commercial yogurt samples, the values ranged between 63.78 ± 1.25 (FY4) and 90.78 ± 0.26 (PY10). WI increased during storage for almost all yogurt samples except FY3 and FY4 (bananas and blueberries), for which the values of this parameter decreased. After the expiration date, hue angle (h°) decreased significantly for samples FY3, PY9, and PY10, and it increased for all other yogurt samples. Samples FY3, FY4, PY9, and PY10 exhibited yellow-green hues (h° > 90°), whereas samples FY2, FY5, FY6, FY7, and FY8 tended toward red-purple tones (h° values close to 0°); in contrast, sample FY1 displayed a yellow-red coloration.

Figure 6 illustrates the total color difference between the commercial yogurt samples investigated in this study. Thus, yogurts with apricots, blueberries, blackberries, and raspberries (FY1, FY4, and FY6) had no statistically significant differences in terms of total color difference (being in group ab), as did yogurts with berries and strawberries, raspberries, sour cherries, and plain yogurts (being in group bc). The color difference was greater than 3 for all yogurt samples except for sample FY3 (the banana sample), for which the color difference was not very visible to the human eye because ΔE* < 3.

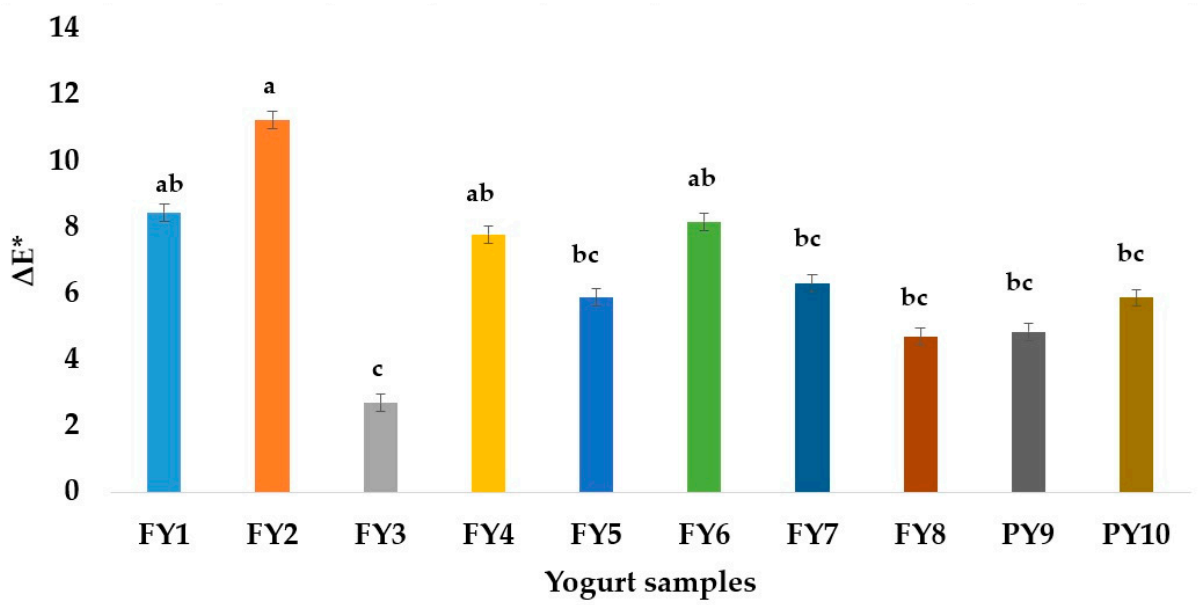

Figure 6. Total color difference (ΔE*) of yogurt samples. Means labeled with different lowercase letters (a–c) denote significant differences ($p < 0.05$) among the samples.

Syneresis, or whey separation, is a parameter that has a negative effect on consumer acceptance of yogurt and is undesirable in coagulated dairy products, as it can be considered a defect in yogurt quality [69,70]. Furthermore, this defect (syneresis) may contribute to a reduction in the product's shelf life. Syneresis decreases as the total solids content of yogurt increases, while a yogurt pH between 3.85 and 4.5 does not affect syneresis [71]. The incorporation of sweeteners, salt, and flavoring agents can mitigate syneresis and thereby contribute to extending the shelf life of yogurt [71]. Fiber from fruit and vegetables can reduce the syneresis of yogurts and improve their water retention capacity [29]. According to Table 5, the syneresis was the highest in sample PY9 (plain yogurt with 2% fat), while it was the lowest in sample FY2 (yogurt with 11.2% strawberries) before the ED. Table 5 indicates that the syneresis values of samples FY1 and PY9 do not differ significantly nor do those of samples FY3, FY5, and FY7. After the ED, the syneresis values increased for

all samples. The highest value was observed in sample FY1 (apricot yogurt), followed by sample PY9, whereas the lowest value was recorded for sample FY2. Şengül et al. [63] also observed that the syneresis values of strawberry yogurt increase during storage and that increased fruit content decreases syneresis values. However, depending on the type of fruit, syneresis may increase with the amount of fruit added to the yogurt, as was the case with the addition of cherry pulp to yogurt [61]. This may be due to the high acidity content of sour cherries [61]. According to Roy et al. [58], the syneresis of yogurt samples increased during storage, possibly due to low solid content, high incubation temperature, and inadequate storage conditions. They reported a syneresis of over 46% for yogurt samples with 5% banana pulp, a value much higher than those obtained in this study (for FY3). Moreover, syneresis values decline as the proportion of added banana in the yogurt increases.

Table 5. Syneresis and whey-holding capacity of commercial yogurts before and after the expiration date.

Sample	Syneresis (%)		Water-Holding Capacity (%)	
	Before ED	After ED	Before ED	After ED
	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM
FY1	30.76 ± 0.66 ^{a}	51.70 ± 1.68 ^{a}	69.24 ± 0.66 ^{f}	48.30 ± 1.68 ^{g}
FY2	1.74 ± 0.15 ^{f}	2.49 ± 0.22 ^{g}	98.26 ± 0.15 ^{a}	97.51 ± 0.22 ^{a}
FY3	22.10 ± 0.62 ^{b}	26.03 ± 1.63 ^{c}	77.90 ± 0.62 ^{e}	73.97 ± 1.63 ^{e}
FY4	7.59 ± 0.01 ^{e}	9.39 ± 0.08 ^{f}	92.41 ± 0.01 ^{b}	90.61 ± 0.08 ^{b}
FY5	20.24 ± 0.21 ^{b}	26.79 ± 0.79 ^{c}	79.76 ± 0.21 ^{e}	73.21 ± 0.79 ^{e}
FY6	8.50 ± 0.13 ^{de}	11.78 ± 0.03 ^{e}	91.50 ± 0.13 ^{bc}	88.22 ± 0.03 ^{c}
FY7	21.11 ± 1.10 ^{b}	28.28 ± 0.39 ^{c}	78.89 ± 1.10 ^{e}	71.72 ± 0.39 ^{e}
FY8	9.90 ± 0.13 ^{cd}	13.39 ± 0.64 ^{e}	90.10 ± 0.13 ^{cd}	86.61 ± 0.64 ^{c}
PY9	31.10 ± 1.72 ^{a}	38.33 ± 0.05 ^{b}	68.91 ± 1.72 ^{f}	61.67 ± 0.05 ^{f}
PY10	10.72 ± 0.68 ^{c}	18.53 ± 0.11 ^{d}	89.28 ± 0.68 ^{d}	81.47 ± 0.11 ^{d}

ED—expiration date; SEM—standard error of the mean. Different lowercase letters within columns indicate significant differences in mean values ($p < 0.05$).

The highest water-holding capacity (WHC) (98.26 ± 0.15%) was observed for yogurt with strawberries (FY2), while the lowest WHC (68.91 ± 1.72%) was recorded for plain yogurt with 2% fat (PY9) (Table 5). The incorporation of fruit such as strawberries, blueberries, blackberries, raspberries, and sour cherries into yogurt can enhance water-holding capacity (WHC) due to the high water-binding properties of their fibers [60,72]. Bananas contain soluble dietary fiber and proteins that possess hydrophilic groups, which allow them to increase water absorption [73]. Apricots can weaken the gel structure if they replace too much milk, affecting WHC, potentially reducing the water retention capacity of proteins and increasing syneresis (whey separation) [29,60].

The water-holding capacity of the yogurt samples decreased during storage (Table 5), which is attributable to the weakening of the protein network and continued acidification. The greatest decrease was observed in the apricot yogurt sample (FY1), followed by the 2% fat yogurt sample (PY9) and the mixed berries and strawberry sample (FY5), whereas the smallest decreases occurred in the strawberry yogurt sample (FY2) and the blueberry yogurt sample (FY4). Apricots contain organic acids (500–900 mg malic acid/100 g, 30–50 mg citric acid/100 g [74]) that can destabilize the protein matrix if the preparation is too acidic, resulting in a weaker and less compact structure that cannot retain water effectively [60]. The PY9 2% fat sample has a lower fat content and potentially a lower total solids content compared to full-fat options, making it more susceptible to network rearrangement and subsequent whey separation [75]. The fat globules in the protein network improved water

retention capacity [76], which is why the sample with 4% fat (PY10) has a higher WHC than the sample with 2% fat (PY9).

Fruit is abundant in phenolic compounds, ranging from 200 to over 600 mg GAE/100 g of fresh weight [23–26], which contributes to an increase in the total phenolic content (TPC) and antioxidant capacity of fruit yogurts [77]. The DPPH activity of fresh fruit extract can vary between 52.9 and 92.6% (for raspberries) [78], and it can reach up to 58.32% for strawberries or up to 96.96% for blueberries and blackberries [79]. The DPPH and TPC in the yogurt samples are presented in Table 6.

Table 6. DPPH and total phenolic content of commercial yogurts before and after expiration date.

Sample	DPPH (%)		Total Phenolic Content (μg/g)	
	Before ED	After ED	Before ED	After ED
	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM
FY1	5.98 ± 1.30 ^{d}	9.67 ± 1.60 ^{d}	38.42 ± 0.30 ^{d}	94.38 ± 0.61 ^{b}
FY2	7.00 ± 0.50 ^{d}	13.99 ± 0.05 ^{c}	31.77 ± 0.15 ^{e}	72.05 ± 0.18 ^{d}
FY3	2.43 ± 0.20 ^{e}	5.17 ± 0.17 ^{e}	23.19 ± 0.09 ^{f}	44.64 ± 0.09 ^{f}
FY4	24.12 ± 0.05 ^{a}	26.89 ± 0.10 ^{a}	58.04 ± 2.50 ^{a}	103.22 ± 2.80 ^{a}
FY5	5.88 ± 1.50 ^{d}	10.55 ± 2.46 ^{d}	33.87 ± 0.07 ^{e}	64.78 ± 0.09 ^{e}
FY6	18.14 ± 0.09 ^{b}	19.70 ± 0.10 ^{b}	52.79 ± 0.50 ^{b}	86.94 ± 1.05 ^{c}
FY7	7.66 ± 0.30 ^{d}	9.25 ± 0.13 ^{d}	23.71 ± 0.07 ^{f}	37.81 ± 0.09 ^{g}
FY8	12.69 ± 0.13 ^{c}	15.78 ± 0.10 ^{c}	41.75 ± 2.50 ^{c}	85.18 ± 4.90 ^{c}
PY9	1.21 ± 0.20 ^{e}	3.69 ± 0.17 ^{e}	15.83 ± 0.20 ^{g}	30.19 ± 0.18 ^{h}
PY10	0.84 ± 0.30 ^{e}	4.36 ± 0.13 ^{e}	17.41 ± 0.40 ^{g}	26.87 ± 0.35 ^{h}

ED—expiration date; SEM—standard error of the mean. Different lowercase letters within columns indicate significant differences in mean values ($p < 0.05$).

The inhibition of DPPH radical formation in yogurt ranged from 24.12 ± 0.05% (FY4) to 0.84 ± 0.30% (PY10) before the expiration date and from 26.89 ± 0.10% (FY4) to 3.69 ± 0.17 (PY10) after the expiration date. All yogurt samples had a DPPH inhibition percentage of less than 30%, which may indicate low or weak antioxidant activity. Several studies have reported DPPH inhibition values below 20% for plain yogurt [33,80], which are considerably higher than those observed in the present study. There are no statistically significant differences in DPPH values between samples FY1, FY2, FY5, and FY7 prior to the expiration date. After the expiration date, the DPPH values were higher than those recorded before expiration, probably due to the production of bioactive peptides [81]. It was also observed that yogurt samples with higher DPPH scavenging activity had higher TPC values, as reported also by Özer [82]. The highest total phenolic content (TPC) was observed in the blueberry yogurt sample (FY4, 58.04 ± 2.50 μg GAE/g), whereas the lowest TPC values were recorded in the plain yogurt samples (PY9 and PY10, 15.83 ± 0.20 μg GAE/g). The observed increase in TPC after the expiration date may be attributed to the extensive degradation of phenolic compounds by lactic acid bacteria during yogurt storage [83] or to the proteolysis of milk proteins mediated by lactic acid bacteria [84]. The antioxidant activity of yogurt may increase during storage, even beyond the official expiration date, as microbial metabolism can result in the formation of new phenolic acids [84].

3.2. Textural Properties of Commercial Yogurts

Texture properties of commercial yogurts (before and after expiration date) are presented in Tables 7 and 8. Cultures, type of fruits, milk origin, fat content, and emulsion structure are among the factors that affect yogurt hardness [85].

Table 7. Texture characteristics of commercial yogurt samples prior to expiration.

Yogurt Samples	Hardness	Viscosity	Adhesiveness	Cohesiveness	Springiness	Gumminess	Chewiness
	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM
FY1	1.43 ± 0.09 ^{d}	0.52 ± 0.04 ^{de}	1.39 ± 0.00 ^{g}	50.99 ± 2.70 ^{e}	0.68 ± 0.02 ^{cd}	0.73 ± 0.01 ^{cd}	0.50 ± 0.02 ^{ef}
FY2	1.83 ± 0.13 ^{c}	0.61 ± 0.13 ^{d}	2.93 ± 0.06 ^{c}	72.17 ± 1.68 ^{ab}	0.84 ± 0.00 ^{b}	1.32 ± 0.06 ^{b}	1.10 ± 0.05 ^{bc}
FY3	1.15 ± 0.03 ^{de}	0.49 ± 0.01 ^{de}	1.72 ± 0.07 ^{ef}	62.44 ± 1.75 ^{cd}	0.75 ± 0.04 ^{bc}	0.72 ± 0.00 ^{cd}	0.54 ± 0.03 ^{e}
FY4	3.49 ± 0.01 ^{a}	2.10 ± 0.08 ^{a}	7.86 ± 0.14 ^{a}	80.18 ± 5.58 ^{a}	0.98 ± 0.08 ^{a}	2.80 ± 0.19 ^{a}	2.73 ± 0.04 ^{a}
FY5	0.91 ± 0.01 ^{e}	0.39 ± 0.01 ^{e}	1.47 ± 0.07 ^{fg}	61.12 ± 0.47 ^{cd}	0.65 ± 0.01 ^{d}	0.56 ± 0.00 ^{d}	0.36 ± 0.00 ^{f}
FY6	1.28 ± 0.04 ^{de}	0.57 ± 0.01 ^{d}	2.24 ± 0.03 ^{d}	67.73 ± 2.12 ^{bc}	0.75 ± 0.01 ^{bc}	0.87 ± 0.05 ^{c}	0.65 ± 0.05 ^{de}
FY7	1.38 ± 0.10 ^{d}	0.60 ± 0.04 ^{d}	2.20 ± 0.08 ^{d}	65.32 ± 0.35 ^{bcd}	0.79 ± 0.01 ^{b}	0.90 ± 0.07 ^{c}	0.71 ± 0.06 ^{d}
FY8	1.83 ± 0.23 ^{c}	0.79 ± 0.03 ^{c}	2.82 ± 0.12 ^{c}	68.48 ± 2.07 ^{bc}	0.81 ± 0.01 ^{b}	1.25 ± 0.12 ^{b}	1.01 ± 0.08 ^{c}
PY9	1.32 ± 0.16 ^{d}	0.48 ± 0.02 ^{de}	1.76 ± 0.05 ^{e}	62.72 ± 0.66 ^{cd}	0.79 ± 0.05 ^{b}	0.83 ± 0.09 ^{c}	0.65 ± 0.11 ^{de}
PY10	2.49 ± 0.25 ^{b}	1.25 ± 0.09 ^{b}	3.69 ± 0.13 ^{b}	58.15 ± 4.91 ^{de}	0.84 ± 0.00 ^{b}	1.44 ± 0.02 ^{b}	1.20 ± 0.02 ^{b}

Different lowercase letters within columns indicate significant differences in mean values ($p < 0.05$).

Table 8. Texture characteristics of commercial yogurt samples after expiration.

Yogurt Samples	Hardness	Viscosity	Adhesiveness	Cohesiveness	Springiness	Gumminess	Chewiness
	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM
FY1	1.40 ± 0.12 ^{d}	0.53 ± 0.03 ^{e}	1.76 ± 0.01 ^{e}	62.82 ± 0.92 ^{cd}	0.89 ± 0.09 ^{a}	0.88 ± 0.09 ^{d}	0.79 ± 0.16 ^{cde}
FY2	2.13 ± 0.09 ^{b}	1.13 ± 0.03 ^{b}	3.92 ± 0.17 ^{b}	63.36 ± 0.10 ^{cd}	0.84 ± 0.00 ^{a}	1.35 ± 0.06 ^{b}	1.13 ± 0.05 ^{b}
FY3	1.27 ± 0.09 ^{de}	0.57 ± 0.01 ^{e}	2.01 ± 0.14 ^{e}	60.85 ± 0.57 ^{d}	0.87 ± 0.06 ^{a}	0.77 ± 0.06 ^{d}	0.67 ± 0.10 ^{de}
FY4	4.30 ± 0.20 ^{a}	2.71 ± 0.17 ^{a}	10.07 ± 0.63 ^{a}	82.73 ± 0.77 ^{a}	0.89 ± 0.01 ^{a}	3.56 ± 0.20 ^{a}	3.16 ± 0.14 ^{a}
FY5	1.16 ± 0.02 ^{de}	0.52 ± 0.02 ^{e}	1.94 ± 0.10 ^{e}	58.71 ± 0.62 ^{d}	0.84 ± 0.13 ^{a}	0.68 ± 0.00 ^{d}	0.58 ± 0.09 ^{de}
FY6	1.38 ± 0.04 ^{d}	0.62 ± 0.02 ^{de}	2.37 ± 0.04 ^{de}	70.71 ± 4.48 ^{b}	0.89 ± 0.06 ^{a}	0.97 ± 0.03 ^{cd}	0.87 ± 0.09 ^{bcd}
FY7	1.04 ± 0.08 ^{e}	0.49 ± 0.03 ^{e}	1.87 ± 0.01 ^{e}	69.52 ± 4.52 ^{bc}	0.72 ± 0.01 ^{a}	0.72 ± 0.01 ^{d}	0.52 ± 0.01 ^{e}
FY8	1.79 ± 0.03 ^{c}	0.79 ± 0.05 ^{cd}	2.78 ± 0.11 ^{cd}	69.02 ± 2.66 ^{bc}	0.83 ± 0.01 ^{a}	1.23 ± 0.03 ^{bc}	1.02 ± 0.03 ^{bc}
PY9	1.14 ± 0.06 ^{de}	0.50 ± 0.02 ^{e}	1.81 ± 0.04 ^{e}	64.03 ± 1.57 ^{bcd}	0.87 ± 0.03 ^{a}	0.73 ± 0.06 ^{d}	0.64 ± 0.07 ^{de}
PY10	1.91 ± 0.01 ^{bc}	0.96 ± 0.04 ^{bc}	3.33 ± 0.14 ^{bc}	65.36 ± 3.53 ^{bcd}	0.84 ± 0.04 ^{a}	0.91 ± 0.28 ^{cd}	0.75 ± 0.20 ^{cde}

SEM—standard error of the mean. Different lowercase letters within columns indicate significant differences in mean values ($p < 0.05$).

According to Table 7, the hardness of commercial yogurts before the expiration date varied between 0.91 ± 0.01 (FY5, yogurt with berries and strawberries) and 3.49 ± 0.01 (FY4, yogurt with blueberries). During storage, the hardness of the yogurt samples underwent changes; by the expiration date, hardness had decreased in half of the samples (FY1, FY7, FY8, PY9, and PY10), whereas it had increased in the remaining samples (FY2–FY6) (Table 8). Blueberry yogurt (FY4) retained the highest hardness value at the expiration date compared to other yogurts. Fruit addition in yogurts generally increases hardness and strengthens the gel structure due to the contribution of fiber, pectin, polyphenols, and interactions between fruit ingredients and milk proteins [86]. According to ALKaisy and Rahi [87], the decrease in hardness values of commercial yogurts may be attributed to the reduction in pH. In addition, the formation of weak interactions between phenolic compounds present in certain fruits or extracts and casein may contribute to reducing yogurt hardness [85]. Viscosity is associated with the stability of yogurts. Skimmed milk powder increases yogurt viscosity and gel strength, while hydrocolloids increase viscosity and reduce syneresis [88]. The viscosity of commercial yogurts varied between 0.39 ± 0.01 (FY5) and 2.10 ± 0.08 (FY4) before the expiration date, while after expiration, it varied between 0.49 ± 0.03 (FY7) and 2.71 ± 0.17 (FY4). Viscosity increased during storage for almost all samples, except for samples FY7 and PY10 (viscosity decreased) and FY8 (similar viscosity values). Celik et al. [89] observed that fruit yogurts are characterized by lower viscosity and greater whey separation. The addition of fruit diminishes water retention capacity of proteins, thereby reducing viscosity [89]. The adhesiveness of blueberry yogurt (FY4) was higher than that

of other fruit yogurts both before and after the expiration of the yogurt samples, which means better coagulation of the yogurt and a thicker yogurt [90]. The adhesiveness of commercial yogurt samples increased during storage for most samples, except for samples FY7, FY8, and PY10. The adhesiveness of yogurts increases as the pH decreases, according to Nahali et al. [91]. Blueberry yogurt (FY4) had higher cohesiveness values (80.18 ± 5.58 and 82.73 ± 0.77) than other fruit yogurts, both before and after the expiration date. Cohesiveness increased at the expiration date for almost all samples, except for samples FY2, FY3, and FY5 (for which it decreased slightly). An increase in cohesiveness during yogurt storage has also been reported by Wang et al. [92] and Dimitrellou et al. [93], which is associated with the strength of the internal bonds within the product [94]. Springiness decreased for samples FY4, FY7, and PY10; gumminess decreased only for FY7, FY8, PY9, and PY10; while chewiness decreased for FY7, PY9, and PY10.

According to Pădureţ et al. [33], increasing the pomace content in yogurt decreased springiness. The incorporation of black chokeberry enhanced the gumminess and chewiness of yogurt compared with the control, whereas the addition of black chokeberry juice and pomace resulted in a reduction in these textural properties.

3.3. Sensory Attributes of Commercial Yogurts

Sample FY6 obtained the highest score before expiration for the following sensory attributes: appearance and consistency and taste and color—followed by samples FY2 and FY3 in terms of appearance and consistency (the samples ranging from firm consistency, without gas bubbles and whey elimination, with a porcelain appearance and minimal deviations: coagulum of suitable consistency, with low whey removal (max. 2%), slightly sandy appearance)—and color (considered very intense, very pleasant, very suitable), and samples FY8 and FY2 obtained the highest score in terms of taste (considered sour, weak yogurt aroma, slightly sweet) (Figure 7a).

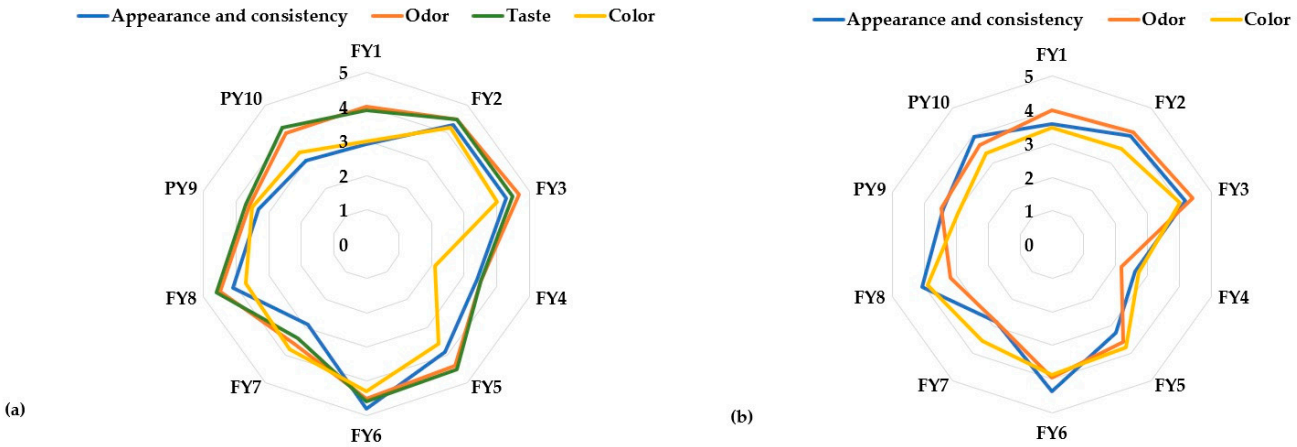

Figure 7. Sensory analysis (—appearance and consistency; —odor; —color; —taste) of commercial yogurt samples (FY1—apricot yogurt, FY2—strawberry yogurt, FY3—banana yogurt, FY4—blueberry yogurt, FY5—berry and strawberry yogurt, FY6—blackberry and strawberry yogurt, FY7—raspberry yogurt, FY8—sour cherry yogurt, PY9—plain yogurt with 2% fat, PY10—plain yogurt with 4% fat) (**a**) before and (**b**) after the expiration date (expired samples were not tasted).

The FY3 yogurt sample was most appreciated for its smell (with a specific yogurt aroma and characteristics specific to lactic fermentation), followed by the FY2 and FY6 samples. The FY7 and FY1 samples were the least appreciated for appearance and consistency, as, according to the evaluators, they had broken coagulation, with whey removal (max. 5%), rare gas bubbles, and a sandy appearance. FY7 also received the lowest score for

the sensory attribute of taste, being classified in the group with a slightly fermented taste, with notes described as slightly foddery, slightly cheesy, slightly yeasty, slightly smoky, slightly metallic, and slightly bitter. In terms of smell, sample FY4 was the least appreciated (the smell being classified as sour, slightly foddery, slightly yeasty, slightly malty, slightly fermented, slightly smoky, and slightly caramel), and this sample also received the lowest score for color (the evaluators considered the color to be slightly unpleasant or slightly inappropriate).

After the expiration of the analyzed products, it was observed that sample PY6 retained its first place in terms of appearance and consistency, as did sample FY3 for smell, while sample FY3 was the most appreciated for color (Figure 7b). Sample FY4 was the least appreciated yogurt sample after its expiration, with agglomerations, whey removal greater than 5%, very soft coagulum, frequent gas bubbles, and slight sediment, as well as a slight smell of mold, yeast, and notes described as fermented, malt, smoked, acetic, caramel; additionally, it was described as having slightly inappropriate color.

3.4. Assessment of the Microbiological Quality of Commercial Yogurts

The microbiological assessment concentrated on two primary microbial groups: lactic acid bacteria (LAB), which drive yogurt fermentation, and total mesophilic bacteria (TMB), which, although not directly involved in fermentation, serve as important indicators of microbiological quality and the potential shelf life of the product. The initial LAB counts were comparable across all yogurt samples, ranging from 6.0 $\log_{10}$ CFU·g^{-1} (sample FY6) to 7.55 $\log_{10}$ CFU·g^{-1} (Table 9). The addition of fruit to yogurt significantly increases the number of LAB, especially in yogurt with sour cherries and bananas [95]. After the expiration date, the analysis revealed a slight decline in LAB counts, indicating that the lactic acid bacteria remain active in the yogurt samples. Lactic acid bacteria concentration remained at probiotic value level (at least 10^6–10^7 CFU/g) [96] in the product to the date of minimum durability. In comparison, Vinderola et al. [97] observed no significant changes in *L. delbrueckii* subsp. *bulgaricus* counts in plain yogurt after 28 days of storage at 5 °C, whereas other studies have reported fluctuations in lactic acid bacteria populations during storage. For example, Ranadheera et al. [98] noted a significant decline in LAB counts over time, and Pascariu et al. [84] found that *L. delbrueckii* subsp. *bulgaricus* counts in stirred fruit yogurts decreased sharply during the fourth week of storage, from approximately 10^8 CFU/g to about 10^5 CFU/g, while counts in plain yogurts remained near 10^6 CFU/g.

Table 9. Microbial counts of the commercial yogurts (in $\log_{10}$ CFU/g).

Sample	LAB		TNMB	
	Before ED	After ED	Before ED	After ED
	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM	Mean Values ± SEM
FY1	7.30 ± 0.03 ^{c}	6.00 ± 0.07 ^{d}	7.43 ± 0.03 ^{c}	8.68 ± 0.02 ^{b}
FY2	7.23 ± 0.01 ^{c}	6.69 ± 0.01 ^{b}	7.25 ± 0.01 ^{e}	8.69 ± 0.01 ^{b}
FY3	7.43 ± 0.01 ^{b}	6.95 ± 0.03 ^{a}	7.46 ± 0.03 ^{c}	8.64 ± 0.01 ^{c}
FY4	7.00 ± 0.03 ^{d}	6.77 ± 0.08 ^{ab}	7.36 ± 0.04 ^{d}	8.60 ± 0.01 ^{d}
FY5	7.00 ± 0.07 ^{d}	6.30 ± 0.15 ^{c}	7.47 ± 0.02 ^{bc}	7.70 ± 0.01 ^{f}
FY6	6.00 ± 0.06 ^{e}	6.00 ± 0.07 ^{d}	6.47 ± 0.01 ^{g}	8.64 ± 0.01 ^{c}
FY7	7.55 ± 0.02 ^{a}	6.84 ± 0.03 ^{ab}	7.44 ± 0.03 ^{c}	8.69 ± 0.01 ^{b}
FY8	7.41 ± 0.02 ^{b}	6.30 ± 0.09 ^{c}	6.60 ± 0.02 ^{f}	8.74 ± 0.01 ^{a}
PY9	7.23 ± 0.03 ^{c}	6.30 ± 0.02 ^{c}	7.53 ± 0.02 ^{b}	8.14 ± 0.01 ^{e}
PY10	7.30 ± 0.04 ^{c}	6.69 ± 0.12 ^{b}	7.69 ± 0.01 ^{a}	7.70 ± 0.01 ^{f}

CFU—colony-forming units, TNMB—total number of mesophilic bacteria, LAB—lactic acid bacteria count, SEM—standard error of the mean. Different lowercase letters within columns indicate significant differences in mean values ($p < 0.05$).

The total number of mesophilic bacteria (TNMB) ranged from 6.60 ± 0.02 $\log_{10}$ CFU·g^{-1} (FY8) to 7.69 ± 0.01 $\log_{10}$ CFU·g^{-1} (PY10), values that fall within those reported (5.18–9.27 $\log_{10}$ CFU·g^{-1}) by Demir et al. [99]. All yogurt samples exhibited an increase in total mesophilic bacteria counts during the storage period, rising from 7.70 $\log_{10}$ CFU·g^{-1} to 8.69 $\log_{10}$ CFU·g^{-1} (Table 9). Jańczuk et al. [100] similarly reported an increase in the TNMB count during yogurt storage, which is considered a sign of post-processing contamination or spoilage [101], as LAB typically decrease due to high acidity and cold temperatures [102].

The presence of total coliform bacteria was noted in the case of sample FY1 (1.30 ± 0.01 $\log_{10}$ CFU·g^{-1}), FY2 (1.60 ± 0.04 $\log_{10}$ CFU·g^{-1}), FY4 (1.69 ± 0.02 $\log_{10}$ CFU·g^{-1}), and PY10 (1.69 ± 0.01 $\log_{10}$ CFU·g^{-1}) during the validity period and at the end of the validity period (sample FY1 (1.30 ± 0.02 $\log_{10}$ CFU·g^{-1}), FY2 (1.60 ± 0.03 $\log_{10}$ CFU·g^{-1}), FY3 (1.95 ± 0.01 $\log_{10}$ CFU·g^{-1}), FY4 (2.17 ± 0.01 $\log_{10}$ CFU·g^{-1}), FY8 (2.20 ± 0.01 $\log_{10}$ CFU·g^{-1}), PY9 (3.01 ± 0.01 $\log_{10}$ CFU·g^{-1}), and PY10 (3.01 ± 0.01 $\log_{10}$ CFU·g^{-1})). Total coliform bacteria were not present in samples of commercial yogurt FY3, FY8, and PY9 before the expiration date, but after expiration, they were identified in these samples containing bananas, cherries, and plain yogurt with 2% fat. At the same time, FY5, FY6, and FY7 (yogurts with berries and strawberries, blackberries and raspberries, as well as raspberries) were the only samples that did not show total coliform bacteria either during the shelf life or after expiration.

Microbiological standards for yogurt usually require that the number of coliforms be ≤10 CFU/mL or g, with the strict absence of *Escherichia coli* to ensure safety [103,104]. The FY1, FY2, FY4, and PY10 yogurt samples exceed this value during the validity period, probably due to post-pasteurization contamination [105]. Some studies demonstrated that common coliform bacteria survive and even grow under the conditions found in commercial yogurt products [104]. Wolkaro et al. [62] reported total coliform counts of 3.72 $\log_{10}$ CFU/mL and 2.81 $\log_{10}$ CFU/mL for traditionally and commercially produced yogurts, respectively, indicating potential deficiencies in hygiene practices and sanitary conditions during and after production. Of all yogurt samples analyzed in the present study, only 60% met safety standards for total coliform bacteria before the expiration date, and only 30% were safe to consume after the expiration date. The presence of coliform bacteria in some commercial yogurts highlights the inconsistent implementation of good manufacturing practices, underscoring the need for enhanced hygiene measures and stricter quality control in certain production facilities to ensure food safety and protect public health. Storage conditions are critical for maintaining the quality of yogurt. Temperature fluctuations can significantly increase the impact on yogurt quality and allow microorganisms to develop [106]. Coliform bacteria can survive cold storage (if they are introduced as post-pasteurization contaminants) [107], allowing them to multiply after the expiration date of yogurts.

Escherichia coli was detected only in two of the analyzed samples, PY9 and PY10 (2.71 ± 0.01 and 2.98 ± 0.01 $\log_{10}$ CFU·g^{-1}), at the end of the validity period. Govaris et al. [108] reported that *Escherichia coli* was no longer detectable after 7 days of storage at 4 °C, whereas Tosun et al. [109] found that, in yogurts inoculated with *E. coli*, microbial inactivation occurred after 13 days. In contrast, Lee and Chen [110] observed the survival of different *E. coli* strains in yogurt for 14 to 18 days, and Cirone et al. [111] reported a similar extended persistence of *E. coli* in yogurt for up to 20 days, demonstrating the bacteria's ability to tolerate acidic conditions. Tirloni et al. [13] observed that *Escherichia coli* (starting concentration of 2 $\log_{10}$ CFU·g^{-1}) was present in plain and strawberry-flavored yogurt samples until days 26 and 23, respectively. The inoculation of yogurt with *Escherichia coli* at a concentration of 5 $\log_{10}$ CFU·g^{-1} showed that the concentration decreased steadily to

the detection limit, but *Escherichia coli* was still present in the plain yogurt samples until day 47 [13]. This microorganism is capable of surviving under acidic conditions at 4 °C for extended periods. The growth of *Escherichia coli* in yogurt can be inhibited by the lactic acid produced by lactic acid bacteria [112].

Enterobacter spp. and *Enterococcus* spp. were absent in all types of yogurt samples. All yogurt samples tested were negative for *Listeria* spp. and *Salmonella* spp.

At the European level, the quality and microbiological safety of yogurts is regulated by Regulation (EC) No. 2073/2005 [113], which is directly applicable in Romania. It states that yogurt, which is a ready-to-eat dairy product, must comply with mandatory safety criteria, the absence of *Salmonella* spp. and *Listeria monocytogenes* in 25 g of product. All yogurt samples analyzed in this study both before and after the expiration date met these criteria (the two species were not identified). According to the Microbiological Specifications for Foods [114], *Enterococcus* spp. and *Enterobacter* spp. (Enterobacteriaceae), which represent hygiene indicators may have a limit between $\leq 10^2$–10^3 CFU/g and $\leq$10–10^2 CFU/g, respectively. These two species were absent in all yogurt samples both before and after expiration. Another hygienic indicator is *Escherichia coli,* which, according to [114], can have a limit of $\leq$10–10^2 CFU/g or absence. This species was not found in any yogurt sample before expiration, and after expiration, it was found only in plain yogurts, exceeding the above limit. No *Escherichia coli* was identified in fruit yogurts after their expiration. Total coliform bacteria is a hygienic indicator that can have a limit of $\leq$10–10^2 CFU/g according to [114]. In other standards, it is set at $\leq$10 CFU/mL or g [115]. The total limit of aerobic mesophilic bacteria (process hygiene indicator) in yogurt is $\leq 10^7$–10^8 CFU/g according to [114], while the limit for lactic acid bacteria (technological indicator) is $\geq 10^7$ CFU/g [116] at the end of the shelf life to ensure the authenticity of the product, in accordance with the Codex Alimentarius Commission standards for fermented milk.

3.5. Principal Component Analysis

Principal component analysis (PCA) was conducted to elucidate the relation between physicochemical, textural, sensory and microbiological parameters of commercial yogurt samples before and after the expiration date (Figure 8).

Figure 8a illustrates the PCA results obtained for commercial yogurts before the expiration date. The highest eigenvalues of 7.18 were recorded by PC1 (representing 35.9% of the total variation), while PC2 recorded eigenvalues of 5.55 (representing 27.8% of the total variation). Samples FY2, FY5, FY6, and FY8 scored positive for both PC1 and PC2, while samples FY7 and PY10 scored negative for both PC1 and PC2. FY4 scored positively on PC1 and negatively on PC2, while FY1 and FY3 had a negative score on PC1 and a positive score on PC2. Physicochemical parameters like TA (0.187), TS (0.319), protein (0.121), fat (0.054), carbohydrates (0.297), DPPH (0.282), TPC (0.304), and WHC (0.271) had positive correlation on PC1, while pH (−0.213) and S (−0.271) had a negative correlation. Negative correlation on PC2 was determined for TS (−0.018), protein (−0.260), DPPH (−0.240), TPC (−0.166), WHC (−0.087), pH (−0.296), and TA (−0.050). Color parameters (YI (−0.128), WI (−0.276), and h (−0.009)) had a negative correlation on PC1, while a positive correlation on PC2 was obtained for YI (0.272) and WI (0.014). Microbiological parameters (LAB and TNMB) showed a negative correlation with both PC1 (−0.245 and −0.276) and PC2 (−0.024 and −0.096), while texture attributes (hardness and viscosity) showed a positive correlation on PC1 (0.055 and 0.070) and a negative correlation on PC2 (−0.382 and −0.024). Sensory attributes had a positive correlation on both PC1 and PC2. After the expiration date (Figure 8b), PC1 had the highest eigenvalues of 8.26, followed by PC2 with 4.54. Overall, PC1 and PC2 explained 64% of the cumulative variance. The yogurt samples FY2, FY6, and FY8 exhibited positive scores on PC1 and negative scores on PC2,

whereas FY4 was the only sample displaying positive scores on both PC1 and PC2. The yogurt samples FY7, PY9, and PY10 exhibited negative scores on PC1 and positive scores on PC2, whereas FY1 and FY3 scored negatively on both PC1 and PC2. Most variables showed positive loadings on PC1, with the exceptions of fat (−0.062), syneresis (−0.212), YI (−0.237), WI (−0.233), and the sensory attributes. Meanwhile, most variables exhibited negative loadings on PC2, with the exceptions of protein (0.042), syneresis (0.152), pH (0.404), WI (0.215), h (0.200), hardness (0.079), viscosity (0.096), and LAB (0.163).

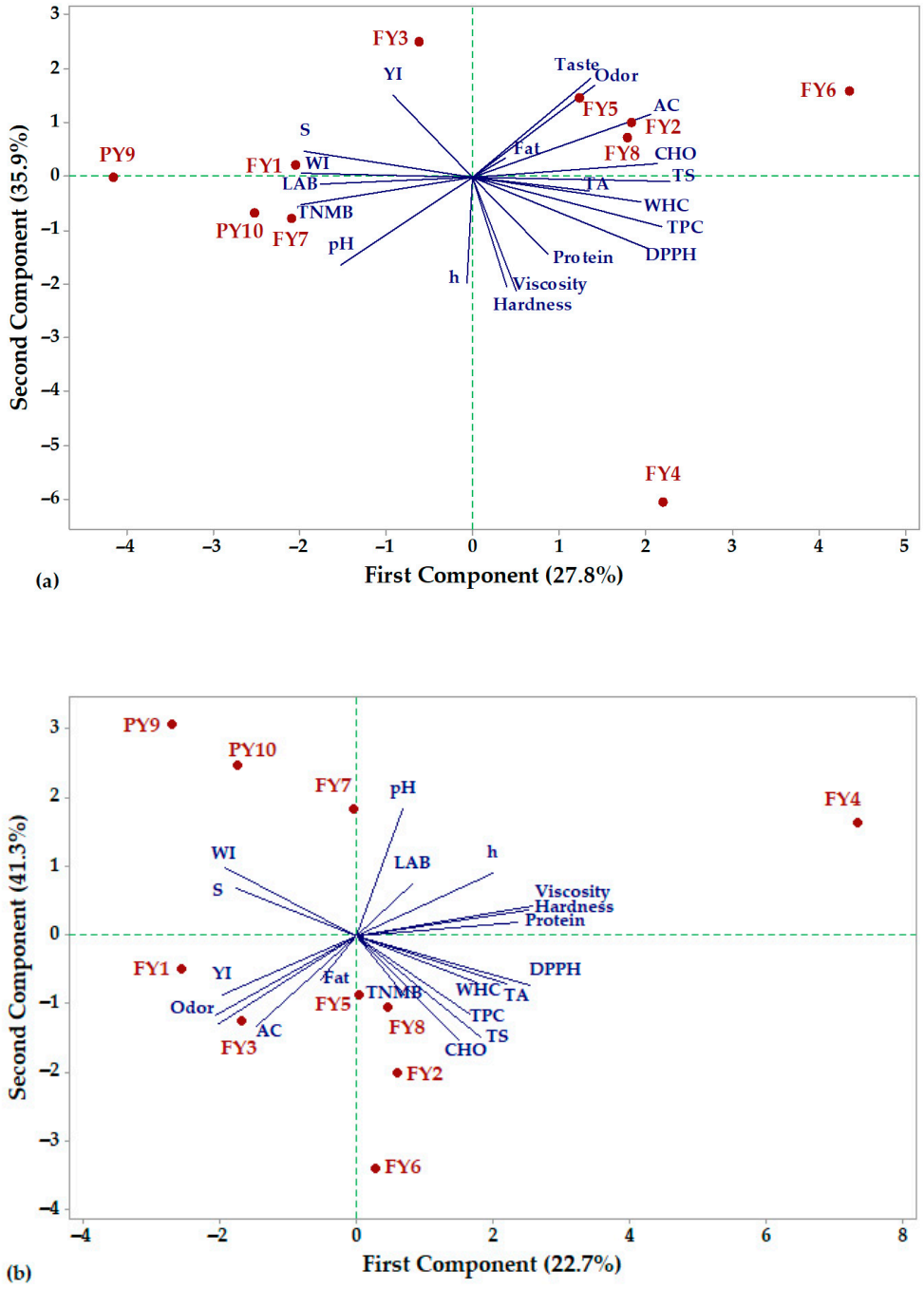

Figure 8. Principal component analysis biplot depicting the relationship between parameters of commercial yogurt samples (**a**) before and (**b**) after the expiration date (AC—appearance and consistency; CHO—carbohydrates; h—hue angle; LAB—lactic acid bacteria; TA—titratable acidity; TPC—total polyphenol content; TNMB—total number of aerobic mesophilic bacteria; TS—total solids; S—syneresis; WHC—whey-holding capacity; WI—whiteness index; YI—yellowness index).

3.6. Pearson Correlation

The Pearson correlation was calculated using the JASP 0.96.0 software, and the results are presented in Figure 9. The results showed that there is a perfect negative correlation between syneresis and water-holding capacity due to the structural rearrangement and contraction of the casein network, which expels water (whey separation) that would otherwise be immobilized within the gel structure [88]. A very strong negative correlation was observed between carbohydrates and whiteness index (carbohydrate-rich ingredients such as fruits impart color to the yogurt matrix, thus reducing light reflectance and decreasing whiteness index), DPPH, and whiteness index (samples with higher antioxidant activity are often associated with bioactive phenolic compounds and tend to have lower whiteness), total phenolic compounds and whiteness index (phenolic compounds possess inherent coloration, decreasing whiteness index as phenolic concentration increases), pH, appearance and consistency (lower pH indicates that yogurts tend to have improved visual and textural qualities), pH and odor (low pH increases the generation of volatile compounds responsible for the typical aroma of fermented dairy products). Carbohydrates account for a substantial portion of the total solids content in yogurt [117]; consequently, a very strong positive correlation was found between these two variables. A very strong positive correlation was observed between total solids content and total phenolic compound content. Yogurt samples with higher solids content likely retain a higher concentration of bioactive compounds, including phenolic compounds. This may be due to the addition of fruit purees, plant extracts, or fortifying agents, which increase both the solids content and the concentration of phenolic compounds [118]. The very strong positive correlation between DPPH radical scavenging activity and total phenolic content indicates that the latter are the main factors contributing to the antioxidant capacity of yogurt [43]. Phenolic compounds donate hydrogen atoms or electrons to neutralize free radicals, which is quantitatively reflected in DPPH assays. A positive correlation between the whitening index (WI) and the total number of aerobic mesophilic bacteria in yogurt often indicates that the proliferation of microorganisms (particularly lactic acid bacteria (LAB)) intensifies the whitening effect during storage. Microbial metabolism can influence the dispersion of milk proteins and fat globules, affecting light scattering properties and increasing perceived whiteness [119]. The observed strong positive correlation between hue angle and textural properties, such as hardness and viscosity, suggests an interaction between color and texture in yogurt. The structural integrity of the yogurt protein network influences the refraction and scattering of light, thereby affecting color perception. The strong positive correlation among sensory attributes—including appearance, texture, and odor—indicates a holistic relationship in consumers' perception of yogurt quality [48,49]. A visually uniform and esthetically appealing product often corresponds to a smooth texture and an olfactory profile perceived as characteristic of high-quality yogurt. These correlations highlight the integrative nature of sensory evaluation, in which visual and olfactory indices collectively inform product acceptability. A strong positive correlation between hardness and viscosity reflects the intrinsic physical relationship between these texture parameters. Both are influenced by the protein network, fat content, and total solids content of the yogurt [120].

After the expiration date of the yogurts, it was observed that the perfectly negative correlation between syneresis and WHC remained unchanged. Furthermore, very strong positive correlations were obtained (as in the first case, before the expiration date) between TS and CHO, DPPH and TPC, h and hardness, h and viscosity, AC and odor, and hardness and viscosity, as well as strong negative correlations between CHO and WI, DPPH and WI, and TPC and WI. However, very strong positive correlations were also found between TS and DPPH (a higher total solids value contributes to stronger antioxidant activity), TS and TA (a higher total solids value provides substances for acid production), protein and

TA (after expiration, protein may be partially hydrolyzed, conducting to higher acidity), protein and viscosity (some protein denaturation can be correlated with higher viscosity), DPPH and hardness, DPPH and viscosity (antioxidant molecules can indirectly affect the yogurt structure), and odor and YI (biochemical reaction can intensify yellow coloration and generate volatile compounds altering odor), while strong negative correlations were determined between TS and WI (a higher total solids value during storage can reduce whitening index). These results highlight the interaction between composition, residual fermentation, and storage-induced biochemical changes in determining yogurt quality after expiration.

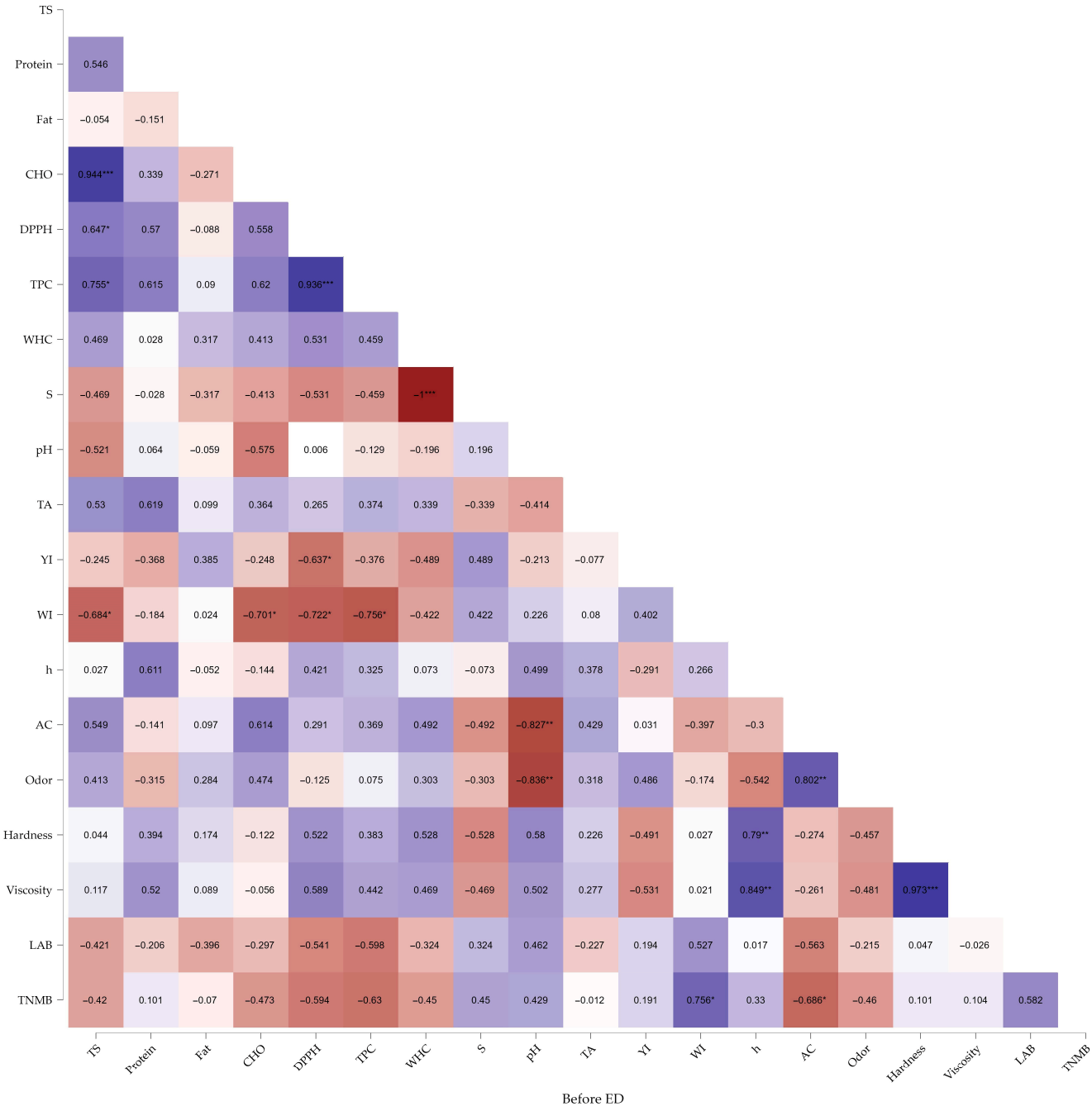

Figure 9. *Cont.*

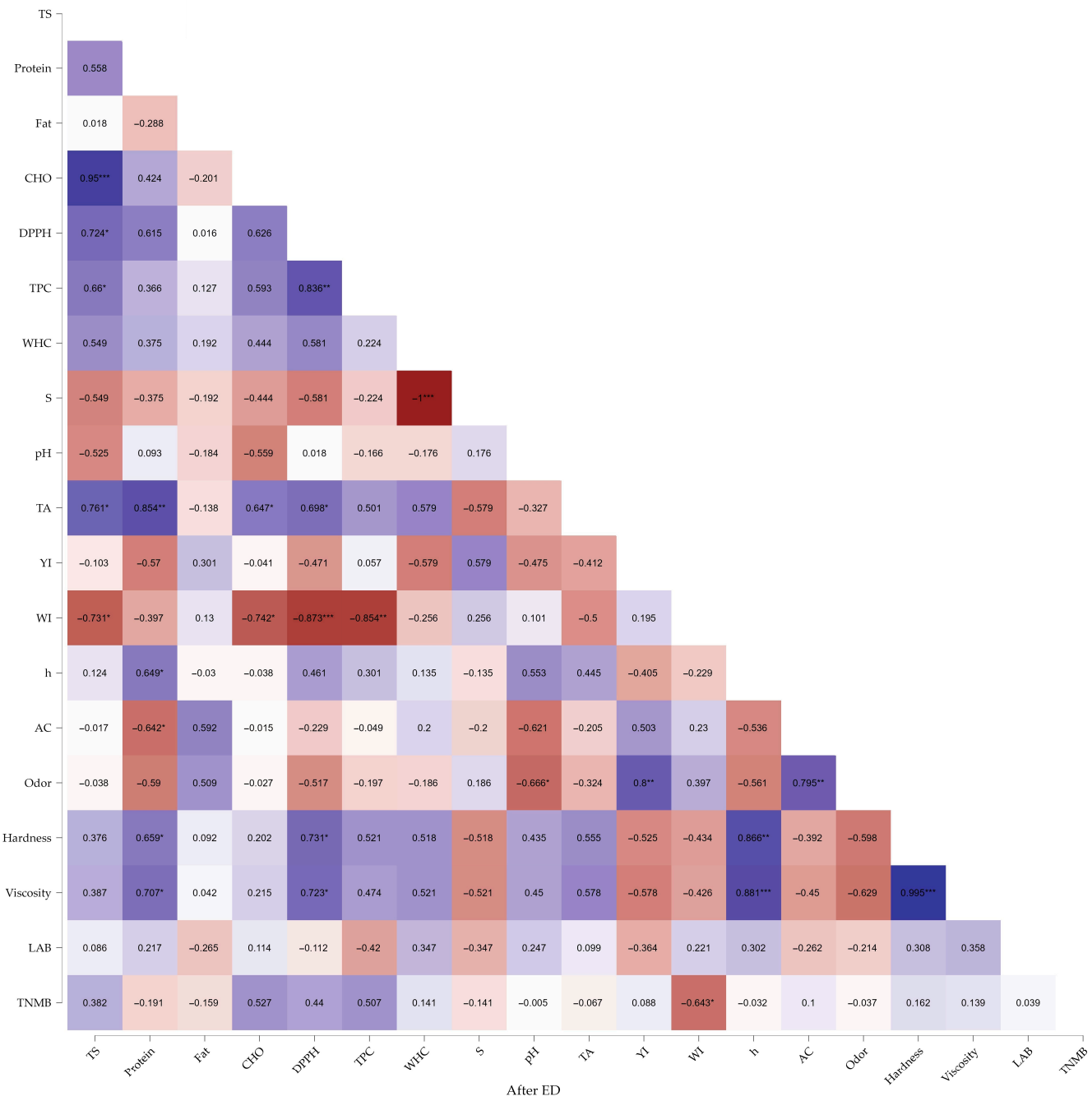

Figure 9. Pearson correlation heatmap (blue colors for positive and red colors for negative correlation). ED—expiration date. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4. Conclusions

Commercial fruit yogurts exhibited changes in physicochemical, textural, sensory, and microbiological properties beyond the stated expiration date, with the magnitude of these changes being highly sample-dependent. Fruit addition generally improved water-holding capacity, hardness, viscosity, cohesiveness, and adhesiveness due to fiber, pectin, and polyphenol interactions with milk proteins, though some yogurts experienced decreased springiness, gumminess, or chewiness over time. Several products retained acceptable sensory quality and probiotic levels of lactic acid bacteria, along with significant total phenolic content and antioxidant activity, indicating that both functional and organoleptic properties can be preserved post-expiration, suggesting that not all yogurts experienced a pronounced quality loss immediately after the expiration date. At the same time, increases

in acidity and syneresis, together with the detection of total coliforms and Escherichia coli in some samples, highlight potential safety risks. Overall, the post-expiration quality and safety of commercial fruit yogurts are strongly influenced by formulation and fruit type, underscoring the importance of cautious, product-specific evaluation while acknowledging that certain yogurts may still maintain beneficial characteristics beyond the labeled shelf life. The results showed that berry yogurts may exhibit improved microbiological stability at the end of the shelf life, possibly due to the presence of bioactive compounds with antimicrobial properties. However, consumption after the expiration date cannot be universally recommended without detailed studies. The use of yogurts after the expiration date can only be considered under controlled conditions and for products that demonstrate verified microbiological safety.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, and further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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