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Pumpkin Pomace Powder as a Bioactive Powder Ingredient for Whey Cheese Production

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Abstract: Pumpkin, a nutritious and economical product with health benefits, is harvested worldwide. This study investigates the feasibility of incorporating fiber-, carotenoid-, and mineral-rich pumpkin pomace powder (PPP), a by-product of pumpkin processing, into whey cheese to enhance its nutritional profile without affecting consumer acceptability. The cheese was enhanced with varying concentrations of PPP (3% and 6%), and each variant was analyzed for its nutritional content, minerals, phytochemicals, color, and sensory properties. The results demonstrate that PPP addition increased the phytochemicals (45.44–82.83 mg GAE/100 g dw) and antioxidant activity (470.25–977.41 μmol TE/g dw) of the enriched cheese. The findings show that the addition of PPP improved the nutritional, color, and minerals of the enhanced whey cheese. The sensory evaluation indicates that with up to a 3% addition of PPP, the obtained cheese was well-received by consumers, who appreciated the subtle changes in flavor and the enhanced color of the product. The structural analysis reveals that including PPP improved the moisture retention of the cheese, contributing to a creamier texture, which is a desirable attribute in cheese. The study concludes that PPP can be effectively used to enrich cheese, offering a phytochemical-enriched cheese that caters to health-conscious consumers while also addressing the issue of food waste in the pumpkin processing industry.

Keywords: pumpkin pomace powder; carotenoids; antioxidants; natural ingredients; value-added products

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1. Introduction

Food waste represents a global problem, and the agri-food sector is among the most important and responsible in this context since the by-products from fruit and vegetable processing are often discarded in landfills despite containing numerous bioactive molecules. Various studies emphasize that by-products of fruits and vegetables might serve as a rich reservoir of bioactive substances [1,2]. Different by-products derived from vegetables have been shown to include a significant abundance of carotenoids, fibers, polyphenols, vitamins, tocopherols, and other microelements. The by-products not only come at a cost to the environment but, more significantly, they have untapped potential for nutritional fortification. The functional qualities of these substances have the potential to enhance

foods and meet consumer preferences for food that contains fewer synthetic components, is more natural, and is abundant in beneficial nutrients [1].

Pumpkin (*Cucurbita* spp.) is a nutrient-rich vegetable, high in vitamins, minerals, and bioactive compounds, particularly β-carotene, a precursor to vitamin A, essential for vision, skin health, and immune function. It also provides antioxidants, vitamins C and E, potassium, and fiber [3].

From 1994 to 2017, global pumpkin production exceeded 27 million tonnes [4], with Asia, particularly China and India, leading as the top producers. In 2020, China produced 7.43 million tonnes, followed by India with 5.11 million tonnes. In Europe, EU member states contributed 2.41 million tonnes, representing 49.39% of total production [5].

Despite the widespread use of pumpkins, a considerable amount of pumpkin material is relegated to waste during the processing of pumpkins for various food products. The processing of pumpkins into puree, juice, candied fruit, and pumpkin seed oil generates a substantial quantity of by-products. The by-products generated during the processing of pumpkins, including shells, seeds, and husk, are typically disposed of. The rapid reproduction of microbes and subsequent environmental degradation is attributed to the ample moisture present in these waste materials [6]. The components of pumpkins resulting from processing are the pulp (72–76%), peel (2.6–16%), and seeds (3.1–4.4%). Pumpkin wastes contain a significant amount of bioactives, such as carotenoid compounds. The waste that consists of the fibrous pulp and carotenoids constitutes pumpkin pomace. Pumpkin pomace, generated by juice extraction, is a significant agro-food waste in Romania. This particular vegetable waste is widely recognized for its substantial content of polyphenolic chemicals, which possess a significant antioxidant capacity, as well as nutritional fibers [7].

It is necessary to implement strategies and initiatives that promote the recovery of solid waste at its source, resulting in the generation of valuable components in subsequent stages, all within the framework of a sustainable economic model, namely, a circular economy [8].

Traditionally seen as an agricultural by-product with limited applications, pumpkin pomace is, in fact, rich in dietary fibers and phytochemicals, particularly potent antioxidants, such as β-carotene. These compounds are crucial for combating oxidative stress in the body, which can lead to inflammation and is linked to a myriad of health issues, including arthritis, cardiovascular diseases, and age-related macular degeneration [9]. Carotenoids are widely recognized for their vibrant red, orange, and yellow hues, predominantly found in fruits and vegetables, which play a significant role in imparting appealing tastes to many food and beverage products [10]. The food industry has utilized pumpkin by-products as a natural pigment and a nutritious fiber source. Pumpkin powders find application in several bakery items, including bread, pies, and cakes [11]. Kuchtová et al. [12] developed pumpkin pomace-incorporated crackers and reported that pumpkin pomace is a valuable source of ash and dietary fibers that can be used as a useful ingredient in baked foods.

Limited research has been conducted on using pumpkin pomace or powder to enhance the flavor and nutritional composition of dairy products [13–15]. El-Dardiry et al. [15] obtained functional beverages enriched with pumpkin pulp that showed significant levels of total carbohydrates, fibers, total phenolic components, and antioxidant activity.

Dairy products are suitable complex food systems that can be utilized to evaluate the qualities of natural food colorants. This is because phenolics and other components can interact with one another, which can decrease their abundance and limit their health advantages. Cheese, a highly versatile and globally popular dairy product, presents an excellent opportunity for innovation in both flavor and nutritional content [16].

Whey cheese is a moist, soft cheese produced from milk, cheese whey, or a combination of both. Fresh whey cheese possesses a subtle and delicate flavor with hints of nuttiness. Producing whey cheese is a cost-effective method of utilizing cheese whey [17,18].

Recent trends in the food industry have emphasized the incorporation of vegetable and fruit powders into cheese as a strategy for enhancing its nutritional properties and sensory profiles. Food by-product powders and extracts are typically employed to enhance shelf life and nutritional value (phenolic compounds, reduced fat, and increased fiber content) with-

out risking safety standards or sensory attributes and acceptance among consumers [19]. Other research mostly concentrates on cheese fortification through the direct integration of various by-products. Dried powdered mango peel was investigated by Serna-Cock et al. [8] for its potential in cheese production as a source of dietary fiber and to augment antioxidant activity. Mango peel or kernels can serve as a substitute for fat in cheese. The substitution of fat with mango kernels in Gouda cheese enhances its taste attributes, total phenolic content, DPPH free radical scavenging activity, total flavonoids, and trans fatty acid concentrations. Roila et al. [20] examined the application of a polyphenolic extract sourced from olive oil by-products (250 and 500 µg/mL) to enhance the storage durability of "Fior di latte" cheese during preservation. The results indicate that the incorporation of the extract markedly enhanced the overall phenolic content of the cheese, hence augmenting its functional value and health-promoting attributes. Lucera et al. [21] discovered that cheese fortified with grape pomace powder demonstrated a markedly greater enhancement in total phenolic content, flavonoids, and antioxidant activity relative to the control cheese. Additional natural biosources, including broccoli, artichokes, corn bran, and tomato peel, were also identified to enhance these actions. Marchiani et al. [22] noted that incorporating grape pomace powders (Barbera and Chardonnay) into semi-hard cheeses (Italian Toma-like) at a concentration of 1.6% (*w*/*w*) markedly enhanced their phenolic content, radical scavenging activity, and antioxidant activity. Also, the integration of tomato powder enriches cheese with lycopene, known for its anti-inflammatory and antioxidant properties, while grape powder can enhance the polyphenol content [8]. Similarly, PPP is expected to enhance the fiber content and antioxidant capacity of cheese, potentially making it a healthier choice for consumers.

Among these, pumpkin pomace powder (PPP) emerges as a particularly promising additive due to its rich nutritional profile and potential health benefits [23]. Pumpkin fiber could also improve the physical quality, nutritional value, flavor, and textural properties of enhanced products [24]. From a sustainability perspective, using pumpkin pomace in cheese aligns with global initiatives to reduce food waste and promote the use of whole-plant ingredients [24]. Due to their high bioactive content and potential nutritional value, agricultural and food by-products hold considerable importance in the development of new, sustainable, functional foods and the production of animal feed [25].

This research aims to explore the feasibility of incorporating PPP into whey cheese formulations during the production process, examining its impact on nutritional enhancement, phytochemicals, color, texture, microstructure properties, sensory qualities, and consumer acceptability. By integrating this by-product into whey cheese production, this study addresses both an environmental concern and consumer demand for healthier, innovative dairy products. Such an avenue is in tune with global efforts to curb food waste and embrace a more circular economy in the food system.

2. Materials and Methods

2.1. Reagents and Chemicals

Folin–Ciocalteu reagent, hexane, acetone, methanol, ethanol, 6-hydroxy 2,5,7,8 tetramethylchromane-2-carboxylic acid (Trolox), [2,20 azinobis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt] (ABTS), gallic acid, sodium acetate solution, aluminum chloride, and sodium carbonate were obtained from Sigma Aldrich Steinheim (Darmstadt, Germany).

2.2. PPP Preparation

In August 2023, a quantity of 10 kg of fully mature pumpkins (*Cucurbita maxima* var. *Gold Nugget*) was acquired from a nearby supermarket in Iasi, Romania. These pumpkins were thereafter stored at a temperature of 4 °C until they were ready for processing.

The pumpkins underwent a process of sorting, followed by washing with distilled water, before shredding and subsequent compression. The peel and seeds were isolated from the pulp by hand, rinsed with purified water, and subsequently blotted on paper towels. The pumpkin pomace was obtained by extracting the pumpkin juice using a

Bosch MES3500 device manufactured by Philips Consumer Lifestyle B.V. in Drachten, The Netherlands. Before conducting the freeze-drying experiment, the pumpkin pomace was stored in plastic bags at a temperature of −20 °C. The pumpkin pomace was subjected to freeze-drying for 48 h at a temperature of −42 °C, with a pressure of 0.10 mBar. The freeze-drying process was carried out using a freeze-dryer (BIOBASE BK-FD10T equipment, Jinan, China) with a moisture content of 7.0%. The resulting PPP was pulverized in a grinding mill for 50 s, with a mean particle diameter of 450 µm. It was then stored at room temperature in an airtight glass jar until it was analyzed. Before the cheese was supplemented, the PPP was subjected to decontamination using sterilization with a UV lamp.

2.3. Extraction of Phytochemicals from PPP

For the extraction of the biologically active compounds from the pumpkin pomace, a method using ultrasound, as described by Sharma et al. [26], was used, with slight modifications. Briefly, 1 g of PPP was solubilized with 10 mL of 70% ethanol solution (for polyphenol and flavonoid extraction) and another 1 g with 10 mL of hexane/acetone (3:1, *v*/*v*). A sonication bath (Elmasonic S 180 H, Elma, Germany) at 30 °C for 30 min was utilized to sonicate the samples. A digital control system was included in the ultrasonic bath to regulate the sonication time, temperature, and frequency. The extraction procedure was conducted with a consistent frequency of 40 kHz and a power output of 100 W. Cold water was introduced to maintain a constant temperature of 40 ± 5 °C in the ultrasonic bath. The supernatant obtained was collected and subjected to centrifugation at 6000 rpm and 10 °C for 10 min. The extraction process was repeated three times, and the liquid portion was thereafter concentrated under reduced pressure at a temperature of 40 °C until it reached the state of dryness (AVC 2–18, Christ, UK), followed by phytochemical characterization.

2.4. Phytochemical Profile of the PPP Extract

2.4.1. Determination of Total Carotenoids and β-Carotene

A spectrophotometric approach (with an Analytik Jena Specord 210 Plus (UV-Vis spectrophotometer, Jena, Germany)) was employed to determine the β-carotene and total carotenoid contents [27]. A quantity of 2 mL of extract (100 mg/mL) solubilized in a solution consisting of a 3:1 ratio of n-hexane to acetone was introduced into the UV quartz cuvette. The photoluminescence was quantified at wavelengths of 470 nm and 450 nm. The contents are expressed in mg/100 g dry weight (dw). The quantification of carotenoids was determined using the following Equation (1):

$$\text{Contents (mg/100 g dw)} = \frac{\text{A} \times \text{Mw} \times \text{Df}}{\text{Ma} \times \text{L} \times \text{m}} \quad (1)$$

where A is the absorbance of the sample, Mw is the molecular weight, Df is the sample dilution rate, Ma is the molar absorptivity for β-carotene in n-hexane (2590 L mol^{-1} cm^{-1}) and carotenoids in n-hexane (2500 L mol^{-1} cm^{-1}), m is the mass/weight of the concentrated extract, and L is the cell diameter of the spectrophotometer (1 cm).

2.4.2. Determination of Total Flavonoid Content

The total flavonoid content values of the extract were determined using the aluminum chloride spectrophotometric technique [27]. A solution was prepared by combining 0.25 mL of the extract with 2 mL of distilled water and 0.075 mL of 5% sodium nitrite ($NaNO_2$). The liquid was supplemented with 0.15 mL of aluminum chloride ($AlCl_3$) after 5 min. The mixture was subjected to measurement using an Analytik Jena Specord 210 Plus (UV-Vis spectrophotometer), Germany, at a wavelength of 510 nm after the addition of 0.5 mL of a 1 M solution of sodium hydroxide (NaOH) six minutes later. The findings are presented in the form of milligrams of catechin equivalents per gram of dw (mg CE/g dw), utilizing a calibration curve ranging from 0.1 to 0.5 mg/mL, with an R^2 value of 0.997.

2.4.3. Determination of Total Polyphenol Content

The total polyphenol content values of the extract were determined using the Folin–Ciocalteu method [27] with spectrophotometric analysis. Briefly, a volume of 200 µL of the extract was completely combined with 15.8 mL of distilled water and 1 mL of the Folin–Ciocalteu reagent. The mixture was supplemented with 3 mL of Na_2CO_3 20% after 10 min. The resulting combination was subjected to storage at ambient temperature in a dark environment for 60 min before being quantified using an Analytik Jena Specord 210 Plus (UV-Vis spectrophotometer), Germany, at a wavelength of 765 nm. The data were calibrated using a calibration curve (0.1–0.5 mg/mL, R^2 = 0.984) and represented as milligrams of gallic acid equivalents per gram of dw (mg GAE/g dw).

2.4.4. Determination of the Antioxidant Activity

A method using the ABTS+ radical was utilized according to the description provided by Xu et al. [28]. Production of the ABTS radical cation (ABTS+) involved the reaction of equal volumes of a 7 mM ABTS stock solution with 2.45 mM $K_2S_2O_8$. The resulting mixture was then left in the absence of light for 16 h before its use. Moreover, portions of a 1 mL solution of ABTS+ were diluted with 35 mL of ethanol to achieve an absorbance value of 0.700 ± 0.02 (A0) at a wavelength of 734 nm. A volume of 1800 µL of the ABTS+ solution and 200 µL of the extract solution (Af) was allowed to react for 2 h in a dark room before its absorbance at 734 nm was measured. The antioxidant activity of the extract was expressed in µmol Trolox equivalent (TE)/g dw based on the calibration curve. The radical scavenging activity was also expressed as the percentage of inhibition based on Equation (2):

$$\text{ABTS} + \text{scavenging activity } (\%) = \frac{\text{A0} - \text{Af}}{\text{A0}} \times 100 \quad (2)$$

2.5. Preparation and Characterization of PPP-Supplemented Whey Cheese

The functionality of enriched whey cheese was tested by utilizing PPP in two distinct ratios (3% and 6%). The experimental group (RCC) comprised whey cheese without the inclusion of powder. The selection of the 3 and 6% concentrations of PPP for fortifying the dairy product under investigation was based on a favorable sensory assessment conducted by panelists, as well as the optimal attributes in terms of visual appeal, consistency, flavor, and color.

The whey-type cheese was made using the whey derived from the manufacture of cheese.

Figure 1 depicts the technological flow of making cheese from whey. After normalizing the whey with citric acid to an acid value of 11° Thörner (ºT), it was heated to 60–65 °C, and whole milk with a 3.9% fat content was added to the mixture. The heating was stopped for five minutes at 72 °C to facilitate the albumin's degradation. Once the temperature reached 84–85 °C, the heating process was resumed, and 250 mL of DAIRSAL+ was added. Once the whey reached a temperature of 88–90 °C, the heating process was stopped, and the whey was further collected in special baskets to drain and cool. The cooled whey cheese was divided into three batches: RCC, RCPPP3, and RCPPP6. Then, the powder was incorporated and mixed (Figure 1). The product was then dosed and packaged in thermo-welded plastic cups and stored at a temperature of 4–6 °C.

The AOAC 2000 techniques [29] were employed to assess the physicochemical properties of the supplemented samples, including their moisture and dry matter contents, pH, protein, fat, carbohydrates, fiber, ash, salt, and energetic values.

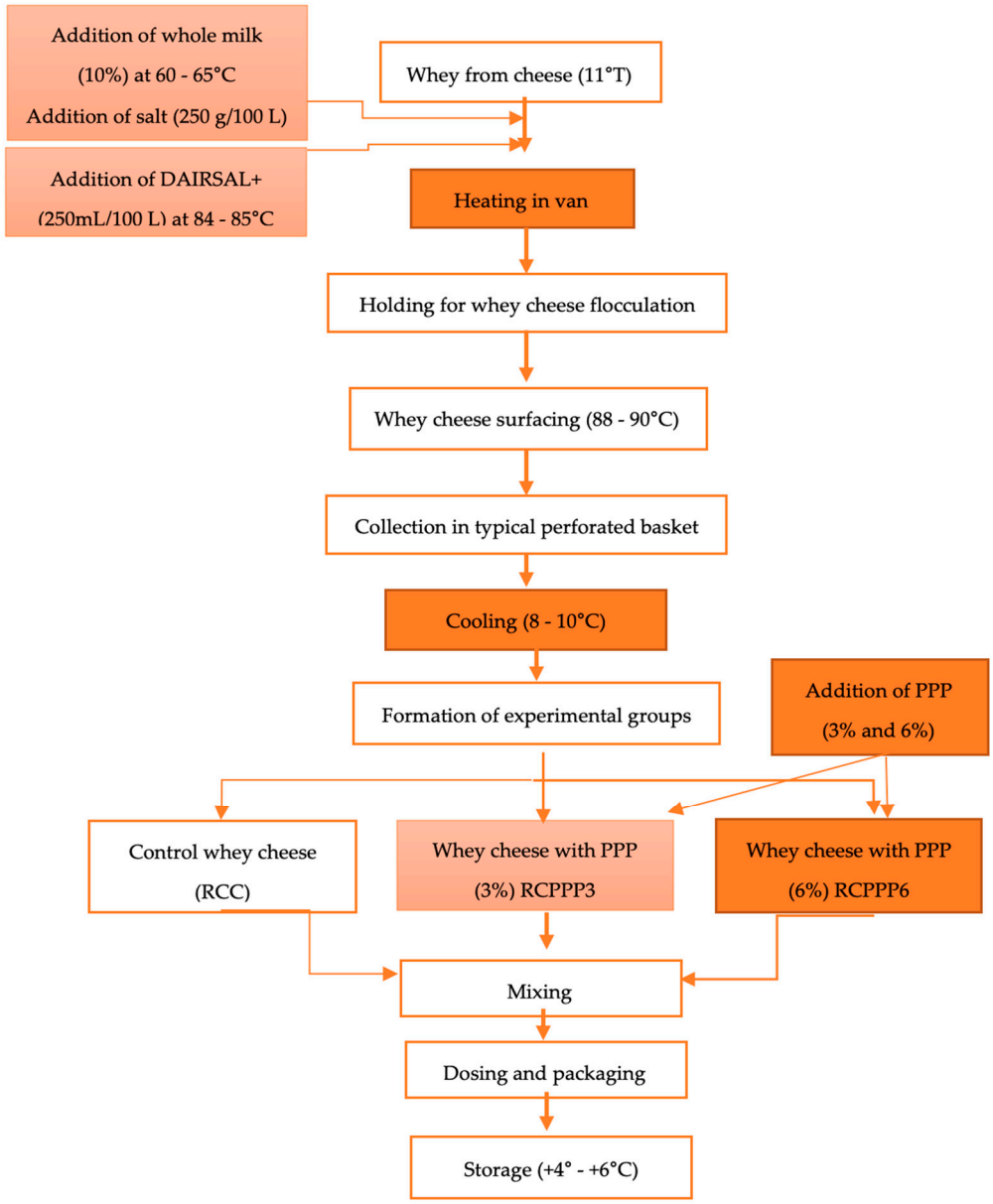

Figure 1. Flowchart of whey cheese production.

2.6. Characterization of Phytochemicals and Storage Stability of the PPP-Supplemented Whey Samples

The methodologies previously mentioned in Section 2.4 were employed to evaluate the total carotenoid, flavonoid, and phenolic contents and the antioxidant activity of whey cheese supplemented with PPP. To investigate storage stability, the samples were placed in light-resistant glass containers and maintained at a temperature of 4 °C for 21 days. Subsequently, changes in the phytochemical composition were noted.

2.7. Color Evaluation of PPP-Supplemented Whey Samples

The CIELAB attributes (L*, a*, and b*) were employed to assess the color of the pumpkin pomace and PPP-enriched samples using a MINOLTA Chroma Meter model CR-410 (Konica Minolta, Osaka, Japan), as outlined in Dag et al. [30]. The calculation of the chroma (C*), hue angle (H*), and total color difference (ΔE) parameters was performed as follows:

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

Hue angle (H*) = 180 + arctan(b*/a*) was also determined for quadrant II (−a*, +b*),

$$\Delta E = \sqrt{L^{*2} + a^{*^2} + b^{*2}}.$$

2.8. Textural Parameters of PPP-Supplemented Whey Samples

A Mark 10 ESM 300 texturometer (Johnson Scale Co., Inc., 36 Stiles Lane, Pine Brook, NJ, USA) equipped with a 7i-50 series digital dynamometer (with a measurement resolution of 0.05 N) was employed to assess the textures of the samples. The compression tests were conducted using a cylindrical probe, specifically, type TA4 (Johnson Scale Co., Inc., 36 Stiles Lane, Pine Brook, NJ, USA), which had a diameter of 38.1 mm and a height of 20 mm. The warp samples used for texture examination were cylindrical, measuring 30 mm in diameter and 40 mm in height. The texture tests were conducted by subjecting the warp samples to dual compressive stress using a cylindrical probe, resulting in the acquisition of a distinctive force-versus-time diagram. All texture tests were repeated three times.

2.9. Mineral Evaluation of PPP-Supplemented Whey Samples

A flame atomizer system was used to measure the mineral amounts of the samples using atomic absorption spectrometry (ContrAA 700, Analytik Jena, Jena, Germany). The results are given in mg/100 g dw.

Mineral content measurements (calcium, phosphorus, potassium, magnesium, zinc, iron, and sodium) of the raw plant material and cheese samples were conducted using a MiniWAVE Microwave digestion system (SCP Science, Baie-d'Urfé, QC, Canada) equipped with a 50 mL Teflon vial. One gram of the homogenized sample was measured and placed into a Teflon vial. The sample was then subjected to digestion using a mixture of nitric acid (HNO_3) and hydrochloric acid (HCl) in a ratio of 8:2. The digesting process was conducted under the specified parameters, which included a temperature of 180 °C, a digestion time of 50 min, and a microwave power of 1000 W. Following the cooling process, the sample was meticulously transferred into a 25 mL volumetric flask and subsequently diluted with ultrapure water until the desired concentration was reached. A blank sample was included in each digestion run, and each sample was made in triplicate.

2.10. Scanning Electron Microscopy Analysis

A scanning electron microscope (SEM) (Quanta 450, FEI, Thermo Fisher Scientific, Hillsboro, OR, USA) with an energy-dispersive X-ray detector (EDS) (EDAX, AMETEK Inc., Berwyn, PA, USA) was used to describe the morphological characterizations of the products. The EDS spectra study was undertaken using the TEAM version V4.1 system made by EDAX Inc. As a standard, an AlCu sample made of copper foil on an aluminum grid was used for calibration before the study. The samples were studied in a low-vacuum environment with a pressure of about 6.1×10^{-4} Pa. The acceleration voltage of the electrons was 15 kV, and the images were examined at a 500× (10 μm) magnification.

2.11. Sensory Evaluation of PPP-Supplemented Whey Samples

A group of twenty untrained tasters evaluated the sensory attributes of the enriched cheese samples. The panel members were provided with information regarding the overarching objective of the study, as well as the requisite protocols for managing personal data. Participants were given informed consent papers that explicitly detailed the voluntary nature of their involvement, their right to withdraw at any point, and the confidentiality of their information. The participants were instructed to rate a total of 11 descriptors, encompassing attributes such as visual appearance, sectional appearance, odor, scent, hardness, adhesiveness, color, taste, chewability, aftertaste, and overall evaluation. The testers allocated a grade to each attribute using a seven-point hedonic scale, with 1 being extremely low and 7 representing extremely high. The analysis was conducted in compliance with the specifications given in ISO 13299 [31].

2.12. Statistical Analysis

Three measurements were conducted in duplicate, and the mean results were calculated together with their corresponding standard deviations. To detect notable disparities, the experimental data underwent one-way analysis of variance (ANOVA) following the completion of normality and homoscedasticity tests. Post-hoc analysis was conducted using the Tukey method with a 95% confidence interval. A significance level of $p < 0.05$ was used to determine statistical significance. Minitab 18 software was utilized to conduct the statistical analysis. Principal components analysis (PCA) was conducted on the descriptive sensory data using XLSTAT (Trial Version 2024, Addinsoft, Paris, France).

3. Results and Discussion

3.1. Phytochemical Characterisation of PPP

The phytochemical analysis of pumpkin pomace extracts was conducted using spectrophotometric methods, and the results are presented in Table 1. The extracts exhibited a total carotenoid content of 33.02 ± 0.15 mg/100 g dw, a β-carotene content of 29.71 ± 0.09 mg/100 g dw, a total flavonoid content of 134.12 ± 0.14 mg CE/100 g dw, and a total polyphenolic content of 269.15 ± 0.16 mg GAE/100 g dw. The extracts also showed an antioxidant activity of 1365.36 ± 10.12 µmol TE/g dw and an inhibition of 83.31 ± 0.59%. The plant's anti-radical capability was related to its high concentration of phenolic chemicals, particularly flavonoids, which are the main secondary metabolites.

Table 1. Global phytochemical characterization of PPP.

Parameter	PPP
Total Carotenoids, mg/100 g dw	33.02 ± 0.15
β-caroten (mg/100 g dw)	29.71 ± 0.09
Total Flavonoids, mg CE/100 g dw	134.12 ± 0.14
Total Polyphenols, mg GAE/100 g dw	269.15 ± 0.16
Antioxidant Activity, µmol TE/g dw	1365.36 ± 10.12
Inhibition, %	83.31± 0.59
L*	76.20 ± 0.13
a*	8.63 ± 0.09
b*	42.29 ± 0.05
Moisture (%)	8.85 ± 0.01
Ash (%)	6.68 ± 0.01
Protein (%)	11.12 ± 0.04
Carbohydrates (%)	72.74. ± 0.04
Fat (%)	0.61 ± 0.02
Total Dietary Fiber (%)	43.50 ± 0.02
Calcium (Ca, mg/100 g)	23.95 ± 0.02
Phosphorus (P, mg/100 g)	23.09 ± 0.03
Potassium (K, mg/100 g)	53.02 ± 0.07
Magnesium (Mg, mg/100 g)	94.37 ± 0.03
Zinc (Zn, mg/100 g)	3.74 ± 0.11
Iron (Fe, mg/100 g)	11.25 ± 0.04
Sodium (Na, mg/100 g)	48.99 ± 0.01

The acquired results are consistent with the data provided in other investigations. Hussain et al. [32] reported a total carotenoid content of 35.2 ± 0.49 mg/100 g powder and β-carotene of 6.18 ± 0.04 mg/100 g powder for pumpkin pulp powder. Also, pumpkin pulp was reported to have total polyphenols of 134.59 ± 1.24 mg GAE/100 g powder and total flavonoids of 77.11 ± 0.63 mg CE/100 g powder. The total carotenoid values of extracts obtained from two different kinds of *C. maxima* varied between 16.21 µg/g of oil extracts obtained using a conventional extraction method and 34.94 µg/g of oil extract obtained through microwave-assisted extraction. Additionally, the total carotenoid values increased to 38.03 µg/g of oil extract obtained through ultrasound-assisted extraction utilizing corn oil [26]. In contrast, Salami et al. [33] reported carotene concentrations of

11.48 mg/100 g extract (specifically, pumpkin peel extract) obtained using supercritical fluid extraction and 15.22 mg/100 g extract, respectively. Sharma and Bhat [26] established DPPH (1,1-diphenyl-2-picrylhydrazyl) % inhibition values ranging from 55.95% to 93.53% for two pumpkin varieties of the *C. maxima* species using an ultrasound assisted-extraction method. The *Cucurbita* spp. peel extracts exhibited ABTS values ranging from 2.470 to 4.524 µg TE/g dw and DPPH values ranging from 0.947 to 3.333 µg TE/g dw [34].

The PPP exhibited color attributes of 76.20 for the L* value, 8.63 for the a* value, and 42.29 for the b* value. According to the color indices, the powder was found to be located in the first quadrant (+a*, +b*). Other authors have noted a significant range of variation in the colorimetric results. In their study, Pinna et al. [35] examined the characterization of different species of pumpkin waste, specifically the peel and pulp. They reported the following results for the pulp of the Mantovana pumpkin (*C. maxima*): 51.67 ± 0.58 for L*, 6.67 ± 0.58 for a*, and 42.67 ± 0.58 for b*. Sharma and Bhat [26] observed significantly divergent values for the peel extract of two kinds of *C. maxima*. The results of color parameters (L*, a*, and b*) for the *Gold Nugget* variety were 4.52, 2.92, and 3.17, whereas for *Amoro F1*, they were 1.87, 5.48, and 3.01. The variations in our results could be related to the matrix parts and variety.

The chemical composition of the pumpkin pomace is shown in Table 1. The moisture content of the PPP was 8.85%, whereas ash, fat, protein, carbohydrate, and fiber contents were 6.68, 0.61, 11.12, 72.74, and 43.50% on a dry basis, respectively. It was found that the water, ash, protein, fat, total sugar, and total fiber in pumpkin pomace were approximately 7.48, 5.48, 9.21, 1.26, 5.86, and 31.27%, respectively, on a dry basis [36].

The mean values of minerals in the PPP were analyzed using an atomic absorption spectrophotometer and are shown in Table 1. From Table 1, it is clear that the amount of Mg had significant results in the pumpkin pomace, followed by K, Na, Ca, P, Fe, and Zn, which had appreciable amounts. Hussain et al. [32] made a comparison of the minerals present in pumpkin pulp, and the values of Na, K, Fe, Ca, and Zn in pumpkin pulp were 17.87 ± 0.22; 1592 ± 20.3; 41.50 ± 0.45; 1.49 ± 0.02; and 0.46 ± 0.01 mg/100 g, respectively.

According to authors such as Paris [37], pumpkins in different regions have genetic variations in form, size, flavor, color, and nutritional composition. In addition, the nutrient makeup of particular species, namely, *C. maxima*, *C. pepo*, and *C. moschata*, vary based on their respective origins and growth settings. Furthermore, previous studies have provided evidence indicating that pumpkin seeds and pulp serve as notable reservoirs of proteins, carotenoids, tocopherols, and antioxidants while having low caloric content [38].

3.2. Characterization of Bioactive Potential of PPP-Supplemented Cheeses and Storage Stability of the Samples

The bioactive compounds and antioxidant activity of the PPP-enriched cheeses under different storage times are presented in Table 2. Significant differences ($p < 0.05$) in the phytochemical characteristics and antioxidant activity were found among all whey cheese samples. The addition of pumpkin pomace (3% and 6%) to whey cheese enhanced total carotenoids (38.14–76.41 mg/100 g dw), flavonoids (23.92–38.64 mg CE/100 g dw) and polyphenols (45.44–82.83 mg GAE/100 g dw) and its antioxidant capacity (470.25–977.41 µmol TE/g dw).

The increase in the amount of PPP supplementation from 3% to 6% exhibited significant enhancements in the levels of carotenoids, flavonoids, and polyphenols in the cheese samples that were enriched compared to the control samples. The incorporation of powder led to an augmentation in the ABTS scavenging activity of the cheese, exhibiting a significant rise, notably in RCPP6%. This variation might be attributed to the high antioxidant capacity of the pumpkin pomace. Also, pumpkin pomace could be considered a good source of total phenolics. These results are consistent with the findings that pumpkin pomace demonstrates antioxidant action due to the presence of bioactive and functional compounds, especially phenolic compounds and flavonoids [35,36,39].

Table 2. Phytochemical characteristics and antioxidant activity and stability during 21 days of storage for the control and PPP-supplemented cheese samples.

Phytochemical Characteristics	Storage Time, (Days)	RCC	RCPPP3	RCPPP6
Total Carotenoids, mg/100 g dw	0	-	38.14 ± 0.91^{aA}	76.41 ± 1.28^{aB}
	21	-	35.07 ± 0.97^{bA}	73.61 ± 1.35^{bB}
Total Polyphenols, mg GAE/100 g dw	0	9.40 ± 2.33^{aA}	45.44 ± 2.66^{aB}	82.83 ± 2.87^{aC}
	21	6.98 ± 2.11^{aA}	42.09 ± 2.51^{aB}	79.71 ± 2.64^{aC}
Total Flavonoids, mg CE/100 g dw	0	4.23 ± 1.84^{aA}	23.92 ± 2.84^{aB}	38.64 ± 2.99^{aC}
	21	2.02 ± 1.62^{aA}	20.86 ± 2.61^{aB}	35.08 ± 2.54^{aC}
Antioxidant Activity, µmol TE/g dw	0	171.46 ± 3.39^{aA}	470.25 ± 4.15^{aB}	977.41 ± 6.96^{aC}
	21	167.35 ± 3.15^{bA}	466.76 ± 4.07^{bB}	973.12 ± 6.24^{bC}

Means marked with distinct superscript lowercase letters indicate a statistically significant difference ($p < 0.05$) between each investigated phytochemical and storage time. Means with various superscript uppercase letters ($p < 0.05$) indicate a significant difference between each phytochemical parameter and sample variant.

Likewise, Hala et al. [40] found that adding rosemary extract and raising its concentration increased the phenol content and antioxidant activity of ultrafiltered-soft cheeses. The colorants for cream cheese were also evaluated using extracts from the fruit of Sea Buckthorn (*Hippophae rhamnoides* L.) [41]. The primary quantifiable pigments and polyphenols found in the fruits' extracts were carotenoids (8.27 mg/L total carotenoids) and total polyphenols (1842.86 mg/100 g dw). Similarly, the use of tomato powder in processed cheese compositions led to improved functional qualities and increased antioxidant activity in the final product, as well as enhanced taste properties [42].

As expected, during 21 days of storage, the phytochemical content decreased, thus impacting the antioxidant activity. For example, over time, the total carotenoids of the PPP-supplemented samples decreased significantly ($p < 0.05$). The total carotenoids of the PPP-enriched samples were in the range of 38.14–76.41 mg/100 g dw at the start and reached 35.07–73.61 mg/100 g dw after 21 days of storage. As for total polyphenols, there was a slight decrease during storage. So, the total content of polyphenols was 82.83± 2.87 mg GAE/100 g dw for the RCPPP6 cheese on the first day and reached 79.71 ± 2.64 mg GAE/100 g dw for the RCPPP6 cheese on the last day. However, the phytochemicals of the enhanced cheese that were analyzed continued to be higher than those of the control. The decrease in the total phenolic content of the cheeses that contained PPP after storage is likely caused by the susceptibility of free phenolic compounds to oxidation and degradation over time [43]. Due to the reduction in the polyphenols of the cheeses during the 21-day storage period, their antioxidant activity (ABTS) also decreased significantly ($p < 0.05$).

The results we obtained are highly consistent with the findings provided by El-Den [17] and Pasini Deolindo et al. [44], who documented a decline in the phenolic components and antioxidant activity of cheeses with time during storage.

The results presented in Table 2 validate the improved quality of cheeses when enriched with PPP, as evidenced by the increased concentrations of carotenoids and polyphenols. These substances increase the antioxidant activity of the cheese product. The results of this study suggest that PPP could be used as a substitute for synthetic colorants and antioxidants.

3.3. Physico-Chemical Characterization of PPP-Supplemented Cheese Samples

It is possible to hypothesize that the nutritional makeup of cheese is greatly affected by the milk production conditions in each particular type of cheese. In particular, the quantities of lipophilic antioxidants, such as carotenoids, can be influenced by physical and chemical elements, including air, which can vary greatly depending on dietary consumption. This can result in their depreciation during the cheese manufacturing process [45,46].

Table 3 presents the physicochemical properties of whey cheeses with varying pumpkin pomace proportions (3 and 6%) in comparison to the control cheese.

Table 3. Physico-chemical characteristics of control and PPP-supplemented cheese samples.

Physical-Chemical Characteristics	RCC	RCPPP3	RCPPP6
Total solids, %	16.07 ± 0.21 ^{c}	20.73 ± 0.19 ^{b}	24.08 ± 0.27 ^{a}
pH	5.88 ± 0.13 ^{a}	5.86 ± 0.15 ^{a}	5.83 ± 0.17 ^{a}
Fat, %	4.30 ± 0.08 ^{b}	4.54 ± 0.10 ^{a}	4.70 ± 0.11 ^{a}
Protein, %	10.01 ± 0.14 ^{b}	10.35 ± 0.19 ^{b}	10.74 ± 0.22 ^{a}
Carbohydrates, %	0.62 ± 0.09 ^{a}	3.94 ± 0.07 ^{b}	5.66 ± 0.04 ^{c}
Fiber, %	0.00 ± 0.00 ^{c}	3.32 ± 0.12 ^{b}	5.04 ± 0.19 ^{a}
Humidity, %	83.93 ± 0.31 ^{a}	79.27 ± 0.35 ^{b}	75.92 ± 0.38 ^{c}
Salt, %	0.89 ± 0.09 ^{a}	0.78 ± 0.08 ^{a}	0.81 ± 0.09 ^{a}
Ash, %	1.05 ± 0.07 ^{c}	1.90 ± 0.11 ^{b}	2.98 ± 0.16 ^{a}
Energetic value, Kcal/100 g	81.22 ± 0.11 ^{c}	104.66 ± 0.16 ^{b}	117.98 ± 0.19 ^{a}
KJ/100 g	339.49 ± 0.12 ^{c}	437.47 ± 0.17 ^{b}	493.15 ± 0.17 ^{a}

For every physicochemical parameter and sample, means that do not have the same superscript lowercase letter are substantially different at a significance level of $p < 0.05$.

The addition of PPP to cheese greatly improved its chemical composition in comparison to the control. A statistically significant difference ($p < 0.05$) was seen in the proximate makeup of the whey cheese samples with and without PPP. The incorporation of PPP results in significant variations ($p < 0.05$) in moisture, fat, carbohydrates, protein, fiber, ash, energy value, and dry matter content. No significant differences between samples were observed in pH and salt content.

Moreover, the addition of PPP to cheese results in a decrease in salt and moisture content while simultaneously increasing the levels of protein, fat, fiber, carbs, ash, and total solids in direct proportion to the quantity of PPP supplied. The observed outcomes can be attributed to the pumpkin pomace's elevated levels of dietary fiber and crude protein [47].

Adding a higher proportion of PPP results in a substantial increase in the whey cheese's total solid and total protein contents ($p < 0.05$). The total solids exhibited significant variations ($p < 0.05$) between the enriched samples (RCPPP3 and RCPPP6) and the control. The total protein content in the control, RCPPP3, and RCPPP6 cheeses was 10.01%, 10.35%, and 10.74%, respectively. These results indicate increased protein levels following the addition of pumpkin powder. Increasing the pumpkin powder level to 6% during cheese production showed a statistically significant impact ($p < 0.05$) on the fiber content. Among the samples, RCPPP6 had the highest fiber value (5.04%). Moreover, it is evident that the fat content of the formulated cheese increased progressively as the concentrations of PPP increased correspondingly. The results indicate that moisture decreased with the addition of PPP, but the ash content increased with the enhancement of cheese. The cheese exhibiting the highest ash concentration was identified as RCPPP6 (2.98 ± 0.16%), while the lowest ash level was recorded in RCC (1.05 ± 0.07%). The average energy value for RCC was 81.22 ± 0.11 kcal/100 g, whereas for RCPPP6, it was 117.98 ± 0.19 kcal/100 g.

Significant increases in dry matter, ash, fiber, available carbohydrates, and beneficial phytochemicals were observed in ice cream with added pumpkin pulps [14]. The paper also explores the addition of pumpkin pulp to ice cream, enhancing its natural flavor, color, and health-promoting constituents.

3.4. Color Evaluation of PPP-Supplemented Cheese Samples

Given that the color parameter of whey cheese has a substantial impact on consumer approval, it is crucial to evaluate it thoroughly. The color characteristics of L* (whiteness/darkness), a* (redness/greenness), b* (yellowness/blueness), C* (chroma), H* (hue angle), and ΔE (total color difference) of PPP-enriched cheeses, both in the initial moment and after storage stability, were examined and are presented in Table 4. There was a sig-

nificant ($p < 0.05$) difference between unsupplemented cheese and samples supplemented with PPP.

Table 4. Colorimetric parameters of control and PPP-supplemented cheese samples during cold storage for 21 days.

Samples	Storage Time (Day)	L*	a*	b*	C*	H*	ΔE
RCC	0	94.60 ± 0.36^{aA}	-1.85 ± 0.07^{aC}	11.56 ± 0.28^{aC}	11.71 ± 0.09^{aC}	178.59 ± 0.01^{aA}	95.32 ± 0.07^{aA}
	21	91.33 ± 0.51^{bA}	-1.57 ± 0.06^{bC}	13.87 ± 0.29^{bC}	13.96 ± 0.10^{bC}	178.54 ± 0.01^{aA}	92.39 ± 0.06^{bA}
RCPPP3	0	88.82 ± 0.42^{aB}	0.95 ± 0.04^{aB}	16.53 ± 0.43^{aB}	16.56 ± 0.10^{aB}	1.51 ± 0.01^{aB}	90.35 ± 0.06^{aB}
	21	86.22 ± 0.38^{bB}	2.16 ± 0.12^{bB}	19.42 ± 0.48^{bB}	19.54 ± 0.11^{bB}	1.45 ± 0.02^{bB}	88.41 ± 0.05^{bB}
RCPPP6	0	80.27 ± 0.36^{aC}	2.32 ± 0.11^{aA}	21.10 ± 0.29^{aA}	21.23 ± 0.13^{aA}	1.46 ± 0.01^{aC}	83.03 ± 0.04^{aC}
	21	78.56 ± 0.41^{bC}	5.11 ± 0.18^{bA}	24.79 ± 0.33^{bA}	25.31 ± 0.14^{bA}	1.37 ± 0.04^{bC}	82.53 ± 0.03^{bC}

Color parameter variation over storage is highlighted by small letters. The color variations among the samples are indicated by capitalized letters. Values that do not share a lower/uppercase letter are significantly different ($p < 0.05$).

The color parameter research indicates that the inclusion of PPP substantially influenced the cheeses' color. The cheeses that were subjected to experimentation exhibited the highest values of yellowness (b*) and redness (a*) and the lowest values of lightness (L*). In fact, the PPP-enhanced cheese had a darker appearance compared to cheese without powder addition, as indicated by lower L* values. Indeed, a high decrease in the L* value from 94.60 ± 0.36 (RCC) to 80.27 ± 0.36 in RCPPP6 prepared with PPP was observed. Therefore, the lightness (L*) value was reduced with the increase of PPP in the enriched cheeses.

The a* and b* values of PPP samples representing redness/greenness and yellowness/blueness, respectively, were higher compared with the control sample. As can be seen, the a* and b* values for the enriched cheeses increased with PPP addition.

The yellowness value (b*) of PPP-added samples was significantly higher ($p < 0.05$) than the control. The b* values increased after the PPP supplementation of cheese, which led to the predominance of a yellowish tint. This finding can be related to the high carotenoid content of pumpkin pomace [35]. During the storage time, the L* values decreased, and the a* and b* values increased.

Similarly, in another study, the inclusion of pumpkin flour resulted in a decrease in L* values (from 94.89 to 88.67) while leading to an increase in a* (from −2.10 to +4.22) and b* (from 10.79 to 25.88) values [13].

The CIELCH parameters include the C* value, which indicates color saturation, and the H* value, which measures the hue angle and reflects the chromaticity or tone of color. The color saturation (C*) values varied between the control sample and the PPP-added samples and were comparable to the b* color coordinate. Also, the C* values increased after storage. The color's chroma was at its highest value in the RCPPP6 cheese.

The color tone (H*) values had a range of 1.46 to 1.37 for the RCPPP6 sample during storage for 21 days. H* decreased for the PPP-enriched samples.

The total color change of the samples varied from 95.32 ± 0.07 to 83.03 ± 0.04 units, influenced by PPP addition. Increasing the PPP content led to a decrease in the L* and ΔE values. The impact of the PPP on the color of cheese samples is evident, which can be attributed to the natural color of the PPP.

The inclusion of PPP led to significant influence in both the exterior and internal color indices, as expected. The cheeses used in the experiment had a distinct bright yellow coloration, as indicated by a substantial increase in yellowness, which was accompanied by a decrease in lightness.

3.5. Textural Properties of PPP-Supplemented Cheese Samples

The microstructure and chemical composition of cheese, particularly the fat and salt concentration, total solids content, pH, and maturation period, significantly impact its texture [48].

According to the texture profile investigations, whey cheese is classified as a viscoelastic food. It has a very soft consistency that is not pasty or friable [49]. It is compressible and not overly cohesive, with brittle characteristics. The texture remains stable during storage, which is important for marketing and sensory acceptance [50].

Table 5 presents the impact of PPP addition on the textural profile parameters (hardness, adhesiveness, cohesiveness, gumminess, springiness, and chewiness) of cheese samples over a 21-day storage period.

Table 5. Textural parameters of the control and PPP-supplemented cheeses during storage for 21 days.

Parameter	Storage Period, (Day)	RCC	RCPPP3	RCPPP6
Hardness, N	0	4.51 ± 0.19^{cA}	5.63 ± 0.22^{bA}	7.05 ± 0.36^{aA}
	21	2.91 ± 0.11^{cB}	3.11 ± 0.19^{bB}	6.16 ± 0.29^{aB}
Adhesiveness, mJ	0	0.40 ± 0.10^{cA}	0.68 ± 0.13^{bA}	0.89 ± 0.18^{aA}
	21	0.29 ± 0.09^{cB}	0.54 ± 0.10^{bB}	0.70 ± 0.16^{aB}
Cohesiveness, -	0	0.37 ± 0.08^{cB}	0.45 ± 0.13^{bB}	0.52 ± 0.19^{aB}
	21	0.56 ± 0.12^{cA}	0.64 ± 0.16^{bA}	0.73 ± 0.20^{aA}
Springiness, -	0	0.38 ± 0.05^{bA}	0.47 ± 0.15^{abA}	0.54 ± 0.18^{aA}
	21	0.32 ± 0.09^{bB}	0.39 ± 0.12^{abB}	0.46 ± 0.14^{aB}
Gumminess, N	0	1.74 ± 0.13^{cA}	1.82 ± 0.15^{bA}	1.95 ± 0.17^{aA}
	21	1.31 ± 0.12^{cB}	1.42 ± 0.13^{bB}	1.58 ± 0.14^{aB}
Chewiness, N	0	0.73 ± 0.05^{cA}	0.88 ± 0.07^{bA}	0.98 ± 0.10^{aA}
	21	0.54 ± 0.04^{cB}	0.67 ± 0.06^{bB}	0.77 ± 0.08^{aB}

Values that have the same superscript lowercase letter for each textural parameter and sample are not statistically different in terms of time at $p > 0.05$. Textural parameters with the same superscript uppercase letter for each storage time are not statistically different at a significance level of $p > 0.05$.

The findings indicate that the presence of PPP strongly impacted the textural qualities of the cheese samples. Furthermore, the cheese with the highest amount of PPP exhibited the most pronounced impact on its textural features in comparison to the control cheese.

The inclusion of PPP resulted in elevated levels of hardness, cohesiveness, adhesiveness, and springiness in the cheese samples. The addition of PPP resulted in samples with increased hardness and cohesiveness, indicating a greater strength of internal bonds compared to the control. This could be attributed to the spongy network formed by the high dietary fiber content of PPP, as well as its influence on protein–protein interactions, which enhanced the compression force and the firmness of the samples [51].

Likewise, the PPP-added samples exhibited greater gumminess and chewiness compared to the control samples, indicating that they possessed stronger internal linkages as a result of a more rigid network. Gumminess, which is the product of hardness and cohesiveness, and chewiness, which is the product of hardness, cohesiveness, and springiness, are textural criteria that may be determined from the fundamental parameters that they depend on. The increase in textural parameters can be explained by the fact that the cheeses with PPP addition had lower moisture and higher dry matter content compared to the control samples. Furthermore, this pattern can be ascribed to the interactions of the fiber and protein of the PPP with the moisture in cheese, resulting in a more robust three-dimensional structure that contributes to elevated hardness, springiness, cohesiveness, and chewiness. Integrating pumpkin pomace into whey cheese markedly enhances moisture retention due to its abundant soluble fiber content. These fibers function as sponges, absorbing water and retaining it inside the cheese matrix, enhancing its softness and moisture content. This advancement has numerous advantages for consumers because it enhances the texture of the cheese, rendering it more appealing [52].

The most noticeable changes in textural characteristics were detected in cheese samples with additional PPP, resulting in cheeses that were firmer and had a greater springiness

compared to the control samples. Concerning the impact of the storage duration, we also noted a rise in cohesiveness and a decrease in hardness, adhesiveness, springiness, gumminess, and chewiness measurements as a result of the steady reduction in moisture content likely attributable to the elevated solid material content added [53]. Consequently, compared to control cheese, the addition of PPP produced cheese that was more firm and gummy.

An increase in gumminess was observed when the powder was added to the control samples. However, during storage, the gumminess decreased due to a decrease in the fat content. This suggests that the protein bonds are weakened more frequently by the action of proteases and/or irreversible denaturation [53].

The protein matrix of the cheese undergoes a change in structure from a porous consistency to a more compact arrangement. Consequently, all the studied samples showed a rise in the values of cohesiveness and a reduction in the adhesiveness, gumminess, springiness, and chewiness texture criteria throughout storage. The texture investigation demonstrates that the inclusion of PPP improved the textural characteristics of the cheeses in direct correlation with the concentration.

Similarly, El-Dardiry et al. [54] discovered that the textural parameters increased with the amount of quinoa flour in processed cheeses using quinoa paste.

3.6. Mineral Profile of PPP-Supplemented Cheese Samples

The data reported in Table 6 demonstrate that the inclusion of PPP resulted in an elevation of the mineral content (Ca, P, K, Mg, Zn, Na, and Fe) in the PPP-added samples in comparison to the control cheese. The findings suggest that the addition of PPP had a significant effect on the mineral composition of the cheeses compared to the control samples ($p < 0.05$). An increase in mineral content was noticed as the level of powder enrichment rose. The mineral content showed a positive correlation with the amount of PPP added. The differences between the cheese samples in terms of the amounts of Mg, Fe, Na, P, K, Ca, and Zn were found to be statistically significant ($p < 0.05$). The increased concentrations of minerals observed in the PPP-supplemented cheese samples could be attributed to the high mineral content present in pumpkin powder (Table 1).

Table 6. Mineral composition of the control and PPP-supplemented cheeses samples.

Parameter	RCC	RCPPP3	RCPPP6
Calcium (Ca, mg/100 g)	275.75 ± 0.21^{b}	276.05 ± 0.35^{a}	276.75 ± 0.22^{a}
Phosphorus (P, mg/100 g)	180.15 ± 0.07^{b}	180.75 ± 0.21^{b}	181.65 ± 0.22^{a}
Potassium (K, mg/100 g)	128.25 ± 0.50^{b}	129.7 ± 0.14^{b}	132.3 ± 0.26^{a}
Magnesium (Mg, mg/100 g)	17.3 ± 0.85^{c}	19.8 ± 0.01^{b}	23.25 ± 0.49^{a}
Zinc (Zn, mg/100 g)	1.41 ± 0.01^{b}	1.42 ± 0.02^{b}	1.44 ± 0.01^{a}
Iron (Fe, mg/100 g)	0.52 ± 0.02^{c}	0.82 ± 0.01^{b}	1.20 ± 0.01^{a}
Sodium (Na, mg/100 g)	101.15 ± 0.34^{c}	102.82 ± 0.35^{b}	104.2 ± 0.29^{a}

Superscripts with different letters within a row are significantly ($p < 0.05$) different.

The cheese samples were enriched with important elements, such as calcium and phosphorus. The RCPPP6 sample, which included 6% PPP, had the greatest quantity of Ca at 276.75 ± 0.22 mg/100 g.

Regarding phosphorus content, cheese with 6% PPP exhibited the highest concentration of P, followed by cheese with 3% PPP. Furthermore, the cheese that was fortified with 6% PPP had the highest levels of potassium (Na) and magnesium (Mg), while the cheese containing 3% PPP had lower amounts. In contrast, the control sample had the lowest levels of these minerals.

There were statistically significant variations ($p < 0.05$) in the iron, zinc, and potassium content between the samples with PPP added and the control sample. The addition of 3% and 6% of PPP (RCPPP3 and RCPPP6) resulted in increased levels of Zn, Fe, and Na compared to the control cheese. The study's results demonstrate that the use of powdered

PPP raw material in cheese significantly augmented the mineral content in the final product, increasing it by a factor of 0.36 to 34.39 times. Table 1 demonstrates that freeze-dried pumpkin powder contains significant amounts of magnesium (Mg), calcium (Ca), phosphorus (*p*), potassium (K), and sodium (Na). Therefore, PPP is appropriate for inclusion as a bioactive component in food products.

Enas et al. [55] obtained a cream cheese with different levels of 0, 1, 2, and 4% carrot powder, and the obtained results revealed richness in minerals, so carrot powder significantly increased the mineral content of cheese, which was proportional to the amount of carrot powder added. In other studies, Tohamy et al. [56] discovered that including spirulina powder in processed cheese led to higher levels of calcium, potassium, magnesium, iron, and zinc compared to cheese without fortification. Also, Abdelmontaleb et al. [57] found that soft cheese fortified with quinoa flour (0%, 1%, 2%, and 3%) contained higher amounts of minerals compared with the control.

3.7. Microstructure Analysis of PPP-Supplemented Cheese Samples

Observations of the microstructure of the PPP, cheese sample, and PPP-supplemented cheese sample by electron microscopy are shown in Figure 2.

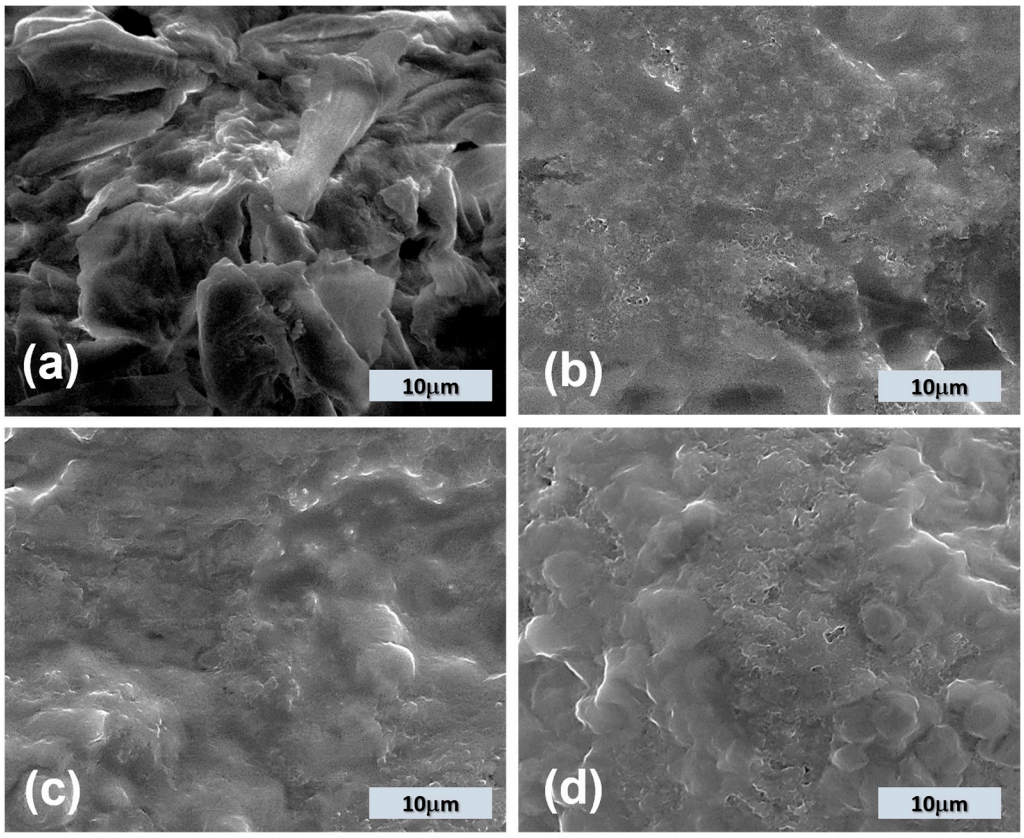

Figure 2. SEM micrographs of PPP (**a**), control whey cheese (RCC) (**b**), and PPP-supplemented cheese: RCPPP3 (**c**) and RCPPP6 (**d**).

The incorporation of PPP can be characterized as a smooth uniform protein evenly embedded and dispersed throughout the cheese structure in contrast to the control sample. The analysis shows that the protein matrix had evenly distributed bigger fat globules throughout the cheese structure, unlike the control sample. The microstructural features of enriched cheeses are consistent with those observed for processed cheese [58].

The cheeses exhibit different microstructures depending on the fiber addition. When observed at a magnification of 500× (10 µm), the whey sample displayed a uniform microstructure without the appearance of granules. Additionally, the typical protein

aggregates commonly found in cheese are visible. In the experimental cheeses (RCPPP3 and RCPPP6), the fiber particles can be observed at 500× magnification.

Figure 3 shows the EDX spectrum of the product being analyzed. The EDX spectrum of the samples reveals the existence of alkali ions (potassium and sodium) and alkaline earth ions (magnesium and calcium) on the surface, which aligns with the data presented in Table 1.

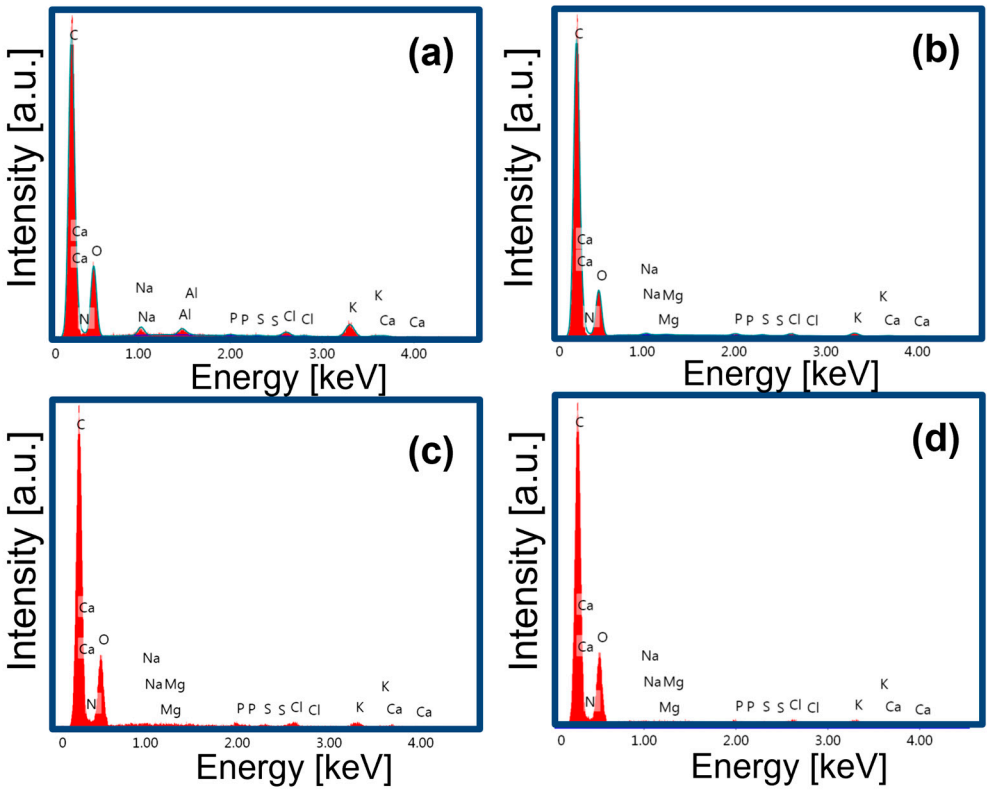

Figure 3. SEM-EDX spectrum of PPP (**a**), control whey cheese (RCC) (**b**), PPP-supplemented cheese: RCPPP3 (**c**) and RCPPP6 (**d**).

The protein aggregates network in the samples with added fiber appears to have a distinct structure compared to that of RCC cheese. Specifically, an open structure with larger aggregates was seen. Similar results were found by [59].

The presence of wide and deep aggregates in the supplemented samples indicated the occurrence of proteolysis, reorganization of the protein matrix, and an increase in the firmness of the whey cheese texture. The observed rise in cheese hardness, as shown in Table 4, corroborated this. In this study, the lower pH of the PPP-enriched samples of whey cheese resulted in the increased breakdown of the sub-micelles into non-linear strands of casein, ultimately leading to the aggregation of the protein matrix. This is validated by Tunick [60].

The microstructure of the cheese samples showed differences, with the RCPPP3 and RCPPP6 cheeses having a diverse composition characterized by a finely interconnected network. The presence of casein micelles was more evident in the specified samples compared to the control cheese. The findings of RCPPP6 reveal a configuration that exhibited both greater density and a more condensed structure. Cheeses using PPP had stronger cross-linking and connections. Due to a more compacted matrix, these cheese samples are harder. The SEM analysis also shows that cheese samples with higher PPP concentrations had more protein aggregates in their matrices than the control group.

Due to the high PPP concentration, the RCPPP6 cheese casein clusters were thicker and more compact than other samples. Due to its dietary fiber, the PPP improves cheese texture and structure. Also, RCPPP6's increased hardness may be connected to its more

compact structure. The results correspond with the findings of Rubel et al. [61] and Abdullah et al. [62], who observed that incorporating hydrocolloids and date pit powder into spreadable whey cheese and processed cheese had a beneficial effect on the texture of the products.

3.8. Sensorial Analysis of PPP-Supplemented Cheese Samples

The sensory evaluation of the developed cheeses was conducted using a seven-point hedonic scale. Figure 4 presents the mean ratings derived from the sensory evaluation. Sensory quality encompasses the examination of organoleptic attributes, such as visual appearance, sectional appearance, odor, scent, hardness, adhesiveness, color, taste, aftertaste, and overall evaluation.

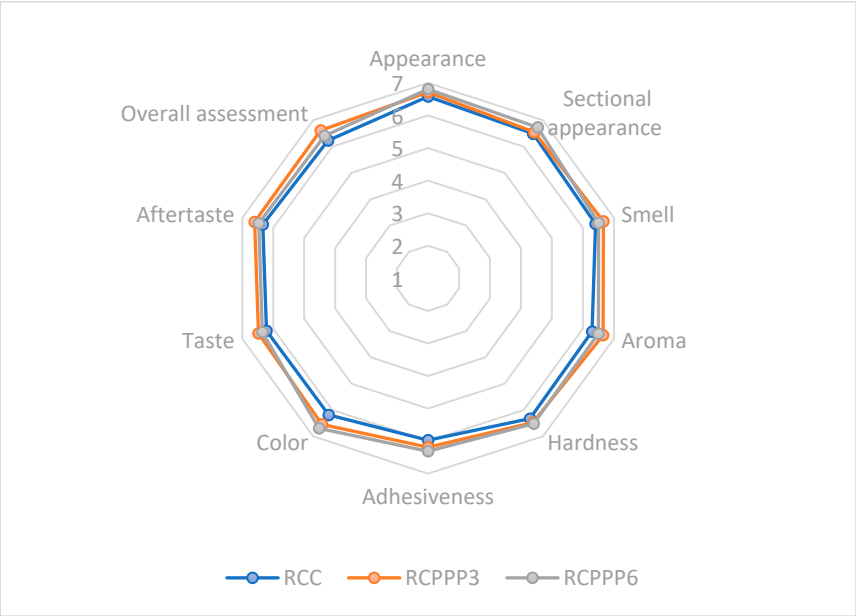

Figure 4. Comparative diagram of the sensory attributes specific to PPP-supplemented cheeses. RCC: cheese without powder addition; RCPPP3 and RCPPP6: cheese with 3 and 6% PPP.

The pumpkin pomace-added cheese received favorable ratings from panelists concerning its aspect, color, scent, taste, and overall acceptability.

The RCPPP3 and RCPPP6 samples displayed a dried granular structure with a delicate and refreshing flavor. The cheese samples with a higher level of PPP (6.0%—RCPPP6) had the lowest scores in terms of aroma, smell, taste, aftertaste, and total scores, while they had the highest scores for appearance, color, and texture. The PPP, which absorbs more water from the cheese milk, could be the reason for this. The addition of 6% pumpkin powder during cheese making led to an increase in the overall percentage, and it caused a rise in the texture characteristics of the cheese, specifically in hardness and adhesiveness. This resulted in the formation of granular texture and an increase in stiffness in the final product.

Pumpkin addition enhances the aroma due to its content of carotenoids and sugars, which are responsible for the pumpkin's flavor. Overall, the smell and aroma scores remained above the acceptable limit, with a score of >6.0. The aftertaste varied for both supplemented sample cheeses; RCPPP6 exhibited a lower and distinct aftertaste perception, probably due to the higher PPP addition.

Regarding texture, the addition of PPP to cheese had a notable impact on the hardness score. This effect is directly related to the results obtained from the textural instrumental analysis.

The PCA biplot, shown in Figure 5, provides a visual representation of the positions of the three cheese samples (plain versus those flavored with PPP) based on the sensory attributes described in Figure 4. The first principal component (PC1) accounted for 41.66%

of the variation and consisted of the two cheese samples with PPP. The second component was 17.22% of the total and consisted only of plain cheese. Hence, the two axes accounted for 58.88% of the overall variation. The attributes of appearance, sectional appearance, adhesiveness, color, and aroma strongly correlated in the first axis, F1. Similarly, the attributes of smell, hardness, taste, aftertaste, and overall assessment were also found to have a positive association in the same quadrant on the first axis, F1. As all the sensory qualities were solely associated with the same axis, F1, the plain cheese was considered neutral. The biplot analysis allows for the precise localization of the placements of the three cheese samples based on their sensory qualities. It also enables the differentiation between sensory attributes through positive correlations, as well as between sensory attributes and cheese samples.

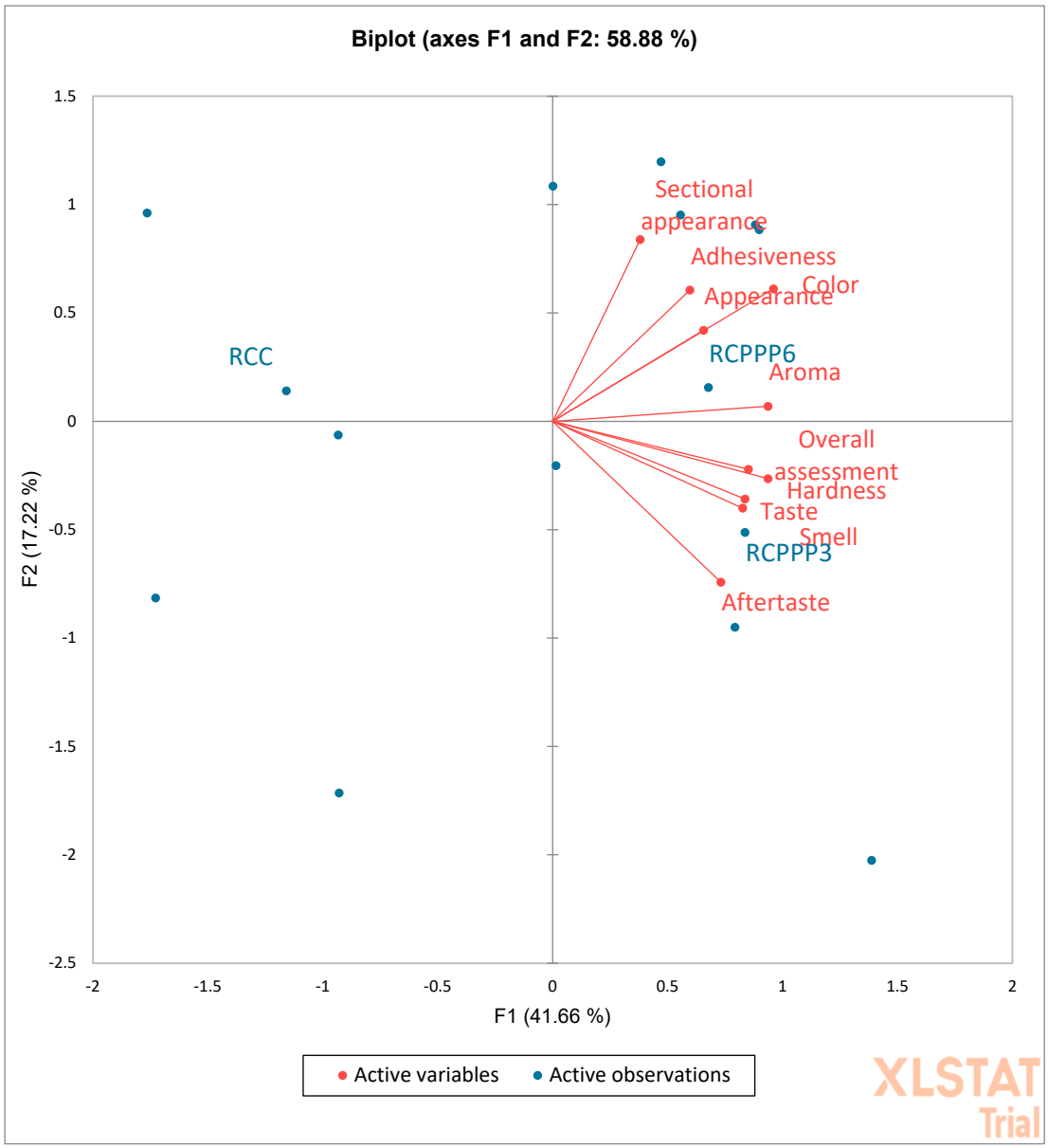

Figure 5. Principal Component Analysis (PCA) biplot of the position of the three cheeses (RCC, RCPPP3, and RCPPP6) for sensory attribute evaluation.

The color of the samples RCPPP3 and RCPPP6 was considered satisfactory when compared to the control. The current study found that adding PPP to cheese samples improved the orange color (Figure 6), which was liked very much by the panelists. In

terms of color and appearance, RCPPP6 (whey cheese with 6% pumpkin powder) had an intense orange color, which was appreciated by the panelists. The overall assessment scores indicate that the whey cheese was more acceptable with 3% of PPP than the cheese sample with 6% of PPP, maybe due to the use of 6% PPP producing a slightly bitter aftertaste.

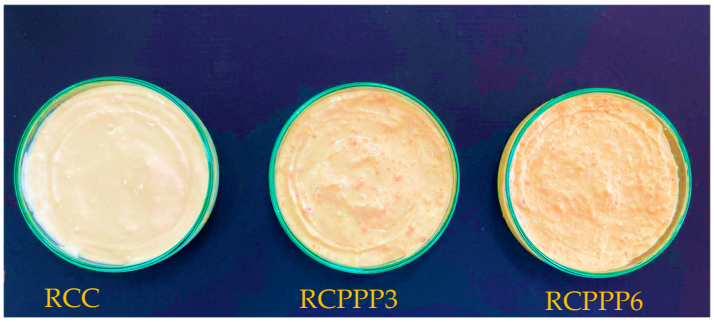

Figure 6. Cheese samples with different percentages of PPP: RCC (control), 3% (RCPPP3), and 6% (RCPPP6).

The experimental cheeses had complex smells and a stronger aroma. In terms of the panelists' overall evaluation, cheese supplemented with 3% powder of pumpkin pomace was the most appreciated by the assessors. The acceptance of a food product typically signifies the actual utilization of the product, encompassing both its purchase and consumption. The addition of plant powder or extracts to fortified products typically improves their overall acceptability, especially in terms of flavor, due to the presence of pleasant aromatic compounds and phenolic substances [63,64].

In another study, the sensory evaluation indicated that beverages containing pumpkin pulp demonstrate superior sensory properties compared to control treatments [15]. In addition, the use of celery leaf during the production of soft white cheese resulted in enhanced flavor and overall acceptance [65]. Conversely, another group discovered that the use of 0.3% (wt/vol) of turmeric powder resulted in a reduction in the intensity of flavors [66].

Mohamed et al. [67] reported that processed cheese made with spirulina powder (*S. maxima*) has a favorable physicochemical composition and exhibits capabilities that scavenge free radicals. The study found that ratios of 1% or 2% of spirulina powder were preferable compared to a ratio of 3%.

The natural ingredient PPP can be used in whey cheese compositions to satisfy consumers' preferences for dairy products that are both more attractive and more effective for health while also providing an environmentally advantageous method for repurposing agricultural by-products.

4. Conclusions

Our findings underscore the significance of pumpkin pomace extract as a valuable reservoir of bioactives, such as minerals, β-carotene, and phenolic compounds with notable antioxidant properties. The findings of this study indicate that the incorporation of 3% PPP into whey cheese did not disrupt the fermentation process of the commercial starter LAB. Moreover, this process of enrichment facilitated the production of a bovine whey cheese that exhibited distinct functional, physicochemical, and sensory characteristics. PPP-enriched cheese exhibited elevated levels of protein and polyphenols and reduced fat content. The findings of this study reveal that the RCPPP3 cheese exhibited notable characteristics in terms of its desirable texture, sensory attributes, and phytochemical qualities. Additionally, the cheese had considerably elevated levels of bioactive components, indicating the potential functional value of PPP. Hence, this dairy product appears to be well-suited for facilitating the human body's capacity to uphold the appropriate equilibrium of vital nutrients, and it could potentially serve as a valuable asset in the market for novel food products.

The incorporation of PPP into whey cheese presents novel opportunities for product innovation and market distinctiveness as consumers increasingly prioritize healthier and more functional food options. To optimize the benefits of this functional component, further research is required to ascertain the most effective inclusion rates and processing parameters for the production of whey cheese. The successful integration of pumpkin pomace into whey cheese not only enhances its nutritional value but also promotes the sustainable use of agricultural by-products, supporting the food industry's move toward more sustainable practices.

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Informed Consent Statement: Group members were informed about the objectives of the study and the handling of personal data. Informed consent forms were provided that clearly outlined the voluntary nature of participation, the right to withdraw at any time, and their confidentiality.

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

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