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Effects of Poppy Seed Cake on Physicochemical, Textural, and Microbiological Properties of Cheese Chips

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ABSTRACT: The purpose of this study was to look into the effects of adding poppy seed cake (PSC) at various rates (1% and 3%) to cheese chips on their physicochemical properties, color, texture, elemental, and microbiological characteristics. The findings revealed that PSC raised pH, dry matter, protein, and ash levels while decreasing fat and salt content ($p<0.05$). The addition of PSC reduced the brightness and yellowness of chips while increasing their redness ($p<0.05$). It also made chips less hard and more fragile. Elemental analysis found that PSC increased calcium, potassium, magnesium, sodium, phosphorus, and zinc levels. PSC significantly increased Lactobacilli levels ($p<0.05$) and decreased total mesophilic aerobic bacteria (TMAB) ($p<0.05$), while also reducing *Bifidobacterium animalis* subsp. *lactis* BB-12 ($p<0.05$). Additionally, PSC was determined to improve probiotic survival as well as general microbiological quality. These findings suggest that PSC could improve the quality and nutritional content of chips. Sensory principal component analysis (PCA) and overall acceptability values indicated that chips with 1% PSC (CP1) achieved higher acceptability scores compared to those with 3% PSC (CP3), due to a better balance of crispy texture, flavor profile, and appearance. Therefore, 1% PSC incorporation is recommended for optimal sensory quality and consumer preference, while still enhancing nutritional value.

Keyword: Poppy seed cake; cheese chips; snacks; compositions; functional cheese.

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INTRODUCTION

Recently, consumers have exhibited heightened interest in producing food sustainably due to greater awareness of ecological pollution and the substantial waste generated by current food-production techniques. Furthermore, they are seeking nutritional products that offer enhanced safety and health benefits. Healthy snacks are those that are often well-balanced in terms of nutrients and contain a large number of compounds that are beneficial for human health (Ciurzyńska et al., 2019; Tylewicz et al., 2020). Cheese, which is widely used in snacks, contains protein, vitamins, zinc, phosphorus, calcium, and essential nutrients (Rakcejeva et al., 2009). Additionally, the use of seeds like poppy, flax, and sesame seeds to enrich snacks with nutrients and fiber has become widespread. Poppy seeds' popularity has grown due to their high nutritional value, as they include vital fatty acids like linoleic acid and antioxidant components like vitamin E (Casado-Hidalgo et al., 2023). Poppy seeds contain on average 46.2-49.4% oil, 21.5-23.5% protein (Muhammad et al., 2021), 4-5% moisture, 4-5% crude fiber, and 5.5% ash (Aklale and Aydeniz-Güneşer, 2019). These seeds are abundant in essential nutrients, providing healthful fiber, fatty acids, vitamins, and minerals (iron, zinc, manganese, magnesium, calcium, copper, phosphorus, and potassium) (Bolaños et al., 2019). Many studies have investigated the use of poppy seeds in different products (Harmankaya et al., 2013; Aklale and Aydeniz-Güneşer, 2019; Blicharz-Kania et al., 2022; Casado-Hidalgo et al., 2023; Al-Juhaimi et al., 2024). PSC, a byproduct of poppies extracted for oil, can be used as cattle feed. Because the protein in poppy seed cake accounts for up to 35% of the dry matter (Blicharz-Kania et al., 2022). However, its high protein content makes it a valuable addition to human diets. It substitutes for animal protein and contributes to the organoleptic and functional properties of the products. Additionally, PSC has a variety of nutritional components that could be used as beneficial ingredients in functional food formulations. This byproduct, which is gluten-free and high in fiber, can be used as an important component in innovative foods (Melo et al., 2022).

The aim of this investigation was to produce probiotic-enriched chips using poppy seed cake (PSC), which is high in fiber and nutrients. For this, 1% and 3% of PSC were added to probiotic-enriched White cheese, and microwave drying was used to produce chips. To evaluate the effects of different PSC incorporation levels and to develop a standardized manufacturing process, the study investigated the microbiological, physicochemical, and some mineral properties of the chips using Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES).

MATERIALS AND METHODS

Materials

The PSC adheres to the standards, comprising 95% dry matter, a maximum of 3% oil, and a maximum of 1% foreign matter. The PSC was provided by a local producer of poppy seed oil in Şuhut, Afyon, Türkiye. The provider of raw cow milk (4±1°C) was the Ünsüt Dairy Products Plant in Isparta, Türkiye.

Cheese and cheese chips production

The investigation was carried out in three replications, with three batches of milk used on various days. For the production of probiotic-enriched White cheese, raw cow milk was pasteurized at 72°C for 2 minutes. After pasteurization, a 40% $CaCl_2$ solution was added at 0.02%. Pasteurized milk was separated into three groups, and the temperature was brought to 30±2°C. The one group was treated without PSC. The other two groups were added with 1% (CP1) and 3% PSC (CP3) heated without roasting (ratios were identified as a consequence of preliminary experimentation). Then, 1g/100 L probiotic culture (*Lactobacillus acidophilus* LA-5® and *Bifidobacterium animalis* subsp. *lactis* BB-12® (FD-DVS nu-trish®, Chr Hansen, Türkiye)) and 1g/100 L mesophilic starter culture (*Lactococcus lactis* subsp. *cremoris*, *Lactococcus lactis* subsp. *lactis*, FD-DVS R-707, Chr Hansen, Türkiye) were added (>10^7 log cfu/g). After pre-ripening, liquid rennet (Naturen® Mandra 175, Chr Hansen, Türkiye) was added. The fermentation was conducted at 30±2°C for 90 min. Then, curd cutting, straining, and pressing processes were applied, respectively. **Cheeses were prepared in triplicate batches. Following production, the unbrined cheeses were stored under refrigerated conditions (+4±1°C) until subsequent processing into chips.**

Cheeses were crumbled into small pieces, and 2.5% salt was added. Then, chips doughs were obtained by kneading. The chips dough was thinned to 0.6±0.1 cm and shaped into round chips. The chips were then pre-dried at 45°C for 60 min in a drying oven (Wiseven, WOF-155, Korea) and then dried at 180 W for 3 min in in a fan microwave oven (Bosch 5870 GH, Germany). With the vacuum setting off, the chips (Figure 1) were vacuum-packed in clear, airtight vacuum bags. The produced chips were stored at +4±1°C. Chips were stored for only 1 day and analyzed.

Analysis of White cheese

For cheeses, titration acidity, fat, dry matter, ash, and protein (AOAC, 1997) analyses were performed. Color was measured at three different points on three randomly selected samples, and the color values were determined using the color meter (CR-400 Minolta Chroma Meter, Japan).

Analysis of cheese chips

Physicochemical analysis

The pH of chips was determined using a digital pH meter (WTW pH 315; Weilheim, Germany). The titratable acidity values were calculated as a percentage of lactic acid (%LA). The fat content was estimated using the Gerber method, dry matter content was analysed using the gravimetric method, ash content was measured by incinerating the samples at 550°C in a muffle furnace (Nüve, MF120, Ankara, Türkiye), salt content was assessed using the Mohr titration method (AOAC, 1997), and protein content was identified by the Micro-Kjeldahl method (Gripon et al., 1975).

Color analysis and texture analysis

The L^* (brightness), a^* (green/red), and b^* (blue/yellow) color values of chips were measured using a color meter (CR-400 Minolta Chroma Meter, Japan). Color measurements were performed at three different spots on both sides of three randomly selected chips from each category. Texture analysis was carried out on the first day of storage using a Texture Stable Micro Systems (TA-XT Plus, UK) texture analyser. Six chips from each group were examined. A three-point bend test was carried out using a Three Point Bend Rig probe (A/3PBT). Texture analysis was performed using probe speeds of 1 mm/s and a distance of 7 mm (between probe and chip surface) (Albay et al., 2024).

Figure 1. Cheese chips containing different ratios (1% and 3%) of PSC (CPC: Control sample without PSC, CP1: Sample with 1% PSC, CP3: Sample with 3% PSC).

Elemental analysis

Sample preparation of chips was carried out according to the EPA 3015A method (2007a). Using the Milestone brand a microwave unit (ETHOS ONE, Milestone, Shelton, CT), a model microwave sample preparation unit, 8 mL HNO_3 + 2 mL H_2O_2 was added to 0.5 grams of the sample using the wet combustion method. The final volume was brought to 20 mL with pure water. ICP OES measurements were performed using Perkin Elmer OPTIMA 5300 DV equipment by the EPA 6010C (2007b) method with the conditions described in Table 1.

Microbiological analysis

The spread plate method was used to evaluate the cheese and chips samples microbiologically. The procedure involved adding 10 g of the sample to 90 mL of sterile Ringer's (1/10) solution (Biokar diagnostics, France) in an aseptic setting. Then, 1 mL of this dilution was transferred into 9 mL of sterile Ringer's solution, and a dilution series was prepared. *Bifidobacterium animalis* subsp. *lactis* BB-12 (*Bifidobacterium* BB-12) was determined using MRS-NNLP agar medium including neomycin sulfate (100 mg/L) (Sigma-Aldrich, Germany), nalidixic acid (50 mg/L) (Sigma-Aldrich, Germany), lithium chloride (3000 mg/L) (Glentham Life Sciences, United Kingdom), and paromomycin sulfate (200 mg/L) (Alfa Aesar, Germany). The NNLP mixture was added to the sterile MRS agar (de Man, Rogosa and Sharpe, Merck, Germany) medium before putting it into petri

Table 1. Conditions applied to the Perkin Elmer OPTIMA 5300 DV instrument for ICP OES measurements

Conditions Applied	
PlasmaGasFlow	15 L/min
AuxiliaryGasFlow	0.2 L/min
NebulizerGasFlow	0.6 L/min
Power	1450 Watts
TorchCassettePosition	-3
PumpSpeed	1.5 mL/minute
Purge	Normal
Resolution	Normal
Integration Time	10 secondsmin/20 secondsmax
Read Delay	60 seconds
Replicates	3

plates after passing through a 0.45 µm disposable sterile filter (Minisart® Syringe Filter, Germany). To prepare MRS-Sorbitol agar in *Lactobacillus acidophilus* LA-5 (*L. acidophilus* LA-5) enumeration, 10 mL of 10% (w/v) D-Sorbitol (Carl Roth, Germany) solution was filtered through a 0.45 µm sterile filter (Minisart® Syringe Filter, Germany) and added to 90 mL of sterile MRS agar medium. Petri dishes were incubated in anaerobic jars at 37°C for 72 hours to count probiotics (Dave and Shah, 1997). Anaerobic media was performed via Anaerocult® A anaerobic kits (Merck, Germany).

MRS agar was used to count Lactobacilli. Using an anaerobic kit and anaerobic jar, Petri plates were incubated at 37°C for 72 hours. Lactococci were detected using M17 agar (Merck, Germany). Following the petri dishes' aerobic incubation at 37°C for 48 hours, Lactococci were enumerated (Gardini et al., 1999). Using Plate Count Agar (Merck, Germany), the total mesophilic aerobic bacteria (TMAB) were evaluated. Petri dishes were incubated in an aerobic atmosphere at 30°C for 72 hours (Anonymous, 1987). To identify coliforms, 1 mL of a 1:10 dilution was inoculated into Eosin Methylen-Blue Lactose Sucrose medium (Merck, Germany). Petri plates were incubated at 37°C for 24-48 hours. According to Halkman (2005), colonies developing in petri plates were counted, and the results are reported as log cfu/g.

Principal component analysis of sensory properties results and statistical analysis

Sensory analyses were conducted by a panel of 10 experienced assessors (7 women and 3 men) from the Department of Food Engineering at Süleyman Demirel University. Participants were briefed about the sensory evaluation for approximately 2 hours. All samples were presented with a three-digit code. Two different sensory analysis methods were used to evaluate the sensory quality parameters of cheese chips enriched with probiotic bacteria during storage. For the first evaluation, a numerical two-way (bipolar) scale ranging from 1 to 10 was used. Texture (softness-hardness, rough structure, thickness structure, chewability, crispy sound), appearance (brownish appearance, yellowish appearance, matte-shiny, mottled appearance), odor (poppy odor, foreign odor, burnt odor, cheese odor), and taste (poppy taste, foreigne taste, oily taste, rancid taste, burnt taste, salty taste) parameters were analyzed. Secondly, a nine-point hedonic scale (1=did not like at all, 9=liked very much) was used to determine general acceptability (Lawless and Heymann, 2010). The samples were stored at 4±1ºC until the sensory analysis was conducted. Cheese chips samples were given to the panelists along with crackers and water.

The results of microbiological, physicochemical, and elemental analyses were evaluated after logarithmic transformation. Analysis of variance (ANOVA) was performed based on the mean values of the measurements, and Duncan's multiple comparison test was applied when significant differences were observed ($p<0.05$; SPSS 26.0 (Ver. 22.0), Chicago, IL, USA). Results were expressed as mean ± standard deviation (Duzgunes et al., 1987).

Principal component analysis (PCA) was applied to the values of appearance, texture, odor, and taste parameters. The JMP Pro 16.0.0 (Ver. 2021) version was used for statistical data evaluation. As a result of PCA, the classification that emerged in chips samples was explained with scatter plots between the first two principal components, PC1 and PC2, in the relevant sections.

RESULTS AND DISCUSSION

Physicochemical composition of raw milk

Raw milk demonstrated specific gravity of 1.030 g/cm³, titratable acidity of 0.15% LA, pH of 6.67, dry matter of 12.90%, fat content of 4.55%, ash content of 0.63%, and protein content of 2.79%.

Physicochemical composition of White cheese

The average titration acidity (%LA), dry matter, fat, ash, and protein values of cheese were 1.46%, 41.37%, 21.37%, 0.27%, and 8.21% for the control sample without PSC, 1.69%, 44.32%, 19.75%, 1.14%, and 9.86% for the sample with 1% PSC, and 1.59%, 48.42%, 17.75%, 2.30%, and 13.13% for the sample with 3% PSC, respectively (Table 2). PSC samples had higher %LA values compared to control samples. Adding PSC to the samples increased dry matter, ash, and protein content while decreasing fat content ($p<0.05$). The sample containing 3% PS had higher dry matter and protein values compared to the poppy seed (3%) added cream cheese study (Aklale and Aydeniz Güneşer, 2019), although the fat value was lower. This may result from the oil-free PSC augmenting the dry matter, leading to a diminished detection of oil content. Similarly, adding flaxseed oil cake to kefir raised its dry matter, protein, and ash contents, according to Łopusiewicz et al. (2019).

The L^*, a^*, and b^* color analysis results for cheese were 91.40, -1.75, and 9.20 in the without PSC sample, 70.55, 2.81, and 12.42 in the CP1 sample, and

66.64, 3.40, and 12.51 in the CP3 sample, respectively (Table 2). Statistical analysis revealed a significant influence of PSC at different rates on all color values of the cheese ($p<0.05$). PSC lowered the brightness, resulting in a darker appearance. In this investigation, increasing the flaxseed oil cake ratio decreased the L* value while raising the a* and b* values (Łopusiewicz et al., 2019). Compared to the CP1 and CP3 chip samples, Aklale and Aydeniz-Güneşer (2019) reported that cream cheeses enriched with 3% blue poppy seeds exhibited brighter color values.

Chips analysis results

Physicochemical analysis results

The chips had pH values ranging from 5.44 to 5.59 (Table 3). Statistical analysis showed that adding PSC at varied rates had a significant impact on the pH values ($p<0.05$). In another study, it was found that adding chia seeds to yogurt had a substantial impact on its initial pH value, causing it to rise ($p<0.05$). It concluded that the buffering capacity of chia seeds contributed to the pH increase. Additionally, because of their high protein, fiber, and mineral content, chia seeds have been reported to have a buffering effect (Nakov et al., 2024). Since poppy seeds also contain proteins, fibers, and minerals like chia seeds, it is theoretically expected that they have a buffering effect. Buffering effects may be crucial in maintaining the pH equilibrium in foods. However, extensive research on the impact of poppy seeds on pH in foods has been limited thus far. The samples had %LA values between 1.00% and 1.36%. Statistical analysis revealed that adding PSC at different rates significantly affected the %LA values ($p<0.05$). The %LA values of the CP1 and CP3 chips were found to give similar results to those of another cheese chip investigation (Albay et al., 2024). The %LA value decreased when PSC was added. Similarly, another study found that yoghurts with chia seeds had lower initial acidity than the control group without chia seeds. However, it was reported that it did not appreciably alter the tendency for acidity to rise during storage (Nakov et al., 2024).

Chips dry matter ranged from 88.16% to 92.49%, fat from 30.50% to 40.83%, protein from 31.54% to 50.01%, ash from 5.54% to 6.89%, and salt from 3.81% to 4.32%. The dry matter value of the CP3 sample was slightly higher than the dry matter values of the control (CPC) and CP1 samples, which were similar to the other study findings (Albay et al., 2024). This situation was impacted by the increased PSC addition rate. Microwave drying increased dry matter values in chips, compared to cheese. It was found that moisture content reduced on a dry matter basis in Cheddar cheese snacks made in a vacuum microwave dryer, with the value in dried cheese decreasing by 4.4 times compared to the initial level (Rakcejeva et al. 2009). With the increase in PSC rate, it was observed that the dry matter, protein, and ash content of the chips rose; however, the fat and salt content diminished ($p<0.05$). PSC is a partially oil-free product derived from oil extraction. As a result, while it has less oil than seeds, it contains more ash, protein, and fiber (Melo et al., 2022). Therefore, the CP1 and CP3 samples had higher dry matter, protein, and ash values compared to the CPC. Blicharz-Kania et al. (2022) established that an increase in PSC correlates with a decrease in moisture content and an increase in protein and fiber content in oat

Table 2. Physicochemical and color analysis results of White cheese (without salt) with varying PSC ratios on the 1st day of storage

	White Cheese Samples		
Parameters**	**Control Cheese**	**Cheese with 1% PSC**	**Cheese with 3% PSC**
Titration acidity (%LA)	1.46 ± 0.13^{b}	1.69 ± 0.28^{a}	1.59 ± 0.18^{b}
Dry matter (%)	41.37 ± 0.32^{c}	44.32 ± 0.13^{b}	48.42 ± 1.90^{a}
Fat (%)	21.37 ± 0.12^{a}	19.75 ± 0.25^{b}	17.75 ± 0.25^{c}
Ash (%)	0.27 ± 0.01^{c}	1.14 ± 0.05^{b}	2.30 ± 0.63^{a}
Protein (%)	8.21 ± 1.27^{b}	9.86 ± 0.81^{b}	13.13 ± 0.49^{a}
L*	91.40 ± 0.42^{a}	70.55 ± 0.98^{b}	66.64 ± 1.78^{c}
a*	-1.75 ± 0.03^{c}	2.81 ± 0.15^{b}	3.40 ± 0.26^{a}
b*	9.20 ± 0.03^{b}	12.42 ± 0.14^{a}	12.51 ± 0.30^{a}

**a-c: Indicates that the difference between samples is statistically significant ($p<0.05$). Data presented are means ±SD.

cookies. Nakov et al. (2024) reported that the inclusion of chia seeds greatly affected the protein level of yogurt. Because of its higher total protein content than poppy seeds, PSC offers enormous potential in the development of nutritional supplements and innovative food products (Melo et al., 2022).

Color analysis results

The L* values for CPC, CP1, and CP3 samples were 73.39, 63.62, and 57.75, respectively. The a* values of the chips ranged from 0.50 to 5.93, while the b* values ranged from 10.78 to 17.54 (Table 3). Statistical analysis showed that adding PSC at varied rates had a significant impact on all color values ($p<0.05$). The brightness value of the CP1 sample was found to be comparable to Dil cheese chips (Albay et al., 2024). Anlı (2020) found that the use of high microwave power reduced the brightness of Lor cheese and increased its greenness and yellowness. According to Rakcejeva et al. (2009), microwave-dried Cheddar cheese turned dark yellow. This was explained by an increase in fat-soluble carotene in the cheese as the moisture content decreased after drying. Similarly, microwave drying increased the yellowness values in chips compared to cheese. The CP1 and CP3 samples had lower yellowness values than those reported by Shedeed et al. (2020). This demonstrates that the pre-drying procedure and microwave cooking time increased the yellow tones of potato chips. The addition of PSC reduced the brightness and yellow color of the chips while increasing the redness. As a result, the chips seemed darker after using PSC. Another research work found that adding PSC to the samples reduced their brightness and yellowness (Blicharz-Kania et al., 2022). Additionally, poppy seeds can be gray, blue, white, or yellow. Their characteristics can vary according to diverse seed colors and edaphoclimatic situations (Melo et al., 2022). A product's color can also be influenced by its type, harvesting, process, storage, composition, climate, and regional differences. Therefore, differences in the color values of the products can be observed.

Texture analysis results

The CPC, CP1, and CP3 samples were found to have hardness values of 859.42 g, 801.77 g, and 494.81 g, and fracturability values of 34.12 mm, 35.53 mm, and 35.97 mm, respectively (Table 3). The addition of PSC resulted in lower chip hardness values. Particularly, the hardness was considerably decreased ($p<0.05$) by the addition of 3% PSC. The inclusion of PSC reduced the hardness of chips, resulting in a more fragile structure. This can be explained by the proteins and fibers in PSC affecting the structural integrity of chips. The hardness values of the CPC and CP1 samples were found to be within the range of the full-fat (920.63 g) and half-fat (616.56 g) chips found in another study (Albay et al., 2024), while the CP3 sample was near the non-fat (312.58

Table 3. Physicochemical, color, and texture analysis results of cheese chips with varying PSC ratios on the first day of storage

	Chips Samples**		
Parameters*	**CPC**	**CP1**	**CP3**
pH	5.44±0.03^{c}	5.49±0.01^{b}	5.59±0.01^{a}
Titration acidity (%LA)	1.36±0.01^{a}	1.06±0.01^{b}	1.00±0.06^{b}
Dry matter (%)	88.16±0.09^{c}	89.97±0.05^{b}	92.49±0.36^{a}
Fat (%)	40.83±0.83^{a}	34.66±0.33^{b}	30.50±0.50^{c}
Ash (%)	5.54±0.06^{b}	6.78±0.12^{a}	6.89±0.05^{a}
Protein (%)	31.54±0.25^{c}	40.64±1.91^{b}	50.01±1.40^{a}
Salt (%)	4.32±0.15^{a}	3.97±0.11^{ab}	3.81±0.04^{b}
L*	73.39±1.71^{a}	63.62±1.81^{b}	57.75±0.29^{c}
a*	0.50±0.62^{c}	4.50±0.37^{b}	5.93±0.08^{a}
b*	17.54±0.42^{a}	13.87±0.71^{b}	10.78±0.94^{c}
Hardness (g)	859.42±56.05^{a}	801.77±83.88^{a}	494.81±174.61^{b}
Fracturability (mm)	34.12±1.46^{a}	35.53±1.25^{a}	35.97±1.42^{a}

*a-c: Indicates that the difference between samples is statistically significant ($p<0.05$). Data presented are means ±SD.
**CPC: Control sample without PSC, CP1: Sample with 1% PSC, CP3: Sample with 3% PSC

g) chips. Blicharz-Kania et al. (2022) reported a substantial rise in the hardness of oat cookies with increasing amount of PSC ($p<0.05$). This could be owing to the difference in structural characteristics between chips and cookies. Cookies are denser and thicker than chips, which are crunchier and thinner. These distinctions may cause PSC to have varying impacts on both products. The hardness values of the CPC and CP1 samples are comparable to potato chips cooked in a microwave oven for 100 sec at 100 W power (Shedeed et al., 2020). Comparing the results of this investigation with those of other studies revealed that pre-drying, microwave power and time, as well as the content and amount of additive added to the chips, all influenced the texture values.

Elemental analysis results

All of the elements found in chips were calcium (Ca), sodium (Na), magnesium (Mg), potassium (K), zinc (Zn), and phosphorus (P) (Table 4). Copper (Cu), iron (Fe), and manganese (Mn) elements were detected to be less than 0.1 mg/g sample, while adding only 3% PSC resulted in a very low Mn element level (0.02 mg/g sample). PSC increased the levels of Ca, K, Mg, Na, P, and Zn elements. The study found that whereas Na (17.00 mg/g sample) and Zn (0.07 mg/g sample) had the greatest levels in the CP1 sample, K (6.81 mg/g sample), Ca (5.24 mg/g sample), Mg (1.60 mg/g sample), and P (8.17 mg/g sample) had the highest values in the CP3 sample. These findings demonstrate that PSC is a rich mineral source that can be employed in chips.

Harmankaya et al. (2013) found that corn chips with poppy seeds had higher B, Cu, and Mn levels than corn chips containing cheese, whereas Fe and Zn contents were identical. This demonstrates that poppy seeds increase the mineral content. Poppy seeds are rich in minerals, particularly K, P, Mg, Ca, and Fe, and they do not contain any toxic elements like As, Cd, or Pb, according to Bolaños et al. (2019). Additionally, they discovered that non-essential elements (such as Al, Sr, Ba, and Ti) were also present in high amounts. Another study found that poppy seeds are a good source of minerals like phosphorus, calcium, zinc, manganese, copper, iron, and magnesium (Muhammad et al., 2021). In another investigation, it was discovered that PSC samples were particularly high in Ca, Mg, Na, and K but low in Fe. Heavy metals, including lead, nickel, cadmium, chromium, and cobalt, were not found in the samples (Yılmaz and Emir, 2017). Melo et al. (2022) detected that PSC had a higher total ash content (10%) than poppy seeds (7.21%) and was a better mineral source. Additionally, PSC was determined to be high in essential minerals like magnesium, calcium, phosphorus, and potassium.

Microbiological analysis results

Table 5 presents the TMAB counts of the present experiment. From this table, it can be seen that the TMAB count in cheese was above 10^6 cfu/g, while the probiotic bacteria, Lacobacilli, and Lactococci counts were above 10^7 cfu/g. Statistical analysis revealed a significant effect of PSC on *Bifidobacterium* BB-12 count in cheese ($p<0.05$). Additionally, a slight increase was observed in the counts of *Bifidobacterium* BB-12, Lactobacilli, and Lactococci with PSC addition ($p<0.05$). However, bacterial counts in microwave-dried chips were lower than those in fresh cheese, which may be attributed to the effects of microwave power and drying time on microbial survival. Similarly, Anlı (2020) reported that microwave-vacuum drying of Lor cheese suppressed TMAB growth, supporting the findings of this study.

The counts of TMAB, *Bifidobacterium* BB-12, *L. acidophilus* LA-5, Lactobacilli, and Lactococci found in chips were 3.73-4.69 log cfu/g, 4.92-5.25 log cfu/g, 4.13-4.49 log cfu/g, 6.52-6.87 log cfu/g,

Table 4. Elemental analysis results of cheese chips with varying PSC ratios on the first day of storage

Sample*	Element Name/ Working Wavelength/ Concentration (mg/g sample)**								
	Ca 317.933	Cu 327.393	Fe 238.204	K 766.490	Mg 285.213	Mn 257.610	Na 589.592	P 213.617	Zn 206.200
CPC	3.89±0.04[a]	< 0.1[a]	< 0.1[a]	4.61±0.17[c]	0.39±0.01[c]	< 0.1[b]	14.57±0.17[c]	6.23±0.11[c]	0.05±0.02[a]
CP1	3.11±0.11[c]	< 0.1[a]	< 0.1[a]	5.88±0.30[b]	1.45±0.06[b]	< 0.1[b]	17.00±0.25[a]	8.04±0.14[b]	0.07±0.01[a]
CP3	5.24±0.17[b]	< 0.1[a]	< 0.1[a]	6.81±0.02[a]	1.60±0.07[a]	0.02±0.01[a]	15.40±0.43[b]	8.17±0.16[a]	0.06±0.01[a]

*a-b: Indicates that the difference between samples is statistically significant ($p<0.05$). CPC: Control sample without PSC, CP1: Sample with 1% PSC, CP3: Sample with 3% PSC

**Data presented are means ±SD

and 3.79-3.86 log cfu/g, respectively (Table 5). The inclusion of PSC significantly influenced the counts of TMAB, *Bifidobacterium* BB-12, and Lactobacilli ($p<0.05$). Notably, the lowest TMAB count (3.73 log cfu/g) was observed in the sample containing 3% PSC, whereas no significant difference was detected between the control (CPC) and 1% PSC (CP1) samples. *L. acidophilus* LA-5 and *Bifidobacterium* BB-12 remained above 10^4 cfu/g. The addition of PSC resulted in a decrease in *Bifidobacterium* BB-12 ($p<0.05$). However, statistically, its effect on *L. acidophilus* LA-5 count was not found to be significant. Different drying techniques or microwave power levels may be employed to maintain the viability of probiotics, and PSC possesses attributes that support this situation. In our investigation, PSC promoted Lactobacilli viability (>10^6 cfu/g). Lactobacilli counts increased with increasing PSC ratio ($p<0.05$); however, their impact on the number of Lactococci was not statistically significant. The high fiber content, which is mostly found in the cake (38% fw), consists of complex carbohydrate polymers that the gastrointestinal flora can ferment into short-chain FAs (butyrate, propionate, and acetate), which provide energy and other benefits. Therefore, the fiber in poppy cake may contribute to a balanced microbiota composition, which is required for a healthy condition (Melo et al., 2022). Łopusiewicz et al. (2019) reported that flaxseed cake has positive impacts on lactic acid bacteria (LAB). A different study determined that increased chia seed concentrations rendered the yogurt matrix or microbial habitat less conducive to LAB survival (Nakov et al., 2024).

In the present work, no coliform group bacteria were found in the samples, possibly due to the microwave drying. Shahvandari et al. (2022) investigated the effect of microwave treatment at varying microwave power and times on microorganisms in raw milk. The study showed that a 90 sec microwave treatment at 180 watts dramatically reduced the number of coliform bacteria. As a result, our study suggests that using 180 Watt microwave drying for 3 min affected coliform group bacteria.

Principal component analysis of sensory properties results

Sensory parameters (softness-hardness, rough structure, thickness structure, chewability, crispy sound, brownish appearance, yellowish appearance, matte-shiny, mottled appearance, poppy odor, foreign odor, burnt odor, cheese odor, poppy taste, foreigne taste, oily taste, rancid taste, burnt taste, salty taste) were evaluated in the principal component analysis (PCA) of the chips samples. The variance (eigenvalue) of the first principal component (PC1) is 13.27, explaining 66.40% of the total variance. The variance of the second principal component (PC2) has been determined as 6.72 and explains 33.60% of the total variance. The first principal component is ordered based on their same sign (-) and distance from zero; it is observed that the Yellowish Appearance (-0.313), Matte-Shiny Appearance (-0.272), Cheese Odor (-0.272), Salty Taste (-0.258), Oily Taste (-0.249), Rancid Taste (-0.246), Brownish Appearance (-0.227), Burnt Taste (0.249), Mottled Appearance (0.246), Poppy Taste (0.271), Chewability (0.273), Poppy Odor (0.273), Foreign Odor (0.273), Rough Structure (0.272). The second principal component is formed by the contrast of Crispy sound (-0.383), Bland Taste (-0.383), Hardness (-0.268), Thickness

Table 5. Microbiological properties of White cheeses (without salt) and cheese chips with added PSC on the first day of storage (log cfu/g)

Parameters*	White cheese samples**			Chips samples**		
	CPC	CP1	CP3	CPC	CP1	CP3
Total mesophilic aerobic bacteria	6.85±0.58^{a}	6.73±0.30^{a}	6.64±0.60^{a}	4.69±0.02^{a}	4.68±0.01^{a}	3.73±0.24^{b}
Bifidobacterium animalis subsp. *lactis* BB-12	7.09±0.07^{b}	7.25±0.10^{ab}	7.37±0.08^{a}	5.25±0.04^{a}	4.97±0.02^{b}	4.92±0.07^{b}
Lactobacillus acidophilus LA-5	7.63±0.36^{a}	7.51±0.12^{a}	7.55±0.18^{a}	4.49±0.20^{a}	4.26±0.20^{a}	4.13±0.10^{a}
Lactobacilli	7.27±0.17^{b}	7.42±0.14^{ab}	7.84±0.16^{a}	6.52±0.22^{b}	6.60±0.09^{ab}	6.87±0.12^{a}
Lactococci	7.14±0.49^{b}	7.42±0.19^{a}	7.43±0.24^{a}	3.79±0.22^{a}	3.81±0.10^{a}	3.86±0.12^{a}

*a-b: Indicates that the difference between samples is statistically significant ($p<0.05$). Data presented are means ±SD.
**CPC: Control sample without PSC, CP1: Sample with 1% PSC, CP3: Sample with 3% PSC

(0.271), Burning Odor (0.384), and Foreign Taste (0.384) (Figure 2).

When examining the graph (Figure 2), the following results were observed: The addition of PSC caused the chips to appear more yellow and brown. As the PSC ratio increased, the chip samples acquired a matte appearance. It has been observed that the crispy sound and texture results of chips with a 3% PSC addition received lower scores compared to those with a 1% PSC addition. The addition of PSC resulted in a lower perception of fat content, while an increase in the proportion of PSC led to a more pronounced bland taste. However, in samples without PSC (CPC), the panelists reported that they perceived the odor and taste of cheese, as well as a stronger salty and bitter taste.As a result of the general acceptability scores, it was determined that the CPC sample received a score of 6.40±0.16, the CP1 sample received a score of 6.95±0.53, and the CP3 sample received a score of 6.25±0.04. According to the results, it was observed that CP1 samples received better scores than CPC and CP3 samples, with CP3 sample having the lowest overall acceptability.

CONCLUSIONS

Significant amounts of the PSC by-product are produced due to the high-scale production and the low efficiency of the oil extraction process. Significant quantities of PSC, a by-product of oil extraction from poppy seeds, are generated due to the high-scale production and relatively low pressing efficiency. Given its high protein, fiber, and mineral content, along with its gluten-free and low-fat nature, PSC offers considerable potential as a functional ingredient in the development of novel fortified food products.

This study showed that PSC has a substantial impact on the physicochemical, color, texture, and microbiological properties of chips. PSC addition significantly increased pH, dry matter, protein, and ash content, while decreasing fat and salt levels ($p<0.05$). The addition of PSC reduced the brightness and yellow color while increasing redness ($p<0.05$). Moreover, PSC reduced hardness values ($p<0.05$), resulting in a more fragile and desirable texture. These findings suggest that PSC can improve the quality of chips. Elemental research has revealed that PSC increases the levels of calcium, potassium, magnesium, sodium, phosphorus, and zinc. The presence of these minerals can improve the PSC's suitability as a functional food ingredient and provide nutritional and health benefits. Furthermore, the good impacts of these minerals on physiological functioning highlight PSC's nutritional and health benefits. According to the microbiological investi-

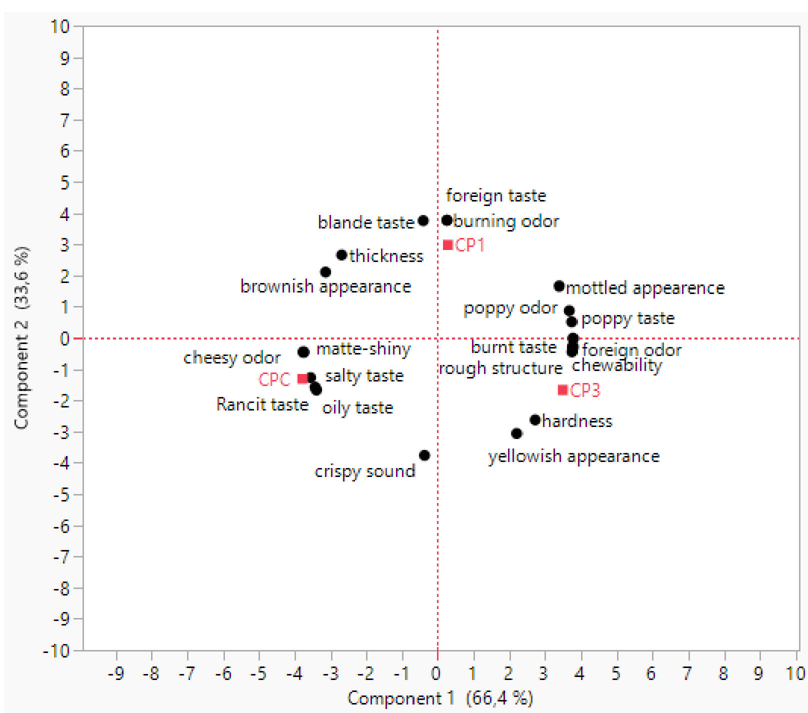

Figure 2. Graph of the Principal Component Analysis (PCA) of cheese chips with added PSC (CPC: Control sample without PSC, CP1: Sample with 1% PSC, CP3: Sample with 3% PSC).

gation results, adding PSC resulted in a decrease in the amount of TMAB ($p<0.05$). While the presence of PSC had no statistically significant effect on *Lactobacillus acidophilus* LA-5 counts, it resulted in a statistically significant decrease in *Bifidobacterium animalis* subsp. *lactis* BB-12 ($p<0.05$). These findings demonstrate that PSC can improve the microbiological quality and contribute to the preservation of health status by promoting a balanced microbiota composition due to its high fiber content.

Although the 3% PSC addition provided the highest nutritional and mineral enhancements, sensory analysis results highlighted that the panelists more favorably perceived chips containing 1% PSC (CP1) in terms of crispy texture, balanced flavor (without excessive blandness), and overall acceptability. Therefore, considering both functional improvements and consumer sensory preference, the addition of 1% PSC is suggested as the optimal formulation for developing enhanced-quality cheese chips.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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