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Wheat fiber's influence on low-fat White cheese chips quality and consumer acceptance

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Abstract

In this study, the possibility of manufacturing cheese chips from enriched probiotic low-fat White cheese (without brine, fresh) containing 0.5 % and 1.5 % wheat fiber (WF) was studied to examine the effect of WF on chips quality. The study found that WF reduced the titratable acidity, fat, water activity, and salt levels of chips ($p<0.05$). WF significantly increased the color values (L* and a*) of the samples ($p<0.05$), resulting in heterogeneous browning. WF substantially increased the hardness and fracturability of chips ($p<0.05$). Carvacrol, nonanal, acetic acid, acetoin, and diacetyl compounds were prevalent in all samples. However, the addition of WF increased furfural levels, which could cause hepatotoxicity, and was found to be the dominant component in a sample containing 1.5 % WF. While the addition of %0.5 WF improved chewability and crispness without impacting overall acceptability, %1.5 WF caused burnt and bland flavors, which decreased consumer preference. The study found that WF influenced the physicochemical, color, texture, and volatile aroma properties of the chips, but it was established that 0.5 % WF would be more appropriate regarding customer acceptance and health.

Keywords: cheese chips; wheat fiber; low-fat snacks; volatile aroma components

Introduction

The snack industry is rapidly developing due to changes in eating habits and lifestyles (Paramasivam et al., 2022). Health concerns associated with fried products are associated with the high-fat content, as well as the formation of hazardous chemicals (e.g., acrylamide) and the rapid digestion of starch, which is reflected in a high glycemic index (Duarte-Correa et al., 2020). The snack food sector has begun manufacturing products with less fat while maintaining the appropriate texture and flavor due to consumer preference for low-fat and fat-free snacks (Akkurt et al., 2021). Many industrial methods are being studied to generate low-fat snacks. Various fat replacers, such as fat mimetic and fat substitutes, have been employed worldwide to manufacture low-fat deep-fried snacks (Paramasivam et al., 2022). In recent years, interest in the use of dietary fibre in food formulations has increased due to its positive effects on health. Due to its high fiber content and light color compared to other fiber sources, wheat fiber (WF) can be utilized to add fiber in a certain percentage/range to some dairy products, such as cheese, without causing sensory issues. Additionally, WF is a tasteless, odorless, calorie-free dietary fiber with high water and fat retention capacity (Albay, 2022).

Cheese is a popular food due to its high protein content and nutritious characteristics (Köprüalan et al., 2022). However, very few snacks are derived from cheese alone. Snacks are usually made from potatoes or corn and covered with dried cheese. The new ingredients used to produce such crunchy snacks are cheese or cheese imitations. Depending on the type of cheese, regular or reduced-fat snacks can be produced (Chudy et al., 2021). In a study on the production of low-fat chips, it has been reported that as the fat content decreases, there are some negative changes in the textural and aroma properties of the chips (Albay et al., 2024). It has been reported that probiotic bacteria increase proteolytic activity in cheeses (Yılmaztekin et al 2004) and also make significant contributions to the development of acidic aroma (Ma et al 2024).

In this study, low-fat and fresh White cheese was utilized as the primary raw material to produce cheese chips. Due to their reduced fat content and lack of ripening, such cheeses are often associated with limited flavor development and may exhibit suboptimal textural properties during processing and in the final product. Nevertheless, it should be noted that these potential drawbacks are significantly influenced by the specific production technologies employed and the point at which fat or flavor-enhancing agents are incorporated. To address these challenges and improve the sensory and functional characteristics of the cheese, mesophilic and probiotic cultures were integrated into the cheese formulation. Furthermore, the study aimed to evaluate whether the addition of WF at two concentrations (0.5 % and 1.5 %) could enhance the viability of the probiotic cultures and improve the technological and sensory properties of the resulting oven-dried cheese chips. The effects of WF inclusion on the physicochemical, textural, and sensory attributes of the final product were comprehensively assessed, with the overarching objective of determining the potential of WF as a functional ingredient in the formulation of healthier, low-fat cheese-based snack products that meet both nutritional and consumer quality expectations.

Materials and methods

Cheese and cheese chips production

The fat content of the milk intended for cheese production was standardized to 1.5±0.1%. It was then pasteurized at 72±2 °C for 2 minutes. After pasteurization, milk (50 L) was cooled to 35±2 °C, and 40 % $CaCl_2$ solution was added at 0.02 %. Then 1g/100 L of probiotic culture (*Bifidobacterium animalis* subsp. *lactis* BB-12® and *Lactobacillus acidophilus* LA-5®; FD-DVS nu-trish®, Chr Hansen) and 1g/100 L of mesophilic starter culture (FD-DVS nu-trish®, Chr Hansen) were added. The milk was divided into three groups, and one group was treated without WF addition (BUK, control group). The other two groups were supplemented with WF (Değirmencibaşı Smart Chemical Trade and Consulting Co. Ltd., İzmir, Türkiye) at 0.5 % (BU1) and 1.5 % (BU2), which were determined as a result of preliminary trials. The properties of the wheat fibers used were reported by the manufacturer as follows: particle size 250 micrometers, pH value 5-8, moisture content <7.5, bulk density 70-110 g/Liter, off-white color, taste and odor neutral, mercury and cadmium content <1 mg/kg, total aerobic mesophilic number <100 CFU/g. After pre-ripening (15 min), liquid rennet (Naturen Mandra, 175IMCU L^{-1}, Chr Hansen) was added. The fermentation process was carried out at 35±2 °C for 90 min. Then, curd cutting, straining, and pressing processes were applied, respectively. White cheese (without salt, fresh) produced with WF (~10 kg) was produced in three replicates. White cheeses produced without adding brine were packed in transparent vacuum bags made of EVOH, PA, and PE plastic polymers (made by heat sealing multi-layered films within the dimensions) and kept at +6±1 °C for one night. Cheese chips were produced the next day.

The fresh White cheese was crumbled into small pieces, and 2 % salt was added. Then, chip 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 55 °C for 100 min in a drying oven (Wiseven, WOF-155, Korea) and then dried at 180 °C for 6 min. After cooling to room temperature, the chips (Figure 1) were vacuum packed in airtight, transparent vacuum bags made of EVOH, PA, and PE plastic polymers (made by heat sealing multi-layered films within the dimensions) with the vacuum setting turned off. The produced chips were stored at +4±1 °C.

Raw milk and cheese analysis

The raw milk used in the study was analyzed for specific gravity, dry matter, titratable acidity (% LA), pH, fat (AOAC, 1997).

For White cheese (without salt, fresh) titrable acidity (% LA), dry matter, fat, and ash analyses were performed (AOAC, 1997). The pH values were determined using a digital pH meter (WTW pH 315; Weilheim, Germany). The water activity levels were determined using a Novasina brand water activity device (Lab Touch-a_w, Lachen, Switzerland). Cheese samples were crushed using a blender. Samples were filled to half cover the water activity container, placed in the device, and the a_w value was read at approximately 20.7 °C. Cheese samples were precisely cut into dimensions of 50x50x25 mm using a knife. Color measurements were subsequently conducted at three distinct points on three randomly selected samples. A CR-400 Minolta Chroma Meter (Japan) was employed to determine the color values, specifically L* (brightness), a* (green/red), and b* (blue/yellow). Calibration of the colorimeter was performed before each measurement following the C (Y: 92.7, x: 0.3135, y: 0.3193) and D65 (Y: 92.7, x: 0.3160, y: 0.3321) values specified on the calibration plate.

Texture profile analysis (TPA) was performed by modifying the methods described by Oluk (2013) and Albay (2022). The samples were sliced into 50x50x25 mm pieces using a cutting knife, then covered in plastic film and stored at room temperature (20±2 °C) until analysis. TPA was conducted using a texture analyzer (Texture Stable Micro Systems, TA-XT Plus, UK) with an SMS P/36R aluminum cylinder probe (AACC standard probe, 36 mm diameter) and a 100 mm long AD/100 aluminum probe adaptor. Each sample was measured four times. Analysis conditions: 5 kg load cell, initial test speed 1.0 mm/s, test speed 1.0 mm/s, final test speed 1.0 mm/s, 30 % compression, holding time 5 s.

Cheese samples (10 g) were diluted with sterile Ringer (1/10) solution for microbiological analyses, preparing dilutions at different ratios. Samples were analyzed for bacterial counting using spread plate procedures. The enumeration of *Bifidobacterium animalis* subsp. *lactis* BB-12 (*Bifidobacterium* BB12) was performed using MRS-NNLP agar medium consisting of nalidixic acid (50 mg/L), neomycin sulphate (100 mg/L), lithium chloride (3000 mg/L), and paromomycin sulphate (200 mg/L). Before pouring the medium into petri plates, the NNLP supplement was aseptically filter-sterilized through a 0.45 µm membrane and incorporated into sterile MRS agar (de Man, Rogosa, and Sharpe; Merck, Germany) under aseptic conditions. For the enumeration of *Lactobacillus acidophilus* LA-5 (LA-5), MRS-Sorbitol agar was prepared by aseptically supplementing sterile MRS agar with a filter-sterilized 10 % (w/v) D-sorbitol solution. Specifically, 10 mL of the sorbitol solution was passed through a 0.45 µm sterile membrane filter (Minisart® Syringe Filter, Germany) and then incorporated into 90 mL of MRS agar prior to plating. Petri dishes were incubated in anaerobic jars at 37 °C for 72 hours to count probiotic bacteria (Dave and Shah, 1997). For the enumeration of lactobacilli, duplicate 100 µl aliquots from serially diluted samples were inoculated onto MRS agar plates. These plates were subsequently incubated anaerobically at 37 °C for 72 hours. Conversely, Lactococci were quantified by inoculating duplicate 100 µl aliquots from the same sample dilutions onto M17 agar plates (Merck, Germany), followed by aerobic incubation at 37 °C for 48 hours (Gardini et al., 1999). Microbiological count results were presented as log CFU/g.

Cheese chips analysis

Physicochemical analysis

The thickness and diameter of the cheese chips were measured using a digital caliper (0.001 mm, Mitutoyo, Tokyo, Japan), following the methodology outlined by AACC (2000). The pH of cheese chips was measured with a digital pH metre (WTW pH 315; Weilheim, Germany). The titrable acidity values were calculated as a percentage of lactic acid (% LA). The dry matter content was analysed using the gravimetric method, fat content was estimated using the Gerber method, ash content was measured by incinerating the samples at 550 °C in a muffle furnace (Nüve, MF 120, Ankara, Türkiye), and salt content was assessed using the Mohr titration method (AOAC, 1997). The water activity was measured using a Novasina brand water activity equipment (Lab Touch-a_w, Lachen, Switzerland). Chips were crushed using a blender. Then, the water activity container was filled halfway and placed in the device. The a_w value measured at roughly 20.7°C.

Color analysis and texture analysis

The L* (brightness), a* (green/red), and b* (blue/yellow) color values were measured using a color metre (CR-400 Minolta Chroma Metre, Japan). Color measurements were taken at three distinct locations on both sides of three randomly chosen samples from each category. Texture analysis of chips was carried out on the first day of storage using a Texture Stable Micro Systems (TA-XT Plus, UK) texture analyzer equipped with a 5 kg load cell. Six samples 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., 2021).

Volatile aroma components analysis (SPME-GC-MS)

Volatile aroma component analysis was performed by solid phase microextraction (SPME) followed by gas chromatography (GC)-mass spectrometry (MS) (Yang and Peppard, 1994). Before analysis, the chips were stored at +4 °C for 1 day. Then, 3.0 g of sample was placed in a 15 mL silicone septal vial (Supelco 27159 15 mL clear PTFE/Silicone septa Cap) and kept at 45 °C for 15 min (without fiber). Extraction was performed using a fiber-vial injection of 75 µm carboxene®/polydimethylsiloxane (CAR/PDMS) (Fused Silica, Supelco Ltd., Bellefonte, PA, USA). The fiber was kept in headspace at 45 °C for 30 min to allow the aroma substances to pass into the fiber structure. The desorption of the volatile compounds to be extracted was carried out in the GC-MS system and kept at 250 °C for 5 min. The Shimadzu GC-2010 gas chromatography system, mass spectrometry system (Shimadzu Corporation, Kyoto, Japan), and Shimadzu GCMS-QP2010SE (Shimadzu Corporation, Kyoto, Japan)

detector were used for the analysis of volatile aroma compounds. The Rx-5sil MS column (30 m x 0.25 mm, i=0.25 µm film thickness; Restek, Bellefonte, Catalog No. 13623, PA, USA) was used for the separation of compounds. The temperature was initially held at 40 °C for 2 min and then increased to 250 °C at a rate of 4°C per minute, and the oven temperature program was set to hold at this temperature for 5 min (injector and detector temperatures: 250 °C, detector voltage: 70 eV). Helium was used as a carrier gas at a flow rate of 1.61 mL/min. GC-MS analysis was performed in scan mode, set between 40-300 amu. SPME conditions were carried out at 60 °C for 15 min without fiber and 30 min with fiber and desorbed at 250 °C (Catalog No. Supelco 57318). Volatile compounds were identified by comparing their Retention Index (RI) and mass spectra with analytical standards. The separated volatile compounds were verified with Tutor, FFNSC (Flavor and Fragrance Natural and Synthetic) mass spectra libraries, Wiley-NIST (National Institute of Standards and Technology), and RI values. The RI was calculated using an alkane series for each compound.

Microbiological analysis

For coliform detection, 1 mL of the 1:10 dilution was taken and inoculated into Eosin Methylene-blue Lactose Sucrose (Merck, Germany) medium by smear method. Petri dishes were kept at 37 °C for 24-48 hours. For yeast-mold count, 1 mL of a 1:10 dilution was taken and inoculated on Potato Dextrose Agar (Merck, Germany) medium by smear method. The inoculated petri dishes were incubated at 25 °C for 4-5 days. As a result of microbiological analysis, colonies were counted as reported by Halkman (2005).

Principal component analysis of sensory properties results and statistical analysis

Sensory analyses were conducted by a panel of 8 experienced assessors (6 women and 2 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 produced with dietary fiber during storage. For the first evaluation, a numerical bipolar scale ranging from 1 to 9 was used. Texture (softness-hardness, thickness structure, chewability, crispiness-brittleness), appearance (whitish-yellow, matte-shiny, mottled appearance), odor (foreign smell, burnt smell, cheese smell), and taste (oily taste, grittiness-bland 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±1 °C until the sensory analysis was conducted. Cheese chips samples were given to the panelists along with crackers and water.

SPSS 26.0 (Ver. 22.0) statistical program was used for the statistical evaluation of the study results. To establish paired comparisons of traits that were statistically significant in ANOVA, we employed analysis of variance followed by Duncan's multiple comparison tests (Duzgunes et al., 1987).

Principal component analysis was applied to the values of hardness, whitish-yellow, matte shiny, mottled appearance, thickness structure, chewability, crispiness-brittleness, foreign smell, burnt smell, cheese smell, oily taste,

Table 1. Physicochemical, color, and texture analysis results of White cheese containing WF

	Cheese samples**		
Parameters*	**CBUK**	**CBU1**	**CBU2**
pH	5.17±0.14^{a}	5.22±0.10^{a}	5.20±0.07^{a}
Titrable acidity (%LA)	0.63±0.01^{b}	0.66±0.01^{a}	0.67±0.01^{a}
Dry matter (%)	36.44±0.18^{b}	38.71±0.28^{ab}	39.52±0.56^{a}
Fat (%)	13.65±0.30^{a}	11.65±0.35^{b}	9.65±0.35^{c}
Ash (%)	1.37±0.07^{b}	1.61±0.19^{a}	1.82±0.26^{a}
Water activity (a_w)	0.92±0.01^{a}	0.92±0.01^{a}	0.92±0.01^{a}
L*	87.89±1.14^{a}	88.97±1.07^{a}	88.21±0.45^{a}
a*	-2.95±0.23^{b}	-3.14±0.31^{a}	-3.05±0.22^{a}
b*	9.07±0.92^{a}	10.09±1.46^{a}	9.03±1.28^{a}
Hardness (N)	9.31±0.03^{a}	10.91±4.67^{b}	21.73±8.07^{c}
Adhesiveness (g*sec)	-8.69±5.93^{a}	-2.26±1.86^{a}	-16.69±15.13^{b}
Springiness	0.85±0.04^{a}	0.85±0.02^{a}	0.71±0.07^{b}
Cohesiveness	0.77±0.03^{a}	0.74±0.02^{a}	0.66±0.02^{b}
Gumminess	740.19±188.61^{b}	1096.76±106.9^{ab}	1176.13±169.85^{a}
Chewiness	623.98±124.22^{b}	821.65±186.13^{ab}	996.03±108.67^{a}
Resilience	0.39±0.03^{a}	0.34±0.02^{a}	0.27±0.03^{b}
Lactococci (CFU/g)	7.71±0.08^{b}	8.01±0.08^{ab}	8.42±0.14^{a}
Lactobacilli (CFU/g)	7.43±0.10^{b}	7.82±0.07^{a}	7.84±0.05^{a}
***Lactobacillus acidophilus* (CFU/g)**	7.34±0.08^{ab}	7.53±0.03^{a}	7.75±0.10^{a}
***Bifidobacterium* BB-12 (CFU/g)**	7.25±0.03^{ab}	7.42±0.07^{a}	7.60±0.09^{a}

**a-c: Indicates that the difference between samples is statistically significant (p<0.05).*
***CBUK: Control cheese sample without WF, CBU1: Cheese Sample with 0.5 % WF, CBU2: Cheese Sample with 1.5 % WF*

grittiness-bland taste, burnt taste, salty taste, and 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

Raw milk and cheese analysis results

The specific gravity, pH, titrable acidity (% LA), dry matter, and ash values of raw cow milk used as raw material were found to be 1.030 g/cm^3, 6.71, 0.16%, 12.00 %, and 0.78 %, respectively. After fat standardization, semi-skimmed raw milk had a fat of 1.59 %. It was observed that the dry matter and titratable acidity values of the raw milk used in the production complied with the Communiqué on Raw Milk and Heat-Treated Drinking Milk (Anonymous, 2000).

Physicochemical, color values and texture analysis results of White cheese containing WF are given in Table 1. The study found a significant difference in lactic acid concentration between WF samples and the control sample ($p<0.05$). A minor rise was noted in the CBU2 sample, indicating that fermentation might be more efficient. Additionally, the statistical difference between samples was found to be significant ($p<0.05$) for dry matter, fat, and ash data. Dry matter and ash content increased as WF concentration rose, indicating that WF may enhance the solid content. A clear decrease in fat content with higher WF levels, likely because WF itself is low in fat and dilutes the overall fat percentage. In another study, the fat content in dry matter determined in White cheese was similar to the value determined in the CBUK sample (Oluk, 2023). Minor differences in a* and b* values were observed, but overall color remained relatively stable across the samples. According to the data obtained, the CBU1 sample is brighter and yellower in color. Shehata et al. (2022) reported that wheat bran reduces the brightness of soft White cheese due to its color and makes it darker. As a result of texture profile analysis, it was determined that the hardness values of CBUK, CBU1, and CBU2 cheeses were 9.31 N, 10.91 N, and 21.73 N, respectively. An increase in the WF ratio led to a significant increase in the hardness values of the cheeses ($p<0.05$). This suggests the formation of a denser cheese matrix. The springiness, cohesiveness, gumminess, and chewiness values of cheeses closely matched the values found in White cheese (Oluk, 2023). The gumminess and chewiness values rose significantly as the WF content increased ($p<0.05$), making the cheese chewier and more resistant to deformation. The addition of 1.5 % WF significantly decreased the adhesiveness, springiness, cohesiveness, and resilience ($p<0.05$). The springiness decreased in CBU2, indicating a firmer but less elastic texture. The cohesiveness and resilience decreased with WF addition, suggesting a more brittle cheese structure. Another study found that adding WF to curds enhanced their hardness and had a significant effect on springiness, cohesion, gumminess, chewiness, and resilience ($p<0.05$) (Albay, 2022). Shehata et al. (2022) found that wheat bran increased the hardness of probiotic soft White cheese while decreasing its springiness and adhesiveness. This investigation revealed that the levels of lactococci, lactobacilli, and probiotic bacteria, specifically *L. acidophilus* and *Bifidobacterium* BB-12, rose in correlation with the increase in WF. This suggests that WF creates a conducive environment for probiotic proliferation. Mohamed

Table 2. *Physicochemical, color, and texture analysis results of chips containing WF*

	Cheese chips samples**		
Parameters*	**BUK**	**BU1**	**BU2**
Thickness (cm)	0.23±0.00^c	0.29±0.01^b	0.34±0.04^a
Diameter (cm)	4.75±0.38^a	4.93±0.26^a	5.10±0.07^a
pH	5.23±0.12^a	5.29±0.75^a	5.37±0.02^a
Titrable acidity (%LA)	0.88±0.01^a	0.86±0.01^b	0.85±0.01^b
Dry matter (%)	91.94±0.38^a	89.81±0.28^a	89.38±0.35^a
Fat (%)	25.00±0.25^a	24.00±0.75^b	19.87±0.12^c
Ash (%)	8.54±0.13^b	9.18±0.53^a	9.21±0.24^a
Water activity (a_w)	0.71±0.03^a	0.61±0.05^b	0.60±0.07^b
Salt (%)	2.12±0.03^a	2.04±0.05^a	1.76±0.07^b
L*	74.53±2.32^b	74.94±0.70^b	79.65±2.49^a
a*	2.04±0.57^b	3.02±1.06^{ab}	4.20±0.06^a
b*	23.89±1.78^a	23.95±1.61^a	24.00±1.34^a
Hardness (N)	8.77±0.42^b	14.62±0.19^a	16.96±3.07^a
Fracturability (mm)	35.49±0.21^b	36.41±0.23^a	36.37±0.55^a

**a-c: Indicates that the difference between samples is statistically significant ($p<0.05$).*
***BUK: Control sample without WF, BU1: Sample with 0.5 % WF, BU2: Sample with 1.5 % WF*

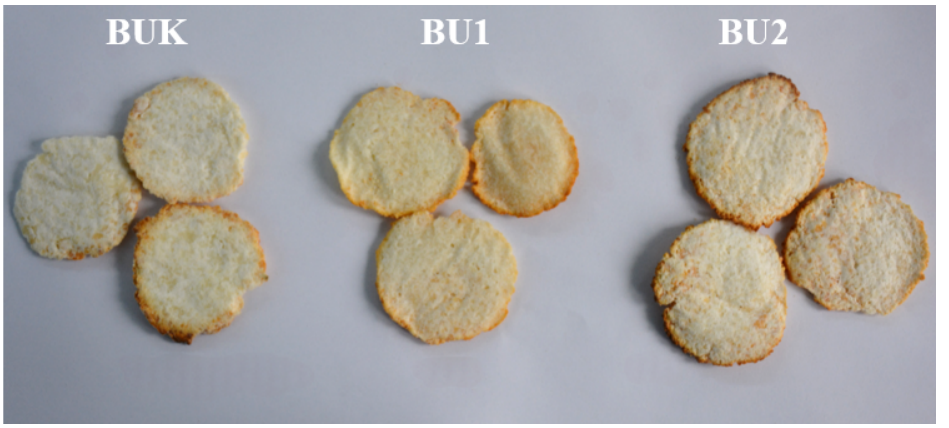

Figure 1. Cheese chips containing different ratios of WF (BUK: Control sample without WF, BU1: Sample with 0.5 % WF, BU2: Sample with 1.5 % WF)

et al. (2015) observed, similar to this study, that the viability of *B. bifidum* and *L. acidophilus* was enhanced in probiotic Labneh cheese prepared with the inclusion of wheat germ extract compared to the control.

Cheese chips analysis results

Physicochemical properties

Measurements revealed that the average diameters of the cheese chips ranged from 4.75 to 5.10 cm, and their thickness varied between 0.23 and 0.34 cm (Table 2). It was observed that the addition of WF significantly increased chips thickness ($p<0.05$). The thicknesses of the BUK and BU1 samples were found to be comparable to chips thicknesses reported in another study by Albay et al. (2021). The pH values of the chips were determined in the range of 5.23-5.37 (Table 2) and were similar to the other study (Uğur and Şimşek, 2021). WF decreased the titrable acidity values ($p<0.05$), with the BU2 sample having the lowest value of 0.85 %. The dry matter contents ranged from 89.38 % to 91.94 %, and similar results were obtained with full-fat and half-fat cheese chips (Albay et al., 2024). The statistical difference between the fat content of the chips was found to be significant ($p<0.05$). Depending on the fiber ratio, the fat ratios in the product composition decreased inversely proportionally, and the highest fat ratio was found in the BUK sample (25.00 %). The fat content of the BU1 sample was close to the fat content of sucrose-containing cheese chips (Uğur and Şimşek, 2021) and cheese puffs (Chudy et al., 2021). There was a statistically significant difference ($p<0.05$) in the ash content of the chips containing WF compared to the control sample. Ertop et al. (2016) observed that samples incorporating wheat brand exhibited higher ash content compared to those containing wheat germ. They attributed this difference to the testa layer present in wheat bran, which is rich in cellulose and ash. The addition of WF decreased the water activity content ($p<0.05$), and the addition of 1.5 % WF significantly reduced the salt content (1.76 %) ($p<0.05$). It was determined that the water activity values of BU1 and BU2 samples were close to the results of cheese chips stored for 30 days (Uğur and Şimşek, 2021). The salt content of the BU2 sample was similar to the other study (Albay et al., 2021), while the salt content of the BUK and BU1 samples was significantly higher ($p<0.05$).

Color properties

The color analysis revealed that the BUK sample (74.53) and the BU1 sample (74.94) had similar brightness values (Table 2). However, it was observed that the addition of 1.5 % WF significantly increased the brightness ($p<0.05$) and BU2 chips were brighter (79.65). The a* values ranged from 2.04 to 4.20, and the addition of WF caused the a* value to increase ($p<0.05$). As seen in Figure 1, heterogeneous browning occurred in oven-dried cheese chips. Akkurt et al. (2021) reported that surface browning in conventionally baked potato chips starts from the edges and progresses inward due to faster drying in this region. Ertop et al. (2016) determined that the sample containing wheat germ from gluten chips prepared with different formulations was brighter due to the fat content of the germ. Similarly, they reported that the sample containing wheat bran had the highest a* value and that the natural color of the bran affected the color of the product. Furthermore, cheese chips were brighter than standard oven-baked potato chips (Akkurt et al., 2021), whereas potato chips were yellower.

Texture properties

Texture analysis revealed that the hardness values of the BUK, BU1, and BU2 samples were 8.77 N, 14.62 N, and 16.96 N, and the fracturability values were 35.49 mm, 36.41 mm, and 36.37 mm, respectively (Table 2). Samples BU1 and BU2, which included WF, were found to be significantly harder and more fragile than the control BUK sample ($p<0.05$). This suggests that WF contributes to an increase in both the hardness and fracturability of the cheese chips. The observed alteration in textural properties can be explained to the increase in overall thickness of the cheese chips due to WF. The fracturability values were similar to those of cheese chips (Albay et al., 2021), while WF chips had a harder texture. In the other cheese chips study, hardness and fracturability values (Uğur and Şimşek, 2021) were significantly lower than this study. Additionally, the BUK sample had similar hardness values to microwave

vacuum-dried low-fat potato chips (Duarte-Correa et al., 2020), while the BUK and BU1 samples had similar hardness values to cheese puffs (Chudy et al., 2021).

Volatile aroma components

It was determined that a total of 56 volatile components, including alcohols (5), aldehydes (14), carboxylic acids (9), esters (2), hydrocarbons (9), ketones (13), and terpenes (4), were formed in cheese chips (Table 3).

Alcohol

A total of five alcohol components were identified in chips. Alcohol components were detected at total concentrations of 11.09 % in the BUK sample, 3.58 % in the BU1 sample, and 8.06 % in the BU2 sample (Table 3). Ethanol and methanethiol were detected in all chip samples. Maltol was detected in samples containing WF. The addition of WF increased ethanol and maltol concentrations. Maltol is a water-soluble flavoring component that enhances flavor and has a nice, sweet fragrance and aftertaste (Taylor and Linforth, 2010). Maltol has been shown to impart a sweet aroma that contributes to the smell of freshly baked bread and is used as an aroma enhancer in bread. Maltol is also found in much higher concentrations in the crust than in the bread and is formed mainly through the Maillard reaction (Xu et al., 2023). Therefore, an increase in maltol can be predicted due to the extra-produced amino acids and peptides that can participate in the Maillard reaction with the addition of WF. Additionally, Oluk (2023) determined that the most abundant alcohol in White cheese was ethanol. Ethanol is the result of the citrate metabolism of *Lactococcus* spp. in cheese (Albay et al., 2024).

Aldehydes

Aldehydes constitute the third main aroma group in BU1 and BU2 samples. As seen in Table 3, 14 aldehyde components were detected in chips. BUK, BU1, and BU2 chips had aldehyde components with concentrations of 8.48 %, 12.81 %, and 18.36 %, respectively. In the BUK sample, the nonanal (2.36 %) and in the BU1 sample, the benzene acetaldehyde (2.73 %) and nonanal (2.39 %) were dominant. The furfural part (3.24 %) of the BU2 sample was the most important. It was followed by nonanal (2.97 %), benzene acetaldehyde (2.87 %), and 3-methylbutanal (2.71 %). The dominant component in the BU2 sample, furfural, rose in the chips as WF content increased. Mesias et al. (2019) found that novelty snacks had significantly greater furfural concentration than conventional snacks. They reported that cereal composition influenced furfural levels in novelty snacks, with the highest levels seen in formulations containing rye and spelt. Additionally, they reported that furfural is formed as an intermediate product of the Maillard reaction and may cause hepatotoxicity. Although toxic effects in the human body have not yet been demonstrated with conclusive evidence, furfural is used as a quality indicator in food products processed at extreme temperatures, such as snacks obtained by frying. Consequently, furfural accumulation should be monitored in low-moisture food products exposed to high temperatures due to health and quality concerns (Ağçam, 2022). Compared to the control sample, chips with 0.5 % WF had methional, isobutyraldehyde, and trans-2-nonenal components. Samples with 1.5 % WF had methional, n-octanal, and 2,4-dimethylpentanal components. Furaneol and Strecker aldehydes, methional, 3-methylbutanal, and methylpropanal are important Maillard-derived aroma compounds in wheat and rye bread. These contribute to the caramel-like and malty aroma of bread (Taylor and Linforth, 2010). Branched-chain aldehydes like 3-methylbutanal are made when isoleucine and leucine are broken down, while acetaldehyde is made when threonine is broken down, lactose is broken down, and ethanol is burned (Oluk, 2023). Agarwal et al. (2018) reported that aldehydes such as nonanal, octanal, hexanal, heptanal, and 2-pentylfuran in potato chips were formed by the heterolytic acid breakdown of methyl linoleate or oleate hydroperoxides in high oleic oil.

Carboxylic acids

Carboxylic acids were the first main aroma group in all cheese chips (Table 3). Nine carboxylic acid components were detected in the chips, and the total concentrations of carboxylic acids identified in the samples were quite high. Total carboxylic acid concentrations were 51.17 %, 60.10 %, and 46.55 % in the BUK, BU1, and BU2 samples, respectively. According to the results obtained, a higher carboxylic acid number and total concentration occurred in the chips with 0.5 % WF addition. Acetic acid was the dominant aroma component in all chips. The concentrations of acetic acid were 49.43 %, 53.29 %, and 43.44 % in the BUK, BU1, and BU2 samples, respectively, and acetic acid constituted a significant portion of the total concentration. Acetic acid contributes to the flavor of cheese and is a byproduct of many chemical processes, including the fermentation of lactic and citric acids and the metabolism of amino acids (Bulat and Topcu, 2020; Albay et al., 2024). Methylpyrazine, 2,6-dimethylpyrazine, and 2-ethyl-6-methylpyrazine were determined in this investigation. Some pyrazine chemicals, like methylpyrazine, are linked to tastes like nuts, roast, and baked goods (Agarwal et al., 2018). Similarly, Oluk (2023) determined the acetic, butanoic, n-decanoic and octanoic acid in White cheese and reported that these short-chain volatile acids have significant effects on the taste of the cheese. Also, hexanoic acid, octanoic acid, and decanoic acid were determined in a cheese study on wheat bran (Shehata et al., 2022).

Esters

Esters are formed by esterification of alcohol and carboxylic acids bound by lactic acid bacteria (Oluk, 2023). It is reported that esters, which are responsible for fruity and floral flavor in cheese, have low sensory perception thresholds (Bulat and Topcu, 2020; Albay et al., 2024). Esters degrade cheese rancidity by acids and ketones (Shehata et al., 2022). Two ester components, geranyl butyrate and acetic acid, allyl acetate were detected in cheese chips (Table 3). These ester components were detected only in the control group without

Table 3. Volatile aroma components of chips containing WF (%)

Examples*	BUK	BU1	BU2
Volatile aroma components			
Alcohols			
Ethanol (CAS) Ethyl alcohol	1.09	1.34	1.56
Maltol	-	1.49	1.89
Methanethiol (CAS) Mercaptomethane	0.82	0.75	0.98
Ethanol, 2-methoxy-, acetate (CAS) 2-Methoxyethyl acetate	2.25	-	3.63
Benzene, methyl(1-methylethyl)- (CAS) Simol	6.93	-	-
Total concentration	***11.09***	***3.58***	***8.06***
Aldehydes			
Nonanal (CAS) n-Nonanal	2.36	2.39	2.97
Propanal, 2-Methyl	0.21	-	1.27
Propanal, 3-(methylthio)- (CAS) Methional	-	0.15	0.38
Hexanal (CAS) n-Hexanal	0.25	0.48	0.76
Heptanal (CAS) n-Heptanal	0.31	0.32	0.48
Benzenacetaldehyde (CAS) Hyasintin	1.45	2.73	2.87
Furfural	0.90	2.00	3.24
Iso butyraldehyde	-	0.74	-
trans-2-Nonenal	-	0.30	-
Butanal, 3-methyl-(CAS) 3-Methylbutanal	0.84	1.20	2.71
Acetaldehyde (CAS) Ethanal	1.44	0.92	1.85
Octanal (CAS) n-Octanal	-	-	0.56
Pentanal, 2,4-dimethyl-(CAS) 2,4-Dimethylpentanal	-	-	0.85
Benzaldehyde (CAS) Phenylmethanal	0.72	1.58	0.42
Total concentration	***8.48***	***12.81***	***18.36***
Carboxylic acids			
Acetic acid (CAS) Ethylic acid	49.43	53.29	43.44
Hexanoic acid (CAS) n-Hexanoic acid	-	1.11	1.22
Hexanoic acid, 2-ethyl-(CAS)Ethylhexanoic acid	-	0.28	-
Butanoic acid (CAS) n-Butyric acid	-	0.77	0.74
Decanoic Acid (CAS) Capric Acid	0.59	1.42	-
Pyrazine, methyl-	-	0.47	0.38
Pyrazine, 2,6-dimethyl-	-	-	0.15
Pyrazine, 2-ethyl-6-methyl-(CAS) 2-Ethyl-6-methylpyrazine	-	0.15	-
Octanoic acid (CAS) Caprylic acid	1.15	2.61	0.62
Total concentration	***51.17***	***60.10***	***46.55***
Esters			
Acetic acid, 2-propenyl ester (CAS) allyl acetate	0.49	-	-
Geranyl butyrate	1.55	-	-
Total concentration	***2.04***	***0.00***	***0.00***
Hydrocarbons			
Benzene, methyl-(CAS) Toluene	-	0.07	-
Tetradecane (CAS) n-Tetradecane	-	0.18	-
2,4-Dihidroksi-2,5-dimetil-3(2H)-furan-3-on	-	0.22	0.30
Undekan, 3-methyl-	-	-	0.26
Dodecane (CAS) n-Dodecane	0.61	0.77	-
2-Unddecanone (CAS) 2-Hendakanone	2.34	-	-
2,6,11,15- Tetramethylhexadecane	0.15	-	-
Dean (CAS) n-Dean	-	0.32	0.97
Benzene, 1,4-dimethyl-(CAS) p-Xylene	-	-	0.18
Total concentration	***3.10***	***1.56***	***1.71***
Ketones			
2-Nonanone (CAS) Methyl heptyl ketone	1.74	0.76	1.14
2,3-Butanedione (Diacetyl)	-	4.84	8.78
2-Butanone, 3-hydroxy-(CAS) Acetoin	6.13	2.62	5.57
2-Heptanone (CAS) Heptan-2-one	2.73	1.10	2.07
Tetradecalactone<delta>	-	0.30	-
2-Pentanone, 4,4 Dimethyl-(CAS) 4,4 Dimethyl-2-pentanone	-	0.49	-
Ethanone, 1-(2-furanyl)- (CAS) 2-Acetylfuran	-	0.60	0.50
Ethanone, 1-(1H-pyrrol-2-yl)- (CAS) 2-Acetylpyrrole	-	0.28	-
2-Tridekanon	-	0.29	-
2-Pentanone (CAS) Methyl propyl ketone	0.43	0.18	0.41
2-Propanone, 1-methoxy-(CAS)CH3COCH2OCH3	-	3.17	-
2,3-Pentanedione (CAS) 2,3-Pentanedione	-	1.49	2.30
delta-Dekalactone	0.09	0.72	
Total concentration	***11.12***	***16.84***	***20.77***
Terpenes			
Carvacrol	11.13	3.56	3.77
Phenol, 5-methyl-2-(1-methyethyl)- (CAS) Thymol	0.08	1.15	0.81
α-Terpinene	0.41	-	-
γ-Terpinene	1.39	-	-
Total concentration	***13.01***	***4.71***	***4.58***

**BUK: Control sample without WF, BU1: Sample with 0.5 % WF, BU2: Sample with 1.5 % WF*

WF. It was found that the BUK sample had a total ester concentration of 2.04 %. There was 1.55 % geranyl butyrate and 0.49 % allyl acetate. Bulat and Topcu (2020) detected ethyl acetate and ethyl butyrate in all UF White cheeses. In another study, ethyl octanoate component was detected in bread crust (Xu et al., 2023).

Hydrocarbons

As shown in Table 3, nine hydrocarbon components were formed and most of these components occurred in chips containing WF. The total hydrocarbon concentrations were 3.10 % in the BUK sample, 1.56 % in the BU1 sample, and 1.71 % in the BU2 sample. Although most of the hydrocarbon components occurred in chips containing WF, the addition of WF reduced the total concentration. Toluene in sample BU1 and p-xylene in sample BU2 were similarly detected in another cheese chip study (Albay et al., 2024). Oluk (2023) detected eight hydrocarbons in White cheeses and stated that the hydrocarbons with the highest concentrations were 2-butene and 1-octene. Hydrocarbons, which are frequently reported in many types of cheese, are products of lipid autoxidation. Due to their low detection levels and high thresholds, their contribution to cheese aroma is much less then other volatile components (Albay, 2022).

Ketones

Ketones constitute the third main aroma group in the BUK sample and the second main aroma group in the BU1 and BU2 samples. The total concentrations of the ketone group were 11.12 %, 16.84 %, and 20.77 % in the BUK, BU1, and BU2 samples, respectively (Table 3). The chips contained 13 ketone components, all of which were formed, especially in the BU1 sample. In the BUK sample, the acetoin component was dominant with a concentration of 6.13 %. In the chips containing WF, diacetyl is the dominant ketone component. Diacetyl was determined at concentrations of 4.84 % in the BU1 sample and 8.78 % in the BU2 sample. *Lactobacillus lactis* produces diacetyl, which contributes significantly to the aroma of dairy products. It is formed from citric acid via acetolactate, and its formation is stimulated by the addition of citric acid and the acidic pH required by the citrate transport system. Additionally, the reduction of diacetyl to acetoin by diacetyl reductase produced by some strains of cheese starter cultures is detrimental and taste defects may occur, because acetoin is much less aromatic. The degree of reduction is regulated by the cheese's redox potential (Taylor and Linforth, 2010). Similar to the components in this investigation, seven ketone components were found in the other study (Albay et al., 2024). Oluk (2023) found that acetone, 2-butanone, 2-pentanone, 2-heptanone, and acetoin were the dominant methyl ketones in White cheese. It is stated that the 2-pentanone is formed by ß-oxidation and decarboxylation of hexanoic acid.

Terpenes

A total of four terpene components were identified in the chips, and terpenes constitute the second main aroma group of the BUK sample (Table 3). The total concentrations were 13.01 % in the BUK sample, 4.71 % in the BU1 sample, and 4.58 % in the BU2 sample. The addition of WF decreased the total concentration of terpenes in the chips. Carvacrol was determined to be the dominant terpene component in chips. The carvacrol concentrations of BUK, BU1, and BU2 samples were 11.13 %, 3.56 %, and 3.77 %, respectively. It is thought that carvacrol and thymol pass into milk with feed. Carvacrol and thymol components are higher in the essential oil of the oregano plant (*Origanum vulgare*). Thymol is a naturally occurring phenolic monoterpene that is structurally very similar to carvacrol. It is the main ingredient in essential oil from thyme (*Thymus vulgaris*). Carvacrol and thymol have biological properties such as antioxidants, antiparasitic and antibacterial. Researchers have proven the antifungal activity of aromatic plant essential oils with the main components carvacrol and thymol against mold strains isolated from cheese (Muñoz-Tebar et al., 2021). Additionally, 0.41 % α-terpinene and 1.39 % γ-terpinene were detected in the BUK sample. Agarwal et al. (2018) detected α-pinene and limonene in potato chips flavored with cheese and onion.

Microbiological properties

Microbiological examination revealed that cheese chips contained no yeast-mold or coliform bacteria. It is thought that the application of high heat in the production of cheese chips influences this situation. Microorganisms such as yeasts and molds are highly sensitive to heat. For example, heat treatment at 85 °C for 2 seconds, 72-75 °C for 15-30 seconds, or 63-66 °C for at least 30-32 minutes is reported to inactivate pathogenic microorganisms (Dash et al., 2022).

Principal component analysis of sensory properties results

Sensory parameters (dark brown - yellowish appearance, yellowish appearance, fatty appearance, mottled appearance, dietary fiber appearance, hardness, grainy, chewability, crisp sound, elastic-fragile, thick-thin, cheese odor, foreign odor, burnt odor, salty taste, burnt taste, fatty taste, rancid taste, bland taste, dietary fiber taste) were evaluated in the principal component analysis (PCA) of the chips samples. The variance (eigenvalue) of the first principal component (PC1) is 14.47, explaining 72.39 % of the total variance. The variance of the second principal component (PC2) has been determined as 5.52 and explains 27.60 % of the total variance. The first principal component is ordered based on the same sign (-) and distance from zero. This component reveals the following characteristics: dark brown - yellowish appearance (-0.262), yellowish appearance (-0.262), fatty appearance (-0.262), mottled appearance (0.262), grainy (0.262), cheese odor (-0.262), hardness (-0.260), dietary fiber taste (0.247), foreign odor (0.230), burnt odor (-0.230), rancid taste (-0.230), fatty taste (0.224), chewability (0.224), and crisp sound (0.224). The second principal component is formed by the contrast of thick–thin (0.410), elastic-fragile (0.373), salty taste (0.373), bland taste (-0.363), and burnt taste (0.315) (Figure 2).

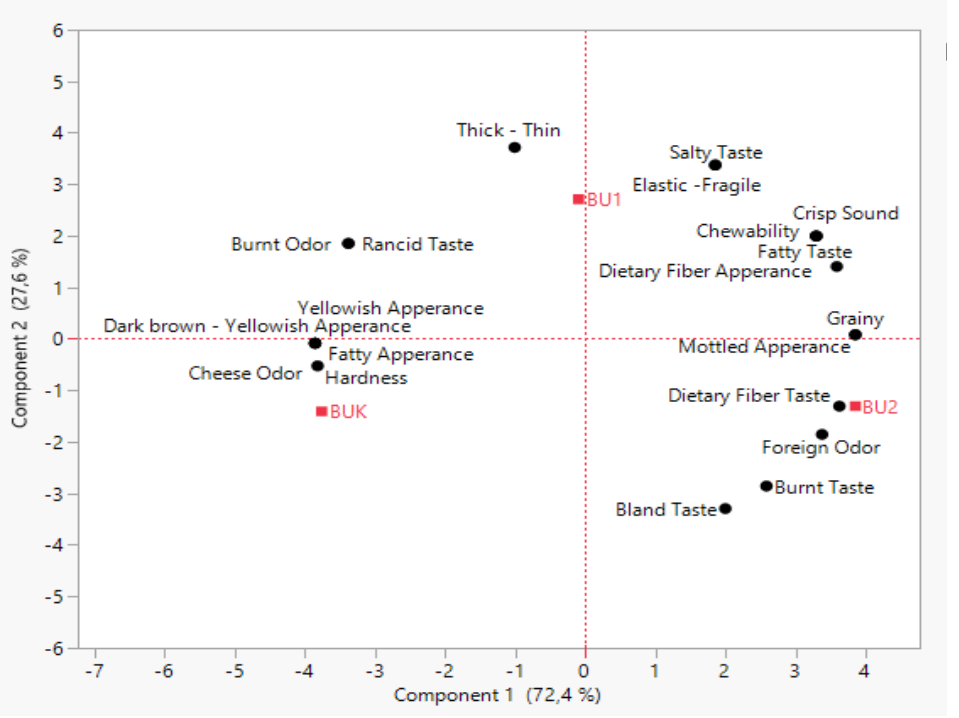

Figure 2. Graph of the Principle Component Analysis (PCA) of chips containing WF (BUK: Control sample without WF, BU1: Sample with 0.5 % WF, BU2: Sample with 1.5 % WF)

Examination of the PCA graph indicates that control samples without WF exhibit a more dominant yellowish color, a pronounced cheese aroma, and greater hardness. In contrast, BU1 samples are characterized by noticeable fiber-related sensory cues in both taste and appearance, along with a more fragile texture and a distinctly more audible crunching sound. In the BU2 samples, a mottled appearance was observed, and taste defects such as foreign, bland, and burnt flavors were detected.

As a result of the general acceptability scores, it was determined that the BUK sample received a score of 6.13±0.97, the BU1 sample received a score of 6.13±0.97, and the BU2 sample received a score of 4.58±0.68. According to the results, it was observed that the BUK and BU1 samples received similar scores, while the BU2 sample had lower overall acceptability. Panelists reported that sample BU2 had a blander taste, a more pronounced wheat fiber flavor, and a rougher appearance.

Conclusion

In this study, the characteristics of cheese chips produced from low-fat cheeses with added WF were examined. WF decreased titratable acidity, fat, water activity, and salt values ($p<0.05$). The color values increased with the addition of WF, and the sample with 1.5 % WF (BU2) was brighter. WF significantly increased the hardness and fracturability of the chips ($p<0.05$). The presence of 1.5 % WF makes the chips harder, which is thought to negatively impact consumer preference. In the BUK sample, the dominant volatile compounds included carvacrol, nonanal, acetic acid, and acetoin; in the BU1 sample, they were carvacrol, benzene acetaldehyde, nonanal, acetic acid, and diacetyl; and in the BU2 sample, carvacrol, furfural, nonanal, acetic acid, and diacetyl were the most prevalent. This study resulted in healthier nutritional profiles, lower fat levels, and higher fiber content in the development of new snacks. Furthermore, as the level of furfural, which is regarded as harmful to one's health, increases with WF and becomes more dominant in the BU2 sample, it is suggested that WF should be utilized at a lower rate in the creation of cheese chips. The inclusion of %0.5 WF improved sensory texture features like crispness and chewability without reducing overall acceptability. However, %1.5 WF caused sensory defects such as burnt and bland flavors, leading to significantly lower consumer preference. Based on these findings, it was determined that incorporating 0.5 % WF into cheese chips would be more appropriate in terms of consumer preference and health.

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Utjecaj pšeničnih vlakana na kvalitetu i prihvatljivost čipsa od nemasnog svježeg sira

Sažetak

U ovom je istraživanju ispitana mogućnost proizvodnje čipsa od obogaćenog probiotičkog nemasnog svježeg bijelog sira (bez salamure), uz dodatak 0,5 % i 1,5 % pšeničnih vlakana (PV), s ciljem utvrđivanja utjecaja PV na kvalitetu čipsa. Rezultati su pokazali da dodatak PV smanjuje titracijsku kiselost, udio masti, aktivitet vode i sadržaj soli u čipsu ($p<0,05$). Statistički značajno povećane su vrijednosti boje (L* i a*) uzrokovane neujednačenim potamnjivanjem tijekom pečenja ($p<0,05$). PV su također znatno povećala tvrdoću i lomljivost čipsa ($p<0,05$). U svim su uzorcima utvrđeni spojevi poput karvakrola, nonanala, octene kiseline, acetiona i diacetila. Međutim, dodatak PV povećao je razinu furfurala - spoja koji može imati hepatotoksične učinke - a upravo je furfural bio dominantna hlapljiva komponenta u uzorku s 1,5 % PV. Iako je dodatak 0,5 % PV poboljšao žvakaću teksturu i hrskavost bez narušavanja opće prihvatljivosti proizvoda, dodatak 1,5 % PV doveo je do pojave okusa zagorjelog i blagog intenziteta, što je negativno utjecalo na potrošačku preferenciju. Zaključno, pšenična vlakna utječu na fizikalno-kemijska svojstva, boju, teksturu i hlapljive arome čipsa, a udio od 0,5 % pokazao se najprikladnijim s obzirom na prihvatljivost potrošača i zdravstvene aspekte.

Ključne riječi: čips od sira; pšenična vlakna; nemasni zalogaji; hlapljive aromatske tvari

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