ARAŞTIRMA MAKALESİ   RESEARCH ARTICLE

Functional White Cheeses with Dried Fruit Addition: Changes in Physicochemical Properties, Ripening Parameters and Casein Fractions

Kurutulmuş Meyve İlaveli Fonksiyonel Peynirlerinin Üretimi: Fizikokimyasal, Olgunlaşma Parametreleri ve Kazein Fraksiyonlarındaki Değişimler

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Abstract

In this study, five types of white-brined cheese were produced to investigate the effects of incorporating different dried fruits on their physicochemical, biochemical, and bioactive properties. Four experimental cheeses were made by adding 2% (w/w) of dried black mulberry, blackberry, black grape, or raspberry to the curd, while one cheese without fruit served as a control. The cheeses were vacuum-packaged and ripened at 7 ± 1 °C for 90 days. Samples were collected on days 3, 30, 60, and 90 of ripening for a series of analyses. These included physicochemical parameters (dry matter, ash, fat, pH, titratable acidity, salt), total protein, ripening indices (water-soluble nitrogen (WSN), non-protein nitrogen (NPN), WSN/TN, NPN/TN), antioxidant activity, total phenolic content, and protein degradation assessed by electrophoretic separation of casein fractions. Cheeses containing different dried fruits showed significant differences in dry matter, pH, salt content, titratable acidity, WSN, NPN, and ripening index values (P<0.05). In contrast, the effects of fruit variety, ripening period, and their interaction on fat and total protein contents were not significant (P>0.05). The dried-fruit-enriched cheeses had much higher antioxidant activity than the control cheese. Likewise, the addition of dried fruits led to a marked increase in total phenolic content in all samples, with the fruit-added cheeses showed higher phenolic content values than that of the control. Electrophoretic analysis results indicated that β-casein and α_{s1}-casein levels decreased in all cheeses during ripening. This reduction in β-casein and α_{s1}-casein was more pronounced in the fruit-fortified cheeses compared to the control. In conclusion, the results demonstrate that dried black mulberry, blackberry, black grape, and raspberry can be effectively used in white cheese production to obtain functional cheeses with enhanced antioxidant and phenolic properties.

Keywords: Cheese, Dried fruit, Biochemical, Ripening, Antioxidant activity, Phenolic compound

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Öz

Bu çalışmada, farklı kurutulmuş meyve ilavesinin beyaz peynirlerin fizikokimyasal, biyokimyasal ve biyoaktif özellikleri üzerindeki etkilerini araştırmak amacıyla beş çeşit beyaz peynir örneği üretilmiştir. Dört adet deneysel peynirin üretiminde pıhtıya %2 (ağırlıkça) oranında kurutulmuş karadut, böğürtlen, siyah üzüm veya ahududu ilave edilmiş, meyve ilave edilmeyen bir peynir ise kontrol olarak kullanılmıştır. Peynirler vakum ambalajda paketlenerek 7 ± 1 °C'de 90 gün boyunca olgunlaşmaya bırakılmıştır. Olgunlaşmanın 3., 30., 60. ve 90. günlerinde çeşitli analizler için örnekler alınmıştır. Bu analizler kapsamında fizikokimyasal parametreler (kuru madde, kül, yağ, pH, titrasyon asitliği, tuz), toplam protein, olgunlaşma indeksleri (suda çözünen azot (WSN), protein dışı azot (NPN), WSN/TN, NPN/TN), antioksidan aktivite, toplam fenolik içerik ve elektroforetik kazein fraksiyonları belirlenmiştir. Farklı kurutulmuş meyve içeren peynirlerde kuru madde, pH, tuz, asitlik, WSN, NPN ve olgunlaşma indeksi değerlerinde istatistiksel olarak önemli farklılıklar saptanmıştır (P<0.05). Buna karşın, meyve çeşidi, olgunlaşma süresi ve bunların etkileşimlerinin peynirlerin yağ ve toplam protein içerikleri üzerindeki etkileri istatistiksel olarak önemli bulunmamıştır (P>0.05). Kurutulmuş meyve ilave edilen peynirlerin antioksidan aktivite değerleri, kontrol peynirine göre çok daha yüksek bulunmuştur. Aynı şekilde, kurutulmuş meyve ilavesi tüm peynir örneklerinde toplam fenolik içerikte belirgin bir artışa yol açmış ve meyve ilaveli peynirlerde bu bakımdan kontrol peynirine göre daha yüksek değerler belirlenmiştir. Elektroforetik analiz sonuçları, olgunlaşma süresince tüm peynir örneklerinde β-kazein ve α_{s1}-kazein düzeylerinin azaldığını göstermiştir. β-kazein ve α_{s1}-kazein oranlarındaki azalma, kurutulmuş meyve ilave edilmiş peynirlerde kontrol örneğindekinden daha fazla olmuştur. Sonuç olarak, kurutulmuş karadut, böğürtlen, siyah üzüm ve ahududu meyvelerinin, yüksek antioksidan ve fenolik içerikli fonksiyonel beyaz peynir üretiminde etkin bir şekilde kullanılabileceği belirlenmiştir.

Anahtar Kelimeler: Peynir, Kurutulmuş meyve, Biyokimyasal, Olgunlaşma, Antioksidan aktivite, Fenolik bileşikler

1. Introduction

Animal-derived foods such as milk and dairy products are essential nutritional sources that play a crucial role in the physical development of living organisms. Milk contains the minerals, proteins, fats, and vitamins necessary for human nutrition. In addition to its high nutritional content, it also plays an important role in maintaining bone health (Simsek et al., 2005). It is well established that milk proteins play a significant role in growth and development, exert beneficial effects on calcium absorption and immune function, reduce the risk of cancer and hypertension, contribute to the maintenance of body weight, and provide a protective effect against dental caries (Engindeniz et al., 2021). Among dairy products, cheese is both highly popular and frequently examined in scientific studies (Fox and McSweeney, 1997). One of the cheeses produced in different flavors, aromas, textures, and structures is the "white-brined cheese," which is produced and used in many countries of the Middle East, southeastern Europe, and the eastern Mediterranean, and is named differently depending on the type of milk used (Alichanidis, 2007). White cheese is a soft-textured, salty, and slightly sour-tasting cheese that is matured in brine (Hayaloğlu et al., 2002).

Fresh cheeses are characterized by their high moisture content, mild flavor, and soft, smooth texture. To enhance the nutritional profile of dairy-based fermented products, it is common practice to incorporate grains and other additives. During the manufacturing process, fresh cheeses may be enriched with canned or dried vegetables, fruits, and various spices. Choi et al. (2015) investigated the impact of incorporating fruit liqueur into Gouda cheese during production, reporting that such additions can enhance the nutritional value of the product without compromising its sensory attributes or overall quality. Similarly, Khalifa and Wahdan (2015) demonstrated that cranberry extract serves as a functional additive that contributes to improved storage stability of cheese. Dried fruits represent a concentrated form of fresh fruits, characterized by significantly reduced moisture content due to the removal of water through various modern drying methods, including sun drying and the use of mechanical drying systems (Chang et al., 2016). Among different fruit groups, berries—such as black mulberries, raspberries, blackberries, and black grapes—are notable for their distinct chemical composition, which includes a rich array of organic and inorganic compounds. Owing to their high antioxidant content, these fruits play a crucial role in mitigating oxidative stress-related cellular damage within the human body. Due to the bioactive components they contain (phenolic substances, flavonoids, anthocyanins), they are recognized as natural functional products that increase body resistance and fight diseases by strengthening the immune system (Tosun and Yüksel, 2003). Numerous studies have examined the effects of various foods and food ingredients on different population groups. In recent years, there has been a growing interest in the use of natural compounds as complementary approaches to conventional therapies. In this context, it is essential that consumers are provided with scientifically grounded information to support informed dietary and health-related decisions (Jesus, 2013). Raspberries, which have red color, have some specific benefits such as having a detox effect, helping to lose weight, fighting fluid retention, stimulating blood circulation, increasing body defenses, and protecting eyesight. Blueberries provide benefits like preventing memory loss, reducing the risk of cardiovascular problems, fighting aging, and improving overall health. Blackberries reduce the risk of osteoporosis, fight aging, increase energy levels, prevent joint diseases, improve intestinal transit, prevent diabetes and strengthen the immune system (Delgado, 2014). In recent years, the significance of natural compounds exhibiting antioxidant capacity has gained considerable attention. It has been well established that the consumption of foods containing specific biologically active constituents can lead to favorable health outcomes. As awareness of the relationship between diet and health continues to grow, consumers are increasingly inclined to choose natural products that contribute to overall well-being, prioritizing functional benefits over mere nutritional intake (Silva et al., 2013). Raspberries, which are part of the berry group and the Rosaceae family, yield sweet red fruits that mature in summer and autumn. It contains phenolic compounds, vitamins, flavones, flavonoids, and antioxidants (Balcı and Keles, 2019). Raspberries, which are simple to grow and highly productive, are not only consumed fresh but also used in the production of marmalade, functional fruit juice and ice cream. It stands out as an important industrial food product due to its wide usage area in the food industry.

In recent years, the development of functional dairy products has garnered significant interest due to increasing consumer demand for foods offering health benefits beyond basic nutrition. In this context, the present study was undertaken to formulate innovative functional white cheese varieties through the incorporation of selected dried fruits, aiming to enhance not only the sensory appeal but also the nutritional and bioactive properties of the final

products. Specifically, dried black mulberries (*Morus nigra*), blackberries (*Rubus fruticosus*), black grapes (*Vitis vinifera*), and raspberries (*Rubus idaeus*) were integrated into the white cheese matrix at a standardized concentration. The strategic addition of these fruits was intended to enrich the cheeses with natural antioxidants and phenolic compounds, thereby improving their functional value. Subsequently, the study systematically investigated the effects of fruit incorporation on various quality parameters, including physicochemical characteristics, protein fraction integrity, antioxidant activity levels, and total phenolic content. Comprehensive analyses were performed to elucidate the potential of these functional ingredients in modulating the ripening behavior and enhancing the bioactive profile of traditional white cheese. The findings from this research are expected to contribute valuable insights into the development of next-generation functional dairy products tailored to meet evolving consumer preferences and nutritional needs.

2. Materials and Methods

2.1. Materials

In this study, cow's milk sourced from the Merzifon district of Amasya province was utilized for the production of white cheese samples. The milk used had a fat content of 4.0%, a pH value of 6.5, and a total dry matter content of 13.12%. Coagulation was achieved using a microbial commercial rennet with an enzymatic activity of 8000 mcu mL^{-1}, supplied by Intermak Makina Product Inc. Cheese samples were vacuum-packed immediately following their production process. For this purpose, a 360 µm thick polyethylene film—characterized by low oxygen and odor permeability and suitable for food contact—was employed. The dried fruits used in the production of the cheese samples (freeze-dried blackberry, freeze-dried black mulberry, freeze-dried grape, and freeze-dried raspberry) were procured from Freshbak Organik Doğal Gıda San. Tic. A.Ş. (Izmir, Turkey).
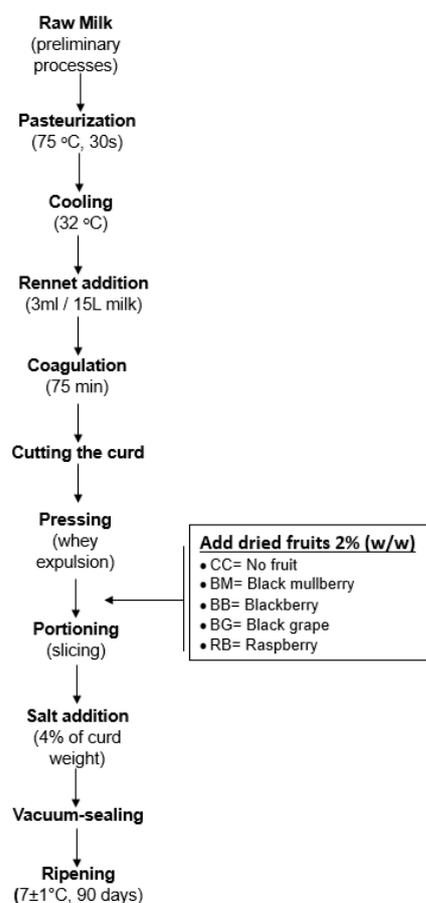
2.2. Cheesemaking

Figure 1. Cheese production flowchart

The production stages of the cheeses are shown in Figure 1. Accordingly, the obtained raw milk was pasteurized at 75°C for 30 seconds after the necessary preliminary processes, and then cooled to 32°C. 3 mL of rennet was added to each 15 L of milk and mixed homogeneously. The mixture was left to stand for 75 minutes until the cheese reached cutting maturity. Following 75 minutes of coagulation, the curd was cut and transferred to a press for whey expulsion. Dried fruits were incorporated into the curd at a concentration of 2% (w/w), with the exception of the control sample (CC), which contained no fruit. The experimental design included the use of four fruit varieties: BM (black mulberry), BB (blackberry), BG (black grape), and RB (raspberry). Following the pressing process, the cheeses were sliced into small portions, and salt was added at 4% of the curd's weight. Subsequently, the samples were vacuum-sealed and subjected to a ripening process at 7±1°C for a duration of 90 days. Two replicate batches were produced for each cheese formulation. On days 3, 30, 60, and 90 of the storage period, analyses were conducted to determine dry matter, fat, titration acidity, pH, salt, antioxidant activity, total phenolic compound, protein, WSN, WSN TN^{-1}, NPN TN^{-1}, and casein fractions.

2.3. Physicochemical analyses of cheeses

Cheese moisture content was determined using the gravimetric method according to the standards outlined by the International Dairy Federation (IDF, 1982). The salt concentration was measured using the classical Mohr titration method, while fat content was analyzed using the Gerber method, a traditional approach widely accepted in dairy fat determination. Titratable acidity was evaluated through a titrimetric method and reported as a percentage of lactic acid, in accordance with AOAC (1996) protocols. The pH levels were measured directly from a cheese macerate prepared in a 1:1 (w/v) ratio with distilled water, utilizing a calibrated pH meter (Ohaus, Starter 3100).

Determination of total nitrogen (TN) was carried out according to the Kjeldahl method (IDF, 1993), using a UDK-149 distillation system (VELP Scientifica, Usmate, Italy). The total protein content of the cheese was then calculated using a nitrogen-to-protein conversion factor of 6.38, which is standard for dairy products. The water-soluble nitrogen (WSN) content, an indicator of proteolysis, and the ripening index (WSN/TN ratio) were determined following the methods described by Kamaly et al. (1989) and Butikofer et al. (1993). Furthermore, protein degradation and casein fractionation were examined by electrophoresis based on the methodology of Creamer (1991), with minor modifications introduced by Celik and Tarakci (2017) to adapt the method for the specific cheese matrix used in this study.

For the determination of antioxidant activity and total phenolic content, water-soluble extracts were prepared using a modified protocol from Kuchroo and Fox (1982). Specifically, 5 g of cheese sample was combined with 10 mL of deionized water and homogenized for 3 minutes using an Ultraturrax homogenizer. The homogenate was then subjected to centrifugation at 10,000 × g for 20 minutes at 4°C. After centrifugation, the oil layer forming at the top was carefully removed using a spatula, and the resulting supernatants were filtered through a 0.45 μm membrane filter. These clarified aqueous extracts were used for both antioxidant activity and total phenolic compound assays.

Antioxidant activity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay, following the protocol developed by Brand-Williams et al. (1995). A DPPH stock solution was freshly prepared each day by dissolving 25 mg of DPPH in one liter of methanol, and the solution was adjusted to yield an absorbance value of 0.700 ± 0.020 at 520 nm. For the assay, 100 μL of the water-soluble cheese extract was transferred into test tubes, and 2.4 mL of DPPH solution was added. The mixture was kept in the dark for 30 minutes at room temperature to allow the reaction to proceed. The reduction in absorbance was then measured at 520 nm using a dual-beam UV-VIS spectrophotometer (UV Mini-1240, Shimadzu, Japan). The antiradical activity was calculated and expressed as the percentage of inhibition.

Total phenolic content was quantified using the Folin–Ciocalteu colorimetric method, which is a widely used procedure for estimating total phenolics in food matrices. In this method, 150 μL of the cheese extract was mixed with 3 mL of a 2.0% sodium carbonate (Na_2CO_3) solution. After standing for approximately 2 minutes, 150 μL of Folin–Ciocalteu's reagent (previously diluted 1:1 with distilled water) was added to the mixture. The mixture was vortexed to ensure homogeneity and then incubated in the dark at room temperature for 45 minutes. The absorbance of the final reaction mixture was recorded at 765 nm using the same spectrophotometer. A standard

curve prepared with gallic acid was used to calculate the total phenolic content, which was expressed in mg gallic acid equivalents (GAE) per 100 g of cheese.

2.4. Statistical analysis

The experimental data were analyzed using a two-factor factorial design with two independent variables: cheese type (five levels: control, black mulberry, blackberry, black grape, and raspberry) and ripening time (four levels: 3, 30, 60, and 90 days). All measurements were performed in duplicate for each treatment. The effects of cheese type, ripening time, and their interaction were evaluated using a two-way analysis of variance (ANOVA). When a significant main effect or interaction was observed (P<0.05), mean separation was performed using Tukey's multiple comparison test, and one-way ANOVA was additionally used to perform the lettering of significant differences within each factor level where appropriate. Results are presented as mean ± standard deviation, and statistically significant differences are denoted by distinct superscript letters. Lowercase letters (a–d) indicate significant differences among ripening periods within the same cheese type, while uppercase letters (A–E) indicate significant differences among cheese types within the same ripening period. All statistical analyses were performed using IBM SPSS Statistics 25.0 (IBM Corp., Armonk, NY, USA).

3. Results and Discussion

3.1. Some physical and chemical analysis results

The dry matter content of cheese, composed of proteins, fats, lactose, minerals, and other non-volatile solids, serves as a crucial quality parameter and reflects the concentration of solids in the final product (Diezhandino et al., 2015). The changes in physicochemical properties during storage are presented in *Table 1*. In this study, dry matter levels were significantly affected by the type of cheese (P<0.05), while storage duration alone did not exert a statistically significant influence (P>0.05). However, the interaction between cheese type and ripening time did exhibit a statistically significant effect (P<0.05). An increasing trend in dry matter was observed throughout the ripening period, which can be attributed to progressive salt penetration and the corresponding decrease in water activity in dry-salted cheeses. Additionally, the inclusion of dried fruits, which possess low moisture and high solid content, contributed to elevated dry matter percentages.

Dry matter values changed slightly with fruit addition and were statistically significant. As storage progressed, the difference became more pronounced (P<0.05). Dodan et al. (2025) determined the dry matter content in cheeses enriched with elderberry and red grape pomace to be 49.25–51.88%; Starkute et al. (2023) reported 31.6–32.5% in cheeses with raspberry, blueberry, and elderberry; Khalifa and Wahdan (2015) found 32.22% in cranberry-enriched cheeses; and Solhi et al. (2020) reported 43.33% in cheeses with tomato powder. Upon examining the results, it is evident that the values determined are comparable to those of the present study and are consistent with the literature.

With respect to milk fat content, statistical evaluation revealed that cheese type, ripening time, and their interaction did not significantly (P>0.05) affect fat levels in the dried fruit-added white cheeses (P>0.05). Nonetheless, a comparative review of the literature indicates that the fats content in the present study were lower than that found in cranberry-enriched cheeses studied by Khalifa and Wahdan (2015), while being comparable or even higher than values reported for capia pepper-infused cheeses made from cow and sheep milk by Koçak and Tarakçı (2025), and siabo herb cheeses analyzed by Tarakçı et al. (2005). Dodan et al. (2025) reported fat contents of 28.02–34.11% in cheeses enriched with elderberry and red grape pomace and, consistent with our study, noted that fruit addition did not significantly affect fat levels.

Acidity, on the other hand, was significantly (P<0.05) influenced by all three factors: cheese type, ripening periods, and their interaction (P<0.05). A consistent increase in titratable acidity was observed across all samples during the ripening process. The control sample's acidity increase is attributed primarily to lactic acid fermentation by indigenous and starter lactic acid bacteria. In contrast, cheeses enriched with dried fruits exhibited markedly higher acidity levels, likely due to the organic acids naturally present in the fruits themselves. The highest titratable acidity was recorded in the BM sample on day 90 of storage, while the lowest value was measured in the control group on day 3. These results are situated between the lower acidity levels reported for black cumin cheeses by

Tarakçı et al. (2005) and Bayram and Tarakçı (2020), and the higher values noted in the work of Vural et al. (2008).

Table 1. Changes in some physical and chemical properties of white cheese samples during storage

Cheese Types	Ripening Period (Days)				Significance
	3	**30**	**60**	**90**	
Dry Matter (%)					
CC	49.03[a,A]±0,39	45.00[a,A]±0,00	46.33[a,A]±0,25	47.02[a,A]±0,91	
BM	49.76[ab,AB]±0,12	48.60[a,B]±0,00	52.19[c,B]±0,36	51.34[bc,AB]±0,88	
BB	51.25[a,B]±0,53	49.83[a,BC]±0,70	49.59[a,AB]±0,33	51.57[a,B]±1,32	C*, R[ns], CxR*
BG	49.32[a,A]±0,76	52.63[ab,D]±1,44	52.15[ab,B]±0,55	53.30[b,B]±0,42	
RB	50.65[a,AB]±0,01	51.00[a,C]±0,00	50.33[a,AB]±0,46	49.34[a,AB]±0,92	
Fat (%)					
CC	21.70[a,A]±0,14	21.55[a,A]±0,07	21.55[a,A]±0,14	21.60[a,A]±0,00	
BM	21.70[a,A]±0,28	21.65[a,A]±0,21	21.65[a,A]±0,21	21.70[a,A]±0,28	
BB	21.25[a,A]±0,35	21.80[a,A]±0,00	21.30[a,A]±0,42	21.65[a,A]±0,28	C[ns], R[ns], CxR[ns]
BG	21.80[a,A]±0,00	21.65[a,A]±0,21	21.55[a,A]±0,07	21.60[a,A]±0,14	
RB	21.50[a,A]±0,14	21.75[a,A]±0,07	21.42[a,A]±0,14	21.75[a,A]±0,07	
Titratable acidity (Lactic acid, %)					
CC	0.43[a,A]±0.02	0.75[b,A]±0.07	0.85[b,A]±0.07	0.90[b,A]±0.00	
BM	0.55[a,AB]±0.07	1.25[b,B]±0.07	1.25[b,B]±0.07	1.65[c,A]±0.07	
BB	0.50[a,AB]±0.00	0.70[a,A]±0.00	0.85[a,A]±0.07	1.50[a,A]±0.56	C*, R*, CxR*
BG	0.60[a,B]±0.00	0.75[ab,A]±0.70	0.85[b,A]±0.70	0.95[b,A]±0.70	
RB	0.50[a,AB]±0.00	0.85[b,A]±0.07	1.00[bc,AB]±0.00	1.00[c,A]±0.07	
pH					
CC	6.15[c,C]±0.07	5.36[a,B]±0,00	5.54[b,C]±0.021	5.40[ab,C]±0.014	
BM	5.61[d,A]±0.00	5.09[b,A]±0,00	5.21[c,B]±0.007	5.05[a,A]±0.007	
BB	5.79[d,B]±0.007	5.33[b,B]±0,00	5.54[c,C]±0.02	5.18[a,B]±0.007	C*, R*, CxR*
BG	5.56[c,A]±0.007	5.48[c,C]±0,06	5.26[b,B]±0.007	5.03[a,A]±0.007	
RB	5.91[c,B]±0.007	5.12[b,A]±0,007	5.05[a,A]±0.007	5.03[a,A]±0.007	
Salt (%)					
CC	1.46[a,A]±0.084	2.07[b,A]±0.042	3.01[c,C]±0.042	3.08[c,B]±0.028	
BM	1.31[a,A]±0.042	2.36[b,BC]±0.035	2.68[c,B]±0.077	3.16[d,B]±0.05	
BB	1.31[a,A]±0.042	2.12[b,AB]±0.11	3.07[c,C]±0.042	3.22[c,B]±0.056	C*, R*, CxR*
BG	1.25[a,A]±0.042	2.54[b,C]±0.042	2.54[b,AB]±0.042	2.88[c,A]±0.021	
RB	1.37[a,A]±0.127	2.39[b,BC]±0.077	2.42[b,A]±0.042	2.87[c,A]±0.035	

Statistical differences (P<0.05) are marked by different letters: lowercase (a–d) for columns and uppercase (A–E) for rows.
Values represent the mean ± standard deviation of two trials.
C: cheese type; R: ripening time; C×R: interaction; *P < 0.05 (significant), ns = not significant (two-way ANOVA).

Statistical analysis of pH values measured during the ripening period of cheeses supplemented with dried fruits revealed that cheese types, ripening periods, and their interaction had a statistically significant effect (P<0.05). Throughout the ripening process, a general decline in pH values was observed. The lowest pH values were found in the BG and RB cheese samples on day 90, while the highest pH was observed in the control sample on day 3. This decrease in pH is primarily attributed to the increasing acidity caused by lactic acid bacteria during ripening. Additionally, it is hypothesized that the naturally acidic composition of the dried fruits contributed to further pH reduction in the experimental cheeses. When compared to the control sample, cheeses containing dried fruits exhibited a more pronounced decline in pH values. The pH values observed in the present study were lower than those reported for herb-infused cheeses, such as the spice-added Circassian cheese studied by Gezmiş and Tarakçı (2020), blueberry-supplemented Turkish white cheese analyzed by Tarakçı and Kurt (2023), and the herb cheeses investigated by Tarakçı and Küçüköner (2006). However, the pH values were higher than those cheeses samples added with observed in the spice-enriched cheeses reported by Tarakçı and Deveci (2019). Starkute et al. (2023) reported pH values of 5.27–5.80 in cheeses supplemented with raspberry, blueberry, and elderberry; Khalifa and Wahdan (2015) found 5.36–6.12 in cranberry-enriched cheeses; and Solhi et al. (2020) determined 5.49–5.90 in cheeses with tomato powder. Across all studies, the pH with fruit addition was lower than that of the control samples.

In terms of salt content, statistical evaluation indicated that cheese types, ripening periods, and their interaction significantly (P<0.05) influenced salt concentration. Among all samples, the highest salt content was measured in

the BB cheese on days 90, whereas the lowest salt content was found in the BG sample. The salt levels of the dried fruit-added cheeses were lower than those documented in Van herb cheeses by Tunçtürk et al. (2014), in cheese reported by Çelik and Uysal (2009), and in spice-enriched samples by Tarakçı and Deveci (2019). However, they were comparable to the findings of Gezmiş and Tarakçı (2020) for Circassian cheese with added spices and the study by Tarakçı and Kurt (2023) on the effect of blueberry powder on Turkish white cheese. Dodan et al. (2025) reported salt contents of 2.32–2.63% in cheeses enriched with elderberry and red grape pomace and, consistent with our study, observed that salt levels increased during storage.

The observed increase in salt concentration over the ripening period is likely due to the diffusion of salt from the surface into the interior of the cheeses, a characteristic process in dry-salted cheese production. The progressive nature of this diffusion accounts for the rise in salt levels with extended storage time.

The variation in antioxidant activity among the dried fruit-enriched cheese samples throughout the ripening period is presented in *Table 2*. The antioxidant activity values ranged from 7.57% to 58.14%, with the highest level observed in the BM sample on day 90, and the lowest in the control sample on day 3. Statistical analysis revealed that the types of cheese, ripening times, and their interaction significantly (P<0.05) influenced antioxidant activity (P<0.05). Cheeses containing dried fruits exhibited markedly higher antioxidant capacities compared to the control sample, indicating the strong contribution of dried fruit components to the antioxidant potential of the product. These results align with previous findings in the literature. Similarly, in low-fat cheese enriched with spray-dried jamun (*Syzygium cumini* L.) juice powder, antioxidant activity was not detected in the control sample but reached 28.14% at 4% fruit-powder addition (Shelke et al., 2023); in soft cheese fortified with *Arbutus unedo* L. extract, fruit addition increased antioxidant activity from around 40% to as high as 60% (Masmoudi et al., 2020); in Gouda cheese enriched with mango (*Mangifera indica* L.) kernel fat, it was 16.38% in the control and rose to as high as 92.61% as the level of addition increased (Khan et al., 2018); and similar enhancements were reported for cheeses supplemented with dried grape skin powder (Frühbauerová et al., 2020).

Table 2. Changes in Antioxidant Activity and Total Phenolic Compound during the ripening of White Cheese samples

	Cheese Types	Ripening Period (Days)				
		3	30	60	90	Significance
Antioxidant activity (%)	CC	7.57[a,A]±0.50	8.56[ab,A]±0.30	8.35[ab,A]±0,00	9.77[b,A]±0.80	
	BM	48.44[a,D]±2.80	55.17[ab,E]±2.10	54.95[ab,D]±2.40	58.14[b,D]±1.50	
	BB	34.20[a,C]±2.10	32.50[a,D]±1.90	34.77[a,C]±0.90	34.06[a,C]±0.70	C*, R*, CxR*
	BG	20.18[a,B]±1.30	24.29[a,C]±0.90	35.48[b,C]±1.90	30.17[b,C]±1.40	
	RB	16.99[a,B]±0.80	17.13[a,B]±1.00	18.20[ab,B]±0.50	19.68[a,B]±0.60	
Total Phenolic (mg GAE/100g)	CC	1.63[a,A]±0.049	2.66[b,A]±0.028	2.73[b,A]±0.021	4.03[c,B]±0.035	
	BM	4.79[a,D]±0.056	7.77[b,D]±0.063	8.53[c,D]±0.028	8.73[c,D]±0.063	
	BB	2.59[a,C]±0.098	4.16[b,C]±0.070	4.36[b,C]±0.049	5.33[c,C]±0.063	C*, R*, CxR*
	BG	2.44[a,C]±0.014	3.20[b,B]±0.056	3.33[b,B]±0.014	3.63[c,A]±0.049	
	RB	1.92[a,B]±0.049	2.73[b,A]±0.042	3.21[c,B]±0.063	3.56[d,A]±0.056	

Statistical differences (P<0.05) are marked by different letters: lowercase (a–d) for columns and uppercase (A–E) for rows.
Values represent the mean ± standard deviation of two trials.
C: cheese type; R: ripening time; C×R: interaction; *P < 0.05 (significant), ns = not significant (two-way ANOVA).

Total phenolic matter content in the cheeses samples added with dried fruits ranged between 1.63 and 8.73 mg GAE/100 g during the ripening periods. The maximum phenolic concentration was recorded in the BM sample on day 90, whereas the minimum was noted in the control sample on day 3. Variance analysis demonstrated a statistically significant (P<0.05) effect of cheese types, ripening times, and their interaction on total phenolic content (P<0.05). The phenolic content in the control sample remained substantially lower throughout the ripening period compared to the dried fruit-added cheeses. The enrichment of the curd with dried fruits led to a consistent increase in total phenolic compounds in all experimental groups. The phenolic values reported in this study are comparable to those in similar investigations, including 0.44 mg/g in cheese enriched with spray-dried jamun (*Syzygium cumini* L.) juice powder (Shelke et al., 2023); 14 mg GAE/g in the control versus 188 mg GAE/g in

mango (*Mangifera indica* L.) kernel fat–enriched cheeses (Khan et al., 2018); and 0.1–0.6 mg/g in cheeses supplemented with grape skin powder (Frühbauerová et al., 2020).

3.2. Changes in protein and ripening parameters of white cheese during ripening

Protein, WSN, and WSN/TN during ripening proteolysis is one of the most significant biochemical processes during cheese ripening and is typically assessed by measuring the levels of nitrogenous compounds such as water-soluble nitrogen (WSN). The amount of nitrogen solubilized in water provides insight into the extent of casein breakdown and is closely associated with the stage of cheese ripening (Taivosalo et al., 2018). The changes in protein content and ripening indicators during storage in white cheese samples are presented in *Table 3*. In the present study, WSN content ranged between 0.18% and 0.79% across all samples during the ripening period. The highest level was found in the BM sample on day 90, while the lowest value was recorded in the control sample on days 3. These values indicate enhanced proteolytic activity in the fruit-added cheeses, especially in later stages of maturation.

Protein content in the dried fruit-enriched cheeses ranged between 22.00% and 31.50%. Among the different formulations, the highest protein content was observed in the BB sample on days 30, whereas the lowest was found in the RB sample on days 3. Statistical analysis revealed that cheese types, ripening period, and their interaction did not have a significant (P>0.05) effect on total protein content (P>0.05). However, in general, the protein content of dried fruit-added cheeses were higher than those previously reported by Bayram and Tarakçı (2020), Tarakçı and Kurt (2023), and Tunçtürk et al. (2014), but lower than the values found in spice-enriched white cheeses produced by Tarakçı and Deveci (2019).

Water-soluble nitrogen (WSN) content, a reliable marker of proteolysis, exhibited statistically significant differences across samples (P<0.05), ranging from 0.17% to 0.51%. The ripening index, defined as the ratio of WSN to total nitrogen (WSN/TN), was used to further assess the maturity level of the cheeses. This index also showed significant variation (P<0.05) based on cheese types and storage periods (P<0.05). The highest ripening index was recorded in the BM sample on days 90, while the lowest was observed in the RB sample on days 3.

Table 3. Changes in protein, WSN, WSN/TN, NPN/TN during the ripening of White Cheeses

	Cheese Types	Ripening Period (Days)				
		3	**30**	**60**	**90**	**Significance**
Protein (%)	CC	$25.25^{a,A}\pm0.21$	$25.10^{a,A}\pm0.28$	$25.30^{a,A}\pm0.37$	$25.20^{a,A}\pm0.00$	
	BM	$25.41^{a,A}\pm0.12$	$25.25^{a,A}\pm0.33$	$25.00^{b,A}\pm0.22$	$24.90^{a,A}\pm0.28$	
	BB	$25.45^{a,A}\pm0.36$	$25.50^{a,A}\pm0.42$	$25.70^{a,A}\pm0.28$	$25.35^{a,A}\pm0.21$	C^{ns}, R^{ns}, CxR^{ns}
	BG	$25.55^{a,A}\pm0.49$	$25.30^{a,A}\pm0.28$	$25.20^{a,A}\pm0.42$	$25.70^{a,A}\pm0.13$	
	RB	$24.80^{a,A}\pm0.14$	$25.10^{a,A}\pm0.21$	$25.25^{a,A}\pm0.13$	$24.75^{a,A}\pm0.27$	
WSN (%)	CC	$0.18^{a,A}\pm0.035$	$0.42^{b,B}\pm0.021$	$0.52^{b,AB}\pm0.021$	$0.53^{b,AB}\pm0.035$	
	BM	$0.29^{a,B}\pm0.007$	$0.72^{b,C}\pm0.35$	$0.76^{b,C}\pm0.021$	$0.79^{b,C}\pm0.021$	
	BB	$0.25^{a,AB}\pm0.028$	$0.39^{b,B}\pm0.007$	$0.57^{c,B}\pm0.007$	$0.64^{c,B}\pm0.042$	C^*, R^*, CxR^*
	BG	$0.24^{a,AB}\pm0.021$	$0.37^{ab,B}\pm0.007$	$0.43^{b,A}\pm0.056$	$0.47^{b,A}\pm0.028$	
	RB	$0.23^{a,AB}\pm0.007$	$0.25^{a,A}\pm0.00$	$0.45^{b,A}\pm0.007$	$0.47^{b,A}\pm0.007$	
WSN/TN (%)	CC	$4.41^{a,A}\pm0.80$	$10.01^{b,B}\pm0.60$	$11.98^{b,B}\pm0.14$	$12.14^{b,A}\pm0.79$	
	BM	$8.39^{a,C}\pm0.24$	$17.64^{b,C}\pm1.28$	$19.52^{b,C}\pm0.21$	$20.54^{b,B}\pm0.77$	
	BB	$5.72^{a,AB}\pm0.28$	$8.00^{b,AB}\pm0.25$	$11.95^{c,B}\pm0.25$	$13.91^{d,A}\pm0.82$	C^*, R^*, CxR^*
	BG	$6.11^{a,AB}\pm0.41$	$9.45^{ab,B}\pm0.07$	$9.72^{b,A}\pm1.13$	$11.25^{b,A}\pm1.15$	
	RB	$6.81^{a,BC}\pm0.16$	$6.83^{a,A}\pm0.06$	$12.48^{b,B}\pm0.14$	$12.76^{b,A}\pm0.23$	
NPN/TN (%)	CC	$1.50^{a,A}\pm0.11$	$2.16^{ab,A}\pm0.24$	$2.65^{b,A}\pm0,19$	$2.69^{b,A}\pm0.21$	
	BM	$2.4^{a,B}\pm0.11$	$4.08^{b,C}\pm0.09$	$4.35^{b,C}\pm0,021$	$4.56^{b,C}\pm0.18$	
	BB	$2.67^{a,BC}\pm0.19$	$3.16^{ab,B}\pm0.12$	$3.36^{b,AB}\pm0,07$	$3.66^{b,B}\pm0.07$	C^*, R^*, CxR^*
	BG	$2.89^{a,BC}\pm0.09$	$3.65^{a,BC}\pm0.34$	$3.47^{a,ABC}\pm0,41$	$3.98^{a,BC}\pm0.11$	
	RB	$3.16^{a,C}\pm0.05$	$3.22^{a,B}\pm0.004$	$3.57^{a,BC}\pm0,16$	$3.64^{a,B}\pm0.21$	

Statistical differences (P<0.05) are marked by different letters: lowercase (a–d) for columns and uppercase (A–E) for rows.
Values represent the mean ± standard deviation of two trials.
C: cheese type; R: ripening time; C×R: interaction; *P < 0.05 (significant), ns = not significant (two-way ANOVA).

These findings were parallel with those of Gezmiş and Tarakçı (2020), who studied spice-enriched Circassian cheese, as well as Tarakçı and Kurt (2023) on blueberry-supplemented Turkish white cheese, Koçak et al. (1998) on kashar cheese, and Tarakçı and Küçüköner (2006) on herb cheeses. Collectively, the data demonstrate that the incorporation of dried fruits accelerates proteolysis and enhances the ripening profile of Turkish white cheese.

Statistical evaluation of the WSN TN^{-1} (water-soluble nitrogen to total nitrogen) ratios in cheeses enriched with dried fruits during ripening indicated that cheese types, storage times, and their interaction had a significant effect ($P < 0.05$). Throughout the ripening period, WSN TN^{-1} ratios ranged from 4.41% to 20.54%. The highest ratio was recorded in the BM sample on days 90, while the lowest was observed in the control sample on days 3. These findings suggest an enhanced degree of proteolysis in cheeses containing dried fruits, particularly at advanced stages of maturation. The increase in WSN TN^{-1} values reflects a more intense degradation of casein proteins, contributing to the development of textural and flavor characteristics.

In parallel, non-protein nitrogen (NPN) content—another marker of proteolytic activity—was evaluated during ripening and ranged from 1.5% to 4.56% across all cheese samples. The highest NPN value was observed in the BM sample on days 90, while the lowest was found in the control sample on days 3. Statistical analysis confirmed that cheese types, ripening periods, and their interaction had a significant ($P < 0.05$) influence on the NPN TN^{-1} ratios ($P < 0.05$). The NPN TN^{-1} levels in dried fruit-added cheeses were higher than those previously reported by Bayram and Tarakçı (2020), Tarakçı and Kurt (2023), and Tunçtürk et al. (2014), but lower than those noted in spice-enriched white cheeses studied by Tarakçı and Deveci (2019). These elevated NPN TN^{-1} values indicate a higher degree of protein breakdown and contribute to the release of low molecular weight peptides and free amino acids during ripening.

3.3. Change in casein fractions of white cheese samples

Casein degradation plays a pivotal role in the biochemical transformation of cheese during ripening. Enzymatic activity from both the indigenous microflora and added cultures leads to the hydrolysis of casein into a wide spectrum of smaller molecules, including amino acids, oligopeptides, proteases, and peptones. This enzymatic breakdown enhances the solubility of nitrogenous compounds in water and is instrumental in shaping the texture and flavor profile of matured cheeses (Kieliszek et al., 2021).

Proteolysis is initiated by enzymes acting on intact casein micelles, especially α-casein and β-casein. Over time, these are converted into smaller fragments such as γ-caseins and $α_{s1}$-casein derivatives. Gel electrophoresis has proven to be a reliable technique for monitoring such proteolytic changes, particularly in the context of large peptide dynamics during cheese ripening (Shafique et al., 2023). During electrophoretic analysis, casein fractions are separated based on molecular size and charge, stained, and scanned digitally. Densitometric analysis is then performed using specialized software to quantify the intensity of protein bands. The results offer insight into the rate and extent of proteolysis by tracking the disappearance of major casein bands and the emergence of specific degradation products (Yen Tan et al., 2007).

$α_{s1}$-casein degradation during cheese ripening occurs in three sequential stages. The process is initiated by coagulating enzymes that cleave the peptide bonds within the αs1-casein structure. Subsequently, a range of endogenous milk enzymes—including catalase, lipase, phosphatase, peroxidase, and proteases—along with microbial enzymes, further hydrolyze $α_{s1}$-casein into smaller peptides of varying lengths. These peptides are then converted into free amino acids through the continued action of bacterial enzymes present in the cheese matrix (Dave et al., 2003).

The changes in casein fractions during ripening and the corresponding graphs are presented in *Figure 2*. It was observed that the inclusion of dried fruits significantly influenced the proteolytic profile of the cheese. Cheeses with dried fruit exhibited higher water-soluble nitrogen (WSN) ratios compared to the control samples, indicating a more advanced degree of proteolysis. Electrophoretic analysis using urea-PAGE revealed a progressive reduction in the intensity of both β-casein and $α_{s1}$-casein bands over the ripening period. This decline was more pronounced in the samples containing dried fruits than in the control, suggesting that enzymatic activity associated with the dried fruits accelerated casein breakdown. These findings are consistent with previous literature indicating that β-casein and $α_{s1}$-casein concentrations diminish during ripening due to the action of proteolytic and peptidolytic enzymes.

The proteolysis process typically unfolds in multiple stages. Initially, proteins are cleaved into peptides and amino acids. In later stages, these amino acids are further broken down into amines, sulfur compounds, and other organic molecules. As the concentration of advanced degradation products increases, the proportion of intact casein diminishes. This cascade of biochemical changes is fundamental to the development of the distinctive textural and flavor attributes of ripened cheese (Ardö et al., 2017).
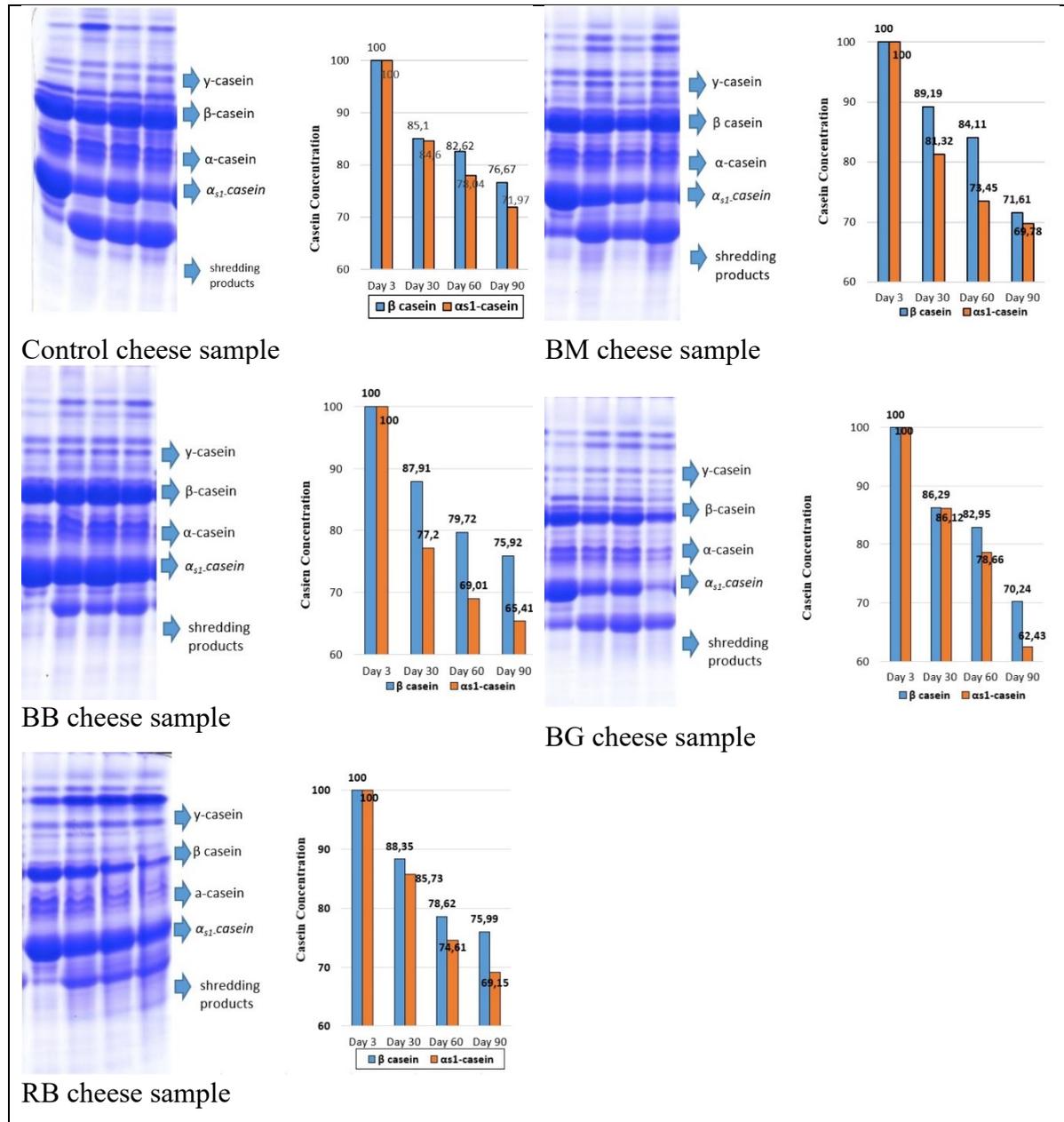

Figure 2. Changes in casein fractions during ripening

3.4. Sensory and textural evaluation

The sensory and textural evaluation results of this study are detailed in the work of Tarakçı and Yolaşan (2024). The analysis demonstrated that the incorporation of dried fruits influenced multiple sensory parameters, including color, appearance, aroma, taste, structure, and overall acceptability. It was noted that cheeses containing dried fruits generally received lower sensory scores compared to the control samples, indicating reduced consumer preference for these variants. The development of sensory properties in cheese begins during curd formation and evolves through ripening, as biochemical and enzymatic transformations alter the protein and fat structures. Specifically, proteolytic and lipolytic activities contribute to the formation of flavor compounds and textural

modifications. The increase in WSN observed in the fruit-added samples is directly linked to these proteolytic processes (Murtaza et al., 2014).

4. Conclusions

This study demonstrated that it is feasible to produce functional Turkish white cheese by incorporating dried fruits such as black mulberries, blackberries, black grapes, and raspberries. The addition of these fruits significantly affected key quality parameters including dry matter, titratable acidity, pH, salt content, water-soluble nitrogen (WSN), non-protein nitrogen (NPN), casein degradation, and overall ripening index. Cheeses with dried fruit exhibited elevated dry matter and acidity values relative to control samples, as well as more extensive casein hydrolysis as evidenced by higher levels of proteolytic by-products. Moreover, the inclusion of dried fruits enhanced the antioxidant capacity and total phenolic content of the cheese, underscoring their functional potential. These findings suggest that dried fruits can be effectively utilized in cheese production to develop value-added dairy products with improved nutritional and functional profiles. Future studies should further explore consumer acceptability and optimize formulation strategies for commercial applications.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: Yolaşan, M., Tarakçı, Z.; Design: Yolaşan, M., Tarakçı, Z.; Data Collection or Processing: Yolaşan, M., Karagöl, M. A.; Statistical Analyses: Karagöl, M. A.; Literature Search: Yolaşan, M., Tarakçı, Z., Karagöl, M. A.; Writing, Review and Editing: Tarakçı, Z., Karagöl, M. A.

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