

Evaluation of the Physicochemical and Microbiological Quality of Cream Cakes Marketed in Trabzon: A Pearson Correlation and Principal Component Analysis (PCA) Approach

Trabzon'da Pazarlanan Kremalı Pastaların Fizikokimyasal ve Mikrobiyolojik Kalitesinin Değerlendirilmesi: Pearson Korelasyonu ve Temel Bileşen Analizi (PCA) Yaklaşımı

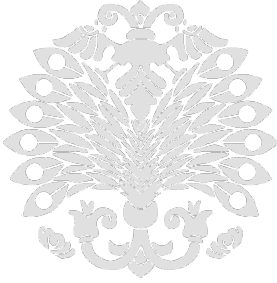
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ABSTRACT

Cream cakes are among ready to eat foods that are highly susceptible to microbial growth due to their high water activity, near neutral pH values, and rich nutrient content. In this study, the physicochemical and microbiological properties of 15 cream cake samples collected from different sales points in the city center of Trabzon were evaluated. Within the scope of the research, analyses of dry matter, ash, pH, and water activity (aw) were performed on the samples, along with counts of total aerobic mesophilic bacteria (TAMB), total aerobic psychrophilic bacteria (TAPB), *Enterobacteriaceae*, coliform bacteria, yeast-mold, and *Staphylococcus aureus*. Additionally, the relationships between quality parameters were examined using Pearson correlation analysis and Principal Component Analysis (PCA). According to the results, dry matter, ash, pH, and water activity values ranged from 40.1–71.4%, 0.39–1.25%, 4.20–8.00, and 0.835–0.887, respectively. Microbiological analyses revealed that in some samples, TAMB, *Enterobacteriaceae*, yeast-mold, and *S. aureus* counts reached levels of 5.9, 5.7, 5.6, and 5.0 log CFU/g, respectively. In particular, the *S. aureus* loads detected in samples CC₈, CC₁₁, and CC₁₂ exceeded the limits specified in the Turkish Food Codex Communiqué on Food Safety Criteria, posing a public health risk. Pearson correlation analysis showed a very strong positive correlation between *Enterobacteriaceae* and coliform bacteria ($r = 0.98$) and a strong positive correlation between yeast-mold and psychrophilic bacteria counts ($r = 0.89$). According to the PCA results, the first two principal components explained 64.59% of the total variance and demonstrated that microbiological load was one of the main factors in the discrimination of the samples. The findings indicate that cream cakes offered for sale in Trabzon exhibit insufficient microbiological quality and that improvements in production hygiene and cold chain practices are necessary.

Keywords: Cream cakes, microbiological quality, physicochemical properties, Pearson correlation analysis, Principal Component Analysis (PCA)

ÖZ

Kremalı pastalar, yüksek su aktivitesi, nötre yakın pH değerleri ve zengin besin içeriği nedeniyle mikrobiyal gelişmeye karşı oldukça duyarlı olan tüketime hazır gıdalar arasında yer almaktadır. Bu çalışmada, Trabzon şehir merkezindeki farklı satış noktalarından toplanan 15 kremalı pasta örneğinin fizikokimyasal ve mikrobiyolojik özellikleri değerlendirilmiştir. Araştırma kapsamında örneklerde kuru madde, kül, pH ve su aktivitesi (aw) analizlerinin yanı sıra toplam aerobik mezofilik bakteri (TAMB), toplam aerobik psikrofilik bakteri (TAPB), *Enterobacteriaceae*, koliform bakteri, maya-küf ve *Staphylococcus aureus* sayımları gerçekleştirilmiştir. Ayrıca, kalite parametreleri arasındaki ilişkiler Pearson korelasyon analizi ve Temel Bileşen Analizi (PCA) kullanılarak incelenmiştir. Sonuçlara göre, kuru madde, kül, pH ve su aktivitesi değerleri sırasıyla %40,1–71,4, %0,39–1,25, 4,20–8,00 ve 0,835–0,887 aralıklarında bulunmuştur. Mikrobiyolojik analizler, bazı örneklerde TAMB, *Enterobacteriaceae*, maya-küf ve *S. aureus* sayılarının sırasıyla 5,9, 5,7, 5,6 ve 5,0 log KOB/g düzeylerine ulaştığını ortaya koymuştur. Özellikle, CC₈, CC₁₁ ve CC₁₂ örneklerinde tespit edilen *S. aureus* yüklerinin Türk Gıda Kodeksi Gıda Güvenilirliği Kriterleri Tebliği'nde belirtilen limitleri aştığı ve bunun halk sağlığı açısından risk oluşturduğu belirlenmiştir. Pearson korelasyon analizi, *Enterobacteriaceae* ile koliform bakteriler arasında çok güçlü pozitif bir korelasyon ($r = 0,98$) ve maya-küf ile psikrofilik bakteri sayıları arasında güçlü pozitif bir korelasyon ($r = 0,89$) olduğunu göstermiştir. PCA sonuçlarına göre, ilk iki temel bileşen toplam varyansın %64,59'unu açıklamış ve mikrobiyolojik yükün örneklerin ayırımında temel faktörlerden biri olduğunu göstermiştir. Bulgular, Trabzon'da satışa sunulan kremalı pastaların yetersiz mikrobiyolojik kalite gösterdiğini ve üretim hijyeni ile soğuk zincir uygulamalarında iyileştirmeler yapılmasının gerekli olduğunu göstermektedir.

Anahtar Kelimeler: Krema pastaları, mikrobiyolojik kalite, fiziko-kimyasal özellikler, Pearson korelasyon analizi, Temel Bileşen Analizi (PCA).



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Food Science and Engineering Research

Introduction

In recent years, rapid urbanization, changing lifestyles, and increasing out-of-home consumption habits have led to a significant rise in demand for ready-to-eat (RTE) foods (Ağır and Akbay, 2021; Darmawan and Rizqullah, 2026; Erdoğan, 2009; WHO, 2022). Among these product groups, cream cakes have become one of the most preferred products in the bakery sector due to their high sensory acceptability, rich composition, and wide range of use from special occasion celebrations to daily consumption (Akgün et al., 1997; Cropotova et al., 2021). These products, which hold an important place in the bakery industry, have a complex structure consisting of flour, sugar, milk, eggs, cream, chocolate, fruits, nuts, and various filling ingredients. Despite being widely preferred by consumers of all age groups due to their high nutritional value and attractive sensory properties, this rich nutrient composition also creates a suitable environment for microbial growth (Hassanzadazar et al., 2018; Sharifzadeh et al., 2016).

Cream cakes are highly susceptible to microbial development owing to their high water activity ($a_w = 0.95\text{--}0.96$), near neutral pH values, and rich protein and carbohydrate content (Akgün et al., 1997; Özlem, 2017; Rahman, 2009). Particularly, the cream phase provides an ideal environment for pathogenic and spoilage microorganisms due to its high moisture content and suitable pH range. Inadequate heat treatment during production, disruption of the cold chain, deficiencies in equipment sanitation, and intensive hand contact during the decoration stage can negatively affect the microbiological safety of these products (Sharifzadeh et al., 2016). Post production contamination occurring during cutting, cream filling, decoration, packaging, and storage stages are considered critical points that directly impact product safety (Akgün et al., 1997; Filip & Fink, 2017; Hassanzadazar et al., 2018). Under these conditions, microorganisms such as Enterobacteriaceae, coliform bacteria, yeasts and molds, and coagulase positive *Staphylococcus* can multiply rapidly (Erol et al., 1996). These microorganisms not only shorten the shelf life of the product but also pose a threat to consumer health by causing foodborne infections and intoxications (Argudín et al., 2010; Smith et al., 2004).

Staphylococcus aureus, one of the most significant microbiological hazards in ready-to-eat cream based products, can cause serious food poisoning through heat-stable enterotoxins it produces under suitable conditions (Argudín et al., 2010). In addition, pathogens such as *Salmonella* spp., *Listeria monocytogenes* and *Escherichia*

coli are frequently reported as public health risks in cream and milk based products (Smith et al., 2004). Studies in the literature indicate that the microbiological quality of cream cakes poses significant risks both in Türkiye and worldwide (Hassanzadazar et al., 2018; Sharifzadeh et al., 2016; Smith et al., 2004). In studies conducted in Türkiye, high levels of coliform bacteria, coagulase positive *Staphylococcus*, and total aerobic mesophilic bacteria have been reported in cream cake samples, with some samples exceeding the limits of the Turkish Food Codex (Akgün et al., 1997; Erol et al., 1996; Konyalı et al., 2005). Similarly, in studies from Iran, a substantial proportion of cream cake samples were found to be non-compliant with national standards in terms of total bacterial count, coliform bacteria and *S. aureus* (Hassanzadazar et al., 2018). Sharifzadeh et al. (2016) reported that approximately one-third of cream cake samples were microbiologically unsatisfactory, while more recent studies continue to highlight hygiene indicator microorganisms and potential pathogens as ongoing concerns in cream based products.

In addition to the microbiological profile, physicochemical properties are also important parameters in evaluating product quality and reliability. Characteristics such as dry matter, ash, pH, and water activity provide valuable information about product composition, storage stability, susceptibility to microbial growth, and shelf life (Begum et al., 2023). In particular, water activity and pH values are among the main environmental factors that directly influence microbial growth (Rahman, 2009). Therefore, the combined evaluation of physicochemical and microbiological properties allows for a more comprehensive assessment of product safety.

In recent years, multivariate statistical methods such as Pearson correlation analysis and Principal Component Analysis (PCA) have been widely used in food quality studies to determine relationships between quality parameters and to classify samples (Granato et al., 2018). However, studies that evaluate the physicochemical and microbiological properties of cream fresh cakes together and support them with these methods remain limited. Furthermore, no current and comprehensive scientific data exist regarding the quality and safety status of cream cakes sold in the city center of Trabzon. This indicates a significant research gap at the regional level.

The aim of this study was to determine the physicochemical and microbiological properties of 15 cream fresh cake samples obtained from different sales points operating in the city center of Trabzon, and to evaluate the obtained results in accordance with the

Turkish Food Codex Communiqué on Food Safety Criteria in terms of public health suitability. Within this scope, dry matter, ash, pH, and water activity analyses were performed on the samples, along with the enumeration of *Enterobacteriaceae*, total aerobic mesophilic bacteria, total aerobic psychrophilic bacteria, coliform bacteria, yeast-mold, and *Staphylococcus aureus*. Additionally, the relationships between physicochemical and microbiological parameters were examined using Pearson correlation analysis, and Principal Component Analysis (PCA) was applied to determine similarities among the samples. This study is one of the comprehensive investigations that evaluates the quality and safety characteristics of cream cakes offered for sale in Trabzon using physicochemical, microbiological, and multivariate statistical approaches together.

Material and Methods

Material

Sample Collection

A total of 15 cream cake samples (CC₁ – CC₁₅) were randomly purchased from different bakeries, pastry shops, and retail outlets operating in the central district of Trabzon, Türkiye. Samples were collected on different days to represent products available to consumers under routine market conditions. Each sample was aseptically transferred to sterile sampling bags, transported to the laboratory under refrigerated conditions ($4 \pm 1^\circ\text{C}$), and analyzed on the same day.

Methods

Physicochemical Analyses

Dry matter content was determined according to the AOAC Method 925.10 by drying samples in a hot-air oven at 105°C until constant weight was achieved (AOAC, 2019). Ash content was determined using the AOAC Method 923.03 by incinerating samples in a muffle furnace at 550°C until complete mineralization was obtained (AOAC, 2019). For pH determination, 10 g of sample was homogenized with 90 mL of distilled water and the pH was measured using a calibrated digital pH meter according to the procedure described by Rahman (2009). Water activity (a_w) was determined at room temperature using a calibrated water activity meter following the principles outlined by Barbosa-Cánovas et al. (2020). All physicochemical analyses

terms of both microbiological quality and food safety

were performed in triplicate, and the results were expressed as mean $\pm$ standard deviation.

Microbiological Analyses

For microbiological analyses, 10 g of each sample was aseptically transferred into sterile stomacher bags containing 90 mL of sterile peptone water and homogenized for 2 min. Serial decimal dilutions were prepared using sterile peptone water following the procedures described by Harrigan (1998) and Jay et al. (2005). Total aerobic mesophilic bacteria (TAMB) were enumerated on Plate Count Agar (PCA) after incubation at 30°C for 48 h according to the method of Harrigan (1998). Total aerobic psychrophilic bacteria (TAPB) were determined on PCA after incubation at 7°C for 10 days as described by Cousin et al. (1992). *Enterobacteriaceae* counts were performed on Violet Red Bile Glucose Agar (VRBG), while coliform bacteria were enumerated on Violet Red Bile Agar (VRBA) following the procedures reported by Downes and Ito (2001). Yeast and mould counts were determined on acidified Potato Dextrose Agar (PDA) after incubation at 25°C for 5 days according to Koburger and Marth (1984). *Staphylococcus aureus* counts were determined on Baird Parker Agar supplemented with egg yolk tellurite emulsion and incubated at 37°C for 24–48 h following the method described by Lancette and Bennett (2001). Microbiological results were expressed as log CFU/g.

Statistical Analysis

All analyses were carried out in triplicate and results were expressed as mean $\pm$ standard deviation. Statistical analyses were performed using SPSS Statistics 22.0 and GraphPad Prism 10.0 software. Relationships among physicochemical and microbiological parameters were evaluated using Pearson correlation analysis. Principal Component Analysis (PCA) was applied to standardized data to investigate multivariate relationships among variables and to visualize similarities and differences among cream cake samples.

Results and Discussion

Microbiological Counts Assessment

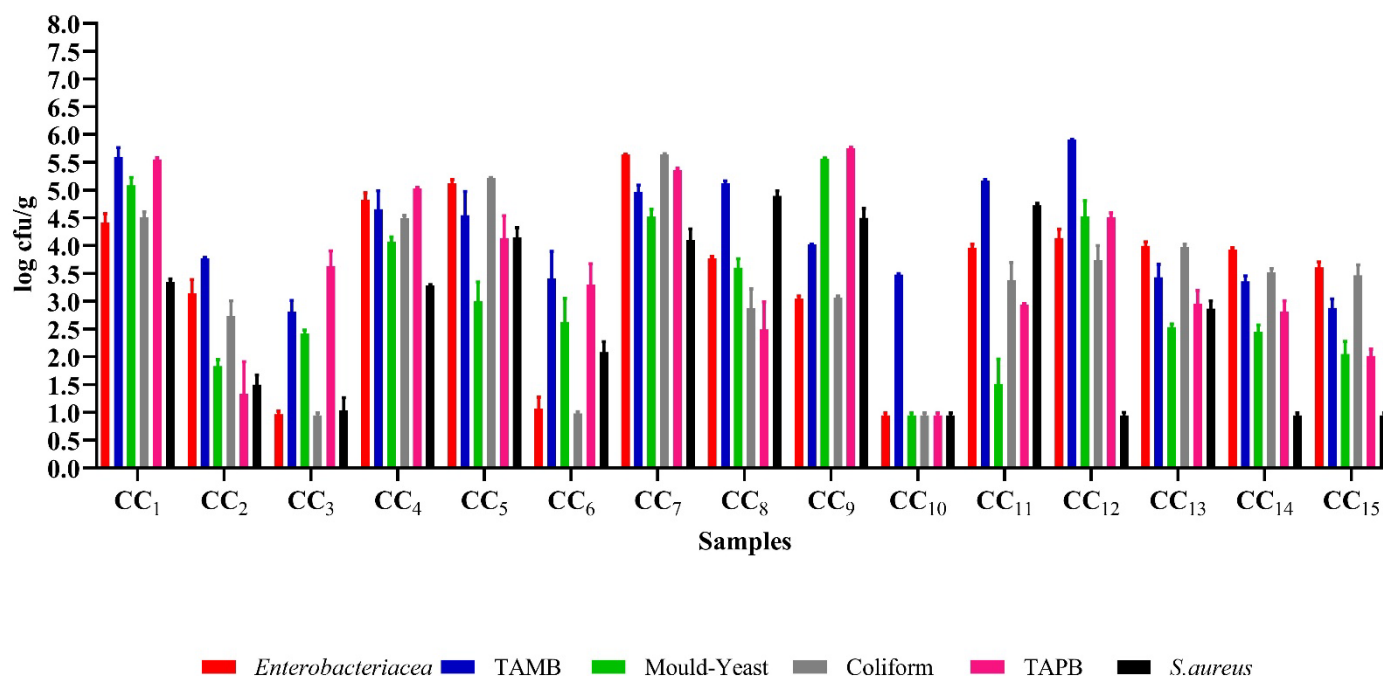
The microbiological analysis results of the cream cake samples (CC₁–CC₁₅) revealed significant differences among the samples and indicated that some samples posed risks in (Figure 1). Total aerobic mesophilic bacteria (TAMB) counts ranged from approximately 2.8 to 5.9 log CFU/g, with

particularly high levels detected in samples CC₁, CC₇, CC₁₁, and CC₁₂. TAMB count is considered an important indicator of production hygiene and overall microbiological quality of the product. Similarly, a study conducted in Iran reported high total aerobic bacterial counts in cream cake samples and noted that microbial growth was accelerated in

products with high moisture content (Sami et al., 2013). The TAMB results obtained in the present study are consistent with the findings in the literature, suggesting that the high microbial loads observed in some samples may originate from post-production contamination or inadequacies in storage conditions (Akgün et al., 1997).

Figure 1

Counts of *Enterobacteriaceae*, total aerobic mesophilic bacteria (TAMB), mould-yeast, coliform bacteria, total aerobic psychrophilic bacteria (TAPB), and *Staphylococcus aureus* in cream cake samples collected from retail outlets in the central district of Trabzon. Results are expressed as mean $\pm$ standard deviation ($n = 3$) and reported as log CFU/g.



When evaluated in terms of yeast and mold counts, particularly high levels ranging from 4.5 to 5.6 log CFU/g were detected in samples CC₁, CC₇, CC₉ and CC₁₂. Cream cakes create a highly favorable environment for yeast and mold growth due to their high water activity ($a_w > 0.90$), rich carbohydrate content, and near neutral pH values. Studies conducted on cream cakes in Iran have reported yeast-mold loads within similar ranges (Sharifzadeh et al., 2016). The yeast-mold count of 5.5 log CFU/g determined in sample CC₉ particularly indicates that a critical level has been reached in terms of product shelf life and sensory quality. This situation may have resulted from deficiencies in storage temperature, packaging integrity, or moisture control.

When *Enterobacteriaceae* and coliform counts were evaluated as hygiene indicators, considerably high values ranging from approximately 4.0 to 5.7 log CFU/g were determined in samples CC₅, CC₇, CC₉, and CC₁₂. The high levels of *Enterobacteriaceae* are associated with

microbiological load in raw materials, environmental or fecal contamination, inadequate equipment sanitation, cross-contamination, and deficiencies in personnel hygiene. Studies on similar products have emphasized that *Enterobacteriaceae* counts originate from sanitation deficiencies in the production environment (Abdelrasoul et al., 2023; Erol et al., 1996). It is noteworthy that the values obtained in some samples in the present study exceeded the upper limits reported in the literature. Furthermore, according to the Turkish Food Codex Communiqué on Food Hygiene Criteria, *Enterobacteriaceae* count is regarded as an important indicator of production hygiene in milk-based products, and high counts require the implementation of corrective actions in the production process. From this perspective, samples CC₅, CC₇, CC₉, and CC₁₂ can be considered risky in terms of hygienic quality (Konyalı et al., 2005).

According to Turkish Food Codex Communiqué on Food Safety Criteria (2025), the limits for coagulase-positive

staphylococci in “cakes and fresh pastries (cream-filled, chocolate, filled, fruit, etc.)” are specified as $n=5$, $c=2$, $m=10^2$ CFU/g, and $M=10^3$ CFU/g. In this study, *S. aureus* counts in samples CC₈, CC₁₁, and CC₁₂ were determined to reach levels of 4.7 – 5.0 log CFU/g. These values correspond to approximately 5×10^4 – 10^5 CFU/g and are about 10 to 100 times higher than the M limit specified in the regulation. Therefore, these samples do not comply with the Turkish Food Codex criteria and can be considered to pose a potential risk in terms of staphylococcal enterotoxin formation. The primary sources of *S. aureus* contamination are known to be human skin flora, nasal secretions, and production personnel. Hence, high counts can be directly evaluated as an indicator of deficiencies in production hygiene. A study conducted on cream filled cakes in Hamedan, Iran, reported a high positivity rate for *S. aureus* and that the isolates had enterotoxigenic potential (Rezaei et al., 2018). Similarly, high staphylococcal loads in ready-to-eat bakery products have been attributed particularly to manual production stages (Abdelrasoul et al., 2023).

When total aerobic psychrophilic bacteria counts were examined, levels ranging from 5.5 to 5.8 log CFU/g were observed in some samples, particularly CC₁ and CC₉. Psychrotrophic bacteria are important microorganisms that limit the shelf life of milk and cream based products due to their ability to grow at low temperatures. Recent review studies have emphasized that psychrotrophic bacteria (especially *Pseudomonas* and *Acinetobacter* species) produce proteolytic and lipolytic enzymes in cold stored cream based products, leading to flavor, aroma, and texture deterioration and significantly shortening shelf life (Biçer et al., 2025; Karanth et al., 2023).

In contrast, samples CC₁₀ and CC₁₅ exhibited better microbiological quality compared to the other samples, with low counts of *Enterobacteriaceae*, coliform bacteria, yeast-mold, psychrophilic bacteria, and *S. aureus*. This demonstrates that even within the same product category, production processes, quality of raw materials, sanitation practices, and storage conditions have a decisive effect on microbiological load.

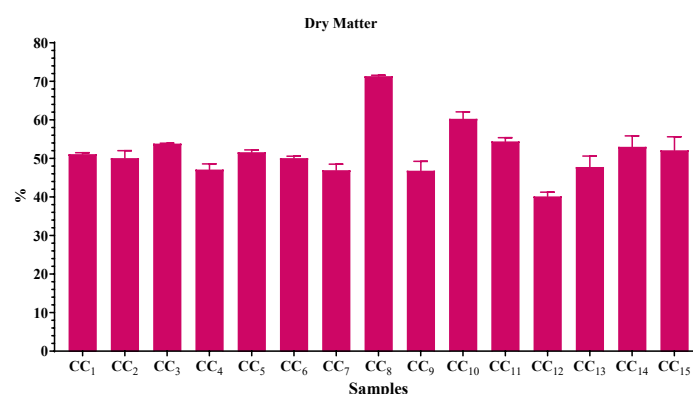
Physicochemical Analyses and Multivariate Statistical Analysis

The dry matter contents determined in the cream cake samples varied over a wide range, from 40.1% to 71.4%, revealing significant differences among the samples. The highest dry matter content was detected in sample CC₈ (71.4%), while the lowest value was observed in sample CC

(40.1%) (Figure 2). The fact that the dry matter contents of the majority of the samples were concentrated in the 47–54% range indicates that these values are directly influenced by formulation differences such as cake to cream ratio, type of cream, sugar and fat content, addition of fruits / sauces, and filling ratio (Cevoli et al., 2020; Dizlek & Altan, 2013).

Figure 2.

Dry matter contents (%) of cream-filled cake samples (CC₁–CC₁₅). Values are expressed as mean $\pm$ standard deviation ($n = 3$). Error bars represent standard deviation of triplicate measurements.



When compared with studies conducted in Türkiye on cream cakes and similar products, the obtained values were generally consistent but showed notable variations. In their research on fresh cakes offered for consumption in Tekirdağ, Konyalı et al. (2005) emphasized that the moisture content (and thus the dry matter ratio) of the products plays a critical role in shelf life and quality, noting that highly moist (low dry matter) cakes have more limited storage stability (Konyalı et al., 2005). Samples with low dry matter content such as CC₁₂, CC₄, CC₇, and CC₉ in the present study show strong parallelism with the Tekirdağ findings and support the idea that a high cream / filling ratio in the formulation reduces the dry matter content (Akgün et al., 1997). Similarly, other Turkish studies on cake and bakery products have reported that dry matter / moisture content varies depending on formulation components (flour, fat, sugar, and hydrocolloids). For instance, in studies on cakes enriched with various functional additives, it was observed that water holding capacity affected the dry matter content of the products and that moisture loss during storage differed according to the formulation (Gözükara, 2013; Işık et al., 2017).

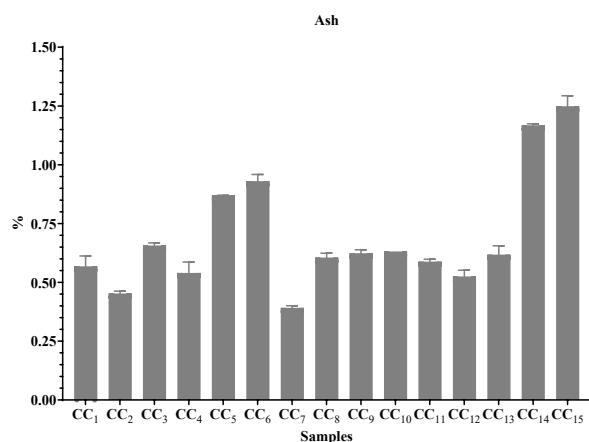
The wide range observed in the current study reflects the lack of standardization in cream cake production in Türkiye and the diversity in formulation strategies among

different patisseries and manufacturers (Ef et al., 2023; Komolka et al., 2016). The high dry matter levels observed in samples CC₈ and CC₁₀ indicate that these products have a denser sponge cake structure or low moisture cream formulations. In contrast, the low dry matter content detected in sample CC₁₂ demonstrates a high water content in the product and emphasizes that the combination of high moisture content and near neutral pH creates a highly favorable environment for microbial growth, particularly for *S. aureus*, yeasts, and molds (Akgün et al., 1997).

The ash contents of the cream cake samples ranged from 0.39% to 1.25%, with significant differences observed among the samples. The highest ash content was determined in samples CC₁₅ (1.25%) and while the lowest value was found in sample CC₇ (0.39%). Relatively higher ash contents were observed in some samples, whereas others exhibited lower levels, indicating variability in the mineral composition of the products. Overall, the ash contents of most samples were distributed within a relatively narrow range, suggesting broadly similar mineral profiles despite differences in formulation (Figure 3).

Figure 3.

Ash contents (%) of cream-filled cake samples (CC₁–CC₁₅). Results are expressed as mean $\pm$ standard deviation ($n = 3$). Error bars represent standard deviations of triplicate measurements.



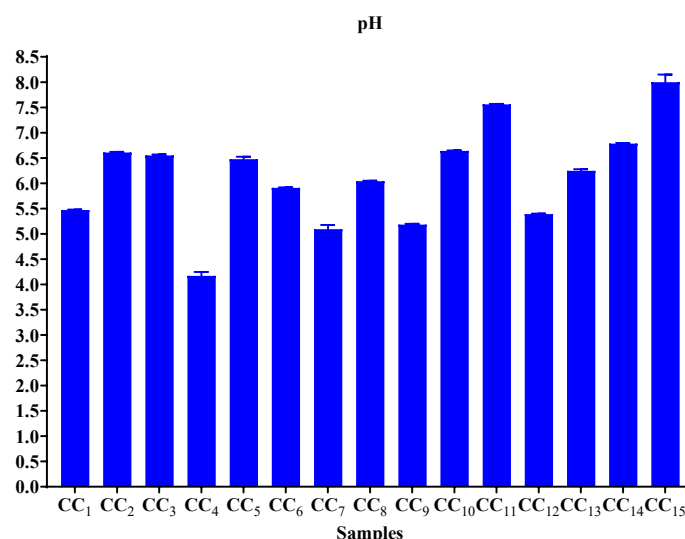
Ash content is an indicator of the total mineral matter in foods and is directly influenced by product formulation, raw materials used (flour, milk and dairy products, eggs, cocoa, nuts, and fruit additives), and production technology. It is considered that samples with high ash content such as CC₁₄ and CC₁₅ contain higher amounts of mineral rich ingredients. In samples with low ash content, the use of more refined raw materials may have been preferred (Akar & Özdemir, 2022; Üzümcü & Özsisli, 2023). When compared with the literature, ash contents in cakes and cream based bakery products are generally reported to range between

0.4% and 1.5% (Begum et al., 2023; Seçim & Uçar, 2014). The values obtained in this study are in full agreement with the aforementioned ranges. International studies have indicated that cocoa, milk based creams, and additives increase ash content, and the present findings are consistent with this literature (Godefroidt et al., 2019; Thongkham & Kongkachuichai, 2024). When compared with similar studies conducted in Türkiye, the results exhibit a compatible profile. In the study by Gözükar (2013) on cakes enriched with pumpkin powder and in the research by Işık et al. (2017) on blueberry added muffin cakes, ash content was observed to vary depending on the mineral composition of the raw materials and ranged between 0.5% and 2.0%. The wide variation in the current study reflects the diversity of recipes used by different manufacturers in cream cake production in Türkiye and shows strong consistency with the national literature (Gözükar, 2013; Işık et al., 2017).

The pH values of the cream cake samples ranged from 4.20 to 8.00, with significant differences observed among the samples. The lowest pH value was determined in sample CC₄ (pH 4.20) and the highest pH value was detected in samples CC₁₅ (pH 8.00). The pH values of the majority of the other samples were concentrated in the 5.5 – 6.8 range (Figure 4). These results indicate that the examined cream cakes are not homogeneous in terms of acidity levels and that formulation differences have a marked effect on the chemical properties of the products.

Figure 4.

pH values of cream-filled cake samples (CC₁–CC₁₅). Results are expressed as mean $\pm$ standard deviation ($n = 3$). Error bars represent the standard deviations of triplicate measurements.



The pH value is one of the fundamental physicochemical

parameters that affects microbiological stability, textural properties, sensory quality, and shelf life in cream cakes. The pH of the product is influenced by the milk and dairy products used, cream type, fruit fillings, cocoa, acid regulators, and fermentation derived components. The low pH value determined in sample CC₄, in particular, may be associated with the use of fruit based fillings or a higher proportion of acidic components in the formulation. In contrast, the high pH values observed in samples CC₁₁ and CC₁₅ indicate formulations dominated by milk based creams or containing components with high buffering capacity (Akgün et al., 1997; Keskin & Güneş, 2025).

When compared with the literature, the pH values of cream cakes and similar bakery products vary considerably depending on product formulation and the type of ingredients used. In general, relatively higher pH values have been reported for conventional and chocolate cakes, whereas fruit containing products tend to exhibit lower values due to the presence of acidic ingredients (Amendola & Rees, 2002). The pH variation observed in the present study was generally consistent with these reported trends and likely reflects differences in cream composition, fruit fillings, and other formulation components. From a food safety perspective, acidic conditions may restrict the growth of many bacterial pathogens, whereas near neutral pH conditions may provide a more favorable environment for microbial proliferation (Atasever & Çubukçı, 2018; Begum et al., 2023).

When compared with similar studies conducted in Türkiye, the results generally show consistency. Studies on cream cakes sold in İstanbul have reported that pH values vary over a wide range depending on formulation components (milk cream, fruit filling) (Akgün et al., 1997; Çalışkan, 2016). The effect of pH on shelf life and microbial stability was also emphasized in the Tekirdağ fresh cake study (Konyalı et al., 2005). The wide variation observed in the present study (4.20–8.00) reflects the diversity of recipes in cream cake production in Türkiye and is consistent with the national literature (Akgün et al., 1997; Konyalı et al., 2005).

The pH values of the cream cake samples showed considerable variation, which may reflect differences in formulation and the ingredients used. Lower pH values in some samples may be associated with acidic fruit fillings, such as sour cherry or strawberry, whereas higher values may be related to the use of leavening agents, particularly sodium bicarbonate, in bakery formulations (Aksoy, 2021; Dizlek & Altan, 2013). From a food safety perspective, the near neutral pH observed in several samples may provide favorable conditions for the growth of pathogenic and

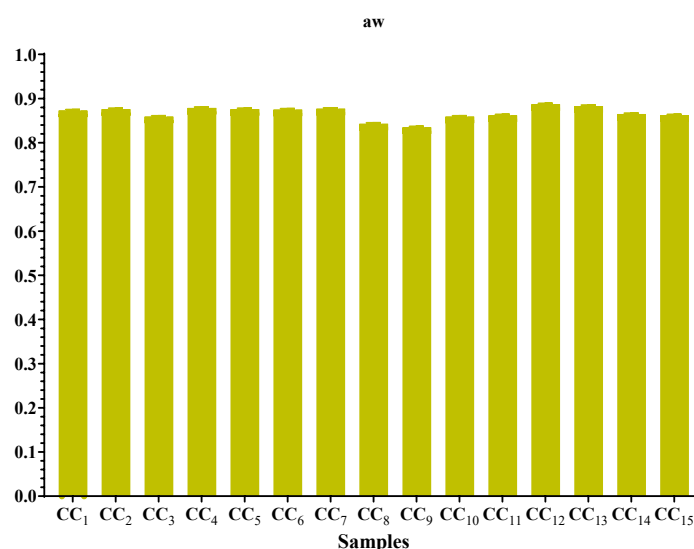
spoilage microorganisms. Therefore, pH alone may not constitute an effective barrier to microbial proliferation in these products, particularly when combined with their high water activity.

The water activity (a_w) values of the cream cake samples were generally high, indicating favorable conditions for microbial growth (Figure 5). Although variation among the samples was limited, all products exhibited a_w levels associated with increased susceptibility to microbiological spoilage. These findings highlight the importance of appropriate hygienic practices and storage conditions for ensuring the microbiological safety of cream cakes.

Water activity (a_w) is one of the fundamental quality parameters that expresses the amount of free water in foods and is considered more decisive than moisture content in terms of microbial growth. Due to the presence of cream, dairy products, and high moisture filling components, high water activity is an expected characteristic in fresh cakes. The water activity values of the 15 different cream cake samples analyzed showed a narrow distribution ranging from 0.84 to 0.89. The majority of the samples (particularly CC₁, CC₂, CC₃, CC₁₀, CC₁₁, and CC₁₂) were concentrated in the 0.86 – 0.88 range. These findings demonstrate that the products possess a high amount of free water, which is highly favorable for biochemical reactions and microbial growth, and confirm that they fall into the category defined in the scientific literature as high-moisture foods.

Figure 5.

Water activity (a_w) values of cream-filled cake samples (CC₁–CC₁₅). Results are expressed as mean $\pm$ standard deviation ($n = 3$). Error bars represent the standard deviations of triplicate measurements.



Similar results have been reported in studies conducted in Türkiye. Previous studies on fresh, cream-filled, and fruit-filled cakes have shown that these products generally exhibit high water activity, with higher cream proportions further increasing a_w and potentially limiting microbiological stability and shelf life (Özlem, 2017; Kaplan & Turgay, 2022). The findings of the present study are consistent with these observations, confirming that fresh cream cakes marketed in Türkiye provide favorable conditions for microbial growth.

This trend is also supported by the international literature. Cream cakes and related bakery products are generally characterized by relatively high water activity, which may facilitate the growth of yeasts, molds, and other microorganisms when appropriate storage conditions are not maintained (Smith et al., 2004). Similar observations have been reported for cream cakes in Iran and cream-filled bakery products in Europe, emphasizing the importance of adequate refrigeration and cold-chain control for maintaining microbiological food safety (Guiné & Florença, 2024; Sharifzadeh et al., 2016; Smith et al., 2004). Accordingly, the high water activity observed in the present samples highlights the microbiological susceptibility of cream cakes and reinforces the importance of strict hygienic practices and temperature control throughout production, storage, and retail.

The variation among the samples is thought to originate from differences in sugar (sucrose) concentration and moisture content in the product recipes. In food systems, sugar acts as an important solute that binds water and reduces water activity. In this context, samples such as CC₉ with relatively lower a_w values can be said to have a higher sugar ratio or a denser cream structure (Plotnikova et al., 2021). In conclusion, the literature supports that these products with high water activity have a very limited shelf life, and strict cold chain conditions (4–6°C) and hygienic storage practices from production to consumption are essential to maintain microbiological stability (Akgün et al.,

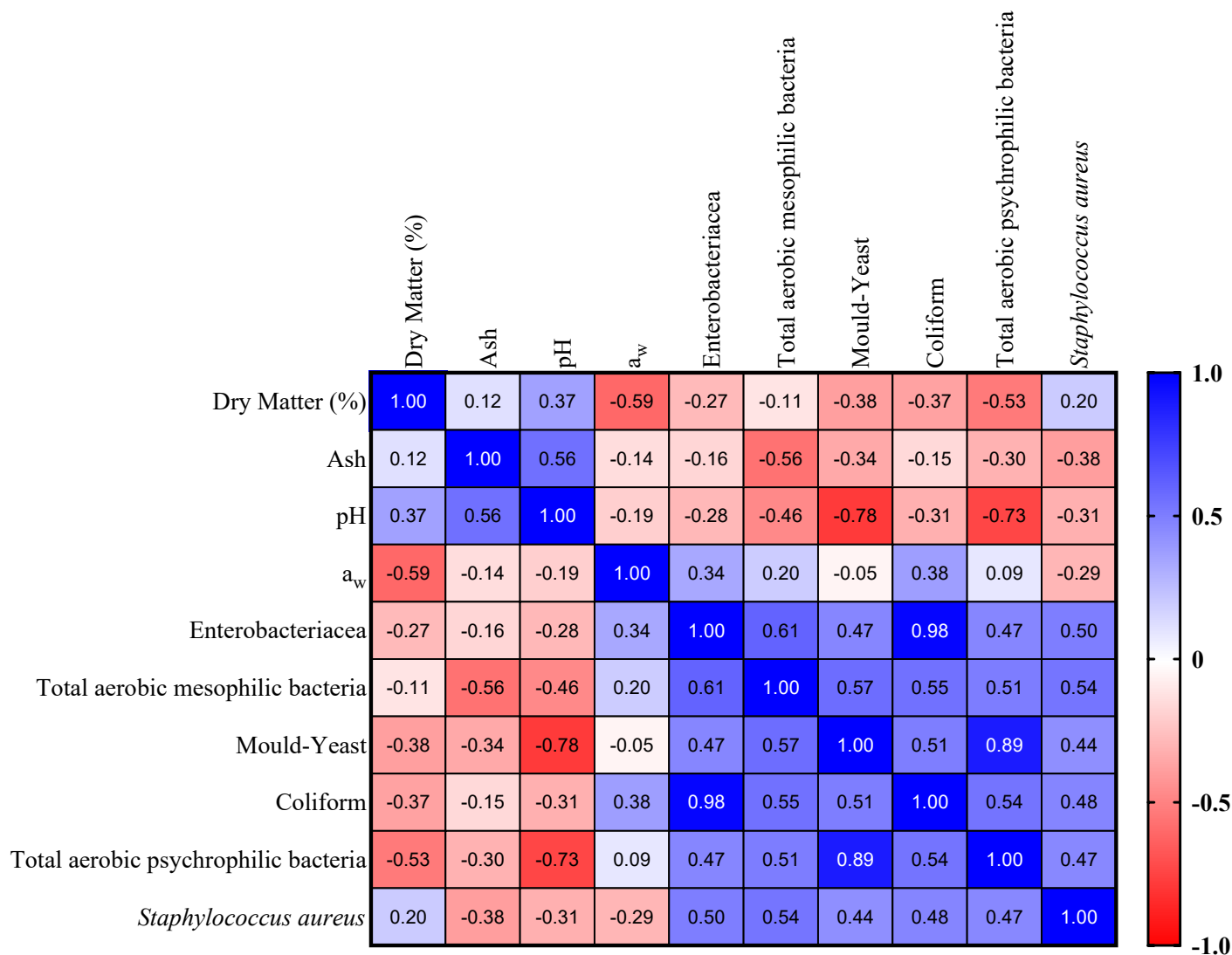
1997; Barbosa-Cánovas et al., 2020; Zardetto et al., 2021).

The results of Pearson correlation analysis performed to evaluate the relationships between the physicochemical and microbiological parameters of the cream cake samples are presented in Figure 6. When the correlation heatmap was examined, strong positive and negative correlations were observed between some parameters.

The strongest positive correlation among the microbiological parameters was found between *Enterobacteriaceae* and coliform bacteria ($r = 0.98$). This result is expected and can be explained by the fact that coliform bacteria constitute a significant portion of the *Enterobacteriaceae* family and both groups are accepted as indicators of production hygiene. Additionally, moderate positive correlations were detected between total aerobic mesophilic bacteria and *Enterobacteriaceae* ($r = 0.61$), coliform bacteria ($r = 0.55$), and *Staphylococcus aureus* ($r = 0.54$). These findings indicate that in samples with increased overall microbial load, hygiene indicator organisms and potential pathogen loads tend to increase together. A very strong positive relationship was observed between yeast-mold counts and total aerobic psychrophilic bacteria counts ($r = 0.89$). This demonstrates that in cream cakes with high moisture content, both fungal growth and psychrotrophic microorganisms capable of proliferating at low temperatures increase simultaneously during storage. Similarly, the positive correlations between yeast-mold and total aerobic mesophilic bacteria ($r = 0.57$), coliform bacteria ($r = 0.51$), and *Enterobacteriaceae* ($r = 0.47$) reveal that microbiological spoilage generally occurs through the simultaneous development of multiple microbial groups. The literature also reports that increased yeast-mold loads in cream filled and milk based products are closely associated with overall microbial load and psychrotrophic bacterial growth (Cropotova et al., 2021; Jamshidi et al., 2017; Sharifzadeh et al., 2016).

Figure 6.

Pearson correlation heatmap showing the relationships between physicochemical parameters (dry matter, ash, pH, and water activity) and microbiological characteristics of cream-filled cake samples. Correlation coefficients (r) range from -1.0 to $+1.0$, where blue colors indicate positive correlations and red colors indicate negative correlations. The intensity of the color reflects the strength of the relationship between variables.



When the relationships between physicochemical parameters and microbiological data were evaluated, pH value showed strong negative correlations particularly with yeast-mold ($r = -0.78$) and total aerobic psychrophilic bacteria counts ($r = -0.73$). This result indicates that the growth of certain microorganism groups increases as pH decreases. It is well known that in samples with low pH, yeasts and molds can become more dominant due to their ability to adapt to acidic conditions (Cropotova *et al.*, 2021). In contrast, the relationships between pH and *Enterobacteriaceae* ($r = -0.28$), coliform bacteria ($r = -0.31$),

and *S. aureus* ($r = -0.31$) were weaker. This suggests that factors other than pH, such as production hygiene, raw material quality, and storage conditions, also play important roles in the growth of these microorganisms (Çalışkan, 2016; Sami *et al.*, 2013).

A moderate negative correlation was determined between dry matter content and water activity ($r = -0.59$). This finding can be evaluated as an expected outcome, where the amount of free water decreases as dry matter content increases in the products. A negative relationship

was also found between dry matter and total aerobic psychrophilic bacteria counts ($r = -0.53$). This result shows that samples with lower dry matter (and thus higher moisture) create more favorable environments for microbial growth. However, the generally low to moderate correlation coefficients between water activity and microbiological parameters (ranging from $r = -0.29$ to 0.38) may be due to the fact that the water activity values of all examined samples were quite close to each other (Smith et al., 2004).

A moderate positive correlation was detected between ash content and pH ($r = 0.56$). This can be explained by the relatively higher pH values in samples with high mineral content due to increased buffering capacity. On the other hand, a negative correlation was found between ash content and total aerobic mesophilic bacteria ($r = -0.56$). However, this relationship is thought to stem more from differences in product formulations rather than reflecting a direct causal mechanism.

When compared with similar studies in the Turkish and international literature, the obtained correlation patterns show substantial consistency. In studies conducted on cream cake samples in İstanbul and Tekirdağ, positive relationships were reported between hygiene indicators (*Enterobacteriaceae*, coliform) and overall microbial load, while the negative effect of pH on fungal growth was emphasized (Çalışkan, 2016). Similarly, in functional cake studies, negative correlations were found between dry matter/water activity and microbiological parameters, along with strong negative relationships between pH and yeast-mold (Cropotova et al., 2021). The strong *Enterobacteriaceae*–coliform ($r = 0.98$) and yeast-mold–psychrophilic ($r = 0.89$) correlations in the present study are parallel to international findings supporting that hygiene and storage-related spoilage in bakery products occurs through multi-microorganism interactions (BIOHAZ, 2012; Jamshidi et al., 2017; Juhaniaková et al., 2014; Sharifzadeh et al., 2016).

The results of Principal Component Analysis (PCA) performed to reveal the multivariate relationships between the physicochemical and microbiological properties of the cream cake samples are presented in Figure 7. According to the PCA results, the first principal component (PC1) explained 46.76% of the total variance, while the second principal component (PC2) explained 17.83%. Together, the first two components accounted for 64.59% of the total variance in the data. This proportion indicates that a significant portion of the variability among the samples was successfully modeled in a two-dimensional plane and that

the PCA model effectively revealed the main sources of variation in the dataset.

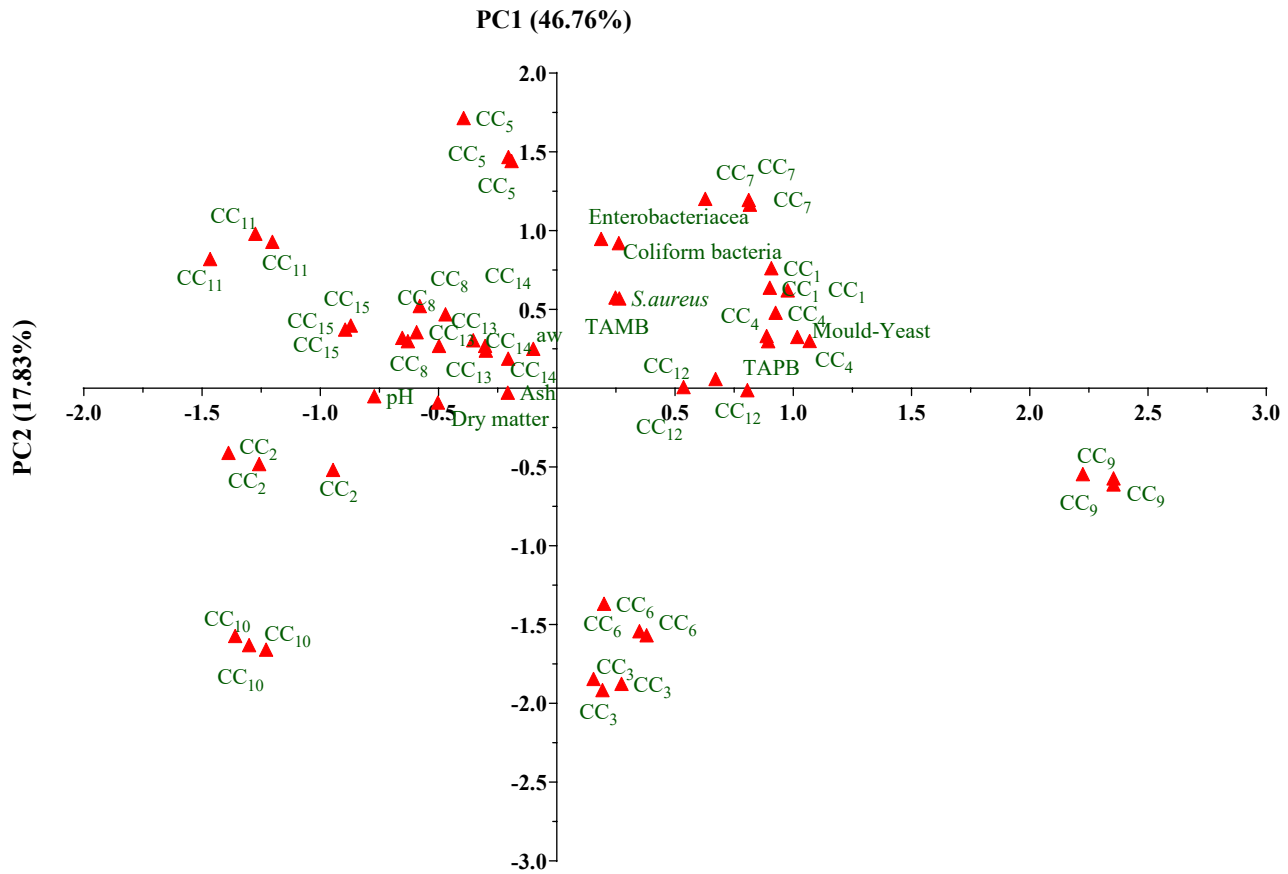
When the biplot graph was examined, the vectors of the microbiological parameters (*Enterobacteriaceae*, coliform bacteria, *Staphylococcus aureus*, total aerobic mesophilic bacteria (TAMB), yeast-mold, and total aerobic psychrophilic bacteria (TAPB) were observed to be positioned in the positive direction of PC1 and close to each other. This clustering indicates strong positive relationships among these parameters and shows that hygiene indicators and spoilage agents increase simultaneously in samples with high microbial loads. The near overlapping vectors of *Enterobacteriaceae* and coliform bacteria particularly confirm the very high correlation between these two variables ($r = 0.98$). Similarly, the positioning of yeast-mold and total aerobic psychrophilic bacteria variables in the same region supports the high correlation coefficient determined between these two parameters ($r = 0.89$) (Jamshidi et al., 2017; Sharifzadeh et al., 2016).

The physicochemical parameters exhibited a different pattern in the biplot. The vectors of dry matter and ash content were located close to each other and largely in the opposite direction of the microbiological parameters, while the pH vector was positioned particularly in the negative direction of the yeast-mold and psychrophilic bacteria vectors. This distribution scientifically supports that high dry matter content has a limiting effect on microbial growth and that low pH suppresses fungal/psychrotrophic development (Akgün et al., 1997; Moura-Alves et al., 2022; Smith et al., 2004).

Regarding the distribution of the samples, CC₁, CC₄, and CC₇ clustered in the region where the microbiological load vectors are concentrated, indicating that they carry a high risk of contamination. The positioning of sample CC₇ particularly close to *Enterobacteriaceae* and coliform bacteria reveals the dominance of hygiene indicator microorganisms in this sample. Sample CC₉ is located in a distinctly isolated position in the PCA plane, suggesting it has a different physicochemical and microbiological profile compared to the other samples. In contrast, samples such as CC₃, CC₆, and CC₁₀ clustered in the lower part of the PCA plane, and their distant positioning from the microbiological parameters indicates that they have a lower contamination profile. Samples CC₁₃, CC₁₄, and partially CC₈ were located in the region associated with physicochemical parameters such as dry matter, ash, and water activity, demonstrating that they were differentiated primarily by their physicochemical composition rather than microbiological properties.

Figure 7.

Principal Component Analysis (PCA) biplot of cream-filled cake samples based on physicochemical properties (dry matter, ash, pH, and water activity) and microbiological parameters



Conclusion

In this study, the physicochemical characteristics and microbiological food safety of fifteen cream cake samples marketed in Trabzon were evaluated. Although physicochemical properties varied among samples, the high water activity observed across the products indicated favorable conditions for microbial growth. Microbiological analyses revealed substantial differences among samples, with CC₈, CC₁₁, and CC₁₂ exceeding the Turkish Food Codex criteria for *Staphylococcus aureus*. Elevated levels of hygiene-indicator microorganisms in some samples further indicated potential deficiencies in sanitation, handling practices, and temperature control.

Correlation and principal component analyses demonstrated that microbiological parameters were more influential than physicochemical characteristics in differentiating the samples, emphasizing that physicochemical characteristics alone cannot ensure the

microbiological safety of cream cakes. Overall, the findings provide market based evidence that post processing hygiene and cold chain management are critical determinants of food safety in these highly perishable ready to eat products. Therefore, effective HACCP based controls, hygienic handling, sanitation practices, and continuous temperature control should be strengthened throughout production, storage, and retail to minimize microbiological hazards and protect consumer health.

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