Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Cheese Type and Pre-Drying Morphology Critically Determine the Flavor Profile, Oxidative Stability, and Storage Performance of Freeze-Dried Cheese Powders

Saqib Manzoor
University of Veterinary and Animal Sciences
Nabila Gulzar
University of Veterinary and Animal Sciences
Saima Inayat
University of Veterinary and Animal Sciences
Ehsaan Ullah Khan
Chinese Academy of Agricultural Sciences
Muhammad Muneeb
Chinese Academy of Agricultural Sciences
Sohail Ahmad
Universitas Airlangga
Ayham Abdulkaderk
alaagri82@gmail.com

Idlib University
Afnan H. Saaty
King Abdulaziz University
Mahmoud Alagawany
Zagazig University

Research Article

Keywords: freeze-drying, cheese powder, sample morphology, volatile compounds, fatty acid profile, enzyme-modified cheese, lipid oxidation

Posted Date: November 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11481650/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Cheese Type and Pre-Drying Morphology Critically Determine the Flavor Profile, Oxidative Stability, and Storage Performance of Freeze-Dried Cheese Powders

Abstract

Freeze-dried cheese powders provide concentrated flavor and extended shelf life, but their quality may depend on cheese type and sample morphology before drying. This study evaluated the effects of cheese type (Cheddar, Mozzarella, and enzyme-modified cheese (EMC)), pre-drying morphology (shreds, slices, and cubes), and storage/ripening time (0, 30, and 60 days) on the physicochemical properties, volatile profile, fatty acid composition, and oxidative stability of freeze-dried cheese powders. Proximate composition, water activity, free fatty acids, peroxide value, total oxidation value, and thiobarbituric acid-reactive substances were determined, while volatile compounds and fatty acids were analyzed by gas chromatography-mass spectrometry. Cheese type, morphology, and storage/ripening time significantly affected most attributes ($p < 0.05$). All powders had high total solids (96.01-97.88%) and low water activity (0.21-0.25). Cheddar developed the most complex volatile profile, whereas EMC showed accelerated flavor development, the highest free fatty acid content (0.26-0.46%), and the highest total oxidation values (5.1-7.5). Mozzarella retained a milder volatile profile and greater oxidative stability. Cubes generally retained higher concentrations of volatile compounds, whereas shreds favored moisture removal and showed greater lipolysis and oxidation. These findings demonstrate that cheese type and pre-drying morphology can be optimized to balance flavor development, oxidative stability, and storage performance.

Keywords: freeze-drying; cheese powder; sample morphology; volatile compounds; fatty acid profile; enzyme-modified cheese; lipid oxidation.

1. Introduction

Cheese powder is a nutrient-rich ingredient widely used in the food industry due to its convenience, extended shelf life, and concentrated flavor profile (Deshawal et al. 2024). As a versatile component, it is used in a variety of products such as snack foods, sauces, and dressings (Shinaliyeva et al. 2025). Consumers choose cheese snacks for their high protein content as an alternative to snacks high in fat and carbohydrates (Shinaliyeva et al. 2025).

Drying increases the shelf life of food products by lowering the moisture content (Pronschinske et al. 2026; Sviridenko et al. 2021). Generally, air drying, smoking, drum drying, and spray drying are used to dry cheese. These dehydration techniques change the physical structure of cheeses, which can affect the nutritional profile of the products (Rosa

and Prudencio (2023); Xin et al. 2022). Freeze-drying is a technique used to create high-quality dried food items. Freeze-dried food products maintain the same color, flavor, and nutritional value as the original food Uwineza and Zhang (2026).

In addition to being rich in nutrients, cheese has a unique fatty acid profile. The fatty acid composition of cheese is influenced by the source of the milk, animal feeding and management practices, and cheese-making processes (Paszczyk et al. 2022). This composition determines the nutritional quality of dairy products and significantly affects the color, texture, flavor, and overall nutritional value of cheese powder (Ponnampalam et al. 2024). In food applications, cheese powder is primarily used as a flavoring ingredient and plays an important role in sensory perception (Zheng et al 2021). Blue cheese powder enhances the concentrations of volatile compounds such as ketones, esters, and alcohols in sausages, whereas brown cheese powder is used in foods to provide umami flavor and Maillard reaction-derived compounds (López-Díaz et al. 2023; Sharma et al. 2020) The volatile profile of cheese powder varies according to the cheese type and commonly includes aldehydes, esters, alcohols, sulfur compounds, terpenes, ketones, and pyrazines (Clarke et al.2021). For example, Danbo cheese powder is rich in sulfur compounds and alcohols, whereas Emmental cheese powder contains esters (e.g., ethyl acetate and propyl butanoate), aldehydes (e.g., 2-methylbutanal, 3-methylbutanal, and hexanal), and methyl ketones (Varming et al. 2013). Similarly, blue cheese powder is characterized by aldehydes (e.g., butanal, 2-methylpropanal, and 2-methylbutanal), esters (e.g., methyl butanoate, methyl pentanoate, and methyl hexanoate), and ketones (e.g., 2-pentanone and diacetyl) (Sutthiwong et al. 2023). Oxidation is a critical issue that affects the quality and shelf life of cheese powder flavor Ritschard and Schuppler (2024). Oxidation is the degradation of lipids present in the cheese, which causes the loss of nutrients as well as the development of off-flavors and rancidity. The presence of volatile organic compounds from lipid oxidation, such as hexanal and heptanal, correlates with negative sensory attributes in dairy powders (Clarke et al. 2020). This may be due to several factors, such as the presence of oxygen, temperature, light exposure, and fatty acid composition. This oxidative degradation affects the sensory attributes and marketability of cheese powder flavor. Different storage conditions can significantly affect the concentration of these volatile organic compounds and, consequently, consumer acceptance (Amer et al. 2023; Kaminarides et al. 2007).

Although cheese powder production and flavor development have been investigated previously, limited information is available on how the surface area-to-volume ratio of cheese samples before freeze-drying affects the physicochemical characteristics, volatile flavor

retention, fatty acid composition, and oxidative stability of the resulting cheese powder. This relationship is important because sample morphology may influence moisture removal, volatile compound retention, lipid hydrolysis, and oxidation during storage.

Therefore, the aim of this study was to develop freeze-dried cheese powder flavors from three cheese varieties, namely Mozzarella, Cheddar, and enzyme-modified cheese (EMC), prepared in different morphologies with varying surface area-to-volume ratios, including shreds, slices, and cubes. Specifically, this study investigated the effects of cheese type, sample morphology, and aging/storage period on the physicochemical characteristics, fatty acid profile, volatile flavor composition, and lipid oxidation stability of freeze-dried cheese powder flavors.

2. Materials and Methods

2.1. Materials

For the preparation of cheeses (Mozzarella, Cheddar, and enzyme-modified cheese), milk was procured from the Dairy Training and Development Center (DTRC) B-Block, University of Veterinary and Animal Sciences, Ravi Campus, Pattoki. DVS (Direct Vat Set) starter culture, rennet, and a blend of enzymes (proteinases, peptidases, lipases, and esterases) were purchased from Christian Hansen Company, Denmark through local suppliers.

2.2. Production of cheese powders

Cheddar, Mozzarella, and EMC cheeses were prepared using the methods of (Nazish et al. 2022; Kendirci et al. 2020) respectively. The Cheddar cheese was ripened for two months. Each month during ripening, the Cheddar cheese was cut into different shapes with varying surface area-to-volume ratios (shreds, slices, and cubes), and then freeze-dried and tested for quality. Similarly, Mozzarella and enzyme-modified cheeses were stored for 60 days. Cheese samples with different surface area-to-volume ratios (shreds, slices, and cubes) were freeze-dried and tested for quality at 0, 30, and 60 days of storage. The surface area-to-volume ratios of the cheese samples were as follows: shreds (0.47 × 0.67cm2: 0.47 × 0.67 × 0.85 cm^3), slices (0.65 × 3 cm2: 0.65 × 3 × 4 cm^3), and cubes (1×1 cm2 :1 × 1 × 1 cm^3).

2.3. Cheese ripening storage conditions

After drying, cheese powder samples were immediately packed in bioplastic polylactic acid (PLA) pouches, heat-sealed, and stored at **8 ± 1 °C and 80 ± 5% relative humidity (RH)** until analysis. Samples were analyzed at predetermined storage intervals (0, 30, and 60 days).

During storage, the packages remained unopened until the designated sampling day to minimize moisture uptake and oxidative deterioration.

2.4. Physicochemical analysis of cheese powders

The powdered flavors of Cheddar, Mozzarella, and enzyme-modified cheeses were analyzed for fat, protein, ash, water activity, and total solids content using the methods outlined in AOAC (2016).

2.4.1. Determination of free fat and encapsulated fat

Free fat was determined according to the solvent extraction method described by Buma (1971) with slight modifications. Approximately 5 g of cheese powder was mixed with petroleum ether (or hexane) and gently agitated for the specified extraction time. The solvent was filtered and evaporated, and the extracted fat was weighed. Total fat content was determined using the AOAC official method. Encapsulated fat was calculated as the difference between total fat and free fat using the following equation:

$$\text{Encapsulated fat (\%)} = \text{Total fat (\%)} - \text{Free fat (\%)}$$

Results were expressed as percentages (%) of the cheese powder on a dry-weight basis.

2.4.2. Determination of water activity.

The water activity (aw) of the samples was determined at 25°C using a water activity meter (Aqualab, Decagon 3TE, Decagon Devices Inc., Pullman, WA). All measurements were performed in triplicate.

2.5. Flavor profile of cheese powder flavors

Flavor compounds were analyzed using gas chromatography–mass spectrometry (GC–MS) following the method described by (Zheng et al. 2024). A 4 g cheese powder sample was transferred into a 20 mL headspace vial, and 10 μL of 2-octanol (1.00 mg/mL) was added as an internal standard. The vial was immediately sealed and incubated in a water bath at 85°C while being stirred at 500 rpm using a magnetic stirrer for 20 min to allow equilibration. A 2 cm, 50/30 μm divinylbenzene/Carboxin/polydimethylsiloxane (DVB/CAR/PDMS) solid-phase microextraction (SPME) fiber was then exposed to the headspace for 30 min. Before extraction, the SPME fiber was conditioned in the GC injector at 250°C for 20 min according to the manufacturer's instructions.

Volatile flavor compounds were analyzed using a GC–MS system (Agilent Technologies Inc., CA, USA) equipped with a DB-WAX capillary column (30 m × 0.25 mm × 0.25 μm; Agilent J&W, CA, USA). The injector temperature was maintained at 250°C, and helium was used as the carrier gas at a constant flow rate of 1.0 mL/min. The GC oven temperature program was as follows: initially held at **40°C for 3 min**, increased to **150°C at 4°C/min**, then to **200°C at 5°C/min**, and finally to **230°C at 20°C/min**, where it was held for 5 min. The MS ion source temperature was maintained at 230°C, and mass spectra were acquired over a scan range of *m/z* 40–450.

Volatile compounds were identified by comparing their mass spectra with the NIST14 and NIST14S libraries, and only compounds with a spectral similarity greater than 80% were retained. Semiquantitative analysis was performed using 2-octanol as the internal standard, and the results were expressed as mg/kg.

2.6 Fatty acid profile of cheese powder flavors

The fatty acid profiles of Mozzarella, Cheddar, and enzyme-modified cheese (EMC) powders were determined during storage using the GC method described in (Zhang et al. 2024). Fatty acid methyl esters (FAMEs) were prepared from 300 μL of a well-mixed, melted cheese powder sample. The sample was transferred into an 11 mL screw-capped test tube, dissolved in 3 mL of *n*-hexane, and mixed with 2 mL of 0.5 N sodium methoxide. The mixture was

vortexed at high speed for exactly 3 min and then allowed to stand for 5 min to achieve phase separation. The upper organic layer was injected into a gas chromatograph (Agilent 7890B, Agilent Technologies, USA) equipped with an autosampler and a DB-5MS capillary column (60 m × 0.25 mm i.d., 0.25 μm film thickness). Fatty acids were identified by comparing the retention times of sample peaks with those of the Supelco 37 Component FAME Mix (Sigma-Aldrich, USA), which served as an external reference standard. Quantification was performed according to the method described in (Zhang et al. 2024).

2.7. Free Fatty acids in cheese powder flavors

For the determination of free fatty acids in cheese powder flavors, approximately 50mL of ethanol was measured into a conical flask, and 2-3 drops of phenolphthalein were added as an indicator. The solution was titrated with 0.1N NaOH until a light pink color appeared, marking the neutralization point of the ethanol. In a separate conical flask, a cheese powder sample was placed, and 50mL of the neutralized ethanol was added to it. Afterward, 2-3 drops of phenolphthalein were added, and the mixture was titrated with 0.1N NaOH until a light pink color developed. The volume of 0.1N NaOH used was recorded, and the value was used in the formula according to (AOCS 1995).

$$\textbf{Free fatty acid} = \frac{\text{Volume of 0.1N NaOH} \times 100 \times 282 \times \text{N}}{\text{Weight of sample}} x\ 100$$

The results were expressed as percentage (%) free fatty acids (as oleic acid equivalent). FFA values were calculated based on the volume of standardized alkali required for neutralization and the sample weight, following the equation specified in the cited method.

2.8. Peroxide value of cheese powder flavor

To determine the peroxide value (PV) of cheese powder, approximately 2-5g of the sample was first dissolved in a mixture of 30mL chloroform and 30mL acetic acid. Then, 0.5mL of potassium iodide (10% w/v) solution was added and allowed to react for 5 minutes. Afterward, 30mL distilled water and a few drops of 1% starch solution were added as an indicator. The mixture was titrated with a 0.01N sodium thiosulfate solution until the blue color disappeared. The peroxide value was calculated using the formula:

$$\textbf{PV} = \frac{[(\text{V1} - \text{V2}) \times \text{N}}{\text{W}} x\ 1000$$

where V1 and V2 are the volumes of sodium thiosulfate used for the blank and sample, N is the normality of the thiosulfate, and W is the sample weight. The result was expressed in milliequivalents of peroxide per kilogram of sample (meq/kg).

2.9. Total Oxidation (TOTOX) Value

The overall oxidative status of the cheese powder was evaluated by calculating the Total Oxidation (TOTOX) value using the peroxide value (PV) and the p-anisidine value (p-AV) according to the following equation:

$$\textbf{TOTOX} = (2 \times \text{Peroxide Value}) + \text{p} - \text{Anisidine Value}$$

Peroxide value was expressed as meq O_2/kg fat, whereas the p-anisidine value was determined according to the AOCS official method. The calculated TOTOX value provides an overall assessment of primary and secondary lipid oxidation products.

2.10 Thio barbituric Acid Reactive Substances (TBARS)

Lipid oxidation was assessed by measuring Thio barbituric acid-reactive substances (TBARS) following the method of Buege and Aust (1978) with minor modifications. Cheese powder samples were homogenized with trichloroacetic acid solution, filtered, and mixed with Thio barbituric acid reagent. The reaction mixture was heated in a boiling water bath for 15 min, cooled to room temperature, and the absorbance was measured at 532 nm using a UV–visible spectrophotometer. A calibration curve was prepared using 1,1,3,3-tetraethoxypropane (TEP), and the results were expressed as mg malondialdehyde (MDA)/kg cheese powder.

2.11. Statistical Analysis

Data from the physicochemical analyses, flavoring compound analyses, and fatty acid profiles were analyzed using two-way ANOVA, whereas free fatty acids, peroxide value, TOTOX, and TBARS were analyzed using three-way ANOVA with PROC GLM in SAS software (Version 9.1). Tukey's HSD test was used to compare significant treatment means; significance was set at $p \leq 0.05$.

3. Results and Discussion

3.1. Physicochemical composition of freeze-dried cheese powder flavors

The physicochemical composition of freeze-dried Cheddar, Mozzarella, and enzyme-modified cheese (EMC) powder flavors is presented in Tables 1-3. Fat, protein, ash, and total solids are expressed as percentages. Cheese type, sample morphology, and storage/ripening period influenced the chemical composition of the powders. Moisture content was significantly affected by cheese type, surface area-to-volume ratio, and ripening/storage period ($P < 0.05$). Fat and ash contents varied significantly with cheese type ($P < 0.05$), whereas surface area-to-volume ratio and ripening/storage period had no significant effect on

these parameters. Protein content was not significantly affected by surface area-to-volume ratio or ripening/storage period, although Cheddar powder showed higher protein values than EMC and Mozzarella. Total solids were influenced by cheese type, morphology, and storage/ripening period.

In Cheddar cheese powder, fat content ranged from 46.16 to 46.95%, protein from 38.29 to 38.88%, ash from 12.32 to 12.99%, and total solids from 97.21 to 97.46%. In Mozzarella cheese powder, fat ranged from 45.43 to 45.85%, protein from 36.04 to 36.98%, ash from 14.12 to 14.65%, and total solids from 97.39 to 97.88%. EMC powder showed relatively higher fat and ash contents, ranging from 47.63 to 47.97% and 15.39 to 15.67%, respectively, whereas protein content ranged from 33.02 to 33.93% and total solids from 96.01 to 96.39%. The water activity (aw) of enzyme-modified cheese powder remained low and stable throughout the 60-day storage period, ranging from 0.22 to 0.25. Shreds showed the lowest aw (0.22), while cubes exhibited the highest value (0.25). The consistently low water activity indicates good microbial stability and extended shelf life of the cheese powder during storage. The water activity (aw) of Cheddar cheese powder remained low and stable during the 60-day ripening period, ranging from 0.22 to 0.24. Shreds exhibited the lowest aw (0.22), followed by slices (0.22) and cubes (0.24), with no notable changes during storage. These low values indicate good microbial and storage stability of the powder.

The higher fat and ash contents in EMC compared with Cheddar and Mozzarella indicate that cheese type was the dominant factor affecting the gross composition of freeze-dried cheese powders. This variation may be attributed to differences in cheese matrix, processing conditions, and compositional characteristics among cheese types, as previously reported for cheese and cheese-powder systems (Karaziack et al. 2024) Cheddar powder contained the highest protein content among the three cheese powders, while EMC showed the highest fat and ash values. The high total solids content suggests substantial water removal during freeze-drying; however, residual moisture and water activity should be reported before concluding powder stability (Liu et al. 2022). Freeze-drying is considered suitable for producing high-quality dried dairy ingredients because it removes moisture under low-temperature conditions and helps preserve nutritional and sensory quality (Liu et al. 2024). These low aw values indicate limited availability of free water, which is generally associated with reduced microbial growth and improved physical stability during storage. However, water activity alone does not provide evidence of oxidative stability, as lipid oxidation is

influenced by additional factors such as oxygen availability, fatty acid composition, light exposure, packaging conditions, and storage temperature (Ali et al. 2023).

Sample morphology also influenced the physicochemical characteristics because shreds, slices, and cubes differed in surface area-to-volume ratio. Shreds have a greater exposed surface area, which can facilitate moisture removal, while cubes have less surface exposure and may retain components more effectively during drying. The role of surface area in heat and mass transfer during drying has been reported previously, and this can explain differences among shreds, slices, and cubes (Árpád et al. 2024). Thus, although freeze-drying produced high-total-solid powders in all cheese types, the interaction between cheese type, morphology, and storage/ripening period contributed to differences in chemical composition and storage behavior.

3.2. Volatile flavor compounds of freeze-dried cheese powder flavors

The volatile flavor compounds of Cheddar, Mozzarella, and EMC powder flavors are presented in Tables 4-6. The concentrations of volatile flavor compounds are expressed as mg/kg. Cheese type, surface area-to-volume ratio, and ripening/storage duration significantly influenced the composition of volatile compounds, including fatty acids, lactones, ketones, aldehydes, diols, alcohols, esters, terpenes, and furans ($P < 0.05$). These changes are consistent with the complex biochemical pathways involved in cheese flavor development, including lipolysis, proteolysis, lactose metabolism, amino acid catabolism, and secondary microbial or enzymatic reactions during ripening and storage (Curioni and Bosset. 2002; Fox et al. 2017).

3.2.1. Volatile fatty acids

Acetic acid, butanoic acid, and heptanoic acid were the main volatile fatty acids detected in the cheese powder flavors. Volatile fatty acid concentrations differed significantly among cheese types, sample morphologies, and ripening/storage periods ($P < 0.05$). Their concentrations increased during ripening/storage in all cheese types. In Cheddar cube powder, acetic acid increased from 10.17 ± 0.04 at day 0 to 357.00 ± 10.00 at 60 days. Butanoic acid increased from 10.90 ± 0.44 to 110.00 ± 3.00, while heptanoic acid increased from 5.89 ± 0.18 to 10.18 ± 0.02 during the same period. Mozzarella showed lower values, with cube powder acetic acid increasing from 9.97 ± 0.04 to 340.00 ± 10.00, butanoic acid from 11.80 ± 0.44 to 100.00 ± 3.00, and heptanoic acid from 4.18 ± 0.18 to 8.18 ± 0.02 by 60 days. EMC cube powder showed acetic acid, butanoic acid, and heptanoic acid increasing from 11.17 ±

0.04, 12.80 ± 0.44, and 6.18 ± 0.18 at day 0 to 355.00 ± 10.00, 110.00 ± 3.00, and 9.18 ± 0.02 at 60 days, respectively.

The increase in volatile fatty acids reflects progressive lipolysis and microbial or enzymatic conversion of milk fat components during ripening/storage. Acetic acid formation in cheese has been associated with lactic acid bacterial metabolism, amino acid catabolism, and lipolytic reactions (Rehman et al. 2000; Carbonell et al 2002). Butanoic and heptanoic acids are important cheese-flavor compounds because they contribute sharp, rancid, fatty, and cheese-like notes. Their increase in Cheddar during prolonged ripening supports the development of a stronger aged-cheese flavor. In contrast, Mozzarella maintained a milder profile because of shorter storage and lower ripening intensity. The higher values in cube samples compared with slices and shreds suggest greater volatile retention in samples with less surface-area exposure. During freeze-drying, greater exposed surface area can promote volatile loss, whereas a lower surface area-to-volume ratio may improve retention of aroma compounds (Nwankwo et al. 2023). Among the volatile fatty acids, acetic acid showed the greatest increase during storage. Its formation is associated with multiple metabolic pathways, including lactose and citrate metabolism as well as amino acid catabolism by starter and non-starter microorganisms. Butanoic acid is mainly produced through lipolytic degradation of milk fat and is recognized as an important contributor to the typical buttery and aged cheese aroma. Heptanoic acid, although detected at lower relative abundance, also increased during ripening, reflecting the progressive release of medium-chain fatty acids from milk lipids.

3.2.2. Lactones and ketones

The main lactones identified were γ-butyrolactone and δ-dodecalactone. Lactone concentrations were significantly affected by cheese type, surface area-to-volume ratio, and storage duration ($P < 0.05$). These compounds increased during storage/ripening and contributed sweet, caramel, fruity, and creamy flavor notes. In Cheddar cube powder, γ-butyrolactone increased from 0.30 ± 0.43 at day 0 to 1.70 ± 0.70 at 60 days, while δ-dodecalactone increased from 0.19 ± 0.00 to 16.12 ± 0.23. Mozzarella cube powder showed γ-butyrolactone increasing from 0.20 ± 0.23 to 1.00 ± 0.70 and δ-dodecalactone from 0.14 ± 0.00 to 14.12 ± 0.23 by 60 days. EMC cube powder showed γ-butyrolactone increasing from 0.29 ± 0.03 to 1.79 ± 0.60 and δ-dodecalactone from 0.22 ± 0.00 to 16.52 ± 0.13 over the same storage period.

Lactone formation is generally associated with lipid degradation and transformation of hydroxy fatty acids. Their increase in the present study indicates the contribution of milk fat degradation and enzymatic activity to the development of sweet and creamy aroma notes in cheese powder flavors (Curioni and Bosset. 2002; Fox et al. 2017). The higher lactone concentrations in EMC and Cheddar compared with Mozzarella may be related to greater enzymatic activity and lipid transformation.

Ketones also increased during storage/ripening. Ketone concentrations were significantly influenced by cheese type, surface area-to-volume ratio, and ripening/storage duration ($P < 0.05$). In Cheddar cube powder, acetophenone increased from 0.15 ± 0.01 at day 0 to 20.12 ± 0.53 at 60 days. Acetoin increased from 0.36 ± 0.12 to 17.86 ± 0.01 during the same period. In Mozzarella cubes, acetophenone increased from 0.13 ± 0.01 to 19.12 ± 0.43 and acetoin from 0.34 ± 0.12 to 16.86 ± 0.15 by 60 days. In EMC cubes, acetophenone increased from 0.17 ± 0.00 to 20.12 ± 0.43 and acetoin from 0.38 ± 0.12 to 16.00 ± 0.15.

The increase in ketones is important because acetoin contributes buttery and creamy notes, acetophenone contributes floral and almond-like notes, and methional contributes a cooked-potato-like aroma. Acetophenone and acetoin may arise from lipid and microbial metabolic pathways, whereas methional is more appropriately linked to methionine catabolism/Strecker-type reactions during cheese ripening (Lu et al. 2018; Wang et al. 2021). The lower accumulation in Cheddar after 60 days indicates more advanced ripening-related flavor development, whereas EMC developed stronger ketone levels within a shorter period because enzyme modification accelerates biochemical reactions. Mozzarella showed comparatively lower ketone formation, which is consistent with its milder cheese flavor. Differences among Cheddar, Mozzarella, and enzyme-modified cheese (EMC) powders are likely attributable to variations in cheese composition, microbial populations, residual enzyme activity, and ripening characteristics. The relatively greater formation of ketones in EMC is consistent with accelerated biochemical reactions promoted by enzymatic modification, which enhances the availability of precursors for volatile compound formation. In addition, differences among sample morphologies (cubes, slices, and shreds) may be related to variations in surface area-to-volume ratio, influencing oxygen exposure, moisture distribution, and enzyme accessibility, thereby affecting the rate of ketone formation during storage.

3.2.3. Aldehydes, alcohols, and diols

Benzaldehyde and octanal were the principal aldehydes reported in the cheese powder flavors. Aldehyde concentrations changed significantly with cheese type, surface area-to-volume ratio, and ripening/storage time ($P < 0.05$). In Cheddar cube powder, benzaldehyde increased from 0.76 ± 0.15 at day 0 to 0.98 ± 0.02 by 60 days, while octanal increased from 0.04 ± 0.00 to 3.87 ± 0.52. Mozzarella cube powder showed benzaldehyde increasing from 0.72 ± 0.15 to 0.81 ± 0.05 and octanal increasing from 0.03 ± 0.00 to 2.68 ± 0.68 by 60 days. In EMC cube powder, benzaldehyde increased from 0.76 ± 0.15 at day 0 to 0.93 ± 0.09 at 30 days and then stabilized, while octanal increased from 0.04 ± 0.00 to 3.92 ± 0.68 by 60 days.

Aldehydes are important aroma compounds but can also indicate lipid oxidation when present at high concentrations. Octanal is associated with fatty, soapy, and citrus-like notes. The increase in aldehydes during storage suggests progressive lipid oxidation and flavor development (Santamarina-García et al 2023; Shahidi and Hossain. 2022). However, aldehydes may also be converted into alcohols or acids during cheese ripening, which can reduce the development of undesirable off-flavors (Murtaza et al 2014). The higher aldehyde content in Cheddar is consistent with its longer ripening period and greater exposure to oxidation reactions.

The concentration of 2,3-butanediol also varied significantly among cheese types, sample morphologies, and storage/ripening periods ($P < 0.05$). In Cheddar cubes, 2,3-butanediol increased from 1.70 at day 0 to 3.60 by 60 days. In Mozzarella cubes, it increased from 1.50 to 2.60 by 60 days, whereas the concentration in EMC cubes increased from 1.80 to 3.41 during the same period. Diols can arise from microbial metabolism and transformation of fatty acids and alcohols, contributing minor fruity notes to cheese flavor (Melkonian et al 2023).

Alcohols, including 1-nonanol and 1-hexanol, also increased during storage/ripening. In Cheddar cubes, 1-nonanol increased from 0.98 ± 0.75 to 2.42 ± 0.11, while 1-hexanol increased from 0.22 ± 0.43 to 5.67 ± 1.18 by 60 days. Alcohols can be generated through lactose metabolism, amino acid metabolism, methyl ketone reduction, and degradation of unsaturated fatty acids. Their role in cheese flavor is also related to ester formation because alcohols can react with fatty acids to form esters during ripening (Fernández-García et al. 2004).

3.2.4. Esters, terpenes, and furans

Esters, terpenes, and furans varied significantly with cheese type, surface area-to-volume ratio, and storage/ripening duration ($P < 0.05$). Esters increased markedly during

storage/ripening and contributed fruity, sweet, pear-like, and apple-like notes. In Cheddar cube powder, pentyl butanoate increased from 0.11 ± 0.00 at day 0 to 20.30 ± 4.80 by 60 days and continued to develop during longer ripening. 1-Methylbutylbutanoate increased from 2.13 ± 0.89 to 8.90 ± 2.79, while ethyl octanoate increased from 1.99 ± 0.75 to 4.12 ± 0.11 by 60 days. In Mozzarella cubes, pentyl butanoate increased to 19.30 ± 2.40, 1-methylbutylbutanoate to 7.90 ± 1.65, and ethyl octanoate to 3.12 ± 0.11 by 60 days. EMC cubes showed pentyl butanoate increasing to 18.30 ± 2.40, 1-methylbutylbutanoate to 8.60 ± 1.65, and ethyl octanoate to 4.00 ± 0.11 by 60 days.

The increase in esters indicates esterification between alcohols and fatty acids during storage/ripening. Esters are important contributors to fruity and sweet notes in cheese and often increase as ripening progresses (Zhang et al. 2023). The stronger ester development in Cheddar reflects the longer ripening period, whereas EMC showed rapid ester formation due to enzymatic modification. Mozzarella had lower ester concentrations, supporting its milder flavor profile.

Limonene concentration was significantly affected by cheese type, surface area-to-volume ratio, and storage duration ($P < 0.05$). Limonene was the main terpene detected and contributed lemon and orange notes. In Cheddar cubes, limonene increased from 0.51 at day 0 to 21.30 by 60 days. Mozzarella cubes reached 16.30 by 60 days, while EMC cubes reached 19.60 by 60 days. Terpenes in cheese are commonly associated with milk origin and animal diet, and they contribute to the aroma profile of dairy products (Fox et al. 2017). Cube samples generally retained higher limonene levels than slices and shreds, supporting the role of reduced surface area in volatile retention.

Limonene concentration was significantly affected by cheese type, surface area-to-volume ratio (morphology), and storage duration ($P < 0.05$). Limonene was the predominant terpene detected and contributed citrus-like (lemon and orange) notes to the aroma profile. However, as terpenes are primarily associated with milk origin and animal feed, their presence reflects initial compositional input rather than de novo formation during ripening (Fox et al. 2017). The observed changes in limonene concentration during storage are therefore interpreted as matrix and process-related effects rather than biosynthesis. These differences reflect cheese-specific structural and compositional characteristics; the firmer protein matrix and longer ripening period of Cheddar cheese enhanced the retention and concentration of hydrophobic volatiles such as limonene. Morphology also played a key role, as cube samples generally retained higher limonene levels than slices and shreds. This is attributed to the lower surface area-to-volume ratio in cubes, which reduces volatilization losses and oxygen exposure,

thereby improving volatile retention during storage. In contrast, increased surface exposure in shredded and sliced forms likely enhanced the diffusion and loss of terpenes.

Furan compounds, particularly furfural and Hom furaneol, also changed significantly with cheese type, storage period, and surface area-to-volume ratio ($P < 0.05$). In Cheddar cube powder, furfural increased from 0.34 at day 0 to 0.44 by 60 days, while Hom furaneol increased from 2.02 to 6.30. Mozzarella and EMC showed lower furan concentrations over 60 days. Furans contribute bread-like, almond-like, burned sugar, and caramel-like notes and may form during processing and storage. Their increase indicates gradual flavor complexity during storage, especially in Cheddar powder.

Overall, the volatile profile showed that Cheddar developed the most intense flavor during extended ripening, EMC produced a strong flavor profile in a shorter time due to enzyme modification, and Mozzarella retained a milder flavor profile. The cube morphology generally improved volatile retention, whereas shreds had greater exposure and lower retention of some volatile compounds.

3.3. Free fatty acid content

The free fatty acid (FFA) content of freeze-dried cheese powder flavors is presented in Table 7. FFA values are expressed as percentages. FFA content was significantly influenced by cheese type, surface area-to-volume ratio, and storage/ripening period ($P < 0.05$). In general, shreds showed higher FFA values than slices and cubes, indicating that greater exposed surface area promoted lipid hydrolysis. This may be because the greater surface area increased contact between fat globules, oxygen, and lipolytic enzymes, increasing fat breakdown (Fox et al. 2017). Lipolysis and FFA release are central to cheese flavor development, but excessive FFA accumulation may increase the risk of rancid or undesirable flavors (Zhang et al. 2023; Collins et al. 2003).

Mozzarella powder showed the lowest FFA accumulation. At day 0, FFA values were 0.12% in shreds, 0.11% in slices, and 0.11% in cubes. By 60 days, these values increased only slightly to 0.15%, 0.14%, and 0.13%, respectively. This limited increase indicates higher lipid stability in Mozzarella powder during storage. The mild increase may be related to the fresh-cheese characteristics of Mozzarella and lower lipolytic activity compared with aged Cheddar and EMC. Mozzarella processing can also reduce native enzyme activity, which may limit FFA formation during storage (Alinovi et al. 2021).

Cheddar powder showed a more pronounced increase in FFA content during ripening. Initial FFA values were 0.13% in shreds, 0.12% in slices, and 0.12% in cubes at day 0. By 60

days, FFA values increased to 0.15%, 0.13%, and 0.12%, respectively. This increase reflects ongoing lipolysis during ripening and storage. Controlled lipolysis is desirable in Cheddar because it contributes to sharp, savory, and mature cheese flavor. Similar development of lipolysis during cheese ripening has been reported in aged cheese systems (Bihola et al. 2025).

EMC cheese powder exhibited the highest free fatty acid (FFA) content among the three cheese types throughout storage (Table 7). At day 0, the FFA values of EMC powder were 0.28%, 0.27%, and 0.26% for shreds, slices, and cubes, respectively, increasing to 0.46%, 0.45%, and 0.44% after 60 days of storage. The higher FFA content of EMC powder is attributed to enzyme modification, which promotes lipolysis and accelerates the release of free fatty acids. EMC is widely used to produce intense cheese flavor in processed cheese products and snack applications (Bihola et al. 2025; Farkye. 2004). However, the elevated FFA levels also indicate a greater susceptibility to oxidative deterioration during storage, highlighting the importance of appropriate packaging and antioxidant strategies to maintain product quality.

Among the cheese types, Cheddar powder showed intermediate FFA values, increasing from 0.13%, 0.12%, and 0.12% at day 0 to 0.16%, 0.15%, and 0.14% after 60 days for shreds, slices, and cubes, respectively. Mozzarella powder exhibited the lowest FFA values, increasing from 0.12%, 0.11%, and 0.11% to 0.15%, 0.14%, and 0.13% over the same storage period.

Sample morphology also significantly influenced FFA formation. Shredded cheese powder consistently exhibited higher FFA values than slices and cubes, whereas cubes showed the lowest values throughout storage. This trend is attributed to differences in surface area-to-volume ratio. Shreds provide a greater exposed surface area, facilitating enzyme–substrate interactions and enhancing moisture and oxygen transfer, thereby promoting lipolysis during storage. In contrast, cubes have the lowest surface area-to-volume ratio, limiting enzyme accessibility and slowing the release of free fatty acids. Slices exhibited intermediate behavior, consistent with their geometric characteristics.

3.4. Fatty acid profile

The fatty acid profiles of Cheddar, Mozzarella, and EMC powder flavors are presented in Tables 8-10. Fatty acid values are expressed as a percentage of total fatty acids. Fatty acid composition was significantly influenced by cheese type, sample morphology, and storage/ripening duration ($P < 0.05$). The main fatty acids reported were C4:0, C6:0, C12:0,

C14:0, C18:0, C18:1, and C18:2. Fatty acid composition is important because it influences both nutritional quality and flavor characteristics of cheese powders (Cobos et al. 2024).

In Cheddar cheese powder, C16:0 (29.36–30.96%) and C18:1 (19.91–20.98%) were the dominant fatty acids, followed by C18:0 (10.72–10.88%) and C14:0 (10.01–11.21%). Short-chain fatty acids such as C4:0, C6:0, and C8:0 (3.60% - 3.63%), (2.36% - 2.41%) and (1.18% -1.25%) were present in lower proportions but contributed significantly to flavor intensity. A gradual increase in several fatty acids (particularly C10:0, C12:0, and C16:0) during storage was observed, which may be attributed to lipolytic activity and concentration effects due to moisture loss and matrix changes. The increase in unsaturated fatty acids such as C18:2 also suggests possible release from complex lipid structures during storage (Hayaloglu et al. 2004)

Medium-chain fatty acids, including lauric acid (C12:0) and myristic acid (C14:0), exhibited only minor changes during storage across all cheese powder types. Lauric acid (C12:0) showed a slight increase in Cheddar, Mozzarella, and enzyme-modified cheese (EMC) powders regardless of sample morphology. Similarly, myristic acid (C14:0) remained relatively stable, with only small variations observed among storage periods and sample geometries. These limited changes indicate that the relative composition of medium-chain fatty acids was largely maintained during storage. Because the fatty acid data are expressed as relative percentages, these small variations should not be interpreted as direct evidence of lipolysis or fatty acid release. Instead, the extent of lipolysis is more appropriately assessed using the free fatty acid (FFA) results presented in Table (8-10). Mozzarella cheese powder showed a comparatively lower level of short-chain fatty acids (C4:0–C10:0) than Cheddar, indicating its relatively milder lipolytic activity and fresh-cheese characteristics. The dominant fatty acids were also C16:0 (~28–30%) and C18:1 (~21–24%), but overall SFA levels were slightly lower than Cheddar. The relatively higher proportion of unsaturated fatty acids in Mozzarella may be due to its less ripened structure and lower enzymatic breakdown of lipids, preserving the native milk fat composition (Collins et al. 2003).

The fatty acid results show that Cheddar developed more noticeable changes in fatty acid composition because of its longer ripening period, while Mozzarella remained comparatively stable during shorter storage. EMC cheese powder showed a fatty acid profile similar to Cheddar but with slightly higher variability and enhanced release of free fatty acids, particularly short-chain and medium-chain fatty acids. This is expected because of enzymatic modification during EMC preparation, which accelerates lipolysis and enhances flavor compound formation. The increase in fatty acids such as C10:0, C12:0, and C14:0 in EMC

indicates strong enzymatic hydrolysis of triglycerides, leading to higher flavor intensity compared to natural cheeses (Zhang et al. 2024)

3.5. Peroxide value and oxidative stability

The peroxide value (PV) of cheese powder flavors is presented in Table 11. PV values are expressed as meq O_2/kg. PV was significantly affected by cheese type, surface area-to-volume ratio, and storage/ripening duration ($P < 0.05$). Lipid oxidation is a major quality concern in dairy powders because it can reduce nutritional quality and generate off-flavors associated with rancidity (Clarke et al. 2022).

Cheddar cheese powder showed the greatest increase in PV during ripening. The PV increased from approximately 0.24 meq O_2/kg at day 0 to 0.46 meq O_2/kg by 60 days. This indicates that primary lipid oxidation increased in Cheddar powder during the 60-day period; it should not be directly compared with 60-day Mozzarella or EMC without a common-time-point analysis. The increase after prolonged storage may be related to longer oxygen exposure, fat composition, and ongoing lipid degradation. Lipid oxidation can accelerate during storage due to oxygen, temperature, light, fatty acid composition, and pro-oxidant interactions [55,56].

Mozzarella powder showed greater oxidative stability over 60 days. PV increased only slightly from approximately 0.24 meq O_2/kg at day 0 to 0.38 meq O_2/kg by 60 days. This small increase suggests that Mozzarella powder was less prone to oxidation during the reported storage period. Previous work has shown that lipid stability in dairy products depends on cheese composition, moisture, fat structure, and storage conditions (Chemat et al. 2023; Shahidi and Zhong. 2010). In Mozzarella and Cheddar powders, peroxide values were consistently highest in shreds, followed by slices and cubes, which can be attributed to the greater surface area of shredded cheese, resulting in increased oxygen exposure and faster oxidation. In EMC powder, peroxide values were considerably higher than in Mozzarella and Cheddar due to the greater availability of free lipids produced during enzyme modification. Although shreds showed slightly higher values than slices and cubes at the beginning of storage, the differences became minimal after 60 days. Overall, storage time was the primary factor affecting peroxide value, while cube-derived powders exhibited slightly better oxidative stability than shredded powders. The overall changes in FFA, PV, TOTOX, and TBARS during storage are presented in Figure 1. The results showed a clear increase in TOTOX values for all cheese flavoring powders in Table 12 during storage, indicating progressive lipid oxidation over time. Among all treatments, EMC cheese powder consistently exhibited the highest TOTOX values throughout storage (5.1–7.5), reflecting its

greater susceptibility to oxidation, likely due to higher levels of free fatty acids and enzyme-modified lipid fractions. Cheddar cheese powder showed moderate TOTOX values (2.1–5.0), with a steady increase during storage, suggesting gradual oxidation of lipids under storage conditions (Abeyrathne et al. 2021). In contrast, Mozzarella cheese powder exhibited the lowest TOTOX values (2.4–4.4), indicating comparatively better oxidative stability. Overall, TOTOX values increased significantly ($p < 0.05$) with storage time in all samples, with the most pronounced changes observed at 60 days.

EMC cheese powder exhibited the highest peroxide value (PV) among the three cheese types throughout storage (Table 11). The PV increased from approximately 1.25 meq O_2/kg at day 0 to 2.00 meq O_2/kg after 60 days of storage, whereas Cheddar and Mozzarella powders showed lower PV values over the same storage period. The higher PV observed in EMC powder is consistent with its greater free fatty acid content, which increases the availability of lipid substrates for oxidation. These findings indicate that enzyme-modified cheese powders are more susceptible to primary lipid oxidation and therefore require appropriate packaging and storage conditions to minimize oxidative deterioration (Rinaldi et al. 2026; Deeth 2020)

TBARS values also increased gradually in all cheese flavoring powders during storage, indicating the formation of secondary lipid oxidation products, primarily malondialdehyde (MDA). Mozzarella cheese powder exhibited the lowest TBARS values throughout storage, followed by Cheddar, while EMC cheese powder consistently showed the highest TBARS values. The elevated TBARS values in EMC powder are likely associated with its higher degree of lipolysis and greater availability of free fatty acids for subsequent oxidation. Powder morphology also influenced oxidative stability; particles with a denser and smoother structure reduced oxygen diffusion and protected encapsulated lipids, whereas particles with a greater exposed surface area facilitated oxygen penetration and resulted in slightly higher oxidation. Overall, both cheese type and storage duration contributed to lipid oxidation, with cheese composition exerting the greater influence on oxidative stability.

Overall, the results demonstrate that cheese type, sample morphology, and storage duration significantly influenced lipid hydrolysis and oxidative stability of freeze-dried cheese powder flavors. EMC cheese powder exhibited greater lipid hydrolysis and oxidation than Cheddar and Mozzarella powders, whereas Mozzarella showed the highest oxidative stability throughout storage. In addition, sample morphology affected lipid stability, with shreds generally exhibiting greater oxidative changes than slices and cubes because of their larger surface area-to-volume ratio. The combined free fatty acid (FFA), peroxide value (PV), p-anisidine value, TOTOX value, and TBARS results provide a comprehensive assessment of

lipid deterioration during storage. Therefore, cheese type, sample morphology, and storage duration are key factors governing the physicochemical properties, flavor profile, fatty acid composition, and oxidative stability of freeze-dried cheese powder flavors.

4. Conclusion

This study demonstrated that cheese type, sample morphology, and storage/ripening duration significantly affected the physicochemical properties, volatile flavor composition, fatty acid profile, and oxidative stability of freeze-dried cheese powder flavors. Cheddar cheese powder developed a more intense and complex flavor profile during ripening. This was mainly due to the accumulation of volatile fatty acids, ketones, lactones, esters, alcohols, and aldehydes that are associated with flavor development and lipid oxidation. Enzyme-modified cheese powder showed rapid flavor formation in a relatively short storage period, primarily due to enzyme-supported lipolysis and enhanced free fatty acid production. However, the higher FFA content in EMC also indicated a higher risk of oxidative deterioration during storage. In contrast, volatile compound formation in Mozzarella cheese powder was relatively low, whereas lipid stability was relatively high, consistent with its mild flavor characteristics. Among the tested morphologies, cube-shaped samples generally showed better retention of volatile aroma compounds than the other tested morphologies, probably because of their lower surface area-to-volume ratio and lower exposure to volatilization and oxidation processes. However, shredded samples resulted in higher moisture removal and lipid hydrolysis, likely due to the greater exposed surface area. The results indicated that freeze-drying is a suitable method for preparing stable cheese powder flavors, but the cheese type, sample morphology, and storage conditions must be optimized to balance flavor intensity, oxidative stability, and the shelf-life performance of the cheese powder. Future studies should include sensory evaluation, odor activity value analysis, packaging optimization, and extended storage trials to validate the industrial applicability of freeze-dried cheese powder flavors.

References

Abeyrathne EDNS, Nam K, Ahn DU (2021) Analytical Methods for Lipid Oxidation and Antioxidant Capacity in Food Systems. Antioxidants 10: 1587. doi:10.3390/antiox10101587.

Ali AH, Khalifa SA, Gan RY, Shah N, Ayyash M (2023) Fatty Acids, Lipid Quality Parameters, and Amino Acid Profiles of Unripened and Ripened Cheeses Produced

607 from Different Milk Sources. J Food Compos Analysis. 123:105588. doi:
608 10.1016/j.jfca.2023.105588.
609 Alinovi M, Mucchetti G, Wiking L, Corredig M (2021) Freezing as a Solution to Preserve the
610 Quality of Dairy Products: The Case of Milk, Curds and Cheese. Crit. Rev. Food Sci.
611 Nutr. 61: 3340–3360. doi:10.1080/10408398.2020.1798348.
612 Amer DA, Albadri AAM, El-Hamshary HA, Nehela Y, El-Hawary MY, Makhlouf AH, Awad
613 SA (2023) Impact of Salting Techniques on the Physio-Chemical Characteristics,
614 Sensory Properties, and Volatile Organic Compounds of Ras Cheese. Foods. 12: 1855.
615 doi:10.3390/foods12091855.
616 Bihola A, Sharma H, Chaudhary MB, Bumbadiya MR, Kumar D, Adil S (2025) Recent
617 Developments in Cheese Technologies. Food Rev Intl 41: 978–1012.
618 doi:10.1080/87559129.2024.2426024.
619 Carbonell M, Nuñez M, Fernández-García E (2002) Evolution of the Volatile Components of
620 Ewe Raw Milk La Serena Cheese during Ripening. Correlation with Flavour
621 Characteristics. Lait 82:683–698. doi:10.1051/lait:2002042.
622 Chemat A, Song M, Li Y, Fabiano-Tixier AS (2023) Shade of Innovative Food Processing
623 Techniques: Potential Inducing Factors of Lipid Oxidation. Molecules. 28: 8138.
624 doi:10.3390/molecules28248138.
625 Clarke HJ, McCarthy WP, O'Sullivan MG, Kerry JP, Kilcawley KN (2021) Oxidative Quality
626 of Dairy Powders: Influencing Factors and Analysis. Foods 10: 2315.
627 doi:10.3390/foods10102315.
628 Clarke HJ, O'Sullivan MG, Kerry JP, Kilcawley KN (2020) Correlating Volatile Lipid
629 Oxidation Compounds with Consumer Sensory Data in Dairy Based Powders during
630 Storage. Antioxidants. 9:338. doi:10.3390/antiox9040338.

631 Cobos A, De Oliveira Filho EF, Miranda M, Ferreiro T, López-Alonso M, Díaz O, Herrero-
632 Latorre C Chemometric Characterization of the Fatty Acid and Trace Element Profiles
633 of Organic and Conventional Galician Cheeses. Applied Food Research 2024, 4,
634 100475, doi:10.1016/j.afres.2024.100475.
635 Collins YF, McSweeney PLH, Wilkinson, M.G. Lipolysis and Free Fatty Acid Catabolism in
636 Cheese: A Review of Current Knowledge. International Dairy Journal 2003, 13, 841–
637 866, doi:10.1016/S0958-6946(03)00109-2.
638 Curioni PMG, Bosset JO (2002) Key Odorants in Various Cheese Types as Determined by
639 Gas Chromatography-Olfactometry. Int Dairy J 12:959–984. doi:10.1016/S0958-
640 6946(02)00124-3.
641 Deeth HC (2020) Stability and Spoilage of Lipids in Milk and Dairy Products. In: Advanced
642 Dairy Chemistry, Volume 2; pp. 345–373. ISBN 978-3-030-48685-3.
643 Deshwal GK, Akshit FNU, Altay I, Huppertz T (2024) A Review on the Production and
644 Characteristics of Cheese Powders. Foods 13:2204. doi:10.3390/foods13142204.
645 Farkye NY (2004) Cheese Technology. Int J Dairy Technol 57:91–98. doi:10.1111/j.1471-
646 0307.2004.00146.x.
647 Fernández-García E, Gaya P, Medina M, Nuñez M (2004) Evolution of the Volatile
648 Components of Raw Ewes' Milk Castellano Cheese: Seasonal Variation. Int Dairy J
649 14:39–46. doi:10.1016/S0958-6946(03)00148-1.
650 Fox PF, Guinee TP, Cogan TM, McSweeney PLH (2017) Fundamentals of Cheese Science.
651 2nd ed. Springer US, New York, NY. ISBN 978-1-4899-7681-9.
652 Hayaloglu AA, Guven M, Fox PF, Hannon JA, McSweeney PLH (2004) Proteolysis in
653 Turkish White-Brined Cheese Made with Defined Strains of Lactococcus. Int Dairy J
654 14:599–610. doi: 10.1016/j.idairyj.2003.12.008.

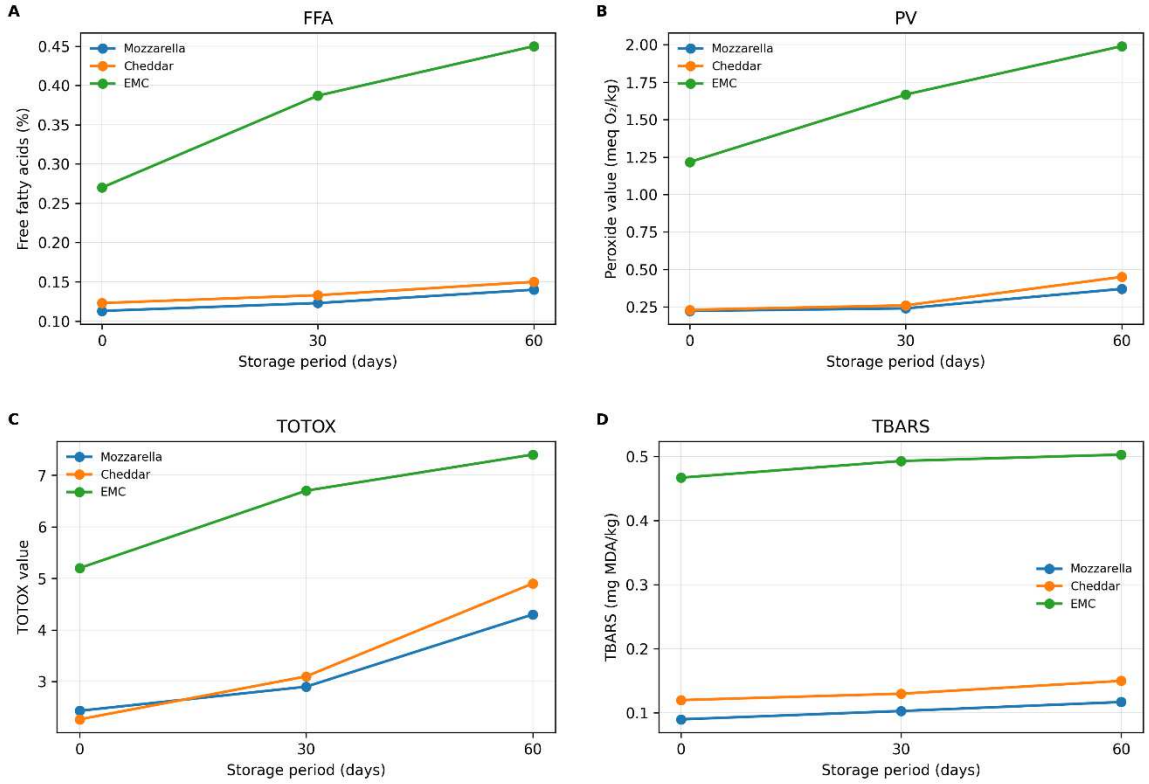
655 Kaminarides S, Stamou P, Massouras T (2007) Changes of Organic Acids, Volatile Aroma
656 Compounds and Sensory Characteristics of Halloumi Cheese Kept in Brine. Food
657 Chemistry 100:219–225. doi: 10.1016/j.foodchem.2005.09.039.
658 Karaziack CB, Vidal C, Pasquini C, Barbin DF, Viotto WH (2024) Application of Near-
659 Infrared Hyperspectral Imaging for Determination of Cheese Chemical Composition.
660 J Food Compos Anal 127:105994. doi: 10.1016/j.jfca.2024.105994.
661 Kendirci P, Salum P, Bas D, Erbay Z (2020) Production of Enzyme-Modified Cheese (EMC)
662 with Ripened White Cheese Flavour: II- Effects of Lipases. Food Bioprod Process
663 122:230–244. doi: 10.1016/j.fbp.2020.05.010.
664 Liu T, Wu J, Aziz T, Xue R, Khowdiary MM, Yang Z (2024) Changes of Physicochemical
665 and Functional Properties of Processed Cheese Made with Natural Cheddar and
666 Mozzarella Cheeses during Refrigerated Storage. Sci Rep 14:3714.
667 doi:10.1038/s41598-024-53748-z.
668 Liu Y, Zhang Z, Hu L (2022) High Efficient Freeze-Drying Technology in Food Industry. Crit
669 Rev Food Sci Nutr 62:3370–3388. doi:10.1080/10408398.2020.1865261.
670 Lu Y, Nawrath M, Sun J, Liu S-Q (2018) Effects of Physicochemical Parameters on Volatile
671 Sulphur Compound Formation from L-Methionine Catabolism by Non-Growing Cells
672 of Kluyveromyces Lactis. AMB Express 8:109. doi:10.1186/s13568-018-0639-7.
673 López-Díaz TM, Alegría Á, Rodríguez-Calleja JM, Combarros-Fuertes P, Fresno JM, Santos
674 JA, Flórez AB, Mayo B (2023) Blue Cheeses: Microbiology and Its Role in the
675 Sensory Characteristics. Dairy 4:410–422. doi:10.3390/dairy4030027.
676 Melkonian C, Zorrilla F, Kjærbølling I, Blasche S, Machado D, Junge M, Sørensen KI,
677 Andersen LT, Patil KR, Zeidan AA (2023) Microbial Interactions Shape Cheese
678 Flavour Formation. Nat Commun 14:8348. doi:10.1038/s41467-023-41059-2.

679 Murtaza MA, Ur-Rehman S, Anjum FM, Huma N, Hafiz I (2014) Cheddar Cheese Ripening
680 and Flavor Characterization: A Review. Crit Rev Food Sci Nutr 54:1309–1321.
681 doi:10.1080/10408398.2011.634531.
682 Nazish HA, Gulzar N, Nadeem M, Rafiq S, Sameen A, Ajmal M, Murtaza S, Saleem IM
683 (2022) Efficacy of Withania Coagulans Fruit Extract as a Coagulant for Mozzarella
684 Cheese at Different Coagulation Temperatures from Curd Formation to Pizza Top. J
685 Food Process Preserv 46:e17167. doi:10.1111/jfpp.17167.
686 Nwankwo CS, Okpomor EO, Dibagar N, Wodecki M, Zwierz W, Figiel A (2023) Recent
687 Developments in the Hybridization of the Freeze-Drying Technique in Food
688 Dehydration: A Review on Chemical and Sensory Qualities. Foods 12:3437.
689 doi:10.3390/foods12183437.
690 Paszczyk B, Polak-Śliwińska M, Zielak-Steciwko AE (2022) Chemical Composition, Fatty
691 Acid Profile, and Lipid Quality Indices in Commercial Ripening of Cow Cheeses
692 from Different Seasons. Animals 12:198. doi:10.3390/ani12020198.
693 Ponnampalam E, Priyashantha H, Vidanarachchi J, Kiani A, Holman B (2024) Effects of
694 Nutritional Factors on Fat Content, Fatty Acid Composition, and Sensorial Properties
695 of Meat and Milk from Domesticated Ruminants: An Overview. Animals 14:840.
696 doi:10.3390/ani14060840.
697 Pronschinske JM, Govindasamy-Lucey S, Jaeggi JJ, Ibáñez RA, Johnson ME, Lucey JA
698 (2026) Impact of Moisture Content and Age on the Properties of Microwaved Shelf-
699 Stable Puffed Snacks Made from Cheddar Cheese. J Dairy Sci 109:4744–4760.
700 doi:10.3168/jds.2025-27726.
701 Rehman S-U, Banks JM, Brechany EY, Muir DD, McSweeney PLH, Fox PF (2000)
702 Influence of Ripening Temperature on the Volatiles Profile and Flavour of Cheddar

703 Cheese Made from Raw or Pasteurised Milk. Int Dairy J 10:55–65.
704 doi:10.1016/S0958-6946(00)00019-4.
705 Rinaldi S, Palocci G, Di Giovanni S, Iacurto M, Tripaldi C (2021) Chemical Characteristics
706 and Oxidative Stability of Buffalo Mozzarella Cheese Produced with Fresh and
707 Frozen Curd. Molecules 26:1405. doi:10.3390/molecules26051405.
708 Ritika, Rizwana (2024) Edible Packaging: Extension of Shelf Life and Improvement of Food
709 Quality. In: Food Coatings and Preservation Technologies; pp. 167–210. ISBN 978-1-
710 394-23758-6.
711 Ritschard JS, Schuppler M (2024) The Microbial Diversity on the Surface of Smear-Ripened
712 Cheeses and Its Impact on Cheese Quality and Safety. Foods 13:214.
713 doi:10.3390/foods13020214.
714 Rosa E, Prudencio ES (2023) A Comprehensive Approach about Comparison between Drying
715 Technologies and Powdered Dairy Products. Food Res Int 173:113326.
716 doi:10.1016/j.foodres.2023.113326.
717 Santamarina-García G, Amores G, Hernández I, Morán L, Barrón LJR, Virto M (2023)
718 Relationship between the Dynamics of Volatile Aroma Compounds and Microbial
719 Succession during the Ripening of Raw Ewe Milk-Derived Idiazabal Cheese. Curr
720 Res Food Sci 6:100425. doi:10.1016/j.crfs.2022.100425.
721 Shahidi F, Hossain A (2022) Role of Lipids in Food Flavor Generation. Molecules 27:5014.
722 doi:10.3390/molecules27155014.
723 Shahidi F, Zhong Y (2010) Lipid Oxidation and Improving the Oxidative Stability. Chem Soc
724 Rev 39:4067. doi:10.1039/b922183m.
725 Sharma P, Segat A, Kelly AL, Sheehan JJ (2020) Colorants in Cheese Manufacture:
726 Production, Chemistry, Interactions, and Regulation. Compr Rev Food Sci Food Saf
727 19:1220–1242. doi:10.1111/1541-4337.12519.

728 Shinaliyeva AZh, Berdembetova AT, Shingisov AU, Makhatova AI, Kanseitova ET (2025)
729 Dairy Snacks: Innovations, Technologies and Prospects. jour 240–249.
730 doi:10.53360/2788-7995-2025-2(18)-29.
731 Sutthiwong N, Lekavat S, Dufossé L (2023) Involvement of Versatile Bacteria Belonging to
732 the Genus Arthrobacter in Milk and Dairy Products. Foods 12:1270.
733 doi:10.3390/foods12061270.
734 Sviridenko GM, Kalabushkin VV, Shishkina AN, Uskova EE (2021) Research on the
735 Possibility of Extending the Shelf Life of Cheese Raw Material and Heat-Treated
736 Cheese by Their Freezing for Further Use in HoReCa. Food Syst 3:39–44.
737 doi:10.21323/2618-9771-2020-3-4-39-44.
738 Uwineza A, Zhang X (2026) Application of Freeze-Drying Technology in the Food Industry:
739 A Review. Foods 15:790. doi:10.3390/foods15040790.
740 Varming C, Andersen LT, Petersen MA, Ardö Y (2013) Flavour Compounds and Sensory
741 Characteristics of Cheese Powders Made from Matured Cheeses. Int Dairy J 30:19–
742 28. doi:10.1016/j.idairyj.2012.11.002.
743 Wang J, Yang ZJ, Xu LY, Wang B, Zhang JH, Li BZ, Cao YP, Tan L (2021) Key Aroma
744 Compounds Identified in Cheddar Cheese with Different Ripening Times by Aroma
745 Extract Dilution Analysis, Odor Activity Value, Aroma Recombination, and Omission.
746 J Dairy Sci 104:1576–1590. doi:10.3168/jds.2020-18757.
747 Xin X, Essien S, Dell K, Woo MW, Baroutian S (2022) Effects of Spray-Drying and Freeze-
748 Drying on Bioactive and Volatile Compounds of Smoke Powder Food Flavouring.
749 Food Bioprocess Technol 15:785–794. doi:10.1007/s11947-022-02779-3.
750 Zhang Q, Wang Y, Meng F, Wang B, Wang Y (2024) Comparative Analysis of the Volatile
751 Flavor Compounds of Monascus-Fermented Cheese with Different Ripening Periods

752 by SPME-GC-MS, SPME-GC×GC-MS, and HS-GC-IMS. Food Biosci 62:105045.
753 doi:10.1016/j.fbio.2024.105045.
754 Zhang Y, Gao P, Zhang W, Zhu H, Wang C, Xie N, Wang Y, Pang X, Marie-Laure F, Lü J, et
755 al (2023) Free Fatty Acid Hydrolyzed with Lipases and Their Effects on Enzyme-
756 Modified Cheese Flavor. Food Sci Anim Prod 1:9240031.
757 doi:10.26599/FSAP.2023.9240031.
758 Zheng A-R, Wei C-K, Wang M-S, Ju N, Fan M (2024) Characterization of the Key Flavor
759 Compounds in Cream Cheese by GC-MS, GC-IMS, Sensory Analysis and
760 Multivariable Statistics. Curr Res Food Sci 8:100772. doi:
761 10.1016/j.crfs.2024.100772.
762 Zheng X, Shi X, Wang B (2021) A Review on the General Cheese Processing Technology,
763 Flavor Biochemical Pathways and the Influence of Yeasts in Cheese. Front Microbial
764 12:703284. doi:10.3389/fmicb.2021.703284.



765

766 **Figure 1.** Changes in lipid hydrolysis and oxidative stability indicators of freeze-dried cheese
767 powders during storage. (A) Free fatty acids (FFA), (B) peroxide value (PV), (C) total
768 oxidation value (TOTOX), and (D) Thio barbituric acid-reactive substances (TBARS) in
769 Mozzarella, Cheddar, and enzyme-modified cheese (EMC) powders at 0, 30, and 60 days of
770 storage. Each data point represents the mean value across the three sample morphologies:
771 shreds, slices, and cubes. FFA is expressed as %, PV as meq O_2/kg fat, and TBARS as mg
772 malondialdehyde (MDA)/kg cheese powder. TOTOX was calculated as 2 × PV + p-AV,
773 where p-AV is the p-anisidine value.

Cheddar cheese	Ripening period	Fat %	Protein %	Moisture%	Ash %	Water Activity (aw)	Total solid %
Cube	0 day	$46.16^{ef} \pm 0.31$	$38.82^{b} \pm 0.12$	$2.96^{a} \pm 0.01$	$12.99^{a} \pm 0.12$	$0.24^{ab} \pm 0.03$	$97.21^{d} \pm 0.11$
	30 days	$46.13^{ef} \pm 0.32$	$38.62^{d} \pm 0.11$	$2.94^{b} \pm 0.03$	$12.98^{a} \pm 0.13$	$0.24^{ab} \pm 0.01$	$97.22^{d} \pm 0.11$
	60 days	$46.02^{f} \pm 0.27$	$38.35^{ef} \pm 0.17$	$2.86^{c} \pm 0.03$	$12.53^{d} \pm 0.17$	$0.24^{ab} \pm 0.02$	$97.27^{d} \pm 0.09$
Shreds	0 day	$46.35^{d} \pm 0.31$	$38.40^{e} \pm 0.12$	$2.85^{a} \pm 0.02$	$12.80^{b} \pm 0.12$	$0.23^{b} \pm 0.03$	$97.25^{d} \pm 0.11$
	30 days	$46.54^{c} \pm 0.38$	$38.47^{e} \pm 0.04$	$2.75^{b} \pm 0.04$	$12.64^{c} \pm 0.02$	$0.23^{b} \pm 0.13$	$97.44^{b} \pm 0.09$
	60 days	$46.21^{e} \pm 0.27$	$38.29^{f} \pm 0.06$	$2.75^{bc} \pm 0.13$	$12.31^{e} \pm 0.05$	$0.23^{b} \pm 0.03$	$97.46^{b} \pm 0.10$
Slice	0 day	$46.45^{dc} \pm 0.21$	$38.58^{d} \pm 0.17$	$2.71^{b} \pm 0.03$	$12.70^{c} \pm 0.15$	$0.23^{a} \pm 0.02$	$97.28^{c} \pm 0.13$
	30 days	$46.29^{e} \pm 0.21$	$38.82^{b} \pm 0.09$	$2.68^{c} \pm 0.03$	$12.69^{c} \pm 0.05$	$0.22^{a} \pm 0.07$	$97.31^{dc} \pm 0.09$
	60 days	$46.95^{a} \pm 0.36$	$38.66^{d} \pm 0.05$	$2.64^{c} \pm 0.03$	$12.32^{e} \pm 0.07$	$0.22^{a} \pm 0.00$	$97.36^{c} \pm 0.08$

Table 1. Physiochemical analysis of Cheddar cheese powder (least square means ± standard error).

Shreds (0.47 × 0.67cm2: 0.47 × 0.67 × 0.85cm3), Slices (0.65 × 3 cm2: 0.65 × 3 × 4 cm3), Cubes (1×1 cm2 :1×1×1 cm3).

Treatment (Mozzarella Cheese)	Storage period	Fat %	Protein %	Moisture %	Ash %	Water Activity	Total solid %
Cube	0 days	$45.80^{a} \pm 0.30$	$36.98^{a} \pm 0.05$	$2.76^{a} \pm 0.03$	$14.41^{b} \pm 0.06$	$0.23^{ab} \pm 0.06$	$97.85^{a} \pm 0.10$
	30 days	$45.73^{b} \pm 0.26$	$36.92^{a} \pm 0.03$	$2.66^{b} \pm 0.03$	$14.39^{cd} \pm 0.03$	$0.23^{ab} \pm 0.04$	$97.78^{b} \pm 0.09$
	60 days	$45.43^{d} \pm 0.22$	$36.64^{c} \pm 0.05$	$2.56^{c} \pm 0.00$	$14.24^{d} \pm 0.09$	$0.23^{ab} \pm 0.02$	$97.84^{a} \pm 0.08$
Shreds	0 days	$45.85^{a} \pm 0.29$	$36.06^{d} \pm 0.14$	$2.75^{a} \pm 0.03$	$14.65^{a} \pm 0.06$	$0.21^{b} \pm 0.03$	$97.40^{d} \pm 0.11$
	30 days	$45.81^{a} \pm 0.28$	$36.04^{d} \pm 0.13$	$2.65^{b} \pm 0.03$	$14.61^{a} \pm 0.05$	$0.21^{b} \pm 0.13$	$97.39^{d} \pm 0.10$
	60 days	$45.62^{c} \pm 0.23$	$36.89^{ab} \pm 0.10$	$2.55^{bc} \pm 0.13$	$14.48^{b} \pm 0.05$	$0.21^{b} \pm 0.23$	$97.52^{c} \pm 0.11$
Slice	0 days	$45.80^{a} \pm 0.27$	$36.94^{a} \pm 0.06$	$2.66^{b} \pm 0.03$	$14.49^{b} \pm 0.05$	$0.22^{a} \pm 0.02$	$97.50^{c} \pm 0.08$
	30 days	$45.78^{ab} \pm 0.26$	$36.91^{a} \pm 0.05$	$2.56^{c} \pm 0.02$	$14.47^{b} \pm 0.04$	$0.22^{a} \pm 0.07$	$97.53^{c} \pm 0.09$
	60 days	$45.66^{c} \pm 0.27$	$36.81^{b} \pm 0.09$	$2.54^{c} \pm 0.02$	$14.12^{e} \pm 0.02$	$0.22^{a} \pm 0.00$	$97.88^{a} \pm 0.10$

Table 2. Physiochemical analysis of Mozzarella cheese powder (least square means ± standard error).

Shreds ($0.47 \times 0.67 cm^2$: $0.47 \times 0.67 \times 0.85 cm^3$), Slices ($0.65 \times 3\ cm^2$: $0.65 \times 3 \times 4\ cm^3$), Cubes ($1 \times 1$ cm2 :$1 \times 1 \times 1\ cm^3$).

Table 3. Physiochemical analysis of Enzymatic modified cheese powder (least square means ± standard error).

Treatment Enzymatic Modified Cheese	Storage period	Fat %	Protein %	Moisture %	Ash %	Water Activity	Total solid %
Cube	0 day	$47.89^{ab} \pm 0.36$	$33.05^{d} \pm 0.08$	$3.76^{a} \pm 0.03$	$15.56^{b} \pm 0.09$	$0.25^{ab} \pm 0.16$	$96.01^{c} \pm 0.10$
	30 days	$47.84^{b} \pm 0.34$	$33.09^{d} \pm 0.11$	$3.66^{b} \pm 0.03$	$15.51^{b} \pm 0.08$	$0.25^{ab} \pm 0.14$	$96.03^{c} \pm 0.10$
	60 days	$47.63^{d} \pm 0.29$	$33.93^{a} \pm 0.16$	$3.56^{c} \pm 0.00$	$15.39^{c} \pm 0.08$	$0.24^{ab} \pm 0.02$	$96.16^{c} \pm 0.09$
Shreds	0 day	$47.97^{a} \pm 0.27$	$33.37^{b} \pm 0.10$	$3.75^{a} \pm 0.03$	$15.67^{a} \pm 0.09$	$0.24^{b} \pm 0.13$	$96.34^{a} \pm 0.07$
	30 days	$47.91^{a} \pm 0.25$	$33.33^{b} \pm 0.08$	$3.65^{b} \pm 0.03$	$15.61^{a} \pm 0.06$	$0.23^{b} \pm 0.03$	$96.36^{a} \pm 0.09$
	60 days	$47.77^{c} \pm 0.22$	$33.22^{c} \pm 0.16$	$3.55^{bc} \pm 0.13$	$15.53^{b} \pm 0.06$	$0.23^{b} \pm 0.03$	$96.39^{a} \pm 0.08$
Slice	0 day	$47.90^{a} \pm 0.32$	$33.26^{c} \pm 0.15$	$3.66^{b} \pm 0.03$	$15.57^{b} \pm 0.10$	$0.22^{a} \pm 0.12$	$96.27^{b} \pm 0.11$
	30 days	$47.86^{b} \pm 0.31$	$33.24^{c} \pm 0.13$	$3.56^{c} \pm 0.02$	$15.55^{b} \pm 0.09$	$0.22^{a} \pm 0.06$	$96.23^{b} \pm 0.10$
	60 days	$47.67^{d} \pm 0.24$	$33.02^{d} \pm 0.11$	$3.46^{a} \pm 0.03$	$15.45^{c} \pm 0.09$	$0.22^{a} \pm 0.10$	$96.35^{a} \pm 0.09$

Shreds ($0.47 \times 0.67 cm^2$: $0.47 \times 0.67 \times 0.85 cm^3$), Slices ($0.65 \times 3\ cm^2$: $0.65 \times 3 \times 4\ cm^3$), Cubes ($1 \times 1\ cm^2$:$1 \times 1 \times 1\ cm^3$).

Table 4. Flavoring compounds in Cheddar cheese powder (least square means ± standard error).

	Compounds	Odor Impression	Treatments	Quantity mg/kg		
				0 day	30 days	60 days
Fatty acids	Acetic acid	Sour	Cubes	10.17 ± 0.04^{g}	158.00 ± 23.00^{f}	357.00 ± 10.00^{e}
			Shreds	10.81 ± 0.24^{g}	155.00 ± 30.00^{f}	350.00 ± 11.00^{e}
			Slices	10.25 ± 0.14^{g}	150 ± 23.00^{f}	345.00 ± 10.10^{e}
	Butanoic acid	Rancid, cheese	Cubes	11.80 ± 0.44^{g}	54.10 ± 1.67^{f}	111.00± 3.00^{e}
			Shreds	10.90 ± 0.34^{g}	53.10 ± 1.57^{f}	110.00 ± 3.99^{e}
			Slices	10.79 ± 0.24^{g}	51.10± 1.87^{f}	108.00 ± 4.00^{e}
	Heptanoic acid	Fatty, Rancid	Cubes	7.18 ± 0.18^{g}	9.18 ± 0.15^{f}	10.18 ± 0.02^{e}
			Shreds	6.99 ± 0.17^{g}	8.16 ± 0.16^{f}	9.16 ± 0.01^{e}
			Slices	5.89 ± 0.16^{g}	8.15 ± 0.17^{f}	9.15 ± 0.06^{e}
Lactones	γ-Butyrolactone	Caramel, sweet	Cubes	0.30 ± 0.13^{g}	0.94 ± 0.83^{f}	1.70 ± 0.70^{e}
			Shreds	0.29 ± 0.03^{g}	0.93 ± 0.83^{f}	1.60 ± 0.70^{e}
			Slices	0.28 ± 0.13^{g}	0.92 ± 0.82^{f}	1.55 ± 0.70^{e}
	δ-Dodecalactone	Fruit, sweet	Cubes	0.19 ± 0.00^{g}	15.01 ± 0.22^{f}	16.12 ± 0.23^{e}
			Shreds	0.17 ± 0.00^{g}	14.01 ± 0.33^{f}	15.99 ± 0.13^{e}
			Slices	0.19± 0.01^{g}	13.01 ± 0.41^{f}	15.12 ± 0.32^{e}
Ketones	Acetophenone	Musty, flower, almond	Cubes	0.17 ± 0.00^{g}	17.01 ± 0.73^{f}	20.12 ± 0.43^{e}
			Shreds	0.16 ± 0.00^{g}	16.01 ± 0.42^{f}	19.99 ± 0.53^{e}
			Slices	0.15± 0.01^{g}	15.01 ± 0.13^{f}	18.12 ± 0.33^{e}
	Acetoin	Butter, cream	Cubes	0.38 ± 0.12^{g}	0.60 ± 0.51^{f}	17.86 ± 0.15^{e}
			Shreds	0.37 ± 0.12^{g}	0.55 ± 0.51^{f}	16.96 ± 0.15^{e}
			Slices	0.36 ± 0.12^{g}	0.50 ± 0.51^{f}	15.86 ± 0.15^{e}
Aldehydes	Methional	Cooked potato	Cubes	0.26 ± 0.05^{g}	0.29 ± 0.05^{f}	0.33 ± 0.05^{e}
			Shreds	0.25 ± 0.05^{g}	0.28 ± 0.05^{f}	0.32 ± 0.05^{e}
			Slices	0.24 ± 0.05^{g}	0.27 ± 0.05^{f}	0.31 ± 0.05^{e}
	Benzaldehyde	Almond, burned sugar	Cubes	0.76 ± 0.15^{g}	0.88 ± 0.09^{f}	0.81 ± 0.05^{e}
			Shreds	0.74 ± 0.15^{g}	0.87 ± 0.09^{f}	0.80 ± 0.05^{e}
			Slices	0.72 ± 0.15^{g}	0.86 ± 0.09^{f}	0.79 ± 0.05^{e}
	Octanal	Fat, soap, lemon	Cubes	0.04 ± 0.00^{g}	2.81 ± 0.36^{f}	2.98 ± 0.68^{e}

			Shreds	0.03 ± 0.00^{g}	2.61 ± 0.36^{f}	2.98 ± 0.68^{e}
			Slices	0.02 ± 0.00^{g}	1.91 ± 0.36^{f}	2.98 ± 0.68^{e}
Diols	2,3-Butanediol	Fruity	Cubes	1.70 ± 0.65^{g}	2.33 ± 0.02^{f}	3.60 ± 0.14^{e}
			Shreds	1.62 ± 0.65^{g}	2.22 ± 0.02^{f}	2.61 ± 0.14^{e}
			Slices	1.53 ± 0.65^{g}	2.11 ± 0.02^{f}	2.52 ± 0.14^{e}
Alcohols	1-Nonanol	Sweet	Cubes	0.98 ± 0.75^{g}	2.02 ± 0.17^{f}	2.42 ± 0.11^{e}
			Shreds	0.96 ± 0.77^{g}	1.92 ± 0.10^{f}	2.15 ± 0.21^{e}
			Slices	0.95 ± 0.78^{g}	1.90 ± 0.19^{f}	2.14 ± 0.11^{e}
	1-Hexanol	Sweet	Cubes	0.22 ± 0.13^{g}	4.30 ± 2.44^{f}	5.67 ± 1.18^{e}
			Shreds	0.21 ± 0.04^{g}	4.20 ± 2.34^{f}	5.55 ± 1.18^{e}
			Slices	0.20 ± 0.02^{g}	4.01 ± 2.33^{f}	5.44 ± 1.28^{e}
Esters	Pentyl butanoate	Sweet	Cubes	0.11 ± 0.00^{g}	0.65 ± 0.30^{f}	20.30 ± 2.40^{e}
			Shreds	0.10 ± 0.00^{g}	0.60 ± 0.40^{f}	19.40 ± 2.40^{e}
			Slices	0.09 ± 0.00^{g}	0.55 ± 0.20^{f}	18.30 ± 2.40^{e}
	1-methylbutylbutanoate	Pear like, sweet	Cubes	2.13 ± 0.89^{g}	7.97 ± 1.20^{f}	8.90 ± 1.65^{e}
			Shreds	2.11 ± 0.98^{g}	7.89 ± 1.22^{f}	8.80 ± 1.62^{e}
			Slices	2.00 ± 0.99^{g}	7.77 ± 1.21^{f}	8.75 ± 1.35^{e}
	Ethyl octanoate	Apple Like	Cubes	1.99 ± 0.75^{g}	3.02 ± 0.17^{f}	4.12 ± 0.11^{e}
			Shreds	1.94 ± 0.77^{g}	2.92 ± 0.10^{f}	4.10 ± 0.21^{e}
			Slices	1.90 ± 0.78^{g}	2.90 ± 0.19^{f}	4.04 ± 0.11^{e}
Terpenes	Limonene	Lemon, orange	Cubes	0.51 ± 0.00^{g}	0.65 ± 0.30^{f}	21.30 ± 2.40^{e}
			Shreds	0.33 ± 0.00^{g}	0.60 ± 0.40^{f}	20.20 ± 2.40^{e}
			Slices	0.21 ± 0.00^{g}	0.55 ± 0.20^{f}	19.30 ± 2.40^{e}
Furans	Furfural	Bread, almond,	Cubes	0.34 ± 0.17^{g}	0.40 ± 0.16^{f}	0.44 ± 0.15^{e}
			Shreds	0.32 ± 0.16^{g}	0.39 ± 0.15^{f}	0.42 ± 0.15^{e}
			Slices	0.30 ± 0.15^{g}	0.37 ± 0.14^{f}	0.40 ± 0.15^{e}
	Hom furaneol	Burned sugar	Cubes	2.02 ± 0.66^{g}	4.70 ± 2.78^{f}	6.30 ± 1.90^{e}
			Shreds	2.00 ± 0.56^{g}	4.50 ± 1.68^{f}	6.20 ± 1.22^{e}
			Slices	1.99 ± 0.44^{g}	4.40 ± 1.55^{f}	6.10 ± 1.80^{e}

Shreds (0.47 × 0.67cm2: 0.47 × 0.67 × 0.85cm3), Slices (0.65 × 3 cm2: 0.65 × 3 × 4 cm3), Cubes (1×1 cm2 :1×1×1 cm3).

Table 5. Flavoring compounds in Mozzarella cheese powder (least square means ± standard error).

	Compounds	Odor Impression	Treatments	Quantity mg/kg		
				0 day	30 days	60 days
Fatty acids	Acetic acid	Sour	Cubes	9.97 ± 0.04^{c}	148.00 ± 23.00^{b}	340.00 ± 10.00^{a}
			Shreds	9.81 ± 0.24^{c}	145.00 ± 30.00^{b}	340.00 ± 11.00^{a}
			Slices	9.25 ± 0.14^{c}	140 ± 23.00^{b}	335.00 ± 10.10^{a}
	Butanoic acid	Rancid, cheese	Cubes	11.80 ± 0.44^{c}	43.10 ± 1.67^{b}	100.00 ± 3.00^{a}
			Shreds	10.80 ± 0.34^{c}	42.10 ± 1.57^{b}	99.00 ± 3.99^{a}
			Slices	10.79 ± 0.24^{c}	41.10 ± 1.87^{b}	98.00 ± 4.00^{a}
	Heptanoic acid	Fatty, Rancid	Cubes	4.18 ± 0.18^{c}	7.18 ± 0.15^{b}	8.18 ± 0.02^{a}
			Shreds	3.99 ± 0.17^{c}	7.16 ± 0.16^{b}	8.16 ± 0.01^{a}
			Slices	3.89 ± 0.16^{c}	7.15 ± 0.17^{b}	8.15 ± 0.06^{a}
Lactones	γ-Butyrolactone	Caramel, sweet	Cubes	0.20 ± 0.03^{c}	0.74 ± 0.13^{b}	1.00 ± 0.70^{a}
			Shreds	0.18 ± 0.00^{c}	0.73 ± 0.03^{b}	0.98 ± 0.70^{a}
			Slices	0.17 ± 0.03^{c}	0.72 ± 0.22^{b}	0.95 ± 0.70^{a}
	δ-Dodecalactone	Fruit, sweet	Cubes	0.14 ± 0.00^{c}	13.01 ± 0.22^{b}	14.12 ± 0.23^{a}
			Shreds	0.13 ± 0.00^{c}	12.01 ± 0.33^{b}	13.99 ± 0.13^{a}
			Slices	0.12 ± 0.01^{c}	11.01 ± 0.41^{b}	12.12 ± 0.32^{a}
Ketones	Acetophenone	Musty, flower, almond	Cubes	0.15 ± 0.00^{c}	16.01 ± 0.73^{b}	19.12 ± 0.43^{a}
			Shreds	0.14 ± 0.00^{c}	15.01 ± 0.42^{b}	18.99 ± 0.53^{a}
			Slices	0.13 ± 0.01^{c}	14.01 ± 0.13^{b}	17.12 ± 0.33^{a}
	Acetoin	Butter, cream	Cubes	0.36 ± 0.12^{c}	0.55 ± 0.51^{b}	16.86 ± 0.15^{a}
			Shreds	0.35 ± 0.12^{c}	0.54 ± 0.51^{b}	15.96 ± 0.15^{a}
			Slices	0.34 ± 0.12^{c}	0.52 ± 0.51^{b}	14.86 ± 0.15^{a}
Aldehydes	Methional	Cooked potato	Cubes	0.24 ± 0.05^{c}	0.27 ± 0.05^{b}	0.32 ± 0.05^{a}
			Shreds	0.23 ± 0.05^{c}	0.26 ± 0.05^{b}	0.31 ± 0.05^{a}
			Slices	0.22 ± 0.05^{c}	0.25 ± 0.05^{b}	0.30 ± 0.05^{a}
	Benzaldehyde	Almond, burned sugar	Cubes	0.72 ± 0.15^{c}	0.80 ± 0.09^{b}	0.81 ± 0.05^{a}
			Shreds	0.71 ± 0.12^{c}	0.79 ± 0.09^{b}	0.80 ± 0.05^{a}
			Slices	0.70 ± 0.13^{c}	0.78 ± 0.09^{b}	0.79 ± 0.05^{a}

	Octanal	Fat, soap, lemon	Cubes	0.03 ± 0.00^{c}	2.51 ± 0.36^{b}	2.68 ± 0.68^{a}
			Shreds	0.02 ± 0.00^{c}	2.50 ± 0.36^{b}	2.64 ± 0.68^{a}
			Slices	0.01 ± 0.00^{c}	1.87 ± 0.36^{b}	2.62 ± 0.68^{a}
Diols	2,3-Butanediol	Fruity	Cubes	1.50 ± 0.65^{c}	2.33 ± 0.02^{b}	3.60 ± 0.14^{a}
			Shreds	1.42 ± 0.65^{c}	2.10 ± 0.02^{b}	2.41 ± 0.14^{a}
			Slices	1.37 ± 0.65^{c}	2.05 ± 0.02^{b}	2.22 ± 0.14^{a}
Alcohols	1-Nonanol	Sweet	Cubes	0.94 ± 0.75^{c}	1.98 ± 0.17^{b}	2.20 ± 0.11^{a}
			Shreds	0.92 ± 0.77^{c}	1.90 ± 0.10^{b}	2.10 ± 0.21^{a}
			Slices	0.91 ± 0.78^{c}	1.89 ± 0.19^{b}	2.14 ± 0.11^{a}
	1-Hexanol	Sweet	Cubes	0.20 ± 0.00^{c}	3.30 ± 2.44^{b}	4.67 ± 1.18^{a}
			Shreds	0.19 ± 0.10^{c}	3.20 ± 2.34^{b}	4.55 ± 1.18^{a}
			Slices	0.18 ± 0.02^{c}	3.01 ± 2.33^{b}	4.44 ± 1.28^{a}
Esters	Pentyl butanoate	Sweet	Cubes	0.10 ± 0.00^{c}	0.60 ± 0.30^{b}	19.30 ± 2.40^{a}
			Shreds	0.09 ± 0.00^{c}	0.58 ± 0.40^{b}	18.40 ± 2.40^{a}
			Slices	0.08 ± 0.00^{c}	0.56 ± 0.20^{b}	17.90 ± 2.40^{a}
	1-methylbutylbutanoate	Pear like, sweet	Cubes	1.13 ± 0.89^{c}	6.97 ± 1.20^{b}	7.90 ± 1.65^{a}
			Shreds	1.11 ± 0.98^{c}	6.89 ± 1.22^{b}	7.80 ± 1.62^{a}
			Slices	1.00 ± 0.99^{c}	6.77 ± 1.21^{b}	7.75 ± 1.35^{a}
	Ethyl octanoate	Apple Like	Cubes	1.97 ± 0.75^{c}	2.92 ± 0.17^{b}	3.12 ± 0.11^{a}
			Shreds	1.92 ± 0.77^{c}	2.82 ± 0.10^{b}	3.10 ± 0.21^{a}
			Slices	1.88 ± 0.78^{c}	2.80 ± 0.19^{b}	3.04 ± 0.11^{a}
Terpenes	Limonene	Lemon, orange	Cubes	0.45 ± 0.00^{c}	0.60 ± 0.30^{b}	19.30 ± 2.40^{a}
			Shreds	0.32 ± 0.00^{c}	0.55 ± 0.40^{b}	18.20 ± 2.40^{a}
			Slices	0.20 ± 0.00^{c}	0.50 ± 0.20^{b}	18.10 ± 2.40^{a}
Furans	Furfural	Bread, almond	Cubes	0.32 ± 0.17^{c}	0.38 ± 0.16^{b}	0.42 ± 0.15^{a}
			Shreds	0.30 ± 0.16^{c}	0.37 ± 0.15^{b}	0.40 ± 0.15^{a}
			Slices	0.29 ± 0.15^{c}	0.36 ± 0.14^{b}	0.38 ± 0.15^{a}
	Hom furaneol	Burned sugar	Cubes	1.02 ± 0.66^{c}	3.70 ± 0.78^{b}	5.30 ± 1.90^{a}
			Shreds	1.00 ± 0.56^{c}	3.50 ± 0.68^{b}	5.20 ± 1.22^{a}
			Slices	0.99 ± 0.44^{c}	3.40 ± 0.55^{b}	5.10 ± 1.80^{a}

Shreds (0.47 × 0.67cm^2: 0.47 × 0.67 × 0.85cm^3), Slices (0.65 × 3 cm^2: 0.65 × 3 × 4 cm^3), Cubes (1×1 cm^2 :1×1×1 cm^3).

Table 6. Flavoring compounds in Enzyme modified cheese powder (least square means ± standard error).

	Compounds	**Odor Impression**	**Treatments**	**Quantity mg/kg**		
				0 days	**30 days**	**60 days**
Fatty acids	Acetic acid	Sour	Cubes	11.17 ± 0.04^c	160.00 ± 23.00^b	355.00 ± 10.00^a
			Shreds	10.81 ± 0.24^c	155.00 ± 30.00^b	350.00 ± 11.00^a
			Slices	10.25 ± 0.14^c	150 ± 23.00^b	345.00 ± 10.10^a
	Butanoic acid	Rancid, cheese	Cubes	12.80 ± 0.44^c	53.10 ± 1.67^b	110.00± 3.00^a
			Shreds	11.80 ± 0.34^c	52.10 ± 1.57^b	109.00 ± 3.99^a
			Slices	10.79 ± 0.24^c	51.10± 1.87^b	108.00 ± 4.00^a
	Heptanoic acid	Fatty, Rancid	Cubes	5.18 ± 0.18^c	7.18 ± 0.15^b	8.18 ± 0.02^a
			Shreds	4.99 ± 0.17^c	7.16 ± 0.16^b	8.16 ± 0.01^a
			Slices	5.77 ± 0.16^c	7.15 ± 0.17^b	8.15 ± 0.06^a
Lactones	γ-Butyrolactone	Caramel, sweet	Cubes	0.29 ± 0.03^c	0.94 ± 0.43^b	1.70 ± 0.70^a
			Shreds	0.29 ± 0.13^c	0.93 ± 0.83^b	1.60 ± 0.70^a
			Slices	0.28 ± 0.11^c	0.92 ± 0.82^b	1.55 ± 0.70^a
	δ-Dodecalactone	Fruit, sweet	Cubes	0.19 ± 0.00^c	15.01 ± 0.22^b	16.12 ± 0.23^a
			Shreds	0.17 ± 0.00^c	14.01 ± 0.33^b	15.99 ± 0.13^a
			Slices	0.19± 0.01^c	13.01 ± 0.41^b	15.12 ± 0.32^a
Ketones	Acetophenone	Musty, flower, almond	Cubes	0.17 ± 0.00^c	17.01 ± 0.73^b	20.12 ± 0.43^a
			Shreds	0.16 ± 0.00^c	16.01 ± 0.42^b	19.99 ± 0.53^a
			Slices	0.15± 0.01^c	15.01 ± 0.13^b	18.12 ± 0.33^a
	Acetoin	Butter, cream	Cubes	0.38 ± 0.12^c	0.59 ± 0.51^b	16.86 ± 0.10^a
			Shreds	0.37 ± 0.10^c	0.54 ± 0.52^b	15.96 ± 0.15^a
			Slices	0.36 ± 0.11^c	0.49 ± 0.33^b	14.86 ± 0.25^a
Aldehydes	Methional	Cooked potato	Cubes	0.25 ± 0.04^c	0.28 ± 0.00^b	0.32 ± 0.01^a
			Shreds	0.24 ± 0.02^c	0.27 ± 0.00^b	0.31 ± 0.04^a
			Slices	0.23 ± 0.01^c	0.26 ± 0.05^b	0.30 ± 0.03^a
	Benzaldehyde	Almond,	Cubes	0.76 ± 0.13^c	0.88 ± 0.09^b	0.81 ± 0.05^a

		burned sugar	Shreds	0.74 ± 0.12^{c}	0.87 ± 0.19^{b}	0.80 ± 0.01^{a}
			Slices	0.72 ± 0.11^{c}	0.86 ± 0.10^{b}	0.79 ± 0.02^{a}
	Octanal	Fat, soap, lemon	Cubes	0.04 ± 0.00^{c}	2.81 ± 0.36^{b}	3.98 ± 0.38^{a}
			Shreds	0.03 ± 0.00^{c}	2.61 ± 0.36^{b}	2.89 ± 0.44^{a}
			Slices	0.02 ± 0.00^{c}	1.91 ± 0.36^{b}	2.52 ± 0.10^{a}
Diols	2,3-Butanediol	Fruity	Cubes	1.80 ± 0.65^{c}	2.33 ± 0.02^{b}	3.41 ± 0.16^{a}
			Shreds	1.62 ± 0.65^{c}	2.22 ± 0.02^{b}	2.31 ± 0.11^{a}
			Slices	1.43 ± 0.65^{c}	2.11 ± 0.02^{b}	2.62 ± 0.14^{a}
Alcohols	1-Nonanol	Sweet	Cubes	0.98 ± 0.75^{c}	2.02 ± 0.17^{b}	2.42 ± 0.11^{a}
			Shreds	0.96 ± 0.77^{c}	1.92 ± 0.10^{b}	2.15 ± 0.21^{a}
			Slices	0.95 ± 0.78^{c}	1.90 ± 0.19^{b}	2.14 ± 0.11^{a}
	1-Hexanol	Sweet	Cubes	0.22 ± 0.03^{c}	4.50 ± 2.44^{b}	4.67 ± 1.18^{a}
			Shreds	0.20 ± 0.00^{c}	4.10 ± 2.34^{b}	4.55 ± 1.18^{a}
			Slices	0.19 ± 0.02^{c}	4.01 ± 2.33^{b}	4.44 ± 1.28^{a}
Esters	Pentyl butanoate	Sweet	Cubes	0.10 ± 0.00^{c}	0.64 ± 0.30^{b}	19.30 ± 2.40^{a}
			Shreds	0.09 ± 0.00^{c}	0.59 ± 0.40^{b}	19.40 ± 2.40^{a}
			Slices	0.09 ± 0.00^{c}	0.55 ± 0.20^{b}	18.30 ± 2.40^{a}
	1-methylbutylbutanoate	Pear like, sweet	Cubes	2.13 ± 0.89^{c}	7.97 ± 1.20^{b}	8.90 ± 1.65^{a}
			Shreds	2.11 ± 0.98^{c}	7.89 ± 1.22^{b}	8.80 ± 1.62^{a}
			Slices	2.00 ± 0.99^{c}	7.77 ± 1.21^{b}	8.75 ± 1.35^{a}
	Ethyl octanoate	Apple Like	Cubes	1.99 ± 0.75^{c}	3.02 ± 0.17^{b}	4.12 ± 0.11^{a}
			Shreds	1.94 ± 0.77^{c}	2.92 ± 0.10^{b}	4.10 ± 0.21^{a}
			Slices	1.90 ± 0.78^{c}	2.90 ± 0.19^{b}	4.04 ± 0.11^{a}
Terpenes	Limonene	Lemon, orange	Cubes	0.49 ± 0.00^{c}	0.62 ± 0.30^{b}	20.30 ± 2.4^{a}
			Shreds	0.32 ± 0.00^{c}	0.57 ± 0.40^{b}	19.20 ± 2.40^{a}
			Slices	0.20 ± 0.00^{c}	0.53 ± 0.20^{b}	18.30 ± 2.40^{a}
Furans	Furfural	Bread, almond	Cubes	0.31 ± 0.17^{c}	0.37 ± 0.16^{b}	0.41 ± 0.15^{a}
			Shreds	0.30 ± 0.16^{c}	0.33 ± 0.15^{b}	0.40 ± 0.15^{a}
			Slices	0.29 ± 0.15^{c}	0.30 ± 0.14^{b}	0.39 ± 0.15^{a}
	Hom furaneol	Burned sugar	Cubes	1.92 ± 0.66^{c}	4.50 ± 1.78^{b}	5.30 ± 1.90^{a}
			Shreds	1.90 ± 0.56^{c}	4.60 ± 1.68^{b}	5.20 ± 1.22^{a}

			Slices	1.89 ± 0.44^{c}	4.30 ± 1.55^{b}	5.10 ± 1.80^{a}

Shreds (0.47 × 0.67cm2: 0.47 × 0.67 × 0.85cm3), Slices (0.65 × 3 cm2: 0.65 × 3 × 4 cm3), Cubes (1×1 cm2 :1×1×1 cm.

Table 7. Effect of storage on free fatty acids of cheese flavoring powder (least square means ± standard error).

Storage periods	Mozzarella cheese flavoring powder FFA%			Cheddar cheese flavoring powder FFA%			EMC cheese flavoring powder FFA%		
	SH	SL	C	SH	SL	C	SH	SL	C
0 days	0.12 ± 0.01^{b}	0.11 ± 0.31^{b}	0.11 ± 0.01^{b}	0.13 ± 0.02^{c}	0.12 ± 0.01^{d}	0.12 ± 0.02^{d}	0.28 ± 0.01^{c}	0.27 ± 0.01^{c}	0.26 ± 0.01^{c}
30 days	0.13 ± 0.02^{b}	0.12 ± 0.02^{b}	0.12 ± 0.02^{b}	0.14 ± 0.01^{c}	0.13 ± 0.10^{c}	0.13 ± 0.01^{c}	0.40 ± 0.01^{b}	0.39 ± 0.01^{b}	0.37 ± 0.01^{b}
60 days	0.15 ± 0.03^{a}	0.14 ± 0.03^{a}	0.13 ± 0.03^{a}	0.16 ± 0.02^{c}	0.15 ± 0.02^{c}	0.14 ± 0.02^{c}	0.46 ± 0.02^{a}	0.45 ± 0.02^{a}	0.44 ± 0.02^{a}

Shreds (SH) ($0.47 \times 0.67 cm^2$: $0.47 \times 0.67 \times 0.85 cm^3$), Slices (SL) ($0.65 \times 3\ cm^2$: $0.65 \times 3 \times 4\ cm^3$), Cubes(C) ($1 \times 1\ cm^2$:$1 \times 1 \times 1\ cm^3$).

Table 8. Effect of Storage on Fatty Acids of Cheddar cheese powder flavor cheese powder (least square means ± standard error).

Fatty Acids	Treatments	Quantity %		
		0 day	30 days	60 days
Butyric acid C4:0	Cubes	3.60±0.01^{c}	3.61±0.01^{c}	3.63±0.01^{c}
	Shreds	3.57±0.02^{c}	3.58 ± 0.00^{b}	3.59 ± 1.00^{a}
	Slices	3.59±0.02^{c}	3.60 ± 2.00^{b}	3.61 ± 0.10^{a}
Caproic acid C6:0	Cubes	2.36±0.03^{c}	2.40±0.03^{c}	2.41±0.03^{c}
	Shreds	2.38±0.04^{c}	2.48±0.24^{c}	2.49±0.14^{c}
	Slices	2.37±0.01^{c}	2.38±0.02^{c}	2.39±0.00^{c}
Caprylic acid C8:0	Cubes	1.18 ± 0.18^{c}	1.20 ± 0.15^{b}	1.25 ± 0.02^{a}
	Shreds	1.09 ± 0.17^{c}	1.10 ± 0.16^{b}	1.11 ± 0.01^{a}
	Slices	1.11 ± 0.16^{c}	1.13 ± 0.17^{b}	1.15 ± 0.06^{a}
Capric acid C10:0	Cubes	2.30 ± 0.43^{c}	2.94 ± 0.83^{b}	3.00 ± 0.70^{a}
	Shreds	2.29 ± 0.43^{c}	2.33 ± 0.83^{b}	2.60 ± 0.70^{a}
	Slices	2.28 ± 0.43^{c}	2.42 ± 0.82^{b}	2.55 ± 0.70^{a}
Lauric acid C12:0	Cubes	4.19 ± 0.00^{c}	4.21 ± 0.22^{b}	4.32 ± 0.23^{a}
	Shreds	4.17 ± 0.00^{c}	4.21 ± 0.33^{b}	4.33 ± 0.13^{a}
	Slices	4.20± 0.01^{c}	4.25 ± 0.41^{b}	4.36 ± 0.32^{a}
Myristic acid C14:0	Cubes	10.17 ± 0.00^{c}	10.71 ± 0.73^{b}	10.82 ± 0.43^{a}
	Shreds	11.16 ± 0.00^{c}	11.21 ± 0.42^{b}	11.09 ± 0.53^{a}
	Slices	10.15± 0.01^{c}	10.01 ± 0.13^{b}	10.12 ± 0.33^{a}
Palmitic acid C16:0	Cubes	30.38 ± 0.12^{c}	30.60 ± 0.51^{b}	30.86 ± 0.15^{a}
	Shreds	30.37 ± 0.12^{c}	30.55 ± 0.51^{b}	30.96 ± 0.15^{a}
	Slices	29.36 ± 0.12^{c}	29.50 ± 0.51^{b}	29.86 ± 0.15^{a}
Palmitoleic acid C16:1	Cubes	2.26 ± 0.05^{c}	2.29 ± 0.05^{b}	2.33 ± 0.05^{a}
	Shreds	2.25 ± 0.05^{c}	2.28 ± 0.05^{b}	2.32 ± 0.15^{a}
	Slices	2.24 ± 0.00^{c}	2.27 ± 0.01^{b}	2.31 ± 0.02^{a}
Stearic acid C18:0	Cubes	10.76 ± 0.15^{c}	10.88 ± 0.09^{b}	10.81 ± 0.05^{a}
	Shreds	10.74 ± 0.15^{c}	10.87 ± 0.09^{b}	10.80 ± 0.05^{a}

	Slices	10.72 ± 0.15^{c}	10.86 ± 0.09^{b}	10.79 ± 0.05^{a}
Oleic acid C18:1	Cubes	20.04 ± 0.00^{c}	20.81 ± 0.36^{b}	20.98 ± 0.68^{a}
	Shreds	20.03 ± 0.00^{c}	20.61 ± 0.36^{b}	20.98 ± 0.68^{a}
	Slices	20.02 ± 0.00^{c}	19.91 ± 0.36^{b}	20.98 ± 0.68^{a}
Linoleic acid C18:2	Cubes	1.70 ± 0.65^{c}	2.33 ± 0.02^{b}	3.60 ± 0.14^{a}
	Shreds	1.62 ± 0.65^{c}	2.22 ± 0.02^{b}	2.61 ± 0.14^{a}
	Slices	1.53 ± 0.65^{c}	2.11 ± 0.02^{b}	2.52 ± 0.14^{a}
Linolenic acid C18:3	Cubes	0.98 ± 0.75^{c}	0.92 ± 0.17^{b}	0.92 ± 0.11^{a}
	Shreds	0.96 ± 0.77^{c}	0.92 ± 0.10^{b}	0.15 ± 0.11^{a}
	Slices	0.95 ± 0.78^{c}	0.90 ± 0.19^{b}	0.14 ± 0.11^{a}
Arachidic acid C20:0	Cubes	0.02 ± 0.00^{c}	0.30 ± 0.00^{b}	0.20 ± 0.10^{a}
	Shreds	0.21 ± 0.10^{c}	0.20 ± 0.04^{b}	0.55 ± 0.11^{a}
	Slices	0.20 ± 0.02^{c}	0.21 ± 0.03^{b}	0.24 ± 0.08^{a}
Eicosenoic acid C20:1	Cubes	0.11 ± 0.00^{c}	0.65 ± 0.30^{b}	0.30 ± 0.00^{a}
	Shreds	0.10 ± 0.00^{c}	0.60 ± 0.40^{b}	0.40 ± 0.10^{a}
	Slices	0.09 ± 0.00^{c}	0.55 ± 0.20^{b}	0.30 ± 0.20^{a}
CLA (Conjugated Linoleic Acid.)	Cubes	0.81 ± 0.00^{c}	0.95 ± 0.30^{b}	0.90 ± 0.00^{a}
	Shreds	0.80 ± 0.00^{c}	0.83 ± 0.40^{b}	0.80 ± 0.10^{a}
	Slices	0.89 ± 0.00^{c}	0.95 ± 0.20^{b}	0.92 ± 0.20^{a}

Shreds (SH) ($0.47 \times 0.67 cm^2$: $0.47 \times 0.67 \times 0.85 cm^3$), Slices (SL) ($0.65 \times 3\ cm^2$: $0.65 \times 3 \times 4\ cm^3$), Cubes(C) ($1 \times 1\ cm^2$:$1 \times 1 \times 1$ cm3).

Table 9. Effect of storage on Fatty Acids of Mozzarella cheese powder flavor (least square means ± standard error).

Fatty Acids	Treatments	Quantity %		
		0 days	30 days	60 days
Butyric acid C4:0	Cubes	2.60 ± 0.01^{c}	2.61 ± 0.01^{c}	2.63 ± 0.01^{c}
	Shreds	2.57 ± 0.02^{c}	2.58 ± 0.00^{b}	2.59 ± 1.00^{a}
	Slices	2.59 ± 0.02^{c}	2.60 ± 2.00^{b}	2.61 ± 0.10^{a}
Caproic acid C6:0	Cubes	1.36 ± 0.03^{c}	1.40 ± 0.03^{c}	1.41 ± 0.03^{c}
	Shreds	1.38 ± 0.04^{c}	1.48 ± 0.24^{c}	1.49 ± 0.14^{c}
	Slices	1.37 ± 0.01^{c}	1.38 ± 0.02^{c}	1.39 ± 0.00^{c}
Caprylic acid C8:0	Cubes	0.18 ± 0.08^{c}	0.20 ± 0.15^{b}	0.25 ± 0.02^{a}
	Shreds	0.09 ± 0.07^{c}	0.10 ± 0.06^{b}	0.11 ± 0.01^{a}
	Slices	0.11 ± 0.00^{c}	0.13 ± 0.10^{b}	0.15 ± 0.06^{a}
Capric acid C10:0	Cubes	1.30 ± 0.43^{c}	1.94 ± 0.83^{b}	1.00 ± 0.70^{a}
	Shreds	1.29 ± 0.43^{c}	1.33 ± 0.83^{b}	1.60 ± 0.70^{a}
	Slices	1.28 ± 0.43^{c}	1.42 ± 0.82^{b}	1.55 ± 0.70^{a}
Lauric acid C12:0	Cubes	3.19 ± 0.00^{c}	3.21 ± 0.22^{b}	3.32 ± 0.23^{a}
	Shreds	3.17 ± 0.00^{c}	3.21 ± 0.33^{b}	3.33 ± 0.13^{a}
	Slices	3.20 ± 0.01^{c}	3.25 ± 0.41^{b}	3.36 ± 0.32^{a}
Myristic acid C14:0	Cubes	9.17 ± 0.00^{c}	9.71 ± 0.73^{b}	9.82 ± 0.43^{a}
	Shreds	9.16 ± 0.00^{c}	9.21 ± 0.42^{b}	10.09 ± 0.53^{a}
	Slices	10.17 ± 0.01^{c}	10.90 ± 0.13^{b}	10.99 ± 0.33^{a}
Palmitic acid C16:0	Cubes	29.38 ± 0.12^{c}	29.60 ± 0.51^{b}	29.86 ± 0.15^{a}
	Shreds	28.37 ± 0.12^{c}	28.55 ± 0.51^{b}	28.96 ± 0.15^{a}
	Slices	29.36 ± 0.12^{c}	29.50 ± 0.51^{b}	29.86 ± 0.15^{a}
Palmitoleic acid C16:1	Cubes	1.26 ± 0.05^{c}	1.29 ± 0.05^{b}	1.33 ± 0.05^{a}
	Shreds	1.25 ± 0.05^{c}	1.28 ± 0.05^{b}	1.32 ± 0.15^{a}
	Slices	1.24 ± 0.00^{c}	1.27 ± 0.01^{b}	1.31 ± 0.02^{a}
Stearic acid C18:0	Cubes	11.76 ± 0.15^{c}	11.88 ± 0.09^{b}	11.81 ± 0.05^{a}
	Shreds	11.74 ± 0.15^{c}	12.87 ± 0.09^{b}	12.80 ± 0.05^{a}

	Slices	12.72 ± 0.15^{c}	12.86 ± 0.09^{b}	11.79 ± 0.05^{a}
Oleic acid C18:1	Cubes	22.04 ± 0.00^{c}	23.81 ± 0.36^{b}	23.98 ± 0.68^{a}
	Shreds	21.03 ± 0.00^{c}	22.61 ± 0.36^{b}	22.98 ± 0.68^{a}
	Slices	22.02 ± 0.00^{c}	21.91 ± 0.36^{b}	21.98 ± 0.68^{a}
Linoleic acid C18:2	Cubes	2.70 ± 0.65^{c}	3.33 ± 0.02^{b}	3.60 ± 0.14^{a}
	Shreds	2.62 ± 0.65^{c}	3.22 ± 0.02^{b}	3.61 ± 0.14^{a}
	Slices	2.53 ± 0.65^{c}	311 ± 0.02^{b}	3.52 ± 0.14^{a}
Linolenic acid C18:3	Cubes	0.98 ± 0.75^{c}	0.92 ± 0.17^{b}	0.92 ± 0.11^{a}
	Shreds	0.96 ± 0.77^{c}	0.92 ± 0.10^{b}	0.15 ± 0.11^{a}
	Slices	0.95 ± 0.78^{c}	0.90 ± 0.19^{b}	0.14 ± 0.11^{a}
Arachidic acid C20:0	Cubes	0.12 ± 0.00^{c}	0.30 ± 0.00^{b}	0.20 ± 0.10^{a}
	Shreds	0.23 ± 0.04^{c}	0.20 ± 0.04^{b}	0.55 ± 0.11^{a}
	Slices	0.22 ± 0.02^{c}	0.21 ± 0.03^{b}	0.24 ± 0.08^{a}
Eicosenoic acid C20:1	Cubes	1.11 ± 0.00^{c}	1.65 ± 0.30^{b}	1.30 ± 0.00^{a}
	Shreds	1.10 ± 0.00^{c}	1.60 ± 0.40^{b}	1.40 ± 0.10^{a}
	Slices	1.09 ± 0.00^{c}	1.55 ± 0.20^{b}	1.30 ± 0.20^{a}
CLA (Conjugated Linoleic Acid.)	Cubes	0.41 ± 0.00^{c}	0.55 ± 0.30^{b}	0.50 ± 0.00^{a}
	Shreds	0.40 ± 0.00^{c}	0.60 ± 0.40^{b}	0.43 ± 0.10^{a}
	Slices	0.39 ± 0.00^{c}	0.52 ± 0.20^{b}	0.51 ± 0.20^{a}

Shreds (SH) ($0.47 \times 0.67 cm^2$: $0.47 \times 0.67 \times 0.85 cm^3$), Slices (SL) ($0.65 \times 3\ cm^2$: $0.65 \times 3 \times 4\ cm^3$), Cubes(C) ($1 \times 1\ cm^2$:$1 \times 1 \times 1\ cm^3$).

Table 10. Effect of Storage on Fatty Acids of EMC cheese powder flavor (least square means ± standard error).

Fatty Acids	Treatments	Quantity %		
		0 day	30 days	60 days
Butyric acid C4:0	Cubes	3.70±0.01^{c}	3.71±0.01^{c}	3.73±0.01^{c}
	Shreds	3.67±0.02^{c}	3.68 ± 0.00^{b}	3.69 ± 1.00^{a}
	Slices	3.69±0.02^{c}	3.70 ± 2.00^{b}	3.71 ± 0.10^{a}
Caproic acid C6:0	Cubes	2.46±0.03^{c}	2.50±0.03^{c}	2.51±0.03^{c}
	Shreds	2.48±0.04^{c}	2.58±0.24^{c}	2.59±0.14^{c}
	Slices	2.47±0.01^{c}	2.48±0.02^{c}	2.49±0.00^{c}
Caprylic acid C8:0	Cubes	1.28 ± 0.18^{c}	1.30 ± 0.15^{b}	1.35 ± 0.02^{a}
	Shreds	1.19 ± 0.17^{c}	1.20 ± 0.16^{b}	1.21 ± 0.01^{a}
	Slices	1.21 ± 0.16^{c}	1.23 ± 0.17^{b}	1.25 ± 0.06^{a}
Capric acid C10:0	Cubes	2.40 ± 0.43^{c}	2.97 ± 0.83^{b}	3.00 ± 0.70^{a}
	Shreds	2.39 ± 0.43^{c}	2.39 ± 0.83^{b}	2.50 ± 0.70^{a}
	Slices	2.38 ± 0.43^{c}	2.32 ± 0.82^{b}	2.58 ± 0.70^{a}
Lauric acid C12:0	Cubes	4.29 ± 0.00^{c}	4.31 ± 0.22^{b}	4.42 ± 0.23^{a}
	Shreds	4.19 ± 0.00^{c}	4.26 ± 0.33^{b}	4.34 ± 0.13^{a}
	Slices	4.25± 0.01^{c}	4.27 ± 0.41^{b}	4.38 ± 0.32^{a}
Myristic acid C14:0	Cubes	10.19 ± 0.00^{c}	10.79 ± 0.73^{b}	10.88 ± 0.43^{a}
	Shreds	11.19 ± 0.00^{c}	11.28 ± 0.42^{b}	11.35 ± 0.53^{a}
	Slices	10.35± 0.01^{c}	10.41 ± 0.13^{b}	10.42 ± 0.33^{a}
Palmitic acid C16:0	Cubes	30.48 ± 0.12^{c}	30.70 ± 0.51^{b}	30.96 ± 0.15^{a}
	Shreds	30.47 ± 0.12^{c}	30.65 ± 0.51^{b}	30.99 ± 0.15^{a}
	Slices	29.36 ± 0.12^{c}	29.50 ± 0.51^{b}	29.86 ± 0.15^{a}
Palmitoleic acid C16:1	Cubes	2.26 ± 0.05^{c}	2.29 ± 0.05^{b}	2.33 ± 0.05a
	Shreds	2.25 ± 0.05^{c}	2.28 ± 0.05^{b}	2.32 ± 0.15^{a}
	Slices	2.24 ± 0.00^{c}	2.27 ± 0.01^{b}	2.31 ± 0.02^{a}
Stearic acid C18:0	Cubes	10.76 ± 0.15^{c}	10.88 ± 0.09^{b}	10.81 ± 0.05^{a}
	Shreds	10.74 ± 0.15^{c}	10.87 ± 0.09^{b}	10.80 ± 0.05^{a}
	Slices	10.72 ± 0.15^{c}	10.86 ± 0.09^{b}	10.79 ± 0.05^{a}

Oleic acid C18:1	Cubes	20.04 ± 0.00^{c}	20.81 ± 0.36^{b}	20.98 ± 0.68^{a}
	Shreds	20.03 ± 0.00^{c}	20.61 ± 0.36^{b}	20.98 ± 0.68^{a}
	Slices	20.02 ± 0.00^{c}	19.91 ± 0.36^{b}	20.98 ± 0.68^{a}
Linoleic acid C18:2	Cubes	1.70 ± 0.65^{c}	2.33 ± 0.02^{b}	3.60 ± 0.14^{a}
	Shreds	1.62 ± 0.65^{c}	2.22 ± 0.02^{b}	2.61 ± 0.14^{a}
	Slices	1.53 ± 0.65^{c}	2.11 ± 0.02^{b}	2.52 ± 0.14^{a}
Linolenic acid C18:3	Cubes	0.88 ± 0.75^{c}	0.82 ± 0.17^{b}	0.92 ± 0.11^{a}
	Shreds	0.86 ± 0.77^{c}	0.99 ± 0.10^{b}	0.95 ± 0.11^{a}
	Slices	0.95 ± 0.78^{c}	0.90 ± 0.19^{b}	0.94 ± 0.11^{a}
Arachidic acid C20:0	Cubes	0.32 ± 0.13^{c}	0.30 ± 0.00^{b}	0.20 ± 0.10^{a}
	Shreds	0.34 ± 0.04^{c}	0.20 ± 0.04^{b}	0.55 ± 0.11^{a}
	Slices	0.20 ± 0.02^{c}	0.21 ± 0.03^{b}	0.24 ± 0.08^{a}
Eicosenoic acid C20:1	Cubes	0.24 ± 0.00^{c}	0.68 ± 0.30^{b}	0.39 ± 0.00^{a}
	Shreds	0.13 ± 0.00^{c}	0.61 ± 0.40^{b}	0.45 ± 0.10^{a}
	Slices	0.19 ± 0.00^{c}	0.57 ± 0.20^{b}	0.36 ± 0.20^{a}
CLA (Conjugated Linoleic Acid.)	Cubes	0.94 ± 0.00^{c}	0.98 ± 0.30^{b}	0.99 ± 0.00^{a}
	Shreds	0.93 ± 0.00^{c}	0.91 ± 0.40^{b}	0.95 ± 0.10^{a}
	Slices	0.99 ± 0.00^{c}	0.97 ± 0.20^{b}	0.96 ± 0.20^{a}

Shreds ($0.47 \times 0.67 cm^2$: $0.47 \times 0.67 \times 0.85 cm^3$), Slices ($0.65 \times 3\ cm^2$: $0.65 \times 3 \times 4\ cm^3$), Cubes ($1 \times 1\ cm^2$:$1 \times 1 \times 1\ cm^3$).

Table 11 Effect of storage on Peroxide value of cheese flavoring powder (least square means ± standard error).

Storage periods	Mozzarella cheese powder flavor Per - Oxide Value			Cheddar cheese powder flavor Per - Oxide Value			EMC cheese powder flavor Per - Oxide Value		
	SH	SL	C	SH	SL	C	SH	SL	C
0 day	0.24±0.21^{b}	0.22±0.01^{b}	0.21±0.12^{b}	0.24±0.03^{e}	0.23±0.01^{f}	0.22±0.02^{e}	1.25±0.01^{c}	1.21±0.02^{c}	1.19±0.03^{b}
30 days	0.25±0.11^{b}	0.24±0.11^{b}	0.23±0.11^{b}	0.27±0.03^{e}	0.26±0.01^{f}	0.25±0.01^{e}	1.68±0.02^{b}	1.67±0.01^{b}	1.65±0.01^{a}
60 days	0.38±0.12^{a}	0.37±0.21^{a}	0.36±0.13^{a}	0.46±0.02^{d}	0.45±0.02^{e}	0.44±0.02^{d}	2.00±0.02^{a}	1.99±0.03^{a}	1.98±0.02^{a}

Shreds (SH) (0.47 × 0.67cm^{2}: 0.47 × 0.67 × 0.85cm^{3}), Slices (SL) (0.65 × 3 cm^{2}: 0.65 × 3 × 4 cm^{3}), Cubes(C) (1×1 cm^{2} :1×1×1 cm^{3}).

Table 12. Effect of storage on TOTOX Value of cheese flavoring powder (least square means ± standard error).

Storage periods	Mozzarella cheese powder flavor TOTOX Value			Cheddar cheese powder flavor TOTOX Value			EMC cheese powder flavor TOTOX Value		
	SH	SL	C	SH	SL	C	SH	SL	C
0 day	2.5±0.21^{b}	2.4±0.01^{b}	2.4±0.12^{b}	2.4±0.03^{e}	2.3±0.01^{f}	2.1±0.02^{e}	5.3±0.01^{c}	5.2±0.02^{c}	5.1±0.03^{b}
30 days	3.0±0.11^{b}	2.9±0.11^{b}	2.8±0.11^{b}	3.2±0.03^{e}	3.1±0.01^{f}	3.0±0.01^{e}	6.8±0.02^{b}	6.7±0.01^{b}	6.6±0.01^{a}
60 days	4.4±0.12^{a}	4.3±0.21^{a}	4.2±0.13^{a}	5.0±0.02^{d}	4.9±0.02^{e}	4.8±0.02^{d}	7.5±0.02^{a}	7.4±0.03^{a}	7.3±0.02^{a}

Table 12.1 p-anisidine values of cheese flavoring powder (least square means ± standard error).

Storage periods	Mozzarella cheese powder flavor p-anisidine			Cheddar cheese powder flavor p-anisidine			EMC cheese powder flavor p-anisidine		
	SH	SL	C	SH	SL	C	SH	SL	C
0 day	2.02±0.01^{b}	1.94±0.01^{b}	1.98±0.12^{b}	1.92 ±0.03^{e}	1.84 ±0.01^{f}	1.66 ±0.02^{e}	2.80 ±0.01^{c}	2.78 ±0.02^{c}	2.91±0.03^{b}
30 days	2.54±0.01^{b}	2.44±0.11^{b}	2.34±0.11^{b}	2.66 ±0.03^{e}	2.58 ±0.01^{f}	2.50 ±0.01^{e}	3.44 ±0.02^{b}	3.76±0.01^{b}	4.06±0.01^{a}
60 days	3.64±0.10^{a}	3.46±0.21^{a}	3.48±0.13^{a}	4.08 ±0.02^{d}	4.00 ±0.02^{e}	3.92 ±0.02^{d}	5.50 ±0.02^{a}	5.74±0.03^{a}	6.03±0.02^{a}

Table 13 Effect of storage on TBARS value of cheese flavoring powder (least square means ± standard error).

Storage periods	Mozzarella cheese powder flavor TBARS value			Cheddar cheese powder flavor TBARS value			EMC cheese powder flavor TBARS value		
	SH	SL	C	SH	SL	C	SH	SL	C
0 day	0.10 ± 0.21^{b}	0.09 ± 0.01^{b}	0.08 ± 0.12^{b}	0.13 ± 0.03^{e}	0.12 ± 0.01^{f}	0.11 ± 0.02^{e}	0.50 ± 0.01^{c}	0.50 ± 0.02^{c}	0.40 ± 0.03^{b}
30 days	0.11 ± 0.11^{b}	0.10 ± 0.01^{b}	0.10 ± 0.01^{b}	0.14 ± 0.03^{e}	0.13 ± 0.01^{f}	0.12 ± 0.01^{e}	0.52 ± 0.02^{b}	0.50 ± 0.01^{b}	0.46 ± 0.01^{a}
60 days	0.12 ± 0.12^{a}	0.12 ± 0.01^{a}	0.11 ± 0.03^{a}	0.15 ± 0.02^{d}	0.16 ± 0.02^{e}	0.14 ± 0.02^{d}	0.53 ± 0.02^{a}	0.51 ± 0.03^{a}	0.47 ± 0.02^{a}