Lyophilization and Sensory Analysis of Traditional Artisan Turkish Cheeses

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Abstract

Türkiye boasts a rich cheese culture, shaped by its diverse geographical features and climatic conditions. Currently, 40 types of cheese in Türkiye have received geographical indication status, contributing to both the local economy and gastronomic tourism. This study aims to dry artisan Turkish cheeses using the lyophilization (freeze-drying) method, which is intended to improve shelf life, ease packaging and transport, and enable snack-type consumption while preserving nutritional value. To achieve this, Ezine, Kars Kaşar, Kars Gruyère, Smoked Circassian, and Divle Obruk Tulum cheeses were freeze-dried at -70°C for 24 hours using a lyophilization device. Following the drying process, the sensory properties of the cheeses were evaluated by 10 trained panelists based on attributes, such as color, odor, texture, crispness, aroma, mouthfeel, and overall acceptability. According to the results, all cheese samples received above-average scores (mean ± SD): Ezine: 4.50 ± 1.27; Smoked cheese: 4.50 ± 0.71; Kars Kaşar: 4.60 ± 0.70; Kars Gruyère: 4.09 ± 0.94; Divle Obruk: 4.82 ± 0.40. The findings obtained in this study indicated that consuming cheese in an alternative form is feasible. It was observed that the cheeses retained their color, taste, shape, and aroma, and their potential to return to their original state upon rehydration was also evaluated. This alternative form may contribute to the promotion of traditional Turkish products and increase appeal among younger generations. Further studies focusing on packaging and rehydration can be conducted for commercialization efforts in the future.

Keywords: Lyophilization, Cheese, Freeze-drying, Artisan, Geographical Indication.

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1. Introduction

Milk has long been a fundamental component of human nutrition. This is primarily because milk and dairy products contain energy, macronutrients, and a variety of micronutrients such as proteins, carbohydrates, fats, minerals, and vitamins. One of these dairy products is cheese. Cheese production is based on the coagulation of casein, the main milk protein, through the use of enzymes or starter cultures. During this process, whey is removed and the curd solidifies, forming the desired texture. Starter cultures accelerate and control the fermentation process, ensuring that the final product attains the intended characteristics (Hastaoğlu et al., 2021).

Cheese can be classified according to several factors, including the type of coagulant used, ripening conditions, fat and moisture content, and the applied heat treatment method. Beyond its sensory qualities such as flavor and aroma, cheese also offers several health benefits. For instance, due to the presence of lactic acid bacteria, particularly probiotic strains, it exhibits angiotensin-converting enzyme (ACE) inhibitory properties (Kamath et al., 2021). Conjugated linoleic acid (CLA) and phytanic acid, both found in cheese, are two fatty acids known for their positive effects on health. The protein content of cheese can vary between 3% and 40%, depending on the type. During production, the breakdown of proteins leads to the formation of peptides with known biological activities such as antihypertensive, antioxidant, and anti-inflammatory effects. Cheese is also rich in vitamins A, riboflavin, and B12. Its high fat content makes it a suitable vehicle for vitamin D supplementation. Additionally, cheese is a significant source of calcium and contains other essential minerals such as iron, zinc, and selenium (Callaghan et al., 2017).

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Several studies have shown that probiotic microorganisms, which are found in high concentrations in cheese, positively influence flavor and aroma while also shortening the ripening period. This offers significant economic advantages. Fermented milk beverages and yogurt are prominent in the development of probiotic dairy products, yet they are limited by their short shelf lives. In contrast, the longer shelf life and ripening period of cheese make it a more advantageous carrier in this context. The physicochemical properties of cheese provide a favorable environment for probiotics, allowing them to survive longer during both production and storage compared to other dairy products. These advantages are associated with factors such as the fat content, pH level, storage conditions, and low oxygen environment of cheese.

As a concentrated and nutritious food, cheese contains higher levels of fat, protein, and minerals compared to milk, and it is also more easily digestible. The proteins in cheese have high biological value, thereby enhancing its nutritional quality. These proteins possess superior nutritional value compared to plant-based proteins and provide a well-balanced source of essential amino acids required by the human body (Özbay & Tüysüz, 2024).

The term 'artisan' refers to products made with specialized manual techniques, often by individual craftsmen. In the context of cheese, this term evokes traditional Turkish varieties such as Divle Obruk and Kars Gruyère, which are recognized internationally for their distinct qualities (Negizözen & Yılmaz, 2020). This study aims to apply the lyophilization (freeze-drying) method to artisan Turkish cheeses in order to extend their shelf life and contribute to product diversity in the field of gastronomy.

2. Conceptual Framework

Cheese is believed to have originated approximately 8,000 years ago in the "Fertile Crescent" region, located between the Tigris and Euphrates rivers in present-day Iraq. With the advent of the Agricultural Revolution, the domestication of plants and animals began, and humans quickly recognized the nutritional potential of milk produced by domesticated animals. However, milk not only served as a valuable nutritional resource but also provided an ideal medium for bacterial growth. Certain bacteria used the lactose in milk as an energy source, producing lactic acid in the process; under hot and dry climatic conditions, this created favorable conditions for early forms of milk preservation, including spontaneous fermentation and primitive drying techniques. When sufficient acid was produced, caseins, the main proteins in milk, coagulated at their isoelectric point, forming a gel, which led to the accidental emergence of the first fermented dairy products (Fox, 1993). Although this topic is not known yet, it is widely accepted that cheese was first made in Mesopotamia. The word for cheese was incorporated into the Turkish language with the migration of Turks to Anatolia (Bekiroğlu, 2019).

Although cheese production methods vary from region to region, the basic process involves the coagulation of casein through the use of enzymes or starter cultures (microbial cultures added to initiate fermentation with desired characteristics). During this process, the resulting whey is separated, and the remaining curd is compressed to form the desired structure. Key factors that differentiate cheese types include the use and characteristics of starter cultures, ripening conditions, milk composition, and the diet of the animals. As a result, each region has developed its own distinctive cheese varieties.

2.1. Cheese in Türkiye

Türkiye is one of the notable countries in cheese production, thanks to its diverse climatic conditions, vegetation, and geographical landscape. The country spans a wide range of climatic conditions, from the humid climate of the Black Sea region in the north to the high mountains in the east. These differences are reflected in the composition and nutritional value of the milk used in cheese production, as well as in the flavor profiles of the cheeses. Nearly every region in Türkiye produces its own varieties of cheese using distinct techniques. Güzeler and Yıldırım (2016) reported the presence of a large variety of local cheese types in Türkiye. However, despite this rich cheese heritage, many traditional varieties are still produced and promoted only within limited regions. In this context, five artisan cheeses, Ezine, Kars Kaşar, Kars Gruyère, Smoked Circassian, and Divle Obruk, stand out as traditional varieties at risk of being forgotten in the face of industrialization and technological advancement.

Geographical indication (GI) practices have emerged as an important mechanism for protecting local products and enhancing their value. A GI safeguards the unique characteristics of a product that are specific to a particular geographical area and emphasizes its distinctive qualities derived from regional knowledge, traditional production techniques, and cultural heritage. In Türkiye, the registration of geographical indications is overseen by the Turkish Patent and Trademark Office (TürkPatent), a process

initiated with the enactment of Decree Law No. 555 in 1995. As of 2024, a total of 932 products have been registered with geographical indications in Türkiye, 40 of which are cheeses (TürkPatent, 2024). While some of these cheeses, such as Ezine, Erzincan Tulum, and Kars Kaşar, are well known and widely consumed across the country, others are produced and consumed only in specific regions (Güzeler & Koboyeva, 2020). Geographical indication status enables the protection of these products, prevents counterfeiting, and facilitates their promotion based on their authentic qualities.

In addition to the legal protection they provide, geographical indications (GIs) also carry significant economic and touristic value. The registration of GI products has led to revitalization in local economies and increased support for regional producers. Furthermore, GI-certified products can contribute to regional development by becoming focal points of tourism. For example, cheese producers in countries such as France and Italy have positioned their GI-labeled cheeses as attractions not only for local consumers but also for tourists, thereby securing a strong presence in the global market (Anonymous, 2015). Türkiye holds similar potential and is emerging as an important destination in the field of gastronomic tourism through its GI-certified cheese varieties. Notably, Edirne white cheese produced in the Thrace region, Ezine cheese from the Marmara region, and Erzincan Tulum cheese from Eastern Anatolia are among the GI-labeled products that attract attention within the scope of gastronomy tourism (Küpelikılınç, 2020).

The development of gastronomy tourism presents a significant opportunity for promoting Türkiye's rich diversity of local cheeses. Tourists who travel to experience regional flavors also engage with the cultural fabric of the area, thereby enriching their overall experience. Gastronomy tourism not only offers a taste-centered journey but also supports the preservation and sustainability of cultural heritage. Türkiye's cheese diversity is being introduced to broader audiences through geographical indication schemes, contributing to both national recognition and economic development. In addition to revitalizing local economies, GI-certified cheeses also have the potential to enhance the global visibility of Turkish cheese varieties (Hastaoğlu et al., 2021). As of now, a total of 40 cheeses have been registered in Türkiye by TürkPatent, including 15 as designation of origin (one of which is registered internationally) and 25 as geographical indication of source (Table 1).

2.1.1. Ezine Cheese

White cheese is the most widely produced and consumed cheese type in Türkiye and also holds the highest economic value. Although it can be produced in nearly all regions of the country, it is especially common in Thrace, Marmara, Aegean, and Central Anatolia. Ezine cheese, in particular, is a well-known and widely preferred white cheese that is produced on a large scale in Türkiye. This cheese is made from the milk of animals that graze within the geographically defined northern and western zones of the Kaz Mountains, where they feed on endemic plants such as marjoram, savory, sage, hairy mint, and thyme. Its production requires a specific milk mixture consisting of at least 40% goat's milk, 35–45% sheep's milk, and no more than 25% cow's milk. Ezine cheese has a pale yellowish-white color, medium firmness, and a non-brittle texture with few and small holes. It is classified as full-fat brined white cheese (Çakmakçı & Salık, 2021).

The production of Ezine cheese begins with pasteurizing the mixed milk—composed of goat, sheep, and cow milk in specific ratios—at 60–70 °C for 30 minutes. After pasteurization, the milk is coagulated using rennet derived from calf stomachs at a temperature of 30–35 °C. Once the curd forms, it is cut to separate the whey. The curd is then placed into special cheese molds lined with cheesecloth, and pressure is applied to accelerate the drainage process. After being cut into blocks, the curds are placed in brine containing sea salt until the desired flavor and aroma are developed. The cheeses are then removed from the brine and arranged in a single layer inside metal tins. Dry salt is sprinkled on top, and the cheeses are left to rest for 10–12 hours. After this resting phase, the excess liquid is removed, and the tins are sealed airtight with added brine (Ilgar, 2019).

The milk used in Ezine cheese production comes from specific breeds of animals. These include Holstein (Black and White) dairy cows; Sakız, Dalgıç, Tahirova, and Sakız-Dalgıç crossbred sheep; and Karakeçi (hair goat) and Turkish Saanen goats. The milk from these selected breeds plays a crucial role in creating the distinctive taste and quality of Ezine cheese. Similar cheeses with comparable characteristics are produced in other countries under different names—for instance, Bjalo Salamureno Sirene in Bulgaria, Feta in Greece, Domiati in Egypt, and Telemea in Romania. Each of these reflects the cultural heritage of its respective region through unique production techniques and flavor profiles (Özbay & Tüysüz, 2024). Ezine cheese has a creamy flavor derived from milk fat and a cooked

Table 1. List of geographically indicated cheeses registered in Türkiye

Cheese Name	App. Date	Regist. Number	Regist. Date	Registration Type	Province
Antakya Carra	19.07.2019	679	18.02.2021	Designation of Origin	Hatay
Antakya Künefelik	28.08.2018	979	22.12.2021	Geographical Indication	Hatay
Antep Cheese / Gaziantep	20.04.2017	356	04.06.2018	Geographical Indication	Gaziantep
Atlantı Dededağ Tulum	02.04.2021	1327	26.01.2023	Geographical Indication	Konya
Ağrı Tulum Cheese	05.11.2021	1565	29.03.2024	Geographical Indication	Ağrı
Bergama Tulum	15.01.2020	1597	06.06.2024	Geographical Indication	İzmir
Diyarbakır Örgü	15.02.2010	170	22.02.2013	Geographical Indication	Diyarbakır
Edirne White	10.05.2004	93	23.10.2007	Designation of Origin	Edirne
Elbistan Kelle	16.06.2023	1500	22.11.2023	Geographical Indication	Kahramanmaraş
Erzincan Tulum	21.08.2000	30	29.08.2001	Designation of Origin	Erzincan
Erzurum Civil	17.12.2007	116	11.09.2009	Geographical Indication	Erzurum
Erzurum Moldy Civil	01.03.2010	164	30.11.2012	Geographical Indication	Erzurum
Ezine	24.02.2006	86	10.04.2007	Designation of Origin	Çanakkale
Gümüşhane Deleme	14.03.2018	694	17.03.2021	Geographical Indication	Gümüşhane
Hanak String	08.04.2020	1563	08.04.2024	Designation of Origin	Ardahan
Karaman Divle Obruğu Tulum	16.06.2015	270	08.12.2017	Designation of Origin	Karaman
Kargı Tulum	08.08.2018	933	26.10.2021	Designation of Origin	Çorum
Kars Kaşar	14.02.2014	190	12.10.2015	Designation of Origin	Kars
Kars Gruyere	24.09.2021	1640	17.09.2024	Geographical Indication	Kars
Kırklareli White	06.07.2018	636	23.12.2020	Designation of Origin	Kırklareli
Kırklareli Aged Kashar	05.02.2022	1408	11.07.2023	Designation of Origin	Kırklareli
Malatya Cheese	28.10.2020	1164	06.07.2022	Geographical Indication	Malatya
Malkara Aged Kashar	14.09.2010	261	06.12.2017	Designation of Origin	Tekirdağ
Manyas Kelle	12.09.2019	628	16.12.2020	Geographical Indication	Balıkesir
Maraş Parmak / Sıkma	19.09.2016	727	17.04.2021	Geographical Indication	Kahramanmaraş
Mengen	13.11.2018	1482	06.10.2023	Geographical Indication	Bolu
Pınarbaşı Uzunyayla Circassian	06.02.2020	724	14.04.2021	Designation of Origin	Kayseri
Sakarya Abkhaz	02.07.2020	746	03.05.2021	Geographical Indication	Sakarya
Savaştepe Mihaliç Kelle	29.11.2022	1405	10.07.2023	Geographical Indication	Balıkesir
Talas Çörek Otlu Çömlek	23.11.2022	1560	12.03.2024	Geographical Indication	Kayseri
Urfa Cheese / Şanlıurfa	01.10.2018	807	27.07.2021	Geographical Indication	Şanlıurfa
Vakfıkebir Külek	25.06.2018	764	25.05.2021	Geographical Indication	Trabzon
Van Herb	28.07.2017	405	31.12.2018	Designation of Origin	Van
Yozgat Çanak (Bowl)	14.03.2011	281	18.12.2017	Geographical Indication	Yozgat
Yüksekova Çirek	11.02.2020	1086	18.04.2022	Geographical Indication	Hakkâri
Çankırı Küpecik	29.12.2017	907	01.10.2021	Geographical Indication	Çankırı
Çayeli Koloti	20.11.2020	1199	24.08.2022	Designation of Origin	Rize
İvrindi Kelle	16.02.2021	1025	09.02.2022	Geographical Indication	Balıkesir
İzmir Tulum	15.06.2010	1006	24.01.2022	Geographical Indication	İzmir

milk aroma resulting from heat treatment. The use of sea salt in its production prevents the cheese from melting and disintegrating, while also facilitating the release of moisture during maturation. Additionally, the cheese is produced exclusively with natural rennet (Subaşı, 2021).

2.1.2. Kars Kaşar Cheese

Kaşar cheese, known for its sliceable and semi-hard texture, belongs to the pasta filata cheese group. The defining characteristic of this group is that the curd is kneaded after reaching a specific level of acidity by immersing it in hot water. There are various theories regarding the origin of the name “Kaşar.” One suggests that it derives from the Latin word coerceo, meaning "to press under pressure," referring to the squeezing of whey from the curd. Another theory traces it to the Hebrew word kasher (kosher), indicating food that is religiously permissible for Jewish people. It is believed that Kaşar cheese was first produced in Thessaloniki by a Jewish woman, and its origin may be linked to the Balkans and Italy. Larger and harder versions of Kaşar are referred to as Caciocavallo in Italy. Similar cheeses are found under different names in other countries: Kaskaval in Bulgaria, Kačkavalj in the former Yugoslavia, Caşcaval in Romania, Kasseri in Greece, Kaskaval in Hungary, Kavkazskij syr in Russia, and Rumi in Egypt. Additionally, Italy's Provolone and Mozzarella, France’s Fromage à pâte filée, and England’s Cheddar also share similarities with Kaşar in terms of production techniques (Aydemir, 2010).

Kaşar cheese began to be produced by Turks after their migration to Anatolia. Traditionally, the highest quality Kaşar is made from sheep's milk, although today it is commonly produced using a mixture of cow and sheep milk. In some regions, goat milk is also included. Kaşar cheeses produced in Eastern Anatolia are generally smaller in size, weighing around 6 kilograms, while those produced in the Thrace region are larger, typically weighing between 11 and 12 kilograms (Üçüncü, 2004, as cited in Aydemir, 2010).

The production of Kaşar cheese in Kars dates back to the early years of the Turkish Republic. It was first produced in 1926 in the village of Kümbetli by workers under Filibeli Fehmi Bey and Süleyman Bey. The milk is filtered through several layers of cloth immediately after milking and then transported to the production facility. Its temperature is adjusted to 27–33 °C, and a commercial rennet is added to initiate coagulation. After gentle stirring, the curd is covered with cheesecloth. Coagulation takes 40–90 minutes, after which the curd is cut into rice-sized pieces. After resting for 5–10 minutes, a cheesecloth is placed over the vat, and the whey is drained. The remaining curd is transferred to straining cloths, tied at four corners, and hung from a rod to drain. The bundle is then pressed between wooden boards for 3–4 hours. The curd is reshaped into squares and left under pressure for another 3–8 hours in rooms kept at 16–25 °C. After pressing, the curd is removed from the cloth, cut into large pieces, and left to ferment. Completion of fermentation is determined by testing whether the curd becomes pliable and sticks together when placed in hot water. Once this condition is met, the curd is considered ready for kneading. The fermented curd is placed into perforated metal baskets and boiled for 2–3 minutes in 75 °C water containing 5% salt. The cheese is stirred with wooden paddles to remove excess water, then kneaded and folded by hand on the processing table. Air bubbles are pressed out manually, and the cheese is shaped into loaves. A technique called “belly tying” is applied, where the base of each cheese is twisted and pinched off using thumbs. The formed cheeses are placed into molds while still warm and pierced with metal rods to release trapped moisture. They are flipped regularly until cooled, then kept in the molds for one more day. After unmolding, they are moved to a salting room, where coarse salt is applied for two days, and the cheeses are turned frequently to facilitate maturation (Aydemir, 2010).

2.1.3. Kars Gruyère Cheese

Gruyère cheese is a European-origin variety that holds a notable economic and cultural place among Türkiye’s domestically produced cheeses. With increasing domestic demand, both its production and import have been rising steadily each year. It is primarily produced in large quantities in the Eastern Anatolia Region, especially in and around the province of Kars. It is known that Gruyère was introduced to Kars through the Russians, who also taught the local population how to produce it (Ulutaş et al., 1993). The first Gruyère cheese production facility in Anatolia was established in the village of Boğatepe by a Swiss cheesemaker who had settled there. Subsequently, Swiss and German cheese experts brought in by the Russians trained the local people in cheese-making, leading to the establishment of numerous production sites throughout the Kars–Ardahan region. After the Bolshevik Revolution in 1917 and the withdrawal of the Russian army, many of these skilled individuals emigrated, posing a risk to the continuity of local Gruyère-making knowledge. However, ethnic groups such as the Kıçak, Karapapak, and Karakalpak, who

fled the Russian occupation and settled in the Ardahan–Kars area, were able to continue production using their previous experience and training they received from local Malakans, thereby preserving this tradition to the present day (Arınç, 2018).

Kars Gruyère cheese closely resembles Swiss Emmental in terms of hardness, production method, and technology used. Its name is derived from the town of Gruyères in the Swiss canton of Fribourg. While Germans and Swiss call it "Greyezer," the cheese is referred to as "Gravyer" in Türkiye, "Groyer" in Austria, "Graviera" in Greece, "Grojer" in Yugoslavia and Poland, and "Perniön Gruyere" in Finland. Gruyère is known for its complex production process and is among the high-nutritional-value cheeses that undergo one year of maturation. In Boğatepe village, around 18,000 liters of milk are collected during the lactation season, with approximately 10,000 liters allocated for Gruyère production. Since it takes about 17 kg of milk to produce 1 kg of Gruyère, over half a ton of cheese is produced daily in Boğatepe. The distinctive flavor and color of Kars Gruyère come from the milk of Zavot cows, a breed whose milk contains about 4% fat, contributing to the cheese's signature yellow hue and aromatic flavor. The production process of Gruyère cheese differs significantly from that of Kaşar cheese, as it involves longer kneading, greater milk quantity, and more extended brining durations (Derinalp-Çanakçı, 2020). In the initial step, milk is heated to 34–35 °C and coagulated using natural rennet. After about 45 minutes, the resulting curd is cut into rice-sized particles using wooden cutters and left to rest for approximately 10 minutes. The curd is then stirred and cooked at 57 °C for 40–45 minutes. It is transferred to double-layered cheesecloths and pressed with applied weight. The pressing stage continues with the cheeses resting for 24 hours. After this, the top and bottom surfaces of the cheeses are salted and left for one day. This is followed by five days of dry salting and 5–7 days of brine salting.

The maturation process begins with the cheeses being placed on wooden shelves in sauna-like rooms maintained at 28–32 °C and 85–90% humidity for 3 to 4 weeks. During this phase, "eye" formation (holes) and internal swelling are observed. Finally, the cheeses are ripened at 12–13 °C for 90–150 days. Kars Gruyère can be stored and consumed for more than three years (Güzeler & Koboyeva, 2020).

2.1.4. Smoked Circassian (İsli Çerkes) Cheese

Circassian cheese is traditionally produced by Circassian families in regions of Anatolia where Circassian communities are densely populated, such as Sinop, Düzce, Bolu, Sakarya, Balıkesir, Bursa, Çanakkale, Biga, Hendek, and Gönen. It is also produced in the ancestral lands of Circassians in the Caucasus. Circassian cheese is also believed to be produced in countries with Circassian communities, such as Syria, Jordan, and Israel. Although there is no precise historical documentation on the origin of Circassian cheese, it is estimated to have been produced for at least 150 years. In the past, Circassian families commonly made their own cheeses at home; however, due to changing social conditions over the last 20–25 years, home-based cheese production has declined (Ayar et al., 2015).

Traditional Circassian cheese is usually made from the milk of cows and sheep raised by the families themselves. Because production takes place at the household level, large pots called şuvan are commonly used to heat the milk. In some villages, about 5–6 liters of milk are heated to boiling and then cooled to the proper temperature for coagulation. In other areas, a spoon or ladle of rennet is added as the milk begins to boil, and the milk continues to simmer briefly. The rennet used may be previously soured whey, tart yogurt whey, or commercial rennet. Once added to the milk, the mixture is not stirred, and curdling occurs within a short time. To facilitate curd formation, a small amount of citric acid dissolved in water is sometimes added. When coagulation is complete, lumps form on the surface and the whey becomes clear. At this stage, the curd is scooped out with a perforated ladle and placed into baskets made from woven willow branches, typically 30 cm in diameter and 5–10 cm in height. Alternatively, a portion of the whey may be removed with a ladle, and the basket is dipped directly into the pot to collect the curd. The curd is left in the basket overnight to drain and take shape. The next day, salt is applied first to one side, then the other. On the third day, the cheese is washed with cold water and made ready for fresh consumption (Aydınol, 2010). The cheese is then stored in a cool place for several days to allow the outer surface to harden and form a rind. Traditionally, this cheese was dried in the fireplaces of village homes, but today it is produced in specially designed processing rooms. The cheese is not exposed directly to flame; rather, it is placed on racks and wrapped in cloth, positioned in the hottest part of the smoke, and left to mature until the desired level of smokiness is achieved. The type of wood used in the smoking process is critical: smoke from dry mulberry and acacia wood creates the optimal environment for flavoring the cheese (Turkiye Kültür Portalı, n.d.).

2.1.5. Divle Obruk Tulum Cheese

Divle Obruk tulum cheese is produced in the village of Üç Harman, located in the Ayrancı district of Karaman province in Türkiye. The cheese takes its name from the Divle Obruk (a karstic cave), where it is aged and acquires its unique characteristics. Entirely indigenous to this region, the cheese owes its distinctive features to the specific environmental and geographical conditions of the area (Toklu & Pekerşen, 2019). The curd, made from a mixture of goat's milk (10%), cow's milk (10%), and predominantly sheep's milk (80%) sourced from animals grazing on highland pastures and meadows, is packed into tulums (traditional bags) made from goat or lamb skin. The cheese is then aged in the Divle Obruk cave for five to six months before it becomes ready for consumption. During the periods when animals cannot graze, they are fed with roughage such as dried alfalfa or straw. This special feeding and production method contributes to the cheese's characteristic taste and texture (Çakmakçı & Salık, 2021).

Tulum cheese is generally made from raw milk and matured over a period of 3 to 7 months in caves, cellars, or specially controlled storage environments. The texture of Divle tulum cheese is non-porous, with a sharp odor and a pungent, slightly acrid flavor. The full-fat curd, derived from sheep's milk, is tightly packed into airtight sheep or goat skins. Initially, the cheeses are wrapped in cloth and dried in a cool environment for 9–10 days before the tulums are sealed. For maturation, the tulums are transferred to the Divle cave. They are carefully placed on sloped surfaces to prevent contact with one another. With over 300 years of history, the Divle Obruk cave possesses a unique karstic structure that plays a crucial role in the cheese's maturation. Within this environment, the cheese ages at a stable temperature of 4–5 °C and 80% humidity. The outer surface of the cheese, in contact with the skin, turns a dirty gray, while the interior remains cream or porcelain white. Approximately one month after being placed in the cave, natural molds in blue, white, and red hues begin to grow on the cheese surface. These molds typically dry out by September or October, and as the cheese continues to mature, the red mold layer naturally begins to peel away. This distinctive process contributes to the cheese's complex aroma and texture (Toklu & Pekerşen, 2019).

2.2. Lyophilization (Freeze-Drying)

Lyophilization is a stabilization technique in which substances are first frozen and then subjected to sublimation and desorption processes to reduce the solvent content to a minimum, thereby preventing biological or chemical reactions. This method, which combines cryopreservation and freeze-drying technologies, enables long-term storage of substances. Lyophilization is commonly used for preserving biological materials, allowing products to remain dry and biologically active, resulting in extended shelf life and easy rehydration (Karagül & Altuntaş, 2018).

Today, freeze-drying is widely employed in the food and pharmaceutical industries (e.g., vaccines, proteins, peptides, colloidal carriers, etc.) for drying high-value products and improving their stability, despite its high cost and energy consumption. One of the main reasons for preferring this method in food processing is its ability to produce high-quality products with excellent rehydration properties and prolonged shelf life (Özdemir, 2021). Water in products can exist either in a free form or bound to the matrix through various interactions. While free water freezes at 0 °C, bound water does not behave in the same manner. The objective of freeze-drying is to remove all ice (frozen water) and a certain amount of bound water. This is a multi-stage and complex process. The freezing phase of the product usually takes place under atmospheric pressure. The primary drying phase (actual lyophilization) involves the sublimation of ice into vapor under low pressure. The secondary drying phase aims to reduce the residual moisture content of the product to the desired final level (Nowak & Jakubczyk, 2020).

Historically, lyophilization dates back to ancient times. The Aztecs and Eskimos used this method to preserve food. Similarly, the Incas applied the same principle for drying meat under the low-oxygen atmospheric conditions and sunlight exposure of the Altiplano plains in the Andes Mountains centuries ago. Toward the end of the 1880s, the technique began to be tested in laboratory settings, and its fundamental principles were gradually understood. By 1890, it was reported that tissues could be dried at approximately –20 °C and subatmospheric pressure. In 1905, researchers demonstrated that animal tissues could be dried under a pressure 1 atm lower by using a chemical pump. However, lyophilization only began to see practical application in the 1930s, when it became necessary to process heat-sensitive antibiotics and blood products (Karagül & Altuntaş, 2018).

Freeze-drying consists of three fundamental stages: initial freezing (solidification), primary drying (sublimation of ice), and secondary drying (desorption of unfrozen water) (Özdemir, 2021).

2.2.1. Freezing

Among all stages of lyophilization, the freezing phase is the most critical. This step prevents structural collapse, foaming, and shrinkage of the product. It also helps maintain the physical appearance, solubility, and essential characteristics of the material, while minimizing temperature-sensitive reactions. For optimal pre-freezing, both the solvent (water) and solutes in the solution must be fully crystallized. Crystallization determines the microstructure of the product during the freezing stage. Reaching a suitable freezing temperature aligned with the chemical nature of the substance is essential. The freezing temperature and the final temperature of the material directly affect the quality of the dried product. Rapid freezing promotes the formation of small ice crystals. The higher the density of these crystals, the better the preservation of the product structure. Successfully completing the freezing stage ensures a high-quality final product (Ergün, 2015).

2.2.2. Primary Drying

After freezing, the condenser is cooled and the system temperature must be below –60 °C (Cevher, 2016). The pressure inside the freeze-dryer chamber is reduced via vacuum pumps. In pharmaceutical applications, depending on the target product temperature and container system, chamber pressure is typically maintained between 30 and 300 mTorr. For sublimation to occur and for water vapor to reach the condenser, the chamber pressure must remain below the vapor pressure of the ice on the sublimation surface. When this condition is met, sublimation begins: ice in the outermost frozen layers directly converts to vapor. Among the most crucial variables in lyophilization, product temperature—especially at the sublimation surface—is key. Lower product temperatures and the corresponding low vapor pressure of ice can significantly prolong drying. Research shows that a mere 1 °C increase in product temperature can shorten the primary drying time by approximately 13% (Gaidhani et al., 2015).

During primary drying, vapor generated from ice sublimation and bound water desorption travels through the porous structure of the frozen matrix and is removed via the vacuum system. The water vapor condenses and accumulates as ice on the condenser surface. Once all the frozen water has been removed from the product, the primary drying phase is considered complete (Sadıkoğlu & Özdemir, 2003).

2.2.3. Secondary Drying

Even after primary drying, water molecules may remain adsorbed on the product surface. Although the product may appear dry, its residual moisture content can still exceed 7–8%, which is insufficient to ensure long-term stability of most biological materials. Therefore, a secondary drying phase is implemented to further reduce moisture content without compromising product stability.

Secondary drying reduces residual water while maintaining the cake structure and desired product quality (Ergün, 2015). Unlike primary drying, where low shelf temperatures and moderate vacuum are used, secondary drying is achieved by increasing shelf temperature while minimizing chamber pressure to facilitate desorption. However, shelf temperatures must not be raised excessively, as high temperatures can cause protein polymerization or degradation of biological components. The duration of secondary drying is typically one-third to one-half of the primary drying phase. During this phase, since no ice remains and risks such as “melting traces” are eliminated, the product can withstand higher heat exposure. However, the remaining water is more tightly bound to the matrix, requiring more energy for removal. Traditionally, maximum vacuum levels are employed to enhance desorption (Gaidhani et al., 2015). For temperature-sensitive products, shelf temperatures between 10–35 °C are commonly used, whereas for less sensitive products, 50 °C and above may be applied. By the end of secondary drying, the product’s final moisture content, storage conditions, and duration directly affect its quality. For example, some products retain quality for extended periods at –20 °C, but may degrade within a year if stored at 37 °C (Sadıkoğlu & Özdemir, 2003).

2.3. Lyophilization in Cheese Drying: Technological and Functional Approaches

Ferreira et al. (2017) studied Marajó cheese, developed from raw buffalo milk in the Amazon region of Brazil, using two different drying techniques: spray drying and freeze-drying. The aim of the study was to develop a probiotic starter culture using both drying methods. The results showed that spray-dried samples exhibited higher survival rates and better technological performance. Cultures preserved via spray drying retained approximately 10^9 CFU/g after 60 days at 4 °C, while those subjected to freeze-drying dropped to around 10^7 CFU/g.

Büyüksırıt-Bedir and Kuleaşan (2019) freeze-dried White, Kaşar, and Tulum cheeses and analyzed them. On the first day, physicochemical properties of the samples were examined to establish baseline quality characteristics. White cheese had the highest moisture and salt content, while Tulum cheese stood out with the

highest titratable acidity and fat content. The freeze-dried samples were stored at room temperature for six months, and microbial populations were monitored. Results indicated that Tulum cheese generally had higher microbial counts. The total bacterial count in Tulum was 7.71 ± 0.10 log CFU/g, compared to 5.70 ± 0.07 log CFU/g in White cheese.

Köprüalan et al. (2020) experimentally studied low-fat white cheese dried using three different methods: hot air drying (at 50, 60, and 70 °C with 1.8 m/s airflow), microwave drying (180, 360, 540 W), and freeze-drying (0.2, 0.15, 0.1 mbar). The drying rate of white cheese increased with higher drying temperature, microwave power, and reduced vacuum pressure, thereby shortening the drying time. Measurements of parameters such as temperature, pressure, time, weight, and power were recorded for all three methods. Freeze-drying required slightly less time compared to hot air drying.

Cao et al. (2024) tracked the development of cheese made from pasteurized milk and used lyophilization to dry the cheese samples. Differential scanning calorimetry (DSC), water activity, and moisture content measurements were performed on the dried samples to assess thermal and hygroscopic behavior.

Takma et al. (2024) produced a dried white cheese powder using freeze-drying, incorporating whey protein isolate (WPI) and carboxymethyl cellulose (CMC), and used it in bread formulations. Bread quality characteristics were evaluated by replacing wheat flour with 10%, 15%, and 20% cheese powder. CMC-containing powders were found to reduce water activity, thus potentially contributing to quality preservation during shelf life. The texture properties of bread were significantly affected by the level of cheese powder. The study concluded that white cheese nearing its expiration date could be converted into powder via freeze-drying and repurposed in the food industry as a sustainable, value-added product.

Golzarijalal et al. (2024) employed freeze-drying to preserve the functionality of mozzarella cheese. Six mozzarella samples differing in block size and composition were analyzed both experimentally and numerically during freezing and thawing. A numerical model based on the enthalpy method was developed to solve heat and mass transfer equations. Reducing the NaCl content from 1.34% to 0.07% significantly shifted the phase change temperature from ~4.5 °C to −3 °C. Simulation results showed minimal salt migration in free moisture at a depth of 1–2 cm during freezing, while an 8–10% increase in salt concentration was observed at the block center. A response surface methodology (RSM) was used to generate a predictive model capable of estimating freezing and thawing times under varying block sizes and processing conditions. The RSM model indicated that increased salt content extended freezing time but shortened thawing time.

2. Material and Methods

3.1. Materials

The production sites where the cheeses were manufactured in accordance with traditional methods were identified, and the cheeses were procured from selected appropriate locations (Figure 1). The experimental procedures of this study were approved by the Social Sciences Ethics Committee of Başkent University (Approval No: E-52056571-605.99-224222, Date: 14.04.2023).

Figure 1. Images of the artisan cheeses procured from the market

The differences in moisture content among the cheeses were taken into consideration, and cutting techniques were applied accordingly. Multiple rounds of drying were performed in an effort to achieve optimal results. Except for Ezine cheese, all other cheeses were grated using a regular or mandoline grater. Since Ezine cheese is more susceptible to crumbling, it was cut into cubes of approximately 5 mm.

3.2. Freeze-drying procedure

After an initial 24-hour freezing process at –18 °C, the cheese samples were freeze-dried for 24 hours at –70 °C under vacuum using a freeze-dryer (Teknosem, Toros TRS 4-4 model, Türkiye). The drying procedure was repeated when necessary, based on the quality of the final product.

3.3. Sensory analysis

In this study, an experimental research method was employed. Five types of artisan cheeses dried using the lyophilization method were evaluated through sensory analysis by a panel of 10 trained panelists. The panel size and sample number required for the sensory evaluation and consumer preference testing were determined based on the study by Altuğ-Onoğur and Elmacı (2019). The panelists were asked to rate the cheese samples based on the following criteria: color, odor, texture, cheese crispness, aroma and flavor characteristics, mouthfeel, difference from the original form, and overall assessment, using a scale from 1 (very poor) to 5 (very good). The collected data were analyzed by calculating means and standard deviations, and the results were visualized using a radar chart.

3. Results and Discussion

The appearance of the freeze-dried cheese samples is presented in Figure 2.

Ezine Cheese | Kars Kaşar Cheese

Divle Obruk Tulum | Kars Gruyère

Smoked Circassian

Figure 2. Individual views of the cheeses after freeze-drying

Due to its composition containing three types of milk and a relatively high moisture content, Ezine cheese took longer to dry compared to the other cheese samples. In panelist evaluations, it generally received high scores for color and odor, but was perceived as noticeably different from its original form. The low mouthfeel score was interpreted by some panelists as a result of moisture loss during drying and the lower fat content of goat's milk. Another panelist noted that the removal of moisture actually enhanced the aroma of the cheese. The radar chart representing the sensory evaluation results for Ezine cheese is presented in Figure 3.

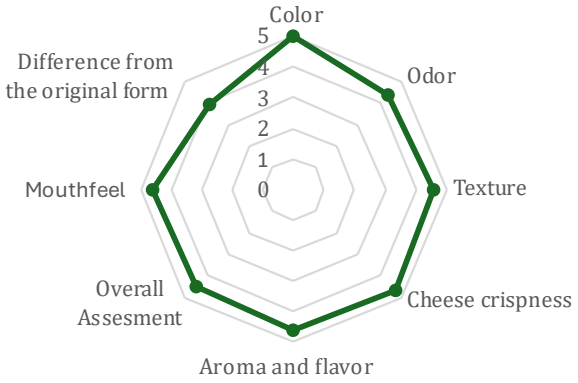

Figure 3. Radar Chart of the Sensory Evaluation for Ezine Cheese

When evaluated in terms of quality criteria, the smoked cheese generally received high scores from the panelists. However, one panelist stated that the original structure of the cheese had deteriorated and, considering the other criteria as well, reported a low overall preference. The radar chart representing the sensory evaluation of the smoked cheese is presented in Figure 4.

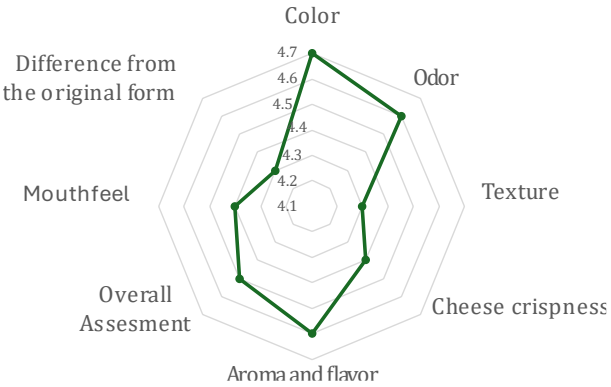

Figure 4. Radar Chart of the Sensory Evaluation for Smoked Cheese

Due to its low moisture content and high fat content, Kars Kaşar cheese achieved the desired level of crispness and a strong aroma. No significant color deterioration was observed following the drying process. Panelists and practitioners considered it a favorable option for introducing a healthy snack and an artisan cheese to households in an alternative form. The radar chart representing the sensory evaluation of Kars Kaşar cheese is shown in Figure 5.

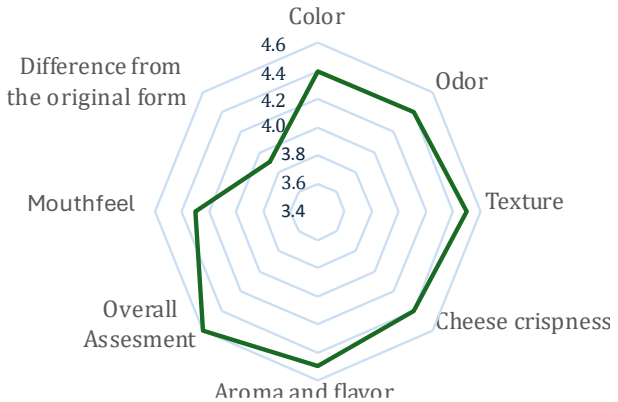

Figure 5. Radar Chart of the Sensory Evaluation for Kars Kaşar Cheese

Kars Gruyère, known for its long and labor-intensive production process, is one of Türkiye's strongly flavored cheeses with limited production and consumption due to factors such as modernization and industrialization. After the drying process, its color slightly lightened and, due to the shape of the cuts, it was sometimes mistaken for Kars Kaşar. Its characteristic holes also disappeared. Panelists noted that the already intense flavor of the Gruyère became even more concentrated with the loss of moisture, which altered its original character. One panelist remarked that the crispness found in Kaşar was lacking, and two other panelists gave it lower scores for overall acceptability. The radar chart representing the sensory evaluation of Kars Gruyère is presented in Figure 6.

When evaluated based on quality criteria, Divle Obruk cheese received high scores compared to the other four cheeses. The lowest score was given by one panelist for texture, while two panelists rated it lower in terms of difference from the original form. One panelist suggested that the cheese might taste even better if processed with additional aromatic ingredients. Due to seasonal limitations in production and the extended ripening period required for this cheese, freeze-drying presents a promising solution for making it available year-round. It also offers potential as a domestic alternative to imported cheeses. As a product carrying local and cultural significance, Divle Obruk cheese has the potential to remain present on tables for longer periods and to gain wider recognition in the field of gastronomy. The radar chart of the sensory evaluation results for Divle Obruk cheese is presented in Figure 7.

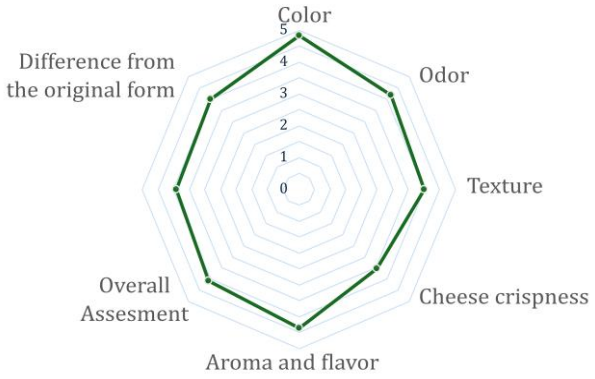

Figure 6. Radar Chart of the Sensory Evaluation for Kars Gruyère Cheese

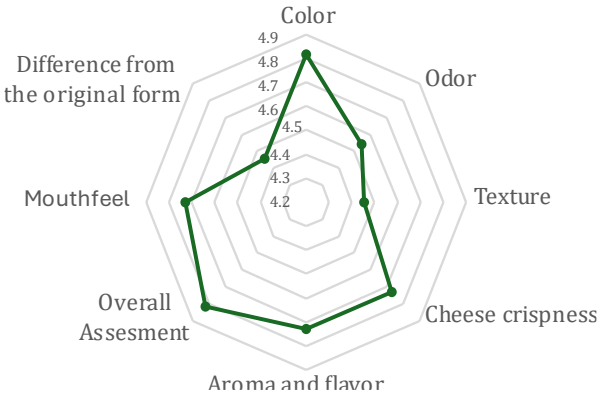

Figure 7. Radar Chart of the Sensory Evaluation for Divle Obruk Cheese

*All sensory attributes were evaluated on a 5-point scale (1 = very poor / least desirable, 5 = very good / most desirable).

Based on these results, all cheese samples received above-average scores in sensory evaluation. These findings indicate that if properly introduced to the market, such cheese products may be well-received by consumers and generate demand.

In their study on low-fat white cheese, Köprüalan et al. (2022) investigated the application of freeze-drying and microwave drying under various conditions prior to explosion puffing drying. The aim was to determine the most suitable processing parameters among alternative drying techniques. Their findings indicated that the dried cheese possessed high sensory quality and could be considered a nutritious snack product.

Table 2. Sensory Evaluation Results of the Cheeses

Sensorial Properties	*Ezine Cheese*	*Smoked Circassian Cheese*	*Kars Kaşar Cheese*	*Kars Gruyère Cheese*	*Divle Obruk Tulum Cheese*
Color	5.00±0.00	4.70±0.48	4.40±0.84	4.82±0.40	4.82±0.40
Odor	4.40±0.97	4.60±0.70	4.40±0.84	4.18±1.08	4.55±1.04
Texture	4.60±0.70	4.30±1.06	4.50±0.71	4.00±1.18	4.45±1.04
Cheese Crispness	4.70±0.48	4.40±0.52	4.40±0.52	3.55±0.69	4.73±0.47
Aroma–Flavor Characteristics	4.60±0.97	4.60±0.70	4.50±0.71	4.36±0.81	4.73±0.47
Overall Acceptability	4.50±1.27	4.50±0.71	4.60±0.70	4.09±0.94	4.82±0.40
Mouthfeel	4.60±0.70	4.40±0.70	4.30±1.06	3.91±0.94	4.73±0.65
Difference from Original	3.99±0.99	4.30±0.95	3.90±0.88	4.00±1.10	4.45±0.82

The results obtained in the present study are consistent with the existing literature, similarly demonstrating that traditional artisan Turkish cheeses exhibit high sensory characteristics.

Koca et al. (2015) reported that the drying temperature significantly affects the drying characteristics of white cheese. In the present study, freeze-drying was applied under specific conditions. Considering that the effectiveness of food processing methods largely depends on the processing parameters and equipment used, it is reasonable to assume that variations in drying conditions would influence both the final product quality and sensory perceptions. Nonetheless, the results presented in Table 2 indicate that the cheeses achieved high levels of sensory acceptability. This suggests that further optimization of drying parameters could potentially lead to even better outcomes.

4. Conclusions

According to the results, Ezine cheese dried more slowly than the other samples due to its composition of three different types of milk and higher moisture content. In panel evaluations, it received generally high scores for color and odor but was perceived as noticeably different from its original form. Divle Obruk cheese received the highest overall scores among the five samples when evaluated based on quality criteria. The smoked cheese was also rated highly in most categories. Kars Kaşar achieved the desired crispness and strong aroma, attributed to its low moisture content and high fat level. Kars Gruyère, which has a long and labor-intensive production process, is a strongly flavored cheese produced and consumed in limited regions due to factors such as modernization and industrialization. After the drying process, a slight lightening in color and the loss of its characteristic holes were observed. Panelists noted that the already intense flavor of Gruyère became even more concentrated with moisture loss. Overall, all cheeses received above-average scores from the panelists (lowest = 4.09 ± 0.94; highest = 4.82 ± 0.40). These findings indicate that it is feasible to consume cheese in an alternative form. If marketed appropriately, such products may attract consumer demand. A limitation of this study is that the products were not packaged. Future studies should explore packaging methods and evaluate the potential for rehydration before consumption.

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Declaration of Competing Interest

The authors declare that they have no financial or non-financial competing interests.

Author's Contributions

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