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Determining the main flavor compounds of cheddar cheese produced from Cow's and Goat's milk through GC-MS analysis and studying protein behavior by SDS-PAGE

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Abstract

Objective

Flavor compounds represent one of the most important attributes of food quality, as they directly affect consumer preference and product acceptance. Aroma and flavor are generated by volatile compounds released during consumption and are essential criteria in evaluating both the sensory and commercial value of foods. Cheese, in special, develops a highly complex aroma that outcomes from a broad range of biochemical and microbiological processes occurring during manufacture and ripening. Cheddar cheese, one of the most broadly consumed varieties, undergoes extensive biochemical transformations that strongly impress its flavor profile. This investigation aimed to identify and describe the major volatile compounds in cheddar cheese made from cow's and goat's milk via gas chromatography–mass spectrometry (GC-MS) analysis and to evaluate proteolysis and protein degradation patterns in both cheese types applying sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS-PAGE).

Materials and methods

Cheddar cheese samples were generated from modified cow's milk (T1) and modified goat's milk (T2). Both cheeses were ripened in controlled chambers at 13 °C for a period of six months. Sampling was carried out at 1, 60, 120, and 180 days of ripening. GC-MS was applied to detect, identify, and classify volatile flavor compounds, while SDS-PAGE was employed to evaluate protein breakdown and quantify the extent of proteolysis.

Results

The GC-MS analysis demonstrated that both cow's and goat's milk cheeses contained diverse volatile compounds, although differences were observed in their concentration and distribution. The compounds were classified into five major groups: esters, carboxylic acids, alcohols, hydrocarbons, and ketones. Specific compounds within these categories were recognized as the main contributors to cheddar cheese flavor. Electrophoresis outcomes disclosed that proteolysis improved progressively during ripening, with meaningful differences observed between cow's and goat's milk cheeses. Goat's milk cheddar showed more pronounced β-casein degradation compared to cow's milk cheddar. The highest level of protein breakdown occurred at 120 days of ripening, after which the rate of degradation stabilized.

Conclusion

The outcomes of this investigation illustrate that the type of milk applied in cheddar cheese manufacture has a substantial impact on both flavor compound composition and protein degradation patterns. Goat's milk cheddar exhibited a more intense proteolysis and distinctive volatile profile compared to cow's milk cheddar, emphasizing the role of milk composition in shaping the sensory characteristics of ripened cheeses.

Keywords: cheddar cheese, flavor compounds, GC-MS, proteolysis, SDS-PAGE

Paper Type: Research Paper.

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Introduction

Milk is a highly complex biological fluid that contains hundreds, and in some cases thousands, of separate molecular species in addition to its main structural components like water, proteins, fats, carbohydrates, and salts (Kadhim and Ibrahim, 2021; Bankole et al., 2023). Owing to this biochemical complexity, milk and its derivatives provide a unique foundation for the development of a broad variety of food products with diverse nutritional and sensory qualities. Among the factors that identify consumer acceptance of milk and dairy products, flavor plays a central role. The flavor of milk and its processed derivatives have long been distinguished as one of the most important criteria affecting consumer preference, purchasing decisions, and ultimately market value (Potts et al., 2017). The sensory perception of flavor in milk is derived from a multifaceted mixture of volatile compounds embedded within the milk matrix. These volatile compounds originate from both intrinsic milk components and biochemical transformations occurring during processing and storage. As such, the analysis of the volatile fraction of milk and dairy products applying modern analytical techniques has become an important method for evaluating product quality and ensuring consumer satisfaction (Povolo et al., 2007). Aroma and flavor perception occur when volatile molecules are released from food during consumption, stimulating olfactory and gustatory receptors. This makes the investigation of flavor compounds essential not only for understanding the biochemical basis of food quality but also for improving the sensory characteristics of dairy products. Cheese, one of the most broadly consumed fermented dairy products, exemplifies the complexity of food flavor formation. The aroma of cheese arises from an intricate interplay of chemical and microbiological processes that act on milk constituents during manufacture and aging (Callon et al., 2005). Via enzymatic and microbial activity, carbohydrates, fats, and proteins are gradually broken down into a broad variety of smaller molecules like free fatty acids, peptides, amino acids, alcohols, aldehydes, ketones, and esters. These compounds interact to form the characteristic aroma profiles of different cheese varieties. Cheese is also highly valued for its nutritional properties. It provides an excellent source of high-quality protein, essential fatty acids, lactose-derived carbohydrates, and a broad spectrum of vitamins and minerals. In special, cheese is rich in calcium and phosphorus, which are essential for bone health, making it beneficial for both infants and the elderly (Jasim and Al-Saadi, 2020; Nole-Jaramillo et al., 2024). Among the numerous cheese types generated worldwide, cheddar cheese occupies a prominent position due to its nutritional richness, distinctive flavor, and widespread versatility in culinary applications. Cheddar cheese contains most of the essential compounds show in milk at higher concentrations, except for lactose, which is largely removed during processing. It is also rich in vitamins and minerals and has a high caloric value. Owing to these properties, cheddar is applied in a broad array of foods, containing baked goods, savory dishes, and infant formulations. Consequently, its widespread availability in markets contributes meaningfully to dietary improvement and public health (Wang et al., 2021). During the ripening process, cheddar cheese undergoes profound physicochemical transformations that impress both its nutritional composition and sensory attributes. One commonly observed phenomenon is the apparent improve in fat percentage as ripening progresses. This change, however, is primarily due to a reduction in cheese moisture during storage, which improves the concentration of total solids, containing fat. Similar observations have been announced in other cheese types (Glowacz et al., 2015; Mulakhudair et al., 2023; Nath et al., 2025), who noted an improve in fat content in soft, low-fat cheeses during storage, attributed to moisture loss. Of the numerous biochemical alters that occur during cheese ripening, protein degradation, or proteolysis, is exclusively critical in flavor development. Proteolysis not only alters the texture of cheese but also leads to the release of peptides and amino acids, which act as direct flavor contributors or as precursors to secondary catabolic reactions that generate volatile aroma compounds. Protein degradation is initiated by enzymes like rennet-derived chymosin, which cleaves casein molecules into large and intermediate peptides. While a substantial portion of whey proteins are lost during whey drainage, the residual caseins undergo continuous hydrolysis during ripening. Lactic acid bacteria (LAB) and secondary microbiota play a central role in this process by secreting proteolytic enzymes that break down caseins into progressively smaller peptides and free amino acids, which in turn undergo further catabolism into alcohols, aldehydes, acids, and esters that contribute to cheese flavor (Gobbetti et al., 2015). The flavor profile of cheddar cheese is therefore shaped by the combined impression of volatile compound production and proteolytic activity. These processes are not uniform across cheese types, as they are strongly impressed by factors like milk source, microbial communities, processing conditions, and ripening parameters. Notably, differences between cow’s milk and goat’s milk in terms of fat composition, protein structure, and mineral balance are expected to lead to meaningful differences in the biochemical pathways that drive flavor formation. Goat’s milk is described by shorter-chain fatty acids, like caproic, caprylic, and capric acids, which impart distinctive sensory notes compared to cow’s milk. Consequently, cheddar cheese generated from goat’s milk may exhibit a markedly different volatile profile and proteolytic pattern compared to that generated from cow’s milk. In spite of the longstanding popularity of cheddar cheese, relatively few investigations have systematically compared the flavor compounds and proteolytic processes in cow’s milk versus goat’s milk cheddar applying progressive analytical methods. Gas chromatography–mass spectrometry (GC-MS) is broadly distinguished as one of the most powerful techniques for the identification and quantification of volatile compounds in food matrices, providing high sensitivity and specificity. Meanwhile, sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS-PAGE) proposes a robust method for evaluating protein breakdown and monitoring proteolytic patterns during cheese ripening. Integrating these methods provides a wide understanding of both volatile compound dynamics and protein behavior, thereby proposing new discernments into flavor formation mechanisms. Furthermore, animal breeding in the economy of countries is made of as one of the most meaningful economic branches and holds special impress (Javanmard et al., 2008; Barazandeh et al., 2016; Ahsani et al., 2022). Animal breeding is not only a traditional profession but also a highly successful job, remarked a main factor in strengthening the economies of many people (Rohallah et al., 2007; Mohammadinejad et al., 2022; Mohammadabadi et al., 2024c). A meaningful ratio of the global population is engaged in cattle and goat breeding and depends on its outcomes for food, livelihood, and trade. Furthermore, both cattle and goat breeding play a meaningful task in the agricultural part and contribute substantially to human welfare (Mohammadabadi & Tohidinejad, 2017; Eghtedari et al., 2024). Since the beginning of human existence, food and nutrition have been among the main concerns of humanity, whether in early times when humans lived in primitive situations in deserts, or today, when via technological advances humanity has even conquered outer space (Mohammadabadi et al., 2010; Noori et al., 2017; Mohammadinejad et al., 2024). The issue of food and nutrition has consistently occupied human thought, and in spite of the meaningful improvement achieved in different steps of civilization, food security remains one of the main preferences of human societies. From both economic and social perspectives, nutrition continues to detain a special position in determining welfare and stability (Mohammadabadi et al., 2024a; Nejad et al., 2024; Mohammadabadi et al., 2023). Todays, the magnitude of nutrition is such that it is remarked one of the meaningful indicators of the level of civilization and the degree of improvement of societies (Askari et al., 2011; Mohammadabadi et al., 2024a; Ghasemi et al., 2010). Indeed, in the all-round development of societies, the level of physical and mental health of the population is an identifying agent, and this is directly affected by livestock production and animal breeding (Badakhshan & Mohammadabadi, 2015; Nejad et al., 2024). Therefore, the aim of this investigation was to identify and compare the principal flavor compounds in cheddar cheese generated from cow's and goat's milk applying GC-MS, and to investigate the extent of protein degradation during ripening via SDS-PAGE analysis. By linking volatile compound analysis with proteolytic profiles, this investigation seeks to clarify how milk origin impresses the biochemical processes that underlie cheddar cheese flavor development. Such knowledge is of both scientific and practical importance, as it can contribute to improving cheese quality, tailoring products to consumer preferences, and supporting the diversification of cheese production from different milk sources.

Materials and methods

Materials: Fresh cow's milk and goat's milk were derived from local farms located near the Al-Kifl district in Babil Governorate, Iraq. Both types of milk were gathered under hygienic situations, transported to the laboratory in sterile stainless-steel containers, and processed immediately upon arrival to ensure freshness and minimize microbial contamination. The commercial rennet (chymosin enzyme) applied for milk coagulation was procured from the Turkish company MUCO REN, while the cheddar cheese starter culture was supplied by the Italian company SACCO. The starter culture consisted of freeze-dried strains of *Lactococcus lactis* subsp. *lactis* and *Lactococcus lactis* subsp. *cremoris*, which are broadly applied in cheddar cheese manufacture due to their acidifying and flavor-developing properties. In addition, annatto natural coloring was applied to impart the characteristic yellow-orange color typical of cheddar cheese.

Manufacture of cheddar cheese: Cheddar cheese was manufactured subsequent the procedure described by Hill and Ferrer (2020), with some modifications to suit local laboratory situations. Raw cow's milk and raw goat's milk were processed separately. Each batch of raw milk was standardized to achieve the desired fat-to-protein ratio and then pasteurized at 63 °C for 30 minutes applying the low-temperature, long-time (LTLT) method. Pasteurization was followed by rapid cooling to 30 °C, which is attended optimal for the growth of lactic acid starter cultures. The cooled milk was inoculated with the mixed starter culture (*Lactococcus lactis* subsp. *lactis* and *Lactococcus lactis* subsp. *cremoris*) via direct vat inoculation, in accordance with the supplier's instructions. The inoculated milk was left to ripen for 30 minutes at 30 °C to permit acidification. Subsequent this step, annatto dye was added to the milk, after which rennet solution was incorporated to induce coagulation. The milk was left undisturbed for 35 minutes, during which a firm coagulum was formed. The curd was then cut into uniform cubes applying sterile stainless-steel knives and permitted to rest for 15 minutes without stirring to facilitate syneresis. Subsequently, the curd was gently stirred before the cooking stage. Cooking was carried out by gradually raising the temperature of the curd–whey mixture from 30 °C to 39 °C over almost 20 minutes, while stirring continuously to ensure even heat distribution and controlled whey expulsion. Once the desired firmness was achieved, whey was drained from the vat. The cheddaring process was carried out by stacking curd slabs on top of one another and periodically turning them to facilitate acid development and further whey removal. This step was continued until the pH of the curd reached 5.20–5.25, which occurred after almost two hours. At this stage, the slabs were milled into small pieces applying a clean, sterile cheese mill. Dry salt was added to the curd at the recommended rate and mixed thoroughly to ensure uniform distribution. The salted curd was transferred into stainless steel molds lined with sterile cheesecloth. Molding was followed by pressing under continuous pressure for different hours to expel residual whey and obtain the characteristic block shape of cheddar cheese. After pressing, the cheeses were removed from the molds and coated with molten paraffin wax to prevent microbial contamination and excessive moisture loss during aging. The waxed cheeses were then placed in a ripening chamber maintained at 13 °C and relative humidity of almost 85%, where they were aged for a total of six months.

GC-MS analysis of flavor compounds: Volatile flavor compounds were extracted from cheddar cheese samples applying the method described by Duppeti et al. (2023), with slight modifications. Almost 5 g of cheese was homogenized, and the volatile fraction was gathered. A 1 µL aliquot of the extract was injected into the gas chromatograph–mass spectrometer (GC-MS) system. The GC-MS system was equipped with a capillary column coated with a phenyl-arylene polymer stationary phase, suitable for the separation of complex volatile mixtures. The injector temperature was initially set at 40 °C for 2 minutes, improved to 65 °C after 5 minutes, and then raised to 240 °C after 9 minutes, subsequent a programmed temperature gradient. The injection was carried out in splitless mode, and desorption of volatile organic compounds (VOCs) was achieved thermally. High-purity helium gas (99.99%) was applied as the carrier at a constant flow rate. The mass spectrometer was operated with an ionization voltage between 33 and 450 eV, and mass spectra were recorded in full-scan mode. Volatile compounds were recognized by comparing retention indices and mass spectra with those of authentic standards, as well as by referencing the NIST mass spectral library, in accordance with the approach described by Pawliszyn (1997).

Protein degradation analysis by SDS-PAGE: Proteolysis during cheddar cheese ripening was evaluated applying sodium dodecyl sulfate–polyacrylamide gel electrophoresis (SDS-PAGE). Cheese samples were gathered at different ripening intervals and prepared based on standard protein extraction protocols. Electrophoresis was carried out applying a Bio-Rad Mini-PROTEAN system, subsequent the method described by Fling and Gregerson (1986). Protein extracts were mixed with SDS sample buffer, denatured by heating at 95 °C for 5 minutes, and loaded onto polyacrylamide gels. Electrophoresis was carried out under constant voltage until satisfactory band separation was achieved. Protein bands were visualized applying Coomassie Brilliant Blue staining, and the extent of β-casein degradation was evaluated by comparing the band intensity at different ripening stages.

Results and discussion

Qualitative and quantitative analysis of flavor compounds using GC-MS: Gas chromatography–mass spectrometry (GC-MS) analysis disclosed the presence of multiple volatile compounds in cheddar cheese generated from both cow's milk and goat's milk. These compounds improved in number and concentration as ripening progressed, affirming that the biochemical and microbial transformations occurring during storage are directly responsible for flavor development. Importantly, the profiles of volatile compounds differed between the two cheese types, which reflects the intrinsic compositional differences of cow's and goat's milk. Not all found compounds, however, contributed meaningfully to the final sensory perception of cheddar cheese; rather, only a subset of major compounds was found to play a central role in defining its characteristic aroma and flavor. These key volatiles were classified into five principal groups: esters, carboxylic acids, alcohols, hydrocarbons, and ketones (Table 1).

Table 1. Main flavor compounds responsible for the flavor of cheddar cheese generated from cow's milk (T1) and goat's milk (T2) immediately after manufacturing and during the ripening period

Treatment	Flavor compound group	Area (%)	Main flavor compounds
T1 (Cow's milk)	Esters	71.93	Bis(2-ethylhexyl) phthalate
T2 (Goat's milk)	Esters	1.240.10	n-Butyric acid 2-ethylhexyl esterHexadecanoic acid, butyl ester
T1	Carboxylic acids	2.66	Acetic acid
T2	Carboxylic acids	4.971.17	n-Hexadecanoic acidOctanoic acid
T1	Alcohols	31.17	1-Heptatriacotanol
T2	Alcohols	1.73	Ethanol
T1	Hydrocarbons	3.30	Squalene
T2	Hydrocarbons	1.07	Tritetracontane
T1	Ketones	2.27	Cyclopentane, (2-hexyloctyl)-
T2	Ketones	1.16	Decanoyl chloride

Esters: In cheddar cheese made from cow's milk (T1), the dominant ester was bis(2-ethylhexyl) phthalate, which accounted for 71.93% of the ester fraction. This compound imparts a sweet, fruity note and raises the overall aroma profile of the cheese. The result agrees with Pinho et al. (2003), who recognized this ester as an influential contributor to the aroma of ripened cheeses. In goat's milk cheddar (T2), two esters were of special importance: n-butyric acid 2-ethylhexyl ester and hexadecanoic acid butyl ester, which appeared in smaller but meaningful amounts during mid- to late-ripening (Figure 1). These esters are related to fruity and buttery notes and were previously announced as characteristic volatiles in goat's milk cheeses (Castillo et al., 2007). Their late appearance during ripening highlights the progressive role of esterification reactions, which depend on both microbial esterases and the availability of free fatty acids as substrates. Esters are exclusively valued in cheese flavor because they contribute pleasant fruity notes that balance the sharper acidic and sulfuric compounds. In cheddar, although not always show in large concentrations, esters raise complexity and consumer acceptance (Curioni &

Bosset, 2002). The dominance of different ester types in cow's versus goat's milk cheddar therefore reflects both the fatty acid composition of the starting milk and the enzymatic capacity of the microbial communities involved.

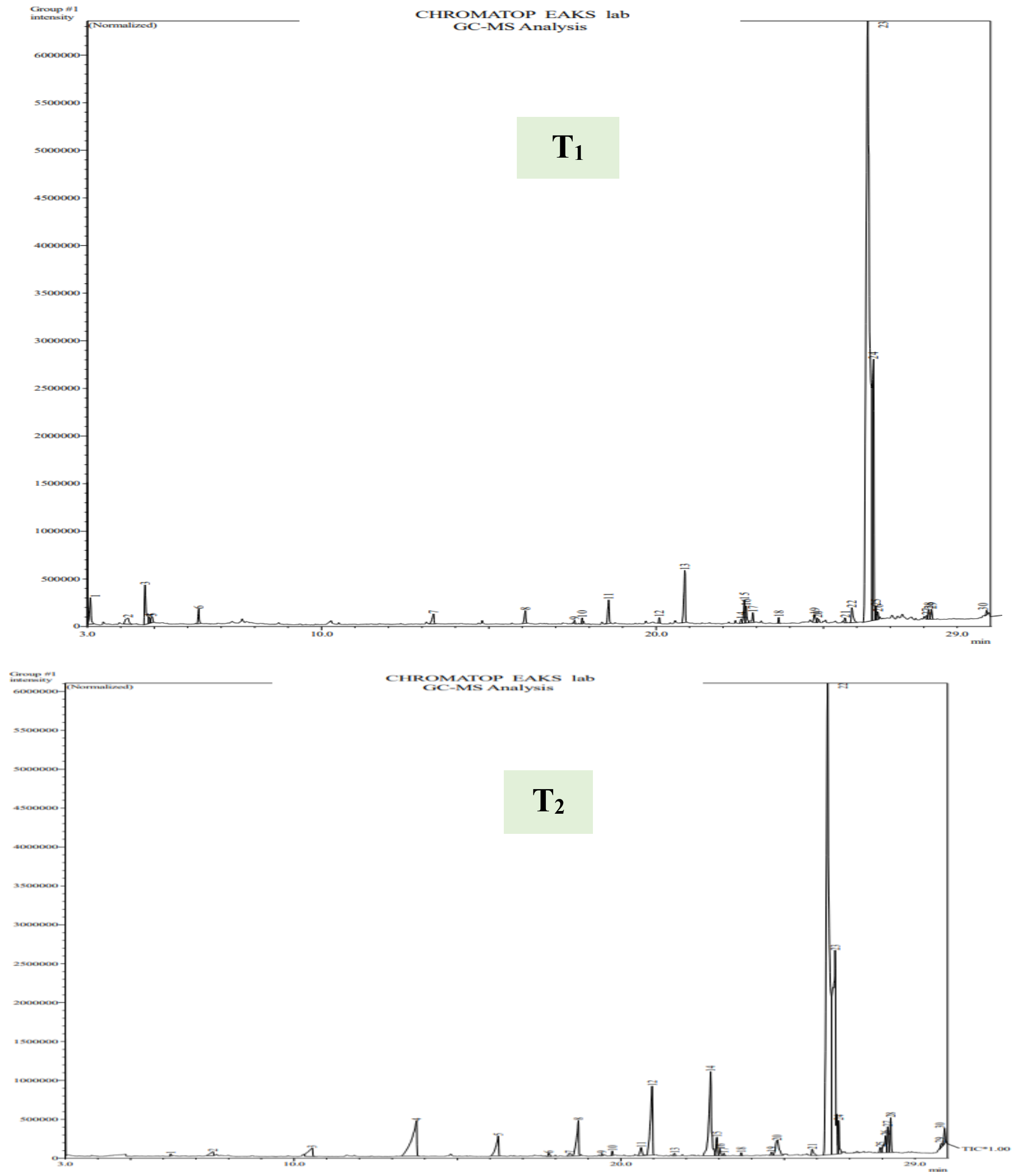


Figure 1. Esterified compounds responsible for fruit flavor and enhancing aroma in cheddar cheese generated from cow's milk (T1) and cheddar cheese generated from goat's milk (T2)

Carboxylic acids: Carboxylic acids were also major contributors to cheddar cheese flavor. In cow's milk cheddar, **acetic acid** was recognized as the predominant compound. Acetic acid is generated primarily via lactose fermentation and citrate metabolism by lactic acid bacteria, and it is broadly distinguished for imparting nutty and slightly pungent notes. Kristoffersen (1967) similarly announced acetic acid as one of the key contributors to nutty flavors in traditional cheddar (Figure 2). In goat's milk cheddar, the most abundant carboxylic acids were n-hexadecanoic acid (palmitic acid) and octanoic acid (caprylic acid). Both are derived from lipolysis of milk fat and are typical indicators of goat milk cheeses. Octanoic acid, in special, has a strong waxy odor that, together with hexanoic acid (caproic acid), gives goat cheese its characteristic pungent and sometimes "animalic" aroma. Hayaloglu et al. (2007) affirmed that medium-chain fatty acids like C6, C8, and C10 are responsible for the distinctive sensory properties of goat cheeses. While these acids are sometimes perceived as undesirable due to their sharpness, they are crucial for distinguishing goat's milk cheddar from its cow's milk counterpart. It is worth noting that goat's milk contains higher levels of short- and medium-chain triglycerides than cow's milk, which explains the stronger presence of volatile fatty acids in goat's milk cheddar (Mulakhudair et al., 2023). This compositional difference in fat is a major factor underlying the sensory differences between the two cheese types.

Alcohols: Alcohols were another important class of volatiles found in the cheeses. In cow's milk cheddar, the main alcohol was 1-heptatriacotanol, a long-chain alcohol derived from fat metabolism. It imparted a sweet and slightly waxy flavor, with higher concentrations producing a more intense aroma. Fillet et al. (2015) described similar effects of long-chain alcohols in cheese, noting their capability to raise both flavor complexity and persistence (Figure 3). In contrast, the primary alcohol found in goat's milk cheddar was ethanol. Ethanol is a common byproduct of lactose metabolism under microaerophilic situations and contributes to a slightly fruity, solvent-like note. McSweeney and Sousa (2000) also announced ethanol as one of the main alcohols in goat cheeses. Interestingly, the absence of long-chain alcohols like 1-heptatriacotanol in goat's milk cheddar contributes to its lighter, sharper aroma compared to the sweeter, fuller aroma of cow's milk cheddar. This aligns with the sensory observations announced by Fillet et al (2015), who emphasized the lack of sweet notes in goat milk cheddar relative to cow milk cheddar.

Hydrocarbons: Among hydrocarbons, cow's milk cheddar was found to contain squalene, a triterpene hydrocarbon that plays a role in stabilizing aroma compounds and providing a mild oily note. Lee et al. (1979) recognized squalene in numerous dairy products and highlighted its role in enhancing aroma retention (Figure 4). In goat's milk cheddar, the dominant hydrocarbon was tritetracontane, a long-chain alkane. Although hydrocarbons are generally attended to have restricted direct sensory impact, their presence can impress cheese aroma by modulating the volatility and perception of other compounds. Bontinis et al. (2012) announced that hydrocarbons are more abundant in goat cheeses and may contribute indirectly to their unique aromatic profile.

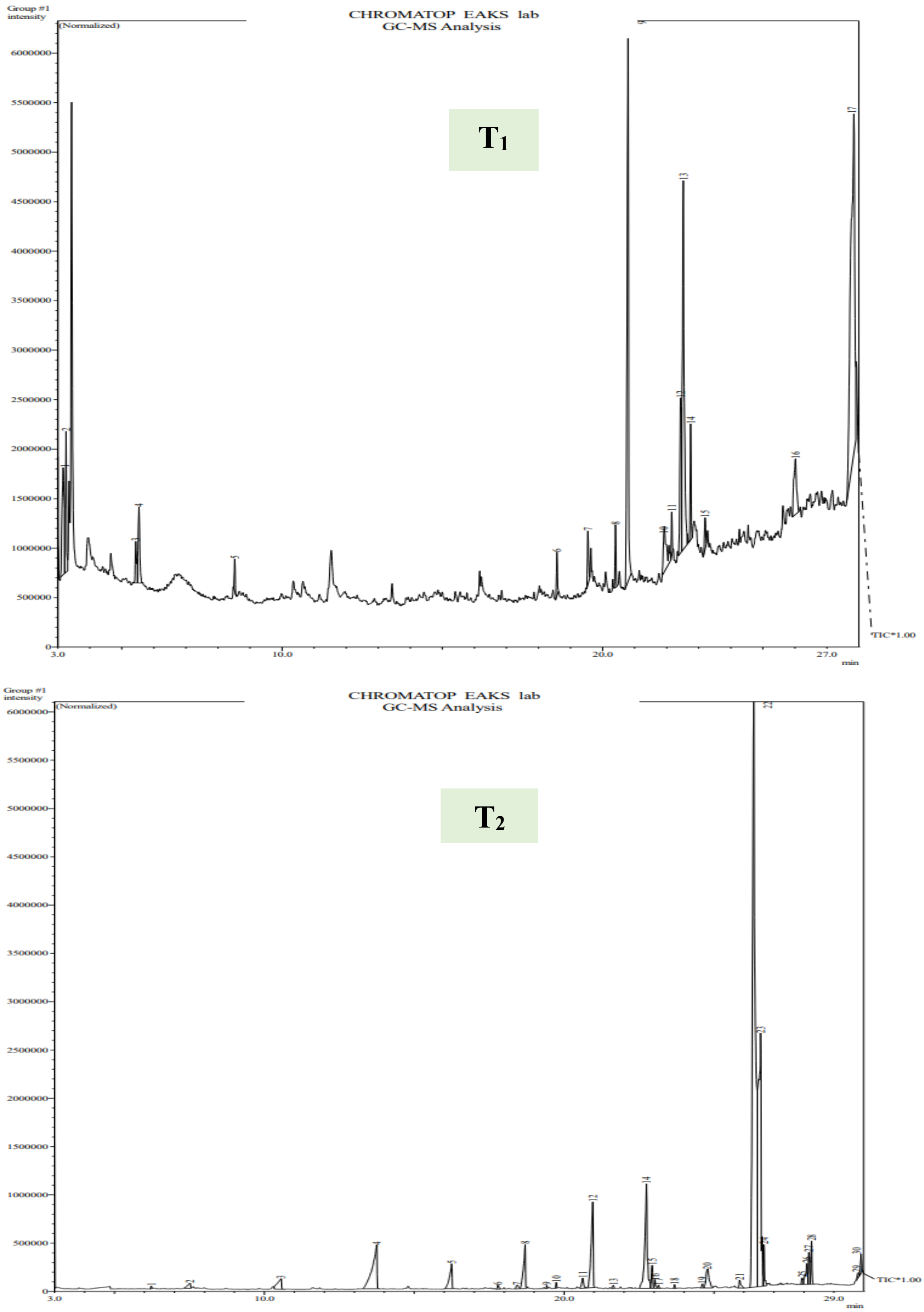


Figure 2. Carboxylic acid compounds responsible for the nutty flavor in cheddar cheese generated from cow's milk (T1) and cheddar cheese generated from goat's milk (T2)

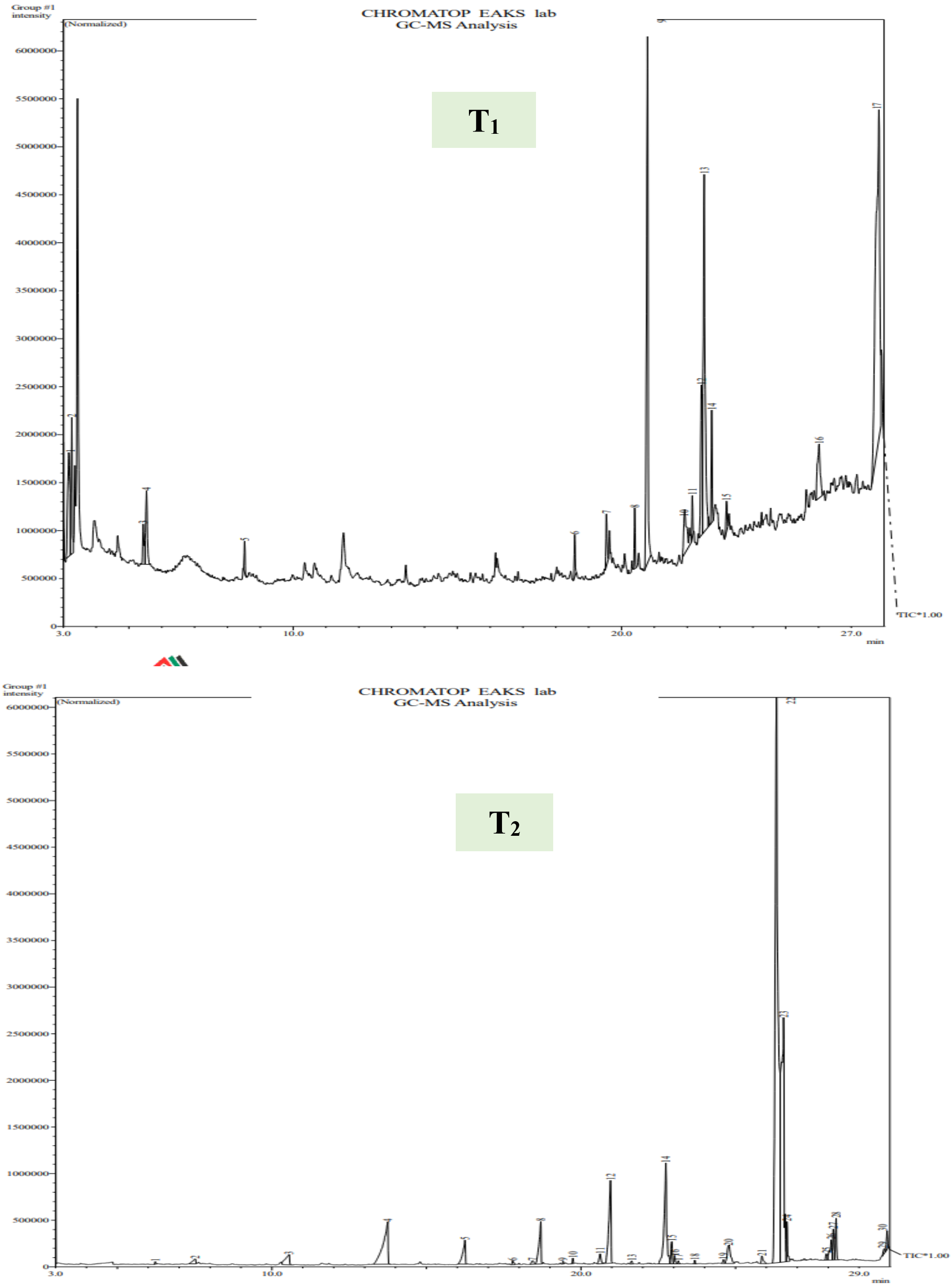
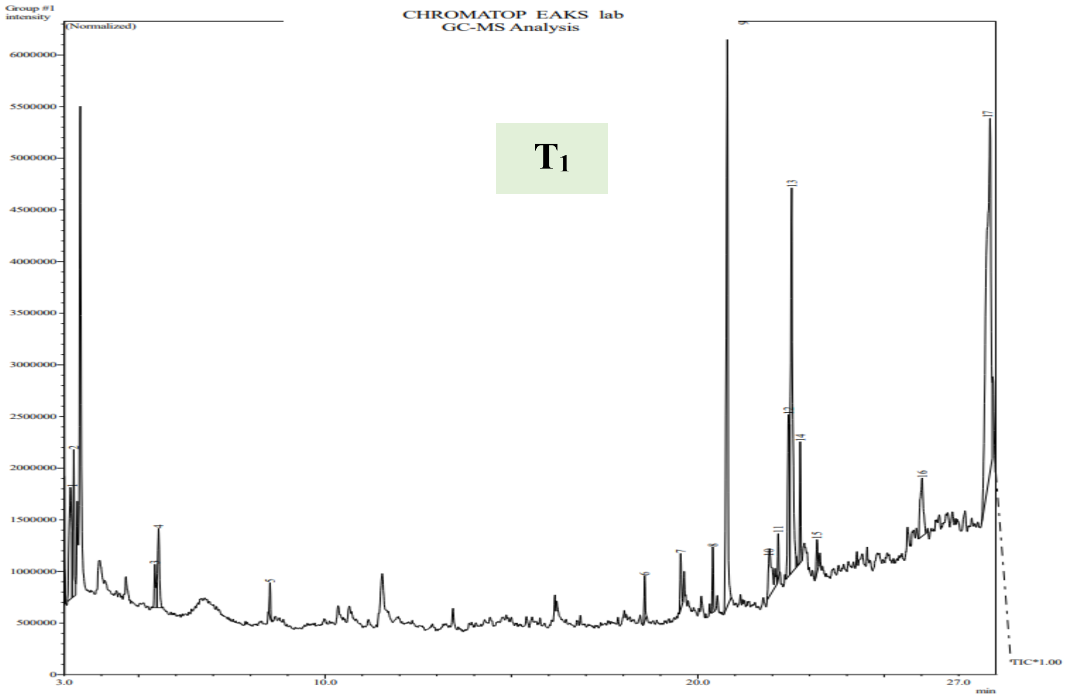


Figure 3. Alcohol compounds responsible for the sweet and waxy flavor in cheddar cheese generated from cow's milk (T1) and cheddar cheese generated from goat's milk (T2)

Ketones: Ketones were also meaningful contributors to cheddar cheese aroma. In cow's milk cheddar, the principal ketone was cyclopentane (2-hexyloctyl), which improved progressively during ripening. This compound is formed via microbial catabolism of free fatty acids and imparts buttery and fruity notes. Similar observations were made by Bontinis et al. (2012), who linked fatty acid-derived ketones to the complex aroma of ripened cheeses (Figure 5). In goat's milk cheddar, the key ketone was decanoyl chloride, which contributes fatty and buttery odors. Wang et al. (2020) affirmed its importance in shaping the sensory profile of goat cheddar. Additionally, 2-undecanone was found exclusively in goat's milk cheddar, further enhancing its buttery aroma. The presence of these ketones underscores the impression of milk type on lipolysis pathways and their impact on flavor development.

Effect of milk type on flavor characteristics: The comparative analysis highlights the central role of milk origin in determining cheddar cheese flavor. Cow's milk cheddar was dominated by acetic acid, bis(2-ethylhexyl) phthalate, 1-heptatriacotanol, squalene, and cyclopentane derivatives, which collectively generated a sweet, nutty, and rounded aroma profile. In contrast, goat's milk cheddar was described by high levels of octanoic and hexanoic acids, ethanol, tritetracontane, and decanoyl chloride, resulting in a sharper, waxier, and more pungent flavor. These outcomes support the hypothesis that fat composition, exclusively the higher proportion of medium-chain fatty acids in goat's milk, is the primary driver of flavor differences. While cow's milk cheddar is generally more acceptable to consumers due to its mildness and sweetness, goat's milk cheddar proposes a distinctive profile that appeals to specific consumer groups. However, the presence of rancid notes related to short-chain fatty acids (C6–C10) can reduce consumer acceptance (Yang et al., 2015). Managing ripening situations and microbial cultures may help balance these flavors to improve marketability of goat milk cheeses.

Proteolysis in cheddar cheese monitored by SDS-PAGE: Electrophoretic analysis (SDS-PAGE) was managed to evaluate proteolysis in cow's and goat's milk cheddar over four ripening stages: day 1, day 60, day 120, and day 180 (Figure 6). Proteolysis is distinguished as one of the most important biochemical processes in cheese ripening, affecting both texture and flavor via the release of peptides and amino acids. The outcomes disclosed clear differences between the two treatments. Both alpha- and beta-caseins degraded progressively during ripening, but beta-casein degradation was meaningfully more pronounced in goat's milk cheddar. This result is in line with Jin and Park (1996), who announced higher susceptibility of goat's milk caseins to proteolysis compared to cow's milk. Alpha-s1-casein also showed marked degradation in both treatments, but degradation was more extensive in cow's milk cheddar. On days 60 and 120, the number of hydrolyzed bands of alpha-s1-casein improved meaningfully, reflecting active enzymatic breakdown. These outcomes agree with Joyner Melito et al. (2018), who demonstrated that alpha-s1-casein degradation accelerates as ripening progresses and contributes to textural softening.



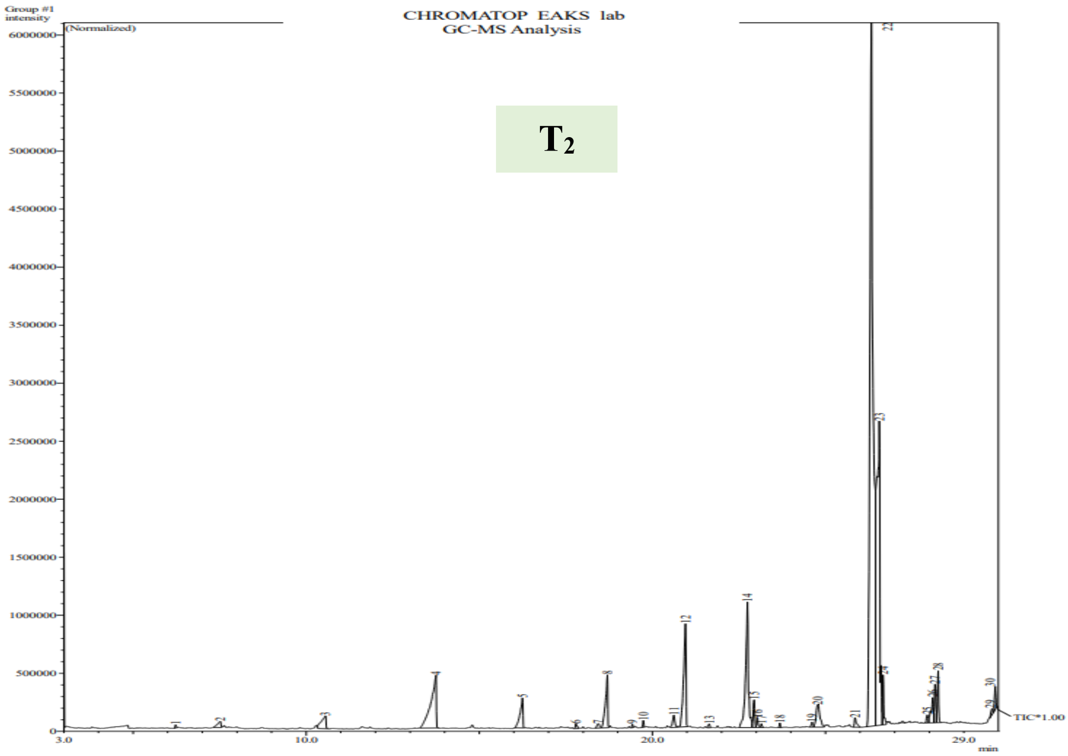


Figure 4. Hydrocarbon compounds responsible for enhancing the smell in cheddar cheese generated from cow's milk (T1) and cheddar cheese generated from goat's milk (T2)

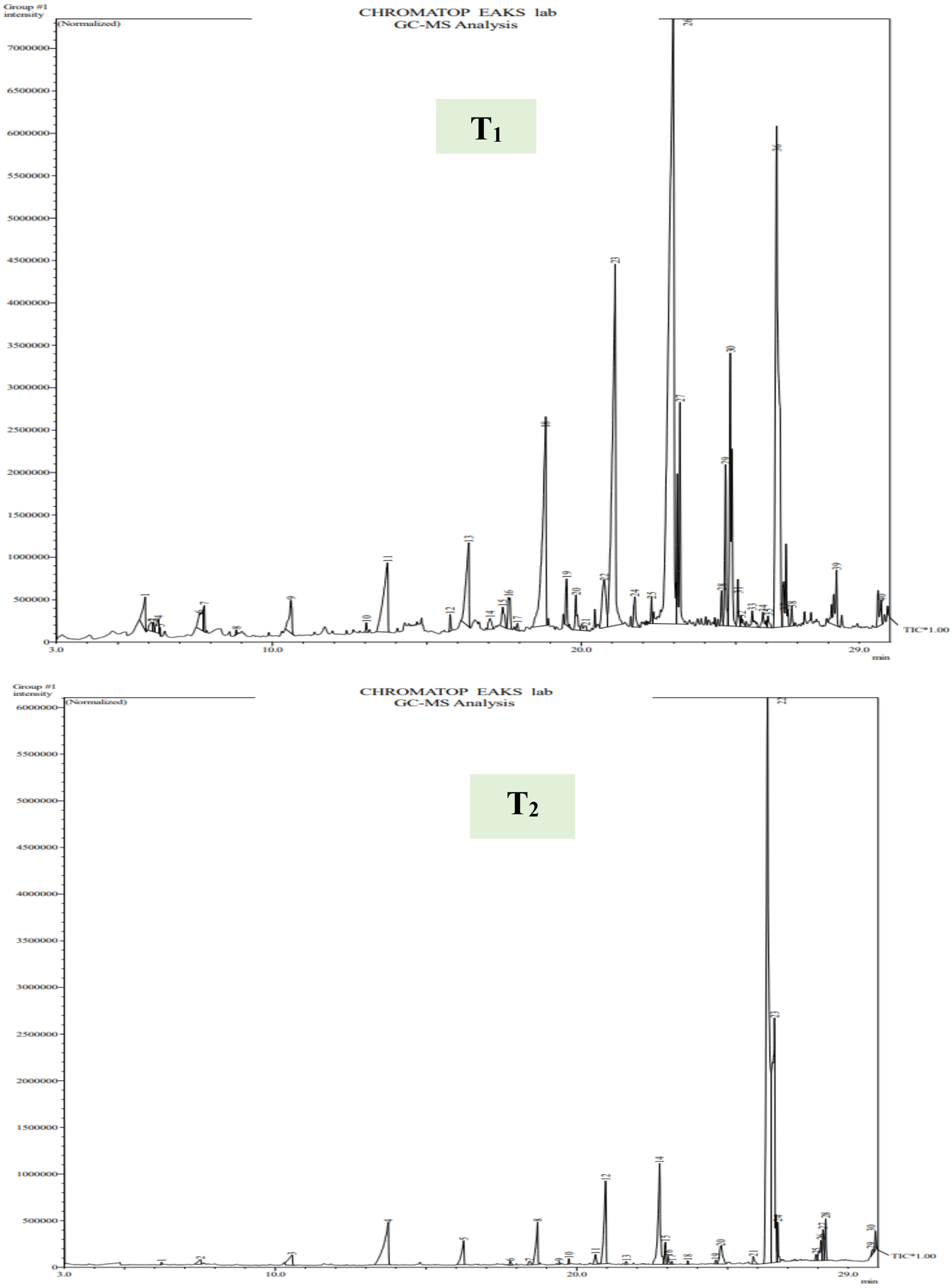


Figure 5. Ketone compounds responsible for the odor in cheddar cheese generated from cow's milk (T1) and cheddar cheese generated from goat's milk (T2)

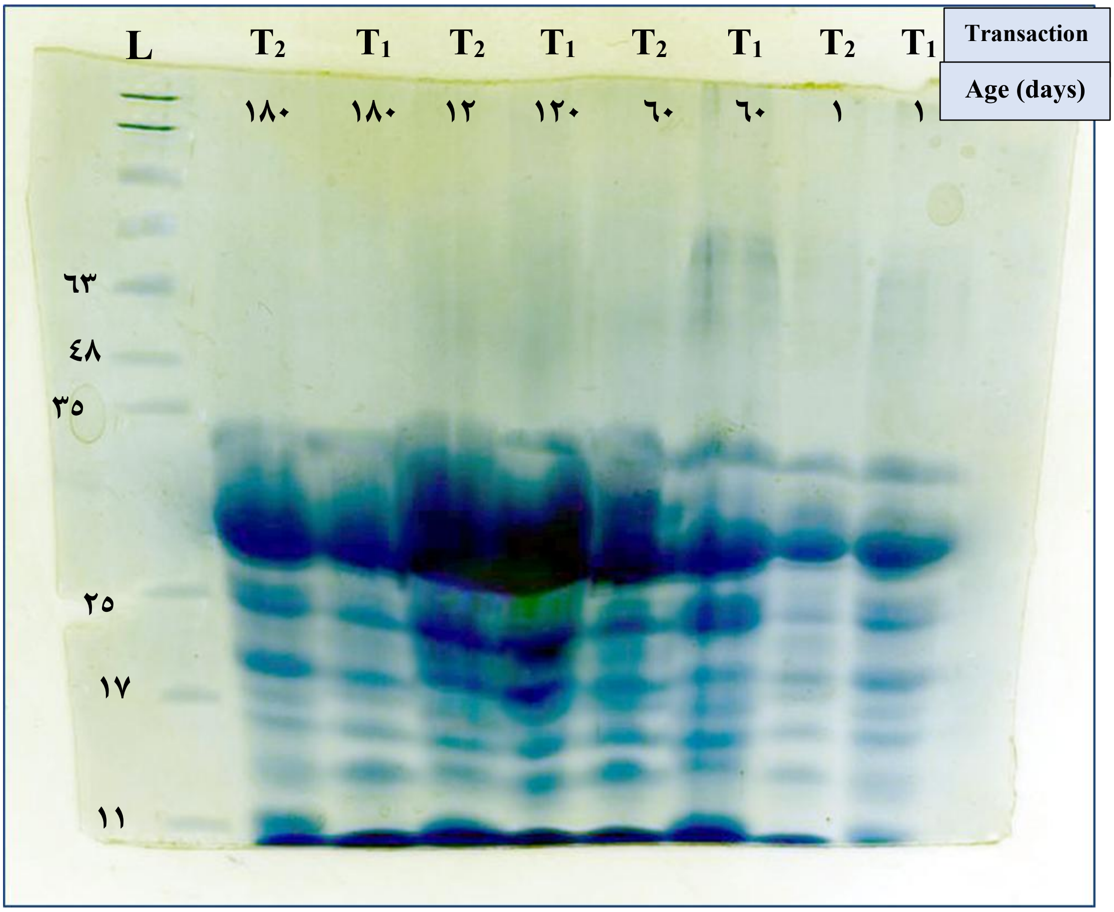


Figure 6. Electrophoresis results for cheddar cheese treatments during (1, 60, 120, 180 days) of ripening

The differences in proteolysis between cow's and goat's milk can be attributed to compositional factors. Goat's milk caseins are described by smaller micelle size, lower alpha-s1-casein content, and higher beta-casein proportion compared to cow's milk. These structural differences raise enzyme accessibility and result in faster proteolysis (Park et al., 2007). Consequently, goat's milk cheddar develops a softer texture and stronger flavor more rapidly than cow's milk cheddar.

Integration of flavor compounds and proteolysis: The combined outcomes of GC-MS and SDS-PAGE provide a wide understanding of cheddar cheese ripening. Proteolysis generates peptides and free amino acids, which serve as precursors for many volatile flavor compounds. For example, microbial catabolism of amino acids yields alcohols, aldehydes, and acids that contribute directly to aroma. Similarly, lipolysis provides substrates for esterification and ketone formation. In cow's milk cheddar, the slower rate of proteolysis correlates with the gradual accumulation of acetic acid, esters, and long-chain alcohols, producing a milder flavor. In goat's milk cheddar, accelerated beta-casein degradation aligns with the rapid improve in short- and medium-chain fatty acids, leading to a more intense and sometimes pungent flavor profile. This integration demonstrates how milk composition influences both biochemical pathways and sensory outcomes during ripening.

Conclusion: The study highlights fundamental differences in the volatile compound profiles and proteolytic patterns of cheddar cheese made from cow's and goat's milk. Cow's milk cheddar develops a balanced nutty, fruity, and sweet flavor dominated by acetic acid, bis(2-ethylhexyl) phthalate, and long-chain alcohols, while goat's milk cheddar exhibits a sharper, more pungent profile due to octanoic and hexanoic acids, ethanol, and medium-chain ketones. SDS-PAGE analysis affirmed that proteolysis, exclusively of beta-casein, is more extensive in goat's milk cheddar, explaining its stronger and faster flavor development. These results underscore the crucial role of milk type in shaping both the biochemical pathways and sensory properties of cheddar cheese.

Author Contributions

Conceptualization and methodology, software and validation, formal analysis and investigation, Fatima Mohammed Ali Al-Hisnawi; resources, both authors contributed equally; data curation, writing—original draft preparation, writing-review, visualization, and supervision, Dhia Ibrahim Jerro Al-Bedrani; funding acquisition, both authors contributed equally

Data Availability Statement

Data are available from the authors upon reasonable request.

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Ethical Considerations

The study was carried out with integrity, with no fabrication, falsification, plagiarism, or scientific misconduct.

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Conflict of Interest

The authors report no conflicts of interest.

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تعیین ترکیبات اصلی طعم‌دهنده پنیر چدار تولیدشده از شیر گاو و بز با استفاده از آنالیز GC-MSو بررسی رفتار پروتئین‌ها به روش SDS-PAGE

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چکیده

هدف: ترکیبات طعم‌دهنده یکی از مهم‌ترین ویژگی‌های کیفی مواد غذایی به شمار می‌روند، زیرا مستقیماً بر ترجیحات مصرف‌کننده و پذیرش محصول اثر می‌گذارند. رایحه و طعم از ترکیبات فرّاری که هنگام مصرف آزاد می‌شوند ایجاد شده و معیارهای اساسی در ارزیابی ارزش حسی و تجاری غذاها هستند. پنیر به‌ویژه، عطری بسیار پیچیده ایجاد می‌کند که حاصل طیف گسترده‌ای از فرآیندهای بیوشیمیایی و میکروبیولوژیکی در طول تولید و رسیدگی است. پنیر چدار، که از پرمصرف‌ترین انواع پنیر به شمار می‌آید، دگرگونی‌های بیوشیمیایی گسترده‌ای را طی می‌کند که به‌طور چشمگیری بر پروفایل طعمی آن اثر می‌گذارد. هدف این پژوهش شناسایی و توصیف ترکیبات فرّار اصلی در پنیر چدار تهیه‌شده از شیر گاو و بز با استفاده از کروماتوگرافی گازی–طیف‌سنجی جرمی (GC-MS) و همچنین ارزیابی الگوهای پروتئولیز و تجزیه پروتئین‌ها در هر دو نوع پنیر به روش الکتروفورز ژل پلی‌آکریل‌آمید–سولفات دو دسیل سدیم (SDS-PAGE) بود.

مواد و روش‌ها: نمونه‌های پنیر چدار از شیر گاو اصلاح‌شده (T1) و شیر بز اصلاح‌شده (T2) تهیه شدند. هر دو نوع پنیر به‌مدت شش ماه در اتاق‌های کنترل‌شده در دمای ۱۳ درجه سانتی‌گراد قرار گرفتند. نمونه‌برداری در روزهای ۱، ۶۰، ۱۲۰ و ۱۸۰ مطالعه انجام گرفت. برای شناسایی، آشکارسازی و طبقه‌بندی ترکیبات فرّار طعم از GC-MS استفاده شد و برای ارزیابی تجزیه پروتئین و تعیین میزان پروتئولیز از SDS-PAGEبهره گرفته شد.

نتایج: نتایج GC-MS نشان داد که هر دو نوع پنیر از شیر گاو و بز حاوی ترکیبات فرّار متنوعی بودند، هرچند تفاوت‌هایی در غلظت و توزیع آنها مشاهده شد. ترکیبات در پنج گروه اصلی دسته‌بندی شدند: استرها، اسیدهای کربوکسیلیک، الکل‌ها، هیدروکربن‌ها و کتون‌ها. ترکیبات خاصی در این دسته‌ها به‌عنوان مهم‌ترین عوامل ایجاد طعم پنیر چدار شناخته شدند. نتایج الکتروفورز آشکار ساخت که میزان پروتئولیز به‌طور پیشرونده در طول رسیدگی افزایش یافت و تفاوت‌های معنی‌داری بین پنیرهای گاوی و بز وجود داشت. پنیر چدار بز تجزیه بتاکازئین بارزتری نسبت به پنیر چدار گاوی نشان داد. بالاترین میزان تجزیه پروتئین در روز ۱۲۰ رسیدگی مشاهده شد و پس از آن نرخ تجزیه تثبیت گردید.

نتیجه‌گیری: یافته‌های این تحقیق نشان می‌دهد که نوع شیر مورد استفاده در تولید پنیر چدار تأثیر چشمگیری بر ترکیب ترکیبات طعمی و الگوهای تجزیه پروتئین دارد. پنیر چدار بز پروتئولیز شدیدتر و پروفایل فرّار متمایزتری نسبت به پنیر چدار گاوی نشان داد و این امر نقش ترکیب شیر را در شکل‌دهی ویژگی‌های حسی پنیرهای رسیده برجسته می‌سازد.

کلمات کلیدی: پروتئولیز، پنیر چدار، ترکیبات طعمی، GC-MS، SDS-PAGE

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