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Research paper

Impact of different level of α-s1 casein on curd stretchability in the production of mozzarella cheese from goat milk

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ABSTRACT

The extensive casein polymorphism in dairy goats can influence the chemical-physical and sensory properties of milk and derivatives. The present study investigated the aptitude of goat milks with different levels of α-S1 casein (α-S1-CN) at producing mozzarella cheese. Two goat farms producing milk with high and low level of α-S1-CN (HI and LO, respectively) were selected to perform cheesemaking trials. The outcomes highlighted a strong relationship between curd stretchability and presence/absence of α-S1-CN. A pH value of 5.0 was suitable for stretching both types of curd, but the presence of this casein fraction determined better elasticity and a wider pH range for stretchability. The profiles of the volatile organic compounds of the mozzarella samples showed significant differences under both the qualitative and quantitative point of view, while the results of the sensory analysis indicated the presence of differences in odour/aroma of the samples, with LO cheese having higher "goaty" flavour.

1. Introduction

Casein polymorphism in goat milk has been reported since the 1980s (Addeo et al., 1988; Boulanger et al., 1984); since then, several genetic variants have been identified for all caseins, with k- and α-S1 fractions being the most variable (Rahmatalla & Brockmann, 2024). Polymorphism of α-S1 casein (α-S1-CN) is connected to different level of synthesis of the protein and its concentration influences some characteristics of the milk, such as nutritional profile, total protein concentration, casein micelle size and mineralization. The variation of these characteristics affects the cheesemaking properties such as coagulation rate, curd firmness, cheesemaking yield and cheese flavour (Ambrosoli et al., 1988; Vassal et al., 1994; Ramunno et al., 2007; Ballabio et al., 2011; Johansson et al., 2015).

During the last decade, the use of goat milk in producing pasta filata cheeses has been proposed by several authors (Imm et al., 2003; Faccia et al., 2015; Paz et al., 2017; Cais-Sokolińska et al., 2018; Faccia et al., 2021a). In general, a challenging point in the production of these cheeses is the stretching aptitude of the curd, which is strongly connected with the casein content of milk and the level of micelle mineralization. In detail, adequate curd stretching characteristic is fundamental to obtain a pasta filata cheese, as curd string must be elastic and smooth in order to be properly moulded into the final cheese; casein fractions are the key component of this process, thus, genetic variability could affect it. This aspect has been poorly investigated and the scarce literature on the effects of casein genetic variants mostly focuses on bovine milk: Franceschi et al. (2020) reported a favourable effect of k-casein B in the production of mozzarella from cow milk; Albarella et al. (2020) investigated the effect of casein composite genotypes on the quality and coagulation traits of milk from the Agerolese cow breed used for manufacturing Provolone del Monaco, finding high variability and a prevalence of the variant with a positive aptitude for pasta filata cheese production; Perna et al. (2015) carried out a study on the effect of genotype on the antioxidant properties of bovine Caciocavallo cheese, concluding that the antioxidant capacity depends on both genetic factors and ripening time. Regarding goat milk, no information is available except for the influence of the casein fractions on coagulability (Amalfitano et al., 2023), but considering the great influence of the type of casein on the micelle structure (Breunig et al., 2024; Martin et al., 1999), an influence on stretchability should be expected. The present study aimed to ascertain the relationship between the level of α-S1 casein in goat milk and the curd stretchability during the production of mozzarella cheese; furthermore, the study investigated the differences in the sensory characteristics and VOC profile of the cheeses derived therefrom.

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2. Materials and methods

2.1. *Milk collection and cheesemaking trials*

The first requirement of the study was to find suitable milks for the experimentation, having different content of α-S1 casein. A screening phase was carried out on bulk milk taken from 29 goat farms located in two regions (Puglia and Basilicata, Southern Italy). The study used bulk milk for two main reasons: certainty of the availability of the milk during the whole experimentation, which was not guaranteed in the case of individual milk, and reproducing the real conditions of the cheesemaking process, in order to get information directly appliable in the dairies. The 29 milk samples were analysed by Polyacrylamide Gel Electrophoresis in the presence of urea (UREA-PAGE) as reported by Andrews (1983) and Natrella, De Palo, et al. (2023) to verify the level of the target fraction. The identification of the α-S1 casein was done according to Moatsou et al. (2004) by comparing the resulting patterns. Then, a relative band quantification (RQ%) was performed according to Faccia et al. (2014), in our case the α-S1 level was quantified as the percentage of the specific band in relation to the β and α bands. This approach was useful in selecting only two farms producing milk with remarkable difference in the level of α-S1 casein, coded as “high” and “low” type (HI and LO, respectively, see Supplementary Fig. 1). The flock of HI farm was composed of Jonica breed goats, whereas the flock of LO farm was composed of goats of different breeds (Jonica, Camosciata delle Alpi and related hybrids). In order to reach an adequate statistical significance, the milk was taken from the farms three times in a short period time and three cheesemaking trials were carried out. By this way, it was also possible to keep under control the compositional fluctuations caused by modification of the flocks connected with addition or removal of animals (health problems, lactation phase, etc.). Each time, the farms supplied about 5 L of milk, taken from the farm refrigerator, which was processed in the Department laboratory on the same day by following the manufacturing scheme reported in Fig. 1. In brief, the milk was heated to 42 °C, added with selected lactic acid bacteria starter (*Streptococcus thermophilus*, 0.18 g L^{-1}, microMilk srl, Cremosano, Italy) and after about 50 min the microbial coagulant was added (0.5 ml of CHY-LACTIS 200, 200 ± 4 IMCU/ml, Linea Lactis SRL, Gioia del Colle, Italy). After coagulation, the coagulum was cut to obtain curd particles with size around 0.5 cm and the resulting curd was kept into the warm whey (about 38 °C) for favouring fermentation. When pH reached the value of 6.0, two third of the whey was drained out and from this time onward pH was continuously monitored. Samples of curd were taken at three different pH values (pH 5.2, 5.1 and 5.0) and stretched under the following conditions: addition of water at 78 °C (3-fold the weight of the curd), kneading the mass until reaching uniform aspect and shaping it in a stainless-steel mold to obtain small pasta filata bricks (10 x 1 × 1 cm, 14.5–15.0 g weight). The bricks were used for texture profile analysis (TPA, 3 replicates for each pH value), as described below. Right after the first TPA, the three replicates of stretched bricks were pooled, stretched again and subjected to a second TPA.

2.2. *Texture profile analysis*

A tensile test was performed, by inserting the curd bricks on a Z1.0 TN texture analyser (Zwick Roell, Ulm, Germany). Suitable tools were manufactured on purpose and adapted to the TPA instrument, composed of jaws on a base (tightened to prevent slippage) and a 4-prong hook tool useful for stretching the sample. The sample loading was done while it was still hot, wrapping it around the 4-prong hook and clipping the ends to the jaws. Then, the tensile analysis was performed with a 1 kN load cell extending the curd sample until breakage. The instrument was set as follows: approach path = none, number of cycles = 1, speed in the measurement cycle = 10 mm s^{-1}. The monitored parameters were the force encountered by the hook tool when stretching the sample (maximum force, “Fmax” [N]) and the height registered (extension, “dL

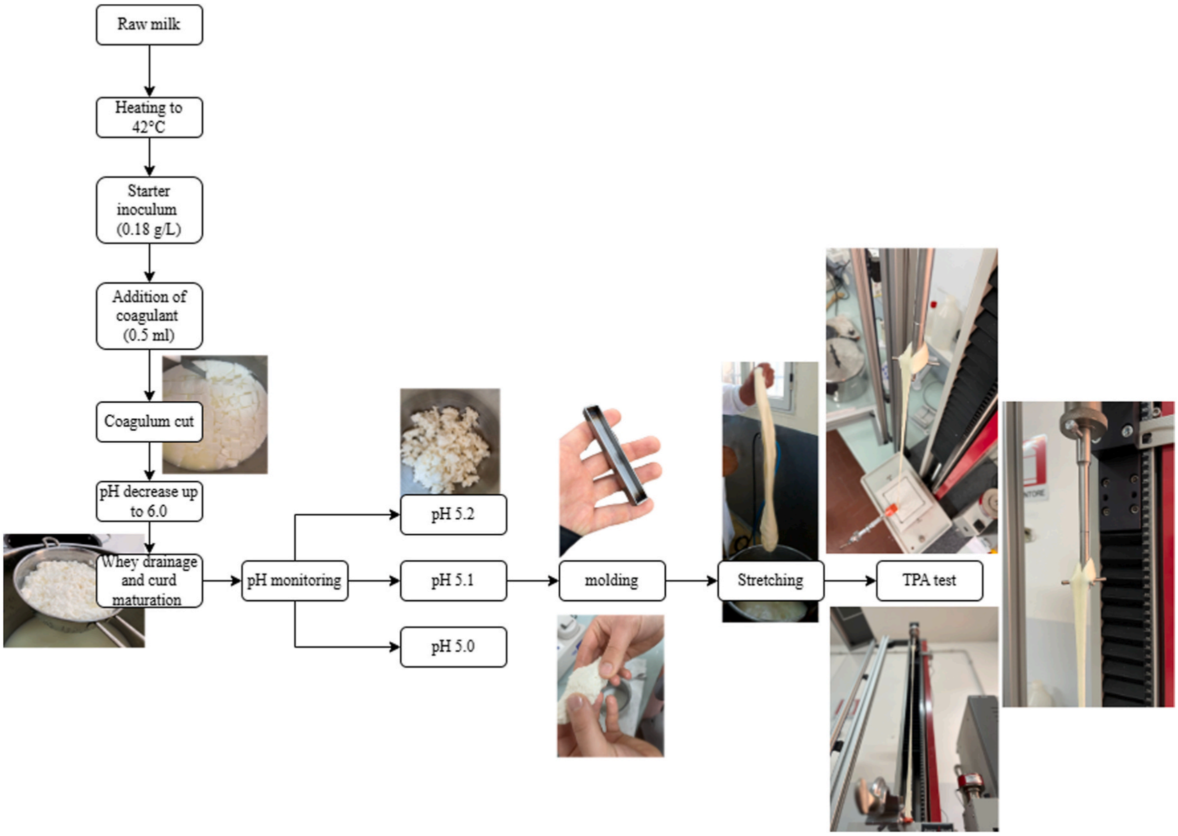

Fig. 1. Flow chart of the experimental trials.

(0N)" [mm]) when N = 0 (when the sample breaks). The analysis was carried out in triplicate.

2.3. *Analysis of milk and cheese*

The milk gross composition (fat, protein, lactose, non-fat solid, total solids, freezing point, fat to protein ratio, density, titratable acidity, free fatty acids, casein, urea, citric acid) was analysed by an infrared spectrophotometer Milkoscan™ FT3 (Foss analytical A/S, Denmark). The gross composition of mozzarella samples was assessed by Near InfraRed (NIR) spectroscopy on a Proximate™ apparatus (Buchi, Flawil, Switzerlamd), whereas determination of the volatile organic compounds (VOC) was performed according to Natrella, Gambacorta, and Faccia (2020); in brief, 1 g of sample was weighed into a glass vial containing the internal standard (3-pentanone, 81.3 ng) and loaded into an GC-MS autosampler then the samples were extracted by SPME technique and analysed by GC-MS (Thermo Fisher Scientific).

2.4. *Sensory analysis*

Sensory analysis of mozzarella was performed by a trained panel composed of seven experts (4 men and 3 women, ranging in age from 25 to 55), selected following the ISO 8586-1993 method. They were members of the Italian Association of Cheese Tasters (ONAF) and had attended a course about cheese qualitative and quantitative descriptive analysis. A preliminary session was done asking the judges "which characteristics should a mozzarella cheese have?", then a list of texture, taste and odour descriptors was defined, supported also by the literature (Natella et al., 2020a,b; Faccia et al., 2021b; Faccia et al., 2021c; Natrella, Gambacorta, & Faccia, 2023). The quantitative descriptive analysis (QDA) was then performed on the mozzarella samples obtained in all trials, served at room temperature (about 40 g each). All the sensory analyses were performed in a sensory laboratory equipped with individual booths for each panelist. For scoring, the panellists used a scale from 0 to 5 points.

2.5. *Statistical analysis*

All the physical-chemical data were tested for normal distribution and variance homogeneity (Shapiro-Wilk test), then analysed by the one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test ($p < 0.05$), concerning stretching parameters, a two-way ANOVA was used considering both pH and casein fraction abundance as variables; these analyses were performed by using Xlstat (Addinsoft, Paris, France). The chord diagram of volatile compounds was performed by using OriginPro 2021 (OriginLab Corporation, Hewhampton, MA, USA).

3. Results and discussion

3.1. *Sample selection and gross composition*

Fig. 2 shows the electropherograms of some bulk milk samples collected during the screening phase (A) and of the milks from the two selected farms, monitored along the three cheesemaking trials (B). The electropherograms evidenced a remarkable difference in the intensity of the αs-CN bands between sample "HI" and "LO", the former containing 3 bands, the latter only two, due to the absence or very poor presence of the third band, identified by Moatsou et al. (2004) as αs1-fraction. In LO sample, β-CN was by far the most abundant casein fraction, whereas in HI αs-CN and β-CN were roughly present at the same level. These differences were present during the whole experimentation, despite of small quantitative variations in the intensity of the bands.

Table 1 shows the gross composition of HI and LO milk samples. No remarkable differences were found, except for the fat content and consequently for the fat to protein ratio ($p < 0.05$). It is worth highlighting that the two milks had a very similar content of total casein, a very important characteristic considering the aim of this experimentation, as we expected to evaluate two milks with the same amount of casein having different fraction composition, with high and low amount of αS1 fraction. According to the literature, a direct correlation among macroconstituents and α-S1 casein content exists (Ambrosoli et al., 1988); our results showed this trend between fat and α-S1 casein, as reported by other authors (Ramunno et al., 2007; Cebo et al., 2012). According to Guinee et al. (1997), Subramanian et al. (2006) and Perreault et al. (2016) the milk fat content could significantly affect the properties of the curd and cheese, in contrast, Moudrá et al. (2017)

Table 1
Goat milk gross composition of high (HI) and low (LO) type.

	HI	LO
Fat %	5.39 ± 0.26^a	4.53 ± 0.50^b
Protein %	3.37 ± 0.12^a	3.38 ± 0.04^a
Lactose %	4.70 ± 0.08^a	4.64 ± 0.10^a
Non-fat solid %	8.27 ± 0.12^a	8.15 ± 0.08^a
^{1}TS %	13.70 ± 0.33^a	12.74 ± 0.63^a
^{2}FP m°C	-543.0 ± 12.17^a	-555.3 ± 7.51^a
^{3}F/P	1.6 ± 0.07^a	1.34 ± 0.13^b
Density g/L	1025.43 ± 1.69^a	1026.90 ± 0.26^a
^{4}TA °TH	15.31 ± 0.28^a	14.99 ± 0.14^a
^{5}FFA meq	0.57 ± 0.06^a	0.58 ± 0.12^a
Casein %	2.59 ± 0.05^a	2.51 ± 0.07^a
Urea mg/dL	48.67 ± 2.39^a	51.00 ± 1.0^a
Citric Acid %	0.072 ± 0.002^a	0.070 ± 0.001^a

$^{a-b}$Mean values in the same row are statistically different at $p < 0.05$.
^{1}total solids; ^{2}freezing point; ^{3}fat to protein ratio; ^{4}TA = titratable acidity; ^{5}free fatty acids.

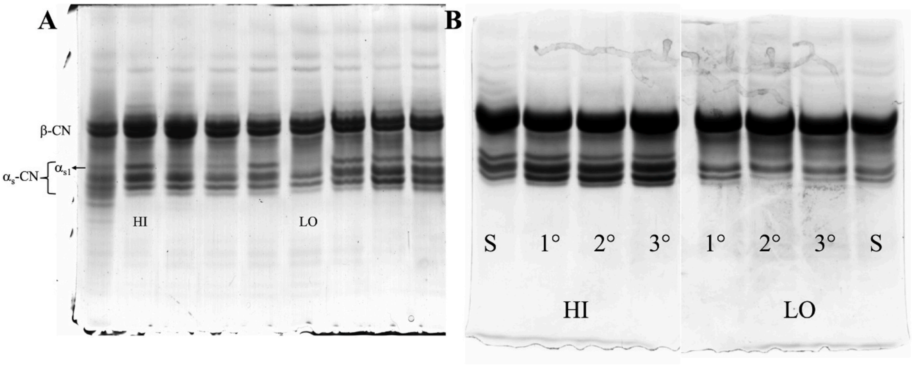

Fig. 2. Urea page of some bulk milk samples collected during the screening phase (A) and of milks from the two selected farms, taken for the three trials (B). HI: milk with normal α-s1-CN content; LO lane: milk without α-s1-CN.

reported no influence on the formation of the gel and curd characteristics. In the present study, no relevant difference was observed both in the coagulation time and curd firmness (empirical assessment), as well as in the gross composition of the cheeses derived therefrom (59.6 %–60.1 % moisture, SEM 0.15–0.28; 19,3 %–19.7 % protein, SEM 0.06-0.02; 17,4 % - 16,9 % fat, SEM 0.08–0.1, for LO and HI, respectively).

3.2. pH optimization and mozzarella stretching trials

Among the cheesemaking parameters, the pH value of the curd at the stretching time was deeply investigated as it represents a fundamental aspect, influencing the plastic and elastic behaviour of the curd and the quality of the finished product. In previous trials carried out in our laboratory on the milks collected during the screening phase, the pH range for stretching the curd was found to be between 5.2 and 5.0, and values above or below this range gave rise to curds too tough or too fragile. Consequently, the stretching properties were investigated within this pH range.

Different methods are available in the literature to assess the stretching behaviour of mozzarella cheese (Ak et al., 1993; Apostolopoulos et al., 1994; Guinee & O'Callaghan, 1997; Fife et al., 2002). Ma et al. (2012) proposed a tensile test by using an oil bath in which mozzarella was stretched in order to avoid excessive standard deviation. In the present investigation we used a tensile test without the oil bath, but all analytical steps were standardised and the temperature was kept under control, in order to achieve the best reproducibility. In fact, our results showed high reproducibility with very limited standard deviation among replicates and trials, as shown in Fig. 3. In this figure, the relationship between pH and curd extension can be observed. As expected, pH showed a pivotal role and, in both samples, the highest level of stretchability was obtained in correspondence of the lowest value. Stretching LO curd at the highest pH resulted in a very rough, poorly cohesive and not shiny cheese (see picture in Fig. 3), with a maximum extension of 97 mm. Similar results were obtained at pH 5.1, whereas at the lowest pH value the cheese became smoother and shinier and showed a significantly higher extension, reaching a value 151.6 mm (corresponding to an increase of more than 55 %). This result suggested that the suitable pH value for LO curd falls in a very narrow range, whereas the range for stretching HI sample was much wider. In fact, for this sample the appearance of the cheese was already good at pH 5.2, the sample being smooth and elastic, with good cohesiveness. As previously observed, the lowest extension was observed at the highest pH, but the elongation registered (178.1 mm) was higher than the best result obtained for the counterpart (151.6 mm at pH 5.0). As the curd pH decreased the stretchability improved, and elongation reached a maximum of 530 mm registered at pH 5.0. The influence of pH on cheese texture is well-known in the literature, as the lower the pH the lower the amount of colloidal calcium phosphate (CCP) embedded in the casein matrix. CCP acts as a cementing agent creating cross-links within the para-casein network (Kosikowski & Mistry, 1997). For pasta filata cheeses, reduction of CCP leads to a higher curd hydration during stretching, making it smoother, meltable, softer, shinier and extensible (Joshi et al., 2003, 2004; McMahon et al., 2005; Faccia et al., 2009; Bhattarai and Acharya, 2010). From the results obtained, it can be concluded that the optimum pH value for stretching the goat curd should be 5.0, independently from the abundance of αs1-CN. This pH value was slightly lower than that reported in previous papers (Faccia et al., 2015, 2021a), where a value of 5.15 was used but no specific investigation was carried out both on stretchability and casein genetic variability.

The elaboration of all TPA data gave rise to the curves reported in Fig. 4, in which it is possible to deepen the stretching behaviour of the samples stretched once (A) or twice (B). For each sample the extension curves are the average of three replicates multiplied by three trials. From Fig. 4A it can be observed that at 5.2 pH the HI sample almost doubled the elongation reached by the LO sample ($p < 0.05$, 178.1 mm vs 97.7 mm, respectively). Still, HI sample quadrupled the stretching extension

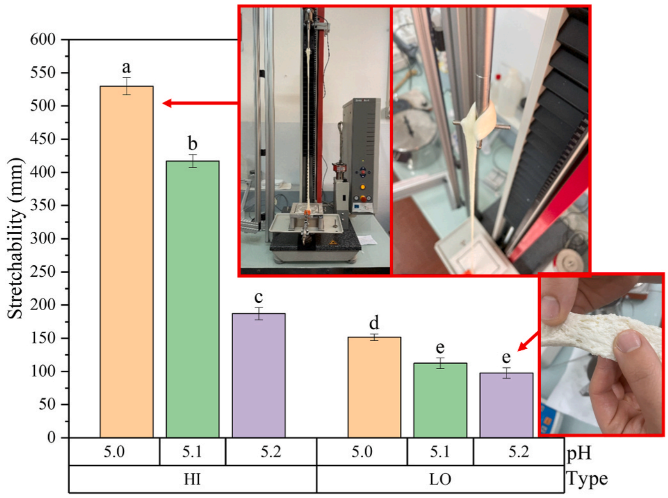

Fig. 3. Average mean of curd stretchability (mm) at different pH of HI and LO samples. $p < 0.05$.

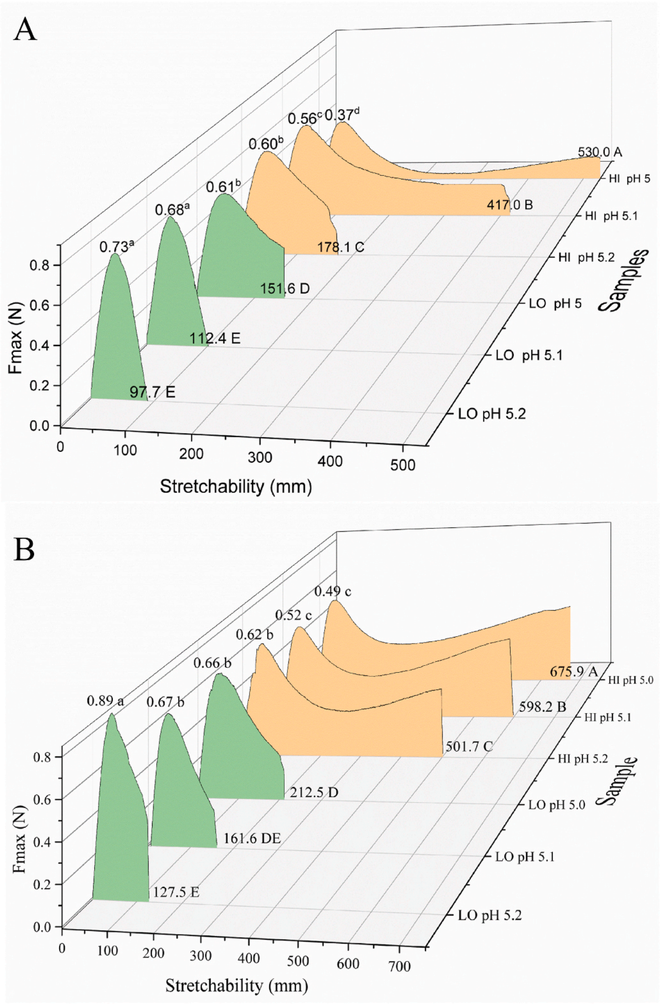

Fig. 4. Texture profile analysis of goat curd samples stretched once (A) or twice (B). Fmax (N) = the force encountered by instrument during curd stretching. Different letters after the maximum stretching value indicate statistical differences at $p < 0.05$.

compared to the LO at pH 5.1 ($p < 0.05$, 417 mm vs 112.4 mm, respectively) and a similar difference in elongation was observed at pH 5.0 ($p < 0.05$, 530 mm vs 151.6 mm, respectively). The samples stretched twice after pooling (4B), evidenced a better performance than samples stretched only one time, both for HI and LO. The latter showed an extension improvement between 30 and 43 % (considering the different pH values), whereas the former between 27 and 182 %. Although the better performances, LO samples still had limited elongation if compared to HI, reaching a maximum of 212.5 mm; whereas HI showed the highest extension improvement at pH 5.2 (from 178.1 to 501.7 mm). Finally, it is worth noting that the extension of the HI mozzarella string at 5.0 pH did not break, reaching the full scale of the instrument (676 mm). The second stretching supplied further information on stretchability since it depleted the cheese of fat as reported in literature (Rowney et al., 2003; Banville et al., 2016); reducing the fat content influences mozzarella texture, as it plays the role of plasticizer and gives cheese a softer texture (Rathod et al., 2025). According to Li et al. (2019) reducing fat causes a reduction of extensibility, but our results showed an opposite trend. This outcome could be attributable to both the second stretching phase and the strong thermal treatment, as reported by Bähler et al. (2016) and Feng et al. (2021).

Fig. 5 shows the Fmax values which represent how much force is needed to stretch the curd. The graph provides information about the hardness of the pasta filata string at its highest resistance point. The higher the Fmax, the harder the mozzarella texture. LO samples had, in general, higher Fmax values than HI curds, demonstrating higher tenacity of the curd string. LO samples at pH of 5.2 and 5.1 showed the highest Fmax (0.73 and 0.66 N, respectively), followed by LO sample at pH 5.0 and HI sample at pH 5.2 (0.61 and 0.60 N, respectively). Then, the lowest Fmax value was observed for HI curd at pH 5.0 (0.37 N). Concerning samples stretched twice, LO at pH 5.2 still showed the highest Fmax value (0.89 N), followed by the other two LO samples and HI sample at pH 5.2 (0.67, 0.66 and 0.62 N, respectively). Finally, HI sample at pH 5.1 and 5.0 showed significantly lower values (0.52 and 0.49 N, respectively).

The outcomes of the study corroborate the literature data on the behaviour of the curd during stretching, as less fat leads to a greater tensile strength (Koca & Metin, 2004; Li et al., 2019; Ma et al., 2012). This was generally true among our finding, but only statistically significant for LO samples at pH 5.2 and 5.0, and HI curd at pH 5.0. According to Mistry and Anderson (1993) low-fat cheese showed firmer texture due to the matrix dominated by casein presence, consequently calcium content plays a pivotal role in stretchability (McMahon et al., 2005; Wadhwani et al., 2011). Thus, the effect of the colloidal calcium is greater, as it acts as a cementing agent that creates cross-links between casein fibers. Then, the lower the pH value, the lower the hardness of the curd, thus Fmax showed significantly lower values when pH decreased, as the curd resulted softer and more extensible. Ma et al. (2012) evaluated the yield load as an index to measure the curd stretching, finding similar results.

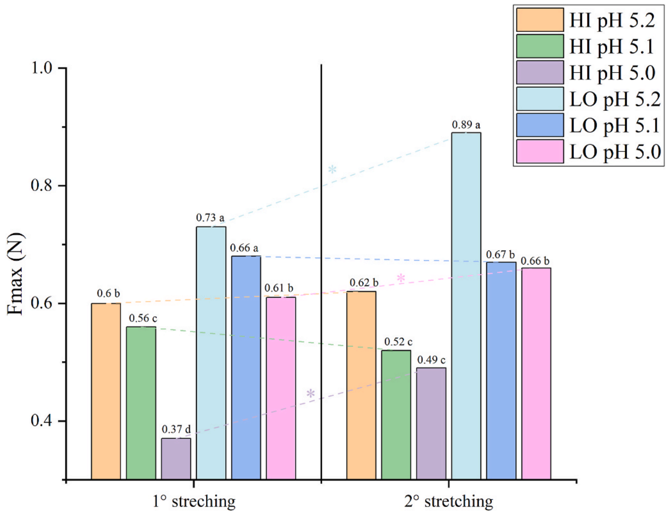

Fig. 5. Maximum Fmax values recorded during tensile test of curds. Different letters indicate statistical differences at $p < 0.05$ considering the first and the second stretching separately, whereas dashed lines with asterisk indicate statistical differences of the same sample between the two stretching phases.

3.3. *The volatile profile of mozzarella cheeses*

The chord diagram of the VOC profile of LO and HI mozzarella samples (stretched at pH 5.0) is reported in Fig. 6. Overall, 35 volatile compounds were identified, 28 for each sample. The total VOC amount was statistically different ($p < 0.05$), with HI showing a higher concentration than LO mozzarella (2435 μg/kg vs 1623 μg/kg, respectively). The former had a very high amount of 3-hydroxy-2-butanone (acetoin) which represents about 50 % of the total VOC amount found (1270 μg/kg). The second most abundant molecule is 2,3-butanedione (diacetyl), which is the precursor of acetoin; its concentration is about 30 % of the total VOC concentration (701 μg/kg). Since the starter added was used for a technological purpose (*S. thermophilus* is known to rapidly convert lactose into lactic acid through the glycolytic pathway), these molecules could have been produced by indigenous bacteria, as the milk was not heat treated; however, a minor contribute of the starter in producing acetoin could be possible, as literature report its ability to generate it (Silva et al., 2023; Xanthopoulos et al., 2001). According to Ott et al. (2000), another possible pathway for acetoin production is the degradation of amino acids, specifically leucine and isoleucine, which may be involved through the action of acetolactate decarboxylase or diacetyl reductase. However, since our samples are fresh, we believe this pathway is limited due to the minimal extent of proteolysis at this stage. Subsequently, at lower concentrations, many other molecules were identified, the most noteworthy: hexanoic acid (or caproic acid), acetic acid and dimethyl sulfide.

Concerning the LO sample, the molecules concentration was more balanced than the HI sample profile. In fact, the most abundant compound (3-metil-1-butanol) represents about 33 % of the total VOC amount (540 μg/kg). It may arise due to the lactic acid bacteria dehydrogenase activity on 3-methyl-1-butanal, often favored by the reducing

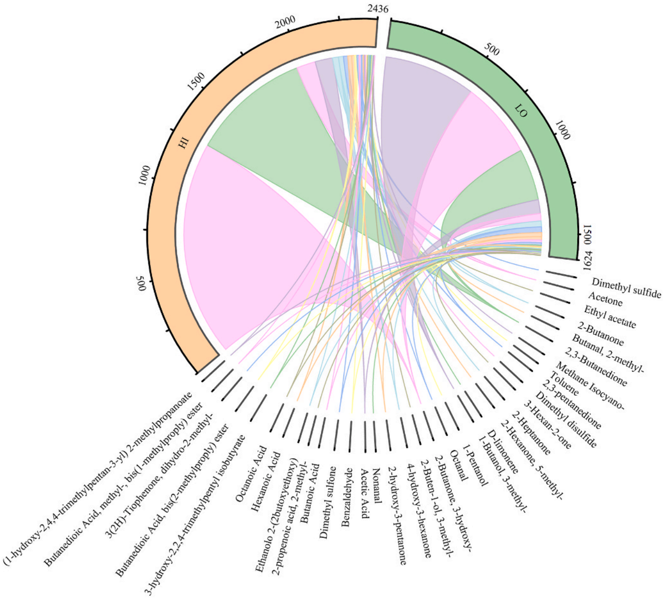

Fig. 6. Chord diagram of volatile organic compounds found in HI and LO mozzarella samples stretched at pH 5.0.

environment of cheese (Garde et al., 2005). The latter was not found in the volatile profile of the cheese because compounds belonging to this class are usually transitional because they are easily reduced to alcohols or oxidised to form acids (Curioni & Bosset, 2002; Garde et al., 2005). The second and third most abundant molecules in the volatile profile of LO mozzarella are acetoin and diacetyl, with concentrations of 451 and 304 μg/kg, respectively. As for HI sample, all other compounds found have concentrations below 100 μg/kg.

Some compounds were exclusive to only one sample, such as dimethyl sulfide, toluene and limonene for HI mozzarella, and ethyl acetate, 2-methylbutanal and nonanal in LO mozzarella. The quali-quantitative differences observed could be attributed to the use of raw milk for cheesemaking, which implies a significant role of indigenous bacteria in VOC production, potentially leading to distinct volatile profiles. Moreover, these differences may play an important role in the odour characterization of the final product. Thus, the odour activity value (OAV) index was considered to obtain information about the theoretical odour active compounds that could possibly discriminate HI from LO sample.

Among all the VOC found, the ones shown in Table 2 are those with the odour activity value > 1. The molecules that have $OAV>1$ could theoretically contribute to the odour of the product as reported in literature (Natrella et al. 2020b, 2022). According to the table, HI mozzarella had 12 aroma active compounds, with diacetyl as the most predominant ($OAV = 13754$). Diacetyl is highly volatile and confers butter, cream, yogurt and cheesy odour notes to dairy products (Attaie, 2009; Clark & Winter 2015). Caproic acid and dimethyl sulfide had high OAV (33–38) and possibly contributed to the animal and sulfur odour notes. Then, acetic and butyric acid had an OAV between 12 and 19, and should be responsible of acetic sweaty odours. As observed in HI sample, LO mozzarella had diacetyl as compound with the highest OAV (5961), followed by 3-methylbutanol (337). The latter was already found in goat cheese as reported by Sonmezdag (2019) and Mondello et al. (2005) and contributed to an unpleasant note in Sepet cheese and Canestrato Sardo (Piombino et al., 2008; Ercan et al., 2011). Finally, also nonanal resulted to be aroma active (it is responsible of fruity odour), along with butyric and hexanoic acid (animal and typical goat odours).

Table 2
Odour activity values (OAV) of the volatile organic compounds found by SPME technique in HI and LO mozzarella samples.

VOC	OT (ppb)	OAV		Descriptors
		HI	LO	
Dimethyl sulfide	0.30 [A]	33	0	Sulphurous, cabbage [H]
2,3-Butanedione (Diacetyl)	0.050 [B]	13754	5961	Cream, butter [I]
2,3-pentanedione	10 [C]	2	3	Butter [I]
Disulfide dimethyl	2.7 [B]	2	0	Onion, cabbage [L]
2-Heptanone	3.5 [D]	1	0	Fruity, banana [M]
1-Butanol, 3-methyl- (Isoamyl alcohol)	1.6 [B]	4	337	Unpleasant odour, alcohol [N]
Octanal	0.7 [E]	7	1	Fruity, ripe fruit [E]
2-Butanone, 3-hydroxy-(Acetoin)	800 [F]	1	0	Cream, butter, yoghurt [F]
Nonanal	0.53 [E]	0	13	Rose, citrus (orange) [E]
Acetic Acid	5.3 [E]	19	15	Acetic, avvinate [E]
Butanoic Acid (Butyric Acid)	1 [G]	12	15	Unpleasant, rancid, faecal [M]
Octanoic Acid (Caprylic Acid)	1.2 [H]	4	4	Fruity-Acid, rancid, dairy-like flavours [O]
Hexanoic acid (Caproic Acid)	0.6 [B]	38	40	Goaty, rancid [M]

[A] Buttery et al., 1990; [B] Nagata and Takeuchi, 2003; [C] Blank et al., 1992; [D] Yang et al., 2008; [E] Cometto-Muñiz and Abraham, 2010; [F] Wang et al., 2021; [G] Leonardos et al., 1974; [H] The Good Scents Company website, 2024; [I] Burdock, 2016; [L] Zhang et al., 2021; [M] O'Neil, 2013; [N] Guard, 1999; [O] King, 1965.

3.4. *Sensory analysis of mozzarella samples*

Fig. 7 reports the differences in the sensory characteristics between LO and HI mozzarella samples (only the samples stretched at pH 5.0 were analysed). According to the panellists, who were expert in evaluating high moisture mozzarella cheese, texture was not different between the samples, but was not the same than bovine mozzarella, due to higher hardness and lesser solubility (data not shown). Concerning taste perception, Heil and Dumont (1993) and Vassal et al. (1994) reported that goat cheese obtained from high αs1-CN milk had a sweeter taste than cheese obtained from low αs1-CN milk that, in turn, had a sharper taste. In the present study, no differences were observed, probably because mozzarella is a fresh cheese that does not undergo to the biochemical changes that takes place during ripening. As to the odour perception, LO mozzarella had significantly higher overall intensity, in contrast with the VOC results, confirming that total VOC concentration might not correspond to the overall odour intensity due to many reasons (odour threshold of the molecules, synergic or antagonistic effect among compounds, etc.). The sour milk and animal odour notes were higher in the LO than HI sample, corroborating the results reported in Table 2. Concerning aroma, LO mozzarella had the highest score ($p < 0.05$) of overall intensity, sour milk and goaty; in addition to this, LO sample gained the highest pleasantness value, as judges rewarded greater complexity from an aromatic point of view. It is important to highlight a limitation of the present study that was the unknown feeding regimen of the dairy goats producing the milk and the different breed composing the flocks. Consequently, the results of the VOC and sensory analysis might be considered with care, since the milk VOC profile can be greatly influenced by feeding (Natrella, Gambacorta, et al., 2020). Nevertheless, the results of the aroma analysis agree with the findings of Heil and Dumont (1993), who reported higher presence of the "goaty" descriptor in the cheese made from milk with low αs1-CN content.

4. Conclusions

The outcomes of the present study showed that the α-S1-CN abundance in in goat milk played a significant role in the production of mozzarella, since it influenced the stretchability of the curd and, possibly, the cheese aroma. The TPA method applied in the experimentation with some modifications was suitable to get the differences in extensibility of the curds during stretching, but a difference was also observed in the appearance of the stretched cheese (glossiness and uniformity). Results showed that for both types of curds, 5.0 pH was the best value for stretching both curds, independently from the level of α-S1-CN; nevertheless, before fixing it as the most suitable value for stretching, more investigation is needed, using a sample set composed of milk with a wide difference in the gross composition. From a sensory point of view, mozzarella made from milk with low α-S1 casein content was judged more aromatic, with typical "goaty" flavour, and more pleasant. Further work is in progress to investigate if the different casein profile can also influence the shelf life of the cheese and to get information about consumer's acceptance.

CRediT authorship contribution statement

G. Natrella: Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **P. Caliandro:** Formal analysis, Data curation. **D. De Angelis:** Writing – review & editing, Software, Formal analysis. **P. De Palo:** Writing – review & editing, Validation, Supervision, Conceptualization. **A. Maggiolino:** Writing – review & editing, Validation, Supervision. **M. Faccia:** Writing – review & editing, Validation, Supervision, Conceptualization.

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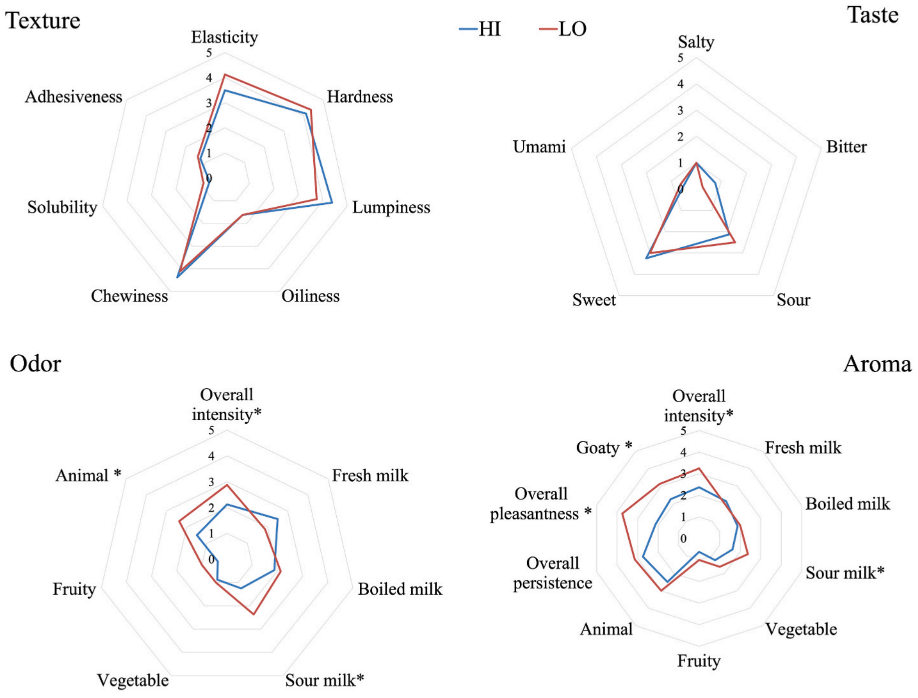

Fig. 7. Quantitative descriptive analysis (QDA) of LO and HI mozzarella samples. *Significant differences at $p < 0.05$.

agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.idairyj.2025.106344.

Data availability

Data will be made available on request.

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