Rheology and texture applied to goat and sheep milk cheeses: principles, applications and future trends
ABSTRACT

Background: There are several types of goat and sheep cheeses around the world, with a relative emphasis on Europe and Asia. The cheese diversity is possible by many factors, including the type of milk, different ingredients and technological process, which can influence the texture and rheology characteristics of these dairy products. Instrumental measures of rheology and texture can be carried out to understand and characterize this variety of cheeses. However there is a lack of a compilation that brings texture and rheology information about goats and sheep cheeses. Scope and Approach: This review tackles the most relevant aspects and concerns of instrumental rheology and texture of goat and sheep milk cheese. Moreover, the main factors that influence cheese rheology and texture, as well as the comparison between these two species (goat and sheep).

Key Findings and Conclusions: The texture is the most critical characteristics of cheese, which determines its acceptability by consumers. The differences in the rheological properties of cheeses made with different types of milk may be due to different casein structures or their concentrations in milk. Rheology deals with the relationship between three variables: strain, stress and time. One of the most popular tests to evaluate the mechanical and rheological properties of cheeses is the uniaxial test and the rheological behavior of the cheese is viscoelastic. All stages of technological processing cheese can influence the rheological and textural characteristics of the cheeses, either improving or damaging them. Studies with sheep cheeses are scarcer than in goat cheese.

Keywords: Caprine Cheeses, Ewe Cheese, Hardness, Spreadability, Viscoelastic Behavior, Viscous Modulus.
GOAT AND SHEEP CHEESES (BACKGROUND)

Goat and sheep milk has been prominent in the cheeses elaboration since the beginning of humanity (Pulina et al., 2018). There are several types of goat and sheep cheeses around the world, with a relative emphasis on Europe and Asia. In Europe the main cheese is Teleme, followed by Greek cheese and Feta cheese. Probably, this distribution is because goat and sheep cheeses are original from the Mediterranean region, spreading to Asia and reaching countries such as Turkey, Lebanon, Iraq, Syria, Iran and Jordan (Hilali et al. 2011; Pulina et al., 2018).

The wide variety of cheeses can be classified according to the native country, the manufacturing process or some end-use property (Koppel and Chambers, 2012). However, in this work, we classified the cheeses based on reports from the literature by goat milk, sheep or the mixture of both (Figure 1).
The cheeses can be consumed fresh or cured. Fresh cheeses are those that can be consumed right after the process of elaboration, without undergoing any process of maturation. As an example of this variety of cheese, there are the cheeses of acid coagulation.
However, there are cured ones that can mature for periods ranging from a few hours to years. The unique characteristics of cheeses are developed during maturation. The duration of this maturation directly influences the moisture content of the cheeses, presenting an inverse relation between both (Gobbetti, Neviani and Fox, 2018).

Maturation is a step in the processing of cheese made by bacteria or fungi, intentionally added to the process to allow biochemical changes that determine the existing cheese varieties. For example, the use of Propionibacterium in Swiss cheese processing, Penicillium roqueforti in blue cheese varieties (Stilton, Danablu and Roquefort), Penicillium camemberti in Camembert or Brie (Gobbetti, Neviani and Fox, 2018; Fox et al., 2017). Often, the final characteristics of the cheeses will be determined by the metabolites generated by these microorganisms, making them essential in the maturation stage.

Cheeses that are matured by bacteria have as main process the metabolization of residual lactose, lactate and citrate, since the starter culture has already metabolized most of the lactose. In the case of Swiss cheeses, for example, Propionibacterium freudenreichii metabolizes lactate to propionate, acetate and CO₂. This CO₂ formed is responsible for the eyes present in Swiss cheeses. Type-Dutch cheeses use bacteria such as Lactococcus lactis ssp. lactis and Leuconostoc spp., which metabolize the citrate to diacetyl and once again the CO₂ produced is responsible for the small eyes of the Type-Dutch cheeses. The cheeses that are matured by fungi have as main metabolite NH₃, coming from the lactate metabolism present in cheeses by these microorganisms. With the production of NH₃, it tends to increase the pH of these cheeses. However, this function is not clear (Fox et al., 2017).

Currently, goat and sheep cheeses are widespread throughout the world, with reports and intensive research in the Europe (Attaie, 2005; Massouras et al., 1998; Van Haekken et al., 2013), Asia (Aminifar et al., 2012, Chen et al., 2010, Farahani et al., 2014), USA (Milani & Wendorff, 2011), Colombia (González-Morelo et al., 2018; Tirado et al., 2018), Africa (Kiiru et al., 2018), Brazil (Moreira et al., 2019; Queiroga et al., 2013; Silva et al., 2017; Silva et al., 2020a; 2020b), and Argentina (Paz et al., 2017). In the literature, the following cheeses of goat and sheep milk are described (Table 1).
Table 1. Cheeses made with goat or sheep milk or mixture reported in the literature and respective native country.

<table>
<thead>
<tr>
<th>Milk source</th>
<th>Type of cheese</th>
<th>Native country</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goat</td>
<td>Creamy ricotta</td>
<td>Italy</td>
<td>Borba et al., 2013.</td>
</tr>
<tr>
<td></td>
<td>Graviera (Greek cheese)</td>
<td>Greece</td>
<td>Samelis et al., 2017; Vandera et al., 2019.</td>
</tr>
<tr>
<td></td>
<td>Colombian Queso Costeño</td>
<td>Colombia</td>
<td>González-Morelo et al., 2018.</td>
</tr>
<tr>
<td></td>
<td>Colombian Caribbean coastal cheese</td>
<td>Colombia</td>
<td>Tirado et al., 2018.</td>
</tr>
<tr>
<td></td>
<td>Mozzarella</td>
<td>Italy</td>
<td>Kiuru et al., 2018; Paz et al., 2017; Singh et al., 2017.</td>
</tr>
<tr>
<td></td>
<td>Caciocavalo cheeses</td>
<td>Italy</td>
<td>Niro et al., 2014.</td>
</tr>
<tr>
<td></td>
<td>Minas fresh cheese</td>
<td>Brazil</td>
<td>Moreira et al., 2019.</td>
</tr>
<tr>
<td></td>
<td>Coalho cheese (Brazilian traditional cheese)</td>
<td>Brazil</td>
<td>Silva et al., 2020a; 2020b; Silva et al., 2017; Queiroga et al., 2013; Bezerra et al., 2017a; 2017b.</td>
</tr>
<tr>
<td></td>
<td>Cheddar-like caprine milk cheese</td>
<td>England</td>
<td>Van Hekken et al., 2013.</td>
</tr>
<tr>
<td></td>
<td>Jack Cheese</td>
<td>USA</td>
<td>Attia, 2005.</td>
</tr>
<tr>
<td></td>
<td>Calenzana (an artisanal Corsican cheese)</td>
<td>Corsica</td>
<td>Casalta et al., 2009.</td>
</tr>
<tr>
<td></td>
<td>Colby-like cheese (semisoft cheese)</td>
<td></td>
<td>Chen et al., 2010.</td>
</tr>
<tr>
<td></td>
<td>Feta Cheese</td>
<td>Greece</td>
<td>Alexandraki and Moatsou, 2018; Bozoudi et al., 2018; Papadopoulou et al., 2018.</td>
</tr>
<tr>
<td></td>
<td>Spanish cheeses</td>
<td>Spain</td>
<td>Martínez et al., 2011.</td>
</tr>
<tr>
<td></td>
<td>Teleme cheese</td>
<td>Greece</td>
<td>Massouras et al., 2006; Pappa et al., 2007.</td>
</tr>
<tr>
<td></td>
<td>Homemade North-Morocco fresh goat cheese</td>
<td>Morocco</td>
<td>Galiou et al., 2015.</td>
</tr>
<tr>
<td></td>
<td>Caciocrotta</td>
<td>Italy</td>
<td>Ioanna et al., 2018.</td>
</tr>
<tr>
<td></td>
<td>Bouhezza (Algerian traditional cheese)</td>
<td>Algeria</td>
<td>Medjoudj et al., 2016.</td>
</tr>
<tr>
<td></td>
<td>Xinotyri</td>
<td>Greece</td>
<td>Pappa et al., 2017.</td>
</tr>
<tr>
<td></td>
<td>Semihard artisanal goat cheeses</td>
<td>Mediterranean countries</td>
<td>Meng et al., 2018.</td>
</tr>
<tr>
<td>Sheep</td>
<td>Graviera (Greek cheese)</td>
<td>Greece</td>
<td>Tsafarakidou et al., 2016; Vandra et al., 2019.</td>
</tr>
<tr>
<td></td>
<td>Siahmazi cheese (an Iranian ewe’s milk variety)</td>
<td>Iran</td>
<td>Farahani et al., 2014.</td>
</tr>
<tr>
<td></td>
<td>‘Torta del Casar’ cheese</td>
<td>Spain</td>
<td>Ordiales et al., 2014.</td>
</tr>
<tr>
<td></td>
<td>Lighvan cheese (Iranian traditional cheeses)</td>
<td>Iran</td>
<td>Aminifar et al., 2012.</td>
</tr>
<tr>
<td></td>
<td>Calenzana (an artisanal Corsican cheese)</td>
<td>Corsica</td>
<td>Casalta et al., 2009.</td>
</tr>
<tr>
<td></td>
<td>Feta Cheese</td>
<td>Greece</td>
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</tr>
<tr>
<td></td>
<td>Spanish cheeses</td>
<td>Spain</td>
<td>Martínez et al., 2011.</td>
</tr>
<tr>
<td></td>
<td>Teleme cheese</td>
<td>Greece</td>
<td>Massouras et al., 2006; Pappa et al., 2007.</td>
</tr>
</tbody>
</table>

The cheese diversity is possible by many factors, including type of milk, different ingredients and technological process, which can influence the texture and rheology characteristics of these dairy products (Gunasekaran and Ak, 2002).

The texture is the most important characteristics of cheese (Gunasekaran and Ak, 2002), which determines its acceptability. With this property, the consumer can identify the specific variety of cheese. The textures of the various types of cheese being distinct, but the factors that determine and influence the changes in texture in all types of cheeses are basically the same, since in the processing of cheeses, few are the variable components (Pappa et al., 2007; Tidona et al., 2019)
The rheological properties of the cheese play a significant role in determining the texture characteristics. It is believed that the cheese has a viscoelastic nature that shows elastic and viscous behavior (Gunasekaran and Ak, 2002). Therefore, the instrumental measures of rheology and texture can be carried out to obtain different information about the different types of cheeses. When one talks about cheeses of goat and sheep milk, there are reports on the traditional and characteristic cheeses of each part of the world, with information of the isolated product (Alexandraki and Moatsou, 2018; Borba et al., 2013; González-Morelo et al., 2018; Kiiru et al., 2018; Silva et al., 2017; Tirado et al., 2018; Vandera et al., 2019).

Thus, due to the lack of a compilation that brings texture and rheology information about goats and sheep cheeses, this review aims to address the main rheology and texture characteristics of several goat and sheep cheeses reported in the literature, in addition to between the two species and bring the influence of the technological processing of cheese on these characteristics.

THE TEXTURE IN GOAT AND SHEEP CHEESES

The texture is defined as all the rheological and structural attributes of products that are perceptible by mechanical means. The textural attributes of food play an important role in consumer appeal, purchasing decisions and occasional consumption (Gunasekaran and Ak, 2002). There are various terms used in describing food texture. Many of the terms used in the literature to describe cheese texture are summarized in Table 2.

Table 2. Different terms used in the literature to describe cheese texture.

<table>
<thead>
<tr>
<th>Sensory term</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesiveness</td>
<td>“Force required to remove material adhering to a specific surface.”</td>
<td>Guiné et al., 2015.</td>
</tr>
<tr>
<td>Creaminess</td>
<td>“The extent to which the texture has broken down to a creamy semiliquid texture, assessed between tongue and palate during mastication.”</td>
<td>Foegeding and Drake, 2007.</td>
</tr>
<tr>
<td>Chewiness</td>
<td>“The effort required to chew the sample to a suitable consistency to swallow.”</td>
<td>Guiné et al., 2015.</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>“Degree at which the sample deforms before breaking, biting with the molars.”</td>
<td>Guiné et al., 2015.</td>
</tr>
<tr>
<td>Elasticity</td>
<td>“The rate of resistance with which the sample returns to its original form after removal of the force that caused the partial compression.”</td>
<td>Guiné et al., 2015.</td>
</tr>
<tr>
<td>Firmness</td>
<td>“The extent of resistance offered by the cheese, assessed during the first 5 chews using the front teeth; ranging from soft to firm.”</td>
<td>Foegeding and Drake, 2007.</td>
</tr>
<tr>
<td>Fraturability</td>
<td>“Force required to fracture the cheese.”</td>
<td>Attaie, 2005.</td>
</tr>
<tr>
<td>Gumminess</td>
<td>“The energy required to disintegrate a semi-solid food into a ready-to-swallow condition.”</td>
<td>Guiné et al., 2015.</td>
</tr>
<tr>
<td>Hardness</td>
<td>“Force needed to deform the product at a certain distance.”</td>
<td>Guiné et al., 2015.</td>
</tr>
<tr>
<td>Resilience</td>
<td>“Is how well a product ‘struggles to regain its original position.’”</td>
<td>Guiné et al., 2015.</td>
</tr>
<tr>
<td>Sensory term</td>
<td>Definition</td>
<td>Reference</td>
</tr>
<tr>
<td>--------------</td>
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</tr>
<tr>
<td>Spreadability</td>
<td>&quot;Force required to flow the cheese between two surfaces.&quot;</td>
<td>Almanza-Rubio et al., 2016.</td>
</tr>
<tr>
<td>Springiness</td>
<td>&quot;The amount of time necessary for the sample to recover. The faster the sample returns, the greater springiness it possesses (no compression = no springiness).&quot;</td>
<td>Bramesco and Setser, 1990.</td>
</tr>
<tr>
<td>Stickiness</td>
<td>&quot;The stickiness of the cheese against the palate and around the teeth during mastication.&quot;</td>
<td>Foegeding and Drake, 2007.</td>
</tr>
</tbody>
</table>

Queiroga et al. (2013), evaluating isolated goat and cow Coalho cheese and its mixture, observed that the texture in the parameters of chewiness and cohesiveness did not present a significant difference in relation to the type of cheese and the time of storage. However, the hardness parameter presented higher values for goat cheese than cow cheese, and was not affected by storage time.

The differences in rheological properties of cheeses made with different types of milk may be due to different casein structures or their concentrations in milk (Queiroga et al, 2013), since bovine milk contains higher levels of casein-α-s1 than goat milk (Ceballos et al., 2009). The Coalho cheese is a traditional Brazilian cheese, whose main raw material is bovine milk. However, when made with goat’s milk, it is the main cheese produced with this milk source. It is a cheese generally consumed after cooking and therefore the fact of obtaining higher values in the texture parameters, when compared to the cheese of bovine milk, does not have significant relevance in its acceptability. The pre-consumption heating provides increased softening and increased product extensibility, being features desirable to its usual consumers.

It is reported in the literature that the increase in the acidity of cheeses during storage causes changes in the characteristics of the protein aggregates, resulting in cheeses with a softer and easily fragmented texture (Queiroga et al., 2013). Moisture is a parameter that also influences cheese texture, since high moisture weakens the protein network, making the cheese softer (Buriti, Rocha, and Saad, 2005). In Queiroga et al. (2013), the highest values of moisture and lower values of hardness were found for cow Coalho cheese in the majority of storage periods evaluated. This fact is possible because the higher moisture content causes the weakening of the protein network and thus making it softer.

In the study by Fang et al. (2016), evaluating the digestion of different Commercial cheeses, varying in texture, exhibited different cheese disintegration and protein digestion patterns during gastric digestion. They further concluded that both cheese and cheese composition affected cheese digestibility and that Cheese disintegration at the end of gastric digestion was higher when initial cheese hardness, cohesiveness, and chewiness were lower. Soft cheese, such as Camembert, needed less force to break apart the cheese matrix.

Almanza-Rubio et al. (2016) report the probable interference of fat content in the spreadability of cream cheeses. In their study with cream cheese, they observed lower values of
spreadability of cream cheeses produced with sonicated milk, which has a decrease in the size of fat globules when compared to cream cheese manufactured with milk without sonication. In fact, the cheeses subjected to heating and with a higher fat content will have greater spreadability because the cheese’s fat will tend to melt with heating, making it more extensible.

**Rheology in goat and sheep cheeses**

Food rheology consists in the science that studies the solids deformation and the liquids fluidity by the influence of applied mechanical forces (Barnes, 1989).

Rheology deals with the relationship between three variables: strain, stress and time. Strain and stress are related to deformation and force, respectively. The deformation explains the effect of size on the deformation of the material due to the difference in length (or height) of the samples, while stress is responsible for the size effect on applied force due to the difference in the cross-sectional area of the samples. Using strain and stress, it can get real properties of the material. The deformation is the measure of the change in size and shape of a material subjected to an external force and the measurement of its rate introduces the third rheological variable, time. Knowledge of the deformation rate concept is necessary to describe the behavior of the material flow and it is simply the time derivative of the deformation (Gunasekaran and Ak, 2002).

One of the most popular tests to evaluate the mechanical and rheological properties of cheeses is the uniaxial test. The mechanical properties commonly determined from this cheese test include $E_D$, deformability modulus, fracture stress $\sigma_f$, fracture strain $\varepsilon_f$ and work for fracture $W_f$ (Gunasekaran and Ak, 2002).

The rheological behavior of the cheese is viscoelastic. A viscoelastic material exhibits both a solid elastic behavior and a viscous liquid under a wide range of conditions. Among the most used rheological tests for cheeses is the uniaxial test, which evaluates the modulus of deformability ($E_D$), stress ($\sigma_f$), fracture stress ($\varepsilon_f$) and fracture work ($W_f$). For cheese evaluation, the following Power-Law equation is required: $\sigma = Ce^n$ ou $\ln\sigma = \ln C + n \ln \varepsilon$, where, $C$ is a constant and $n$ is the exponent meaning the relative contributions of viscous and elastic components. The value $n$ is zero for an ideally elastic material (i.e., without a viscous part) and increases with the extent of the viscous contribution. (Gunasekaran and Ak, 2002).

In cheese rheology, as the behavior of the cheese is viscoelastic, it presents both elastic and viscous behavior. Therefore it is necessary to study the elastic ($G'$) and viscous modulus ($G''$) to better understand the rheological behavior of cheeses. Almanza-Rubio et al. (2016) observed that the elastic modulus ($G'$) has an association with the fat content, due to the fact of the fat decrease in the cheeses results in lower $G'$ values (Brighenti et al., 2008).
In contrast, the viscous modulus ($G''$) presents a probable association with the protein and moisture content of creamy cheeses (Brighenti et al., 2008), because with the use of sonicated milks, which have a reduction of fat globule size, $G''$ is the least altered property when cream cheese is produced with this type of milk. In addition, the milk protein content of the sonicated milk does not change significantly (Almanza-Rubio et al., 2016). The viscosity is also influenced by the temperature, usually decreasing with increasing of the temperature (Silva and Costa, 2019).

The rheological data of cheeses are few described in articles, probably due to the complexity of the theme and the need for further studies to better understand rheological behavior in cheeses.

### Table 3. Values of modulus $G'$ and $G''$ from uniaxial testing of several cheeses.

<table>
<thead>
<tr>
<th>Source milk</th>
<th>Cheese Variety</th>
<th>$G'$</th>
<th>$G''$</th>
<th>Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bovine</td>
<td>White cheese</td>
<td>41.8 Pa</td>
<td>10.4 Pa</td>
<td>Rheometer (Kinexus Pro+, Malvern Inst., Worcestershire, UK)</td>
<td>Alihonuglu et al., 2018.</td>
</tr>
<tr>
<td></td>
<td>Requeijão cremoso</td>
<td>-</td>
<td>-</td>
<td>Paar Physica MCR 300 strain gage (Anton Paar GmbH, Graz, Austria)</td>
<td>Belsito et al., 2017.</td>
</tr>
<tr>
<td>Bovine</td>
<td>Mozzarella</td>
<td>-</td>
<td>-</td>
<td>Rheometer Ares-G2 (TA instruments, Waters LLC, New Castle, DE, USA)</td>
<td>Berta et al., 2016.</td>
</tr>
<tr>
<td></td>
<td>Block-type and spreadable-type processed cheeses</td>
<td>-</td>
<td>-</td>
<td>Viscometer (TR−1 Rheometer, A.T.E.I., Thessaloniki, Greece)</td>
<td>Dimitreli and Thomareis, 2009.</td>
</tr>
<tr>
<td></td>
<td>Spreadable-type processed cheese</td>
<td>4.62 KPa</td>
<td>2.61 KPa</td>
<td>Rheometer Bohlin C-VOR 150 (Bohlin Instruments, Inc., USA)</td>
<td>Dimitreli and Thomareis, 2008.</td>
</tr>
<tr>
<td></td>
<td>Mozzarella</td>
<td>43 to 150 KPa</td>
<td>14 to 41 KPa</td>
<td>Rheometrics Dynamic Analyser, model RDA-700 (Rheometrics Scientific, Piscataway, NJ, USA)</td>
<td>Van Hekken et al., 2007.</td>
</tr>
<tr>
<td>Sheep</td>
<td>Semi-hard cheese</td>
<td>-</td>
<td>-</td>
<td>Rheometer ThermoHaake RS1 (ThermoHaake GmbH, Karlshure, Germany)</td>
<td>Juan et al., 2007.</td>
</tr>
<tr>
<td></td>
<td>La Serena cheese</td>
<td>0.098 N/mm²</td>
<td>-</td>
<td>Instron Compression Tester 1122 (Instron Ltd, High Wycombe, Bucks, UK)</td>
<td>Del Pozo et al., 1988.</td>
</tr>
</tbody>
</table>
Effect of milk composition on textural and rheological characteristics of goat and sheep cheeses

Protein

About the milk composition, the greater influence of the milk composition in the texture and rheology of cheeses is due to the casein content, followed by fat content. Thus, when fat and casein content are altered, they significantly affect the rheological characteristics of the cheeses (McCarthy, 2011). However, in the study by Van Hekken et al. (2013), they observed that high-moisture Cheddar cheeses from goat’s milk containing different amounts of fat have been shown to be influenced by the protein matrix which consisted mainly of β-casein. Although β-casein has been degraded during 6 months of maturation, the level of fat in the matrix had a greater influence on the rheological properties than the protein levels. This behavior can be explained by the fact that the fat content is directly related to spreadability. Its influence becomes greater mainly for rheological parameters that evaluate in cheese the elasticity and the viscosity because the cheese has a viscoelastic behavior.

The texture of goat milk cheeses is influenced by compositional factors such as moisture, salt, fat, pH and degree of proteolysis. The moisture content causes a weakening of the protein network, making the cheese softer. Therefore, moist cheeses tend to be softer. Still, according to Attaiie (2005), the conversion of the curd Monterey Jack cheese to matured is influenced by factors such as lipolysis, acid production during fermentation and storage temperature, leading to variations in its characteristics.

There are reports in the literature that the use of skim milk in cheese production may promote increased hardness, gumminess and elasticity due to reduced fat content in dry matter, thus increasing the proportion of casein in the cheese produced when compared to use of milk integral (Tirado et al., 2018; Van Hekken et al., 2013). Borba et al. (2014) reports that the use of whole milk in creamy ricotta production made with the mixture of goat and cow whey may have improved texture parameters over 14 days of storage. The mixture of bovine milk and goat milk is an excellent alternative for the improvement of cheese texture and, in addition, it allows a greater yield and profitability to the producer of goat milk, since the production of this one is smaller than the one of bovine source.

In the Milewski et al., 2018 study, evaluating the season effect on milk and cheese production, they observed that the total biogenic amines content in cheese during the winter
feeding period was almost twice as high as in summer (1056.4 vs. 567.6 mg/kg). Moreover, the cadaverine value was the highest in winter cheese, whereas putrescine was the highest in cheese during the summer feeding period. This variable possibly influences the pH of the cheeses during processing, since the biogenic amines tend to raise the pH because they have a more alkaline profile. Thus, the increase of pH allows the insolubilization of calcium in the casein micelles, and therefore altering the internal structure and the rheological properties of the cheeses.

**Fat**

Van Hekken et al. (2013) studied cheeses with different fat content (integral fat, low fat and non-fat) and they found that cheeses with full fat and reduced fat (28% fat reduction) had the softest and most flexible textures. Although full fat cheeses tended to have the lowest values of hardness, chewiness, shear stress and shear rigidity, cheeses with reduced fat were not significantly different from full fat cheeses, and were considered very similar in texture. However, reducing the fat content below 19% resulted in harder and less flexible cheese. By the same line of the moisture content, the fat causes a pronounced softness in the cheeses that when they undergo reduction of this present greater hardness and less flexibility.

Tirado et al. (2018), evaluating the rheological properties of Colombian-Caribbean-coast sour cream from goat’s milk, observed that the initial fat content of goat’s milk influenced the rheological properties of Colombian-Caribbean sour cream, presenting the product prepared from goat’s milk with fat content of 4.00% the largest elastic modulus and angle of relaxation times. This fact confirmed the elastic predominance and the creation of more complex structures by caseins and other proteins, giving the sample greater firmness and better adhesion when it was dispersed.

In addition, the season of the year in which goat milk and cheese are produced, influences the fatty acid profile of both products. In the summer, there is an increase in vitamin A and E content in grazing milk, such as fodder, which is a good source of these vitamins, vitamin E being responsible for inhibiting lipid peroxidation, including unsaturation of fatty acids, especially during technological processing and storage of milk and cheese (Milewski et al., 2018). The results observed during the studies of Milewski et al. (2018) suggested that the quality of milk obtained during summer feeding has a higher content of vitamin A and E and a more beneficial profile of fatty acids: a higher proportion of conjugated linoleic acid (CLA) and polyunsaturated fatty acids (PUFA), consequently reflecting the quality of the cheese. When produced in the winter, both products, milk and cheese, presented a higher proportion of monounsaturated fatty acids (MUFA), which resulted in a reduction in the PUFA content and the PUFA / MUFA ratio. Thus, milk production in the summer provides milk with higher
content of vitamins A and E and the healthier fatty acid profile for consumers of this milk and consequently its derivatives, such as cheese.

**Milk source**

The texture of cheeses is also influenced by the milk source, since some cheeses are made with the mixture of sheep and goat milk, or each with bovine milk. Borba et al. (2013), evaluating the instrumental texture of creamy ricotta made with the mixture of goat and cow whey, observed that the instrumental texture profile of creamy ricotta characterized the product as deformable, inelastic, cohesive, soft, delicate and fragile texture. They also observed that there was no change in texture parameters after 14 days of refrigerated storage, which reveals the stability of the product, which would maintain its acceptability throughout its shelf life.

However, Dimitreli et al. (2017), when evaluating the instrumental texture profile of buffalo and cow’s milk cheese in the mix, observed that the texture characteristics reduced with storage time, which may be due to the weakening of the protein matrix due to the proteolytic action of enzymes (Fox and McSweeney, 1996). The concentration of the milk mixture used in this study significantly affected the hardness, chewiness and elasticity of the cheese samples, due to the increase in buffalo milk concentration, which diminished these texture properties. This profile can be attributed to the high fat content of buffalo milk. Thus, when it is altered and the milk source changes the texture characteristics of the cheeses and in this respect, compared to described in the literature, goat’s milk becomes more stable raw material to be manufactured in mixture with bovine milk than buffalo milk.

In relation to goat and bovine whey in mixture, Borba et al. (2013) suggest that the use of whey as the predominant ingredient in the preparation of creamy ricotta did not negatively influence important texture parameters, including texture cohesiveness and elasticity. Therefore, the use of whey for the preparation of cheeses is an excellent way of processing this product, especially if it is observed that Ricotta is a fresh cheese of very pronounced softness.

In the case of sheep cheese, Farahani et al. (2014), characterizing the Siahmazgi cheese, observed the increase of dry matter during five months of ripening. In addition, stress and hardness increased during ripening and fracture deformation values decreased. This may be due to the loss of water content through ripening, as water may cause non-homogeneous areas, promoting the ease of fracture. With this, the same profile of increase of the texture characteristics for the sheep cheese is observed, as well as goat cheese.

**Somatic cell count (SCC)**

Somatic cell count (SCC) on goat cheese influences also influence the rheology and texture of cheeses. Goat milk has a higher amount of SCC than cow or sheep milk, since
dairy goats have apocrine secretion of milk, whereas cows mainly have merocrine secretion (Dulin, Paape and Wergin, 1982). Milk with high SCC content coagulates slowly, causing low cheese production due to higher losses of protein and fat in the serum (Park et al., 2017). The moisture content of goat cheese is higher than that of cow’s cheese, causing greater proteolysis and modifying the proteolytic pattern of goat’s cheese (Grandison and Ford, 1986). It has been described in the literature that the increase of SCC induces decrease in firmness and elasticity and increase in the viscosity of cheese made with goat’s milk (Park et al., 2017).

Effect of technological processing on textural and rheological characteristics of goat and sheep cheeses

In dairy products, the textural and rheological characteristics can be influenced by several stages of the technological process, which will vary depending on the dairy produced. In cheeses, these processing steps have a significant and marked influence, so that their effects on the textural and rheological characteristics of cheeses are described below, in order to better understand the mechanisms by which cheeses are so influenced.

Heat treatment

In relation to heat treatment, the heat stability of goat milk is considerably lower than bovine milk, due to the high content of ionic calcium and low micellar solvation in goat milk, thus contributing to its thermal instability (Park, 2007).

Almanza-Rubio et al. (2016), studying the effect of thermosonication on the rheology and texture of bovine cream cheese, observed that the thermosonication of the milk modified its thermal stability significantly. However, according to the same authors, the thermosonication can be a process utilized to improve the textural and rheological properties. Nevertheless, as it is a paper with bovine milk and already described in the literature the lower thermal stability of goat milk, there are still some questions about the use of thermossonication for goat and sheep milks. More studies need to be done to better elucidate the influence of temperature on cheese texture and rheology, as well as methods of increasing the thermal stability of goat and sheep milks.

In the study of Miloradovic et al. (2016), they observed that at the beginning of ripening, all cheeses had a similar pH. After 40 days of maturation, the pH of the cheeses that were elaborated with milk submitted to the high heat treatment was lower than the pH of the control cheese. This result demonstrated the significant influence of milk heat treatment on pH. In addition, the authors observed that surface hardness and fracture were lower in milk cheeses subjected to high heat compared to control and they concluded that high heat
treatment can be used successfully to increase the yield of white cheeses and mature goats, without any adjustment in the cheesemaking process.

**Homogenization**

In the homogenization, the basic principle is the reduction of milk fat globules by forcing it into high pressure through small holes. In the dairy industry, homogenization is carried out in cheeses where lipolysis is desired to improve flavor and texture, obtaining greater moisture and consequent creaminess (Vélez et al., 2017).

The process of homogenization of milk may lead to alterations in its physical properties, which may or may not be advantageous for cheeses (Van Hekken et al., 2007). The homogenization is capable of breaking the lipid droplets and their surrounding membranes, forming small droplets increasing the total surface area, thereby increasing the amount of total protein associated with the droplet surface and, depending on the temperature of the milk and the pressure used for homogenization, influences the amount and type of protein associated with this droplet (Cano-Ruiz and Richter, 1997; Van Hekken et al., 2007).

**Addition of ingredients**

The addition of ingredients strongly influences the texture and rheology of cheeses and is often used to improve these characteristics. The use of autochthonous lactic acid bacteria (LAB) has been an effective biological method to control foodborne pathogens in products such as goat cheese (Almeida-Júnior et al., 2015; Ferrari et al., 2016). In addition to its ability to increase product safety by prolonging shelf life and inhibiting the growth of pathogenic organisms, LABs also provide improved texture and taste for goat milk products (Souza and Dias, 2017). Still in the production of cheeses can be used microbial transglutaminases (mTGase), which is reported to increase the rennet yield (Kieliszek and Misiewicz, 2014).

The addition of calcium accelerates coagulation or reduces the amount of rennet required and it produces a firmer gel (Gunasekaran and Ak, 2002). Modifications in the manufacturing process as well as the incorporation of adjunct cultures and fat substitutes are strategies that can be used to make cheeses with lower fat levels that still maintain acceptable taste, functionality and texture (Van Hekken et al., 2013).

Silva et al. (2017), evaluating the effect of sodium reduction and addition of flavor enhancer on probiotic Prato cheese processing, observed that the addition of arginine, yeast extract and oregano extract provided higher parameters of elasticity, fracture stress and fracture, which indicates an increase in the firmness and elasticity of the cheeses samples compared to the conventional cheese. The addition of ingredients is thus an important technological tool to improve the rheological and textural characteristics.
Coagulation

In the coagulation, the ability to coagulate is the most important requirement of milk for the manufacture of different types of cheeses. Coagulation is the stage in which the milk undergoes a profound physical and rheological change, called gelation. Milk gel is formed by the aggregation of milk proteins, the caseins (Gunasekaran and Ak, 2002). Milk with adequate coagulation ability yields curds with better rheological properties, affecting the yield and quality of the cheese. Cheeses obtained from milk with low coagulation capacity are more susceptible to losses in storage and can be submitted to incomplete and non-homogeneous serum drainage, generating defects in the maturation stage (Silva and Costa, 2017; Malacarne et al., 2014).

Among the types of coagulation (enzymatic coagulation, acid coagulation and heat coagulation), enzymatic coagulation is the most popular. In this type, gel formation by the association of casein micelles is called the coagulation rate. It is highly dependent on milk temperature, calcium content, concentration and activity of the enzyme solution. Increases in both factors reduce coagulation time and increase firmness. Two possible explanations for this relationship would be that: 1- a hydrophobic bond occurs between para-κ-casein; 2 - the calcium and calcium phosphate binding occurs in the α- and β-caseins (Gunasekaran and Ak, 2002).

When the chymosin is added to milk at the beginning of the coagulation decreases viscosity because of the hairs cut of the enzyme of the surfaces of casein micelles. Then, the lost stabilization of the k-casein layer make micelles more attractive. This process leads to a rapid increase of the viscosity, which culminates with the flocculation of micelles (McCarthy, 2011; Zhao and Corredig, 2020).

Syneresis

One of the most important processes with a significant impact on the quality of the cheese is the syneresis (expulsion of the whey from the curd by cutting, stirring and heating). The conditions of coagulation and syneresis mark the final properties of a cheese, due to its influence on the contents of moisture, protein and fat (García et al., 2014). The syneresis can be influenced, among other factors, by the gel firmness in the cut, curd surface area, any applied pressure, acidity, temperature, milk composition and source of milk (Pan thi et al., 2018; Pazzola et al., 2018; Vacca et al., 2015)

Acidification

In the process of acidification, it is already described in the literature that pH has the greatest effect on the textured properties of the cheese, due to its action on mineral solubilization
and the dissociation of casein’s micelles (Diezhandino et al., 2016). During the process of coagulation (Figure 2), calcium solubilization occurs from casein micelles as a function of the pH reduction in bovine milk. Due to the loss of insoluble calcium inside the casein micelles, the internal structure and rheological properties of curd tested at different pH values presents alteration. If excessive loss of insoluble calcium ions occurs, this negatively affects curd rheology during the acidification process, which is more evident at lower pH values (Hussain et al., 2011; Zhao and Corredig, 2020).

**Figure 2.** Relationship between calcium content, pH and technological processing of cheeses in the stages of heat treatment and coagulation. (A) Effect of temperature on gel formation and coagulation time. (B) Dissociation of casein micelles during the coagulation process and its effect on rheology and pH of cheeses (Adapted from Silva and Costa, 2019).

**Fermentation**

In the fermentation, although the production of acid by the initial microorganisms is the main cause of the flocculation of micelles and the development of the structure, the initial strain can be chosen to influence the rheological properties. In relation to cheeses, Diezhandino et al. (2016), evaluating the rheological and textural characteristics of Valdéon cheese, observed that as the maturation time progresses, occurs an increase in the resistance to deformation and greater elasticity of this cheese, classifying it as a viscoelastic solid. The fermentation temperature may also influence the fermentation, because higher temperatures decrease the apparent viscosity and increase the consistency of cream cheese (Brighenti et al., 2018).

**Ripening and storage**

After, the ripening process takes place. Cheese ripening is a complex process due to physico-chemical changes, which mainly include pH variation, protein degradation and
amino acids accumulation, and these changes are responsible for unique characteristics in the cheese varieties (Farahani et al., 2014).

Garcia et al. (2016), observed that the chewiness, adhesiveness and elasticity did not show significant changes during the maturation of goat cheese coagulated with Cynara scolymus. However, the hardness increased significantly during maturation for 75 days and the gumminess showed significant differences between 15 and 75 days of maturation. These results observed in these parameters were probably due to a decrease in moisture content. The authors also conclude that the texture characteristics of this cheese presented slight deterioration at 75 days of maturation, but it does not prevent the consumption of the cheese in comparison to other analyzed parameters.

About storage, according to Juan et al. (2007), the processing techniques and storage conditions may affect texture features, which may determine the acceptability of the cheeses. In the study by Attaie (2005), evaluating the effect of time on the rheological and proteolytic changes that occur during the maturation of goat milk Monterey Jack cheese, he observed that the texture of this cheese changed markedly with maturation, with significant changes in hardness and elasticity, indicating an increase in the flexibility and fractionation of the cheese. These parameters of texture were influenced in the maturation because with the course of this process, the cheeses lose water, reducing the moisture content and consequently presenting higher values of hardness and elasticity. As the hardness increases, the fracture becomes more pronounced and as the elasticity increases, the cheese becomes more flexible.

In addition to all the variables mentioned, one cannot fail to mention the biochemistry of maturation, as it is also a process that promotes changes in the cheeses resulting from metabolites of bacteria and fungi used in the different varieties of existing cheeses. These microorganisms produce substances that can accelerate proteolysis and lipolysis and influence the rheology and textures of cheeses (Fox et al., 2017).

**New techniques in cheese processing**

In addition to the processes already discussed, new techniques in cheese processing have been used, including Hydrostatic High-Pressure treatment (HHP), which is an innovative technique for preserving food. This technique can improve texture as well as inactive pathogenic microorganisms (Delgado et al., 2017) and has also been used to improve milk goat and quality of goat cheese and improve retention of nutrients, flavor and color (Garcia et al, 2014). Ozturk et al. (2013), determining the impact of HHP in reduced cheddar cheese, low salt content noted that the textured, rheological and microbial were affected by HHP and its application resulted in lower melt temperatures and softer cheese in initial stage of...
maturation. However, the effects of HHP-induced texture and rheology changes were dependent on the age of the cheeses. After one month of maturation, there were no differences between cheeses treated with HHP or untreated. This technique can be used to improve the texture and rheology of cheeses, since the cheese does not go through a very long period of maturation. Possibly, this process would be better utilized for fresh cheeses, which would not have the interference of the age of the cheese.

Another technique used in cheese processing is the use of ultrasound, which may be an alternative to pasteurizing and homogenizing milk. It can be high energy ultrasound (18-100 KHz) or low energy (> 100 KHz) ultrasound (Ashokkumar et al., 2009). It has been used to modify enzyme activities, extract components and improve emulsification, crystallization and freezing process (Knorr et al., 2004). It has been observed that sonication can decrease the size of milk fat globules, denature serum proteins, improve viscosity, decrease fermentation time, and reduce syneresis (Sfakianakis et al., 2015).

According to the study by Almanza-Rubio et al. (2016), evaluating the effect of thermo-sonication on the rheology and texture of cream cheese, the thermosonication of the milk modified the spreadability and the viscoelastic properties of the cream cheese, as well as its thermal stability significantly. According to the same authors, the best thermosonication conditions to improve the textural and rheological properties, as well as the thermal stability of cream cheese, were: lower ultrasound power than 50 W, applied for long times (≤ 30 min) in a range of temperature between 35 to 50°C. As already discussed, the temperature influences the spreadability and viscosity of the cheeses, so the thermosonication is a promising technology for the study of its effects on rheological and textural characteristics.

Microfluidization is a process that has been used in the dairy industry with an alternative to homogenization. It is based on the fact that pressures 10 to 15 times greater than traditional homogenizers create finer emulsions, from the collision of two chains at a 180° angle (Paquin, 1999) and the resulting cavitation, turbulence and shear interrupt the lipid droplet and its surrounding membrane. When this processing is compared with the lower pressure homogenization, the microfluidized milk has smaller lipid droplets. In milk where fat is in the liquid state, microfluidization forms fine emulsions that alter the cheese matrix; Fat droplets become smaller as the pressure increases. The reduction in lipid droplet size is an important consideration in cheese processing, since full fat cheeses have considerable melting when the droplets are large but lose the ability to flow when the droplets are smaller (Van Hekken et al., 2007). Microfluidization may still result in shorter rennet coagulation times and changes in the firmness rates of the curd, with it being more fragile (Tosh and Dalgleish, 1998). In the study by Van Hekken et al. (2007), they observed that for Mozzarella cheese, microfluidization does not improve the melting and texture properties of low fat cheeses and impairs the properties.
of full fat cheeses if microfluidized at temperatures above the melting point of milk fat. This technique still needs improvement for its use in cheese processing, because the results until then recorded are still not favorable. However, with the proper arrangements, perhaps of composition or use of the technique itself, this may be a promising technology in the future.

**Current and future trends in cheese rheology and texture**

Since the 1980s, rheology and texture are research goals around the world. Starting with the Instron Universal Testing Machine, arriving at modern rheometers and texturometers, these two characteristics of cheeses have been increasing the dynamics of studies in several dairy products and especially in cheeses. However, there is a strong need for more elucidative studies on these variables, making one think what would tend in the future in these investigations.

As determinants for the acceptability of cheeses, rheology and texture are studied by evaluating the effect of some modification on the processing in order to guarantee more desirable characteristics to cheeses. Thus, for current and future trends, it is expected that the technologies developed, such as the elaboration of traditional cheeses with changes in either the source of the coagulant, the NaCl content or its substitution or even in critical parameters such as homogenization pressure and fermentation temperature, can be engaged as a way to improve the rheology and texture of these cheeses, as well as support in the study and elucidation of their influences on these characteristics.

Actually, it is known that the source of the coagulant used in cheese processing may influence its rheological characteristics, causing less pronounced changes with maturation. This is interesting for the G’ and G” modules which may present higher values for cheeses made with rabbit chymosin compared to calf chymosins and camel. In addition, texture parameters such as hardness, chewiness and gumminess may have their values increased when cheeses are made with camel chymosin and intermediate values with rabbit chymosin compared to that of calf that obtained the lowest values (Alihanoglu et al. 2018). These strategies can be used to obtain a texture more suited to the consumers’ demand for cheese of a certain hard variety, but which can be obtained with a softer texture, for example.

Another aspect of study is the reduction of salt content in cheeses, which can lead to typical cheeses such as Gouda or Cheddar to softening and non-maintenance of the form. But the softening that occurs after salt reduction increases the mobility of the caseins in the cheese matrix. In this way, the cheese becomes less viscous and more extensible, these characteristics desirable for cooking. In other words, for the producer who wishes to innovate the traditional cheeses without changing the form, they can use composition adjustments,
raw materials and processing conditions that allow the elaboration of the desired end product (Bae et al., 2017).

The homogenization pressure and the fermentation temperature also influence rheology and texture. The cream cheese when submitted to both processes at high intensity presented higher consistency, but in relation to the fermentation temperature, the apparent viscosity was inversely proportional to the temperature intensity (Brighenti et al., 2018).

Thus, it is expected that more studies will be developed with the technological innovations and will allow a greater diversity of papers in this area, especially for goat and sheep cheeses in order to better understand their relationships and influences from the raw material to the final product. In addition, it is essential to apply mathematical models for the rheological behavior of cheeses, approaching the topic more thoroughly and consistently in papers.

CONCLUSIONS

It is concluded that there are several variables that interfere with texture and rheology, but more studies need to be performed and discussed on these characteristics, and more research should address Brazilian cheeses, which still have a limited number of international scientific articles on the subject. In addition, the whole cheese-making process from the choice of raw material, through the stages of processing the cheese to the storage of the final product, contributes significantly to the rheological and textural characteristics of cheeses, and the cheese industry must ensure the control of these steps so that the product obtains the desired characteristics. However, in spite of the studies reported here, those that approach the rheology and texture of cheeses are still scarce, especially when referring to goats and sheep cheeses. It is worth noting that new investments are necessary in this area to provide studies that characterize the factors that influence the acceptability of products, as well as indicate possible defects and defects that occur in the processing and that alter the rheological and textural properties.

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REFERÊNCIAS


