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Different Alternatives to Improve Rheological and Textural Characteristics of Fermented Goat Products - A Review

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Abstract

The goat's milk is one of the main milk produced and consumed, which is also used in the production of a large variety of food (milk, fermented milk, cheese and others) and non-food products (medicines and cosmetics products). In addition, goat milk represents an excellent source of food to human nutrition, which has a distinct characteristic, such as the composition and size of casein micelles' and fat globules structure. These peculiarities in the composition and structure of goat milk are responsible for the unique flavor and texture of goat's milk and derivatives. Furthermore, these peculiarities are responsible for the easy digestion and absorption, besides the hypoallergenic, of goat milk when compared to cow milk. However, goat milk products present a lower hardness, adhesiveness, consistency, stability, extrusion force and a greater tendency to syneresis than cow and sheep milk products. Thus, the goat dairy industry encounters some challenges in relation to the rheological and texture characteristics of goat products. In this context, the aim of this review was to overview some strategies, including the addition of traditional and functional ingredients and new technological processes, applied in fermented goat milk to improve the rheological and textural characteristics.

Keywords: Milk composition; Goat milk; Yogurt; Prebiotic; Fruit pulp; Soy protein; Polysaccharides; Ultrafiltration; High hydrostatic pressure; Ultrasound; Dairy

Introduction

The goat milk is the third most commercialized type of milk, representing 2.6% of world dairy production [1]. This milk is an excellent source of protein, fatty acids, and minerals, which can be used in human nutrition [2] and as cow milk replacer [3,4]. However, it is difficult to make goat milk yogurt with an appropriate flavor [5] and consistency [6] for consumers, when compared to cow milk yogurt. Therefore, in recent years, researchers and industries have sought alternatives to improve the flavor of goat dairy products for non-habitual consumers, removing the unpleasant flavor and to strengthen their texture and rheology [7]. This milk presents essential differences in the composition and size of the casein micelles' and fat globules structure than cow milk [3].

In fact, the casein micelles of goat milk are smaller, have a lower proportion of the αs1-casein and a differential arrangement of the phosphate groups [8]. In addition, the fat globules have a smaller size and high proportion of short- and medium-chain saturated fatty acids, such as butyric, caproic, caprylic and capric acids [3]. These peculiarities confer to goat's milk products a distinct texture and rheology. Therefore, it the fermented goat products, as goat milk yogurt, face some challenges to acceptance for not-habitual consumers not only by the difference of the flavor but also by the texture [5,6]. Thus, goat milk yogurt has lower consistency and apparent viscosity and a greater tendency to syneresis than cow's milk yogurts [6,8].

The lower texture and viscosity of fermented goat products are due to their fragile microstructure, less resistant and susceptible to fast deformation and to the less compact, soft and weak acid gels [8]. These properties are positively correlated with the lower mean diameter, degree of hydration, mineralization and casein content in milk, especially αs1-casein, and with the smallest diameter of non-protein nitrogen in goat milk in relation to cow milk [3]. As a consequence, traditionally the goat dairy industry uses milk proteins and milk of other species (cow and sheep milk) to improve the rheological and textural properties of fermented goat milk products [9-12]. However, other alternatives have been studied, which objective to enhance the texture of the goat derivatives using functional ingredients and new technological processes. Based on the previous considerations, the aim of this review is to discuss the addition of traditional and functional ingredients and application of new technological processes to improve the rheological and textural of fermented goat products by goat dairy industry.

Effects of Conventional Technological Processing

The rheological and textural properties of fermented milk, independent of the dairy matrix, are the result of two distinct events: (1) acid aggregation of casein micelles and (2) production of exopolysaccharides (EPS) by the microorganisms during incubation [13]. Furthermore, rheological and textural characteristics of fermented milk are affected by the amount and the structure of EPS that are released and by the interactions between EPS and caseins micelles [14]. In addition, some factors influence these parameters, as milk composition (dry matter content) [15,16], heat treatment of milk [17-19], cultures used [20-22] and others.

The milk composition and quality are directly related to texture and rheology of the final product. In the processing of fermented milk, such as yogurt, the total solids content can be increased, usually by the addition of skimmed milk [23]. In addition, other ingredients have

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been studied to increased de total solids, as whey protein, soy protein, transglutaminase, prebiotics, maltodextrin and fruit pulp. The increase of total solids by solids-not-fat (SNF) and crude proteins increase aims to promote better water retention capacity of milk proteins, prevent the syneresis and improve the visual and oral consistency of the final product [15].

The heat treatment of the milk is responsible for two main modifications. Firstly, the heat treatment promotes the aggregation, which provides the firmer gels formation. In addition, it causes a decrease in the degree of acidification, necessary to generate the association of the protein matrix in the fermented milk [24]. The aggregation of whey proteins and caseins is fundamental in the physical and chemical properties of the casein micelles and consequently it influences directly the texture [25].

The type of culture starter and probiotic employed also influence the texture and rheology of fermented milk [26]. Certain strains produce EPS [27], which production by lactic acid bacteria have a large variability in respect of chemical composition, molecular size, charge, quantity, and rigidity of the molecules [28]. The EPS are interesting since it can increase viscosity and influence gel strength; besides it can prevent syneresis and gel fracture [29].

Alternative Ingredients in the Formulation of Fermented Goat Milk

The addition of many ingredients, dairy and non-dairy, can improve the rheology and texture of fermented dairy products. In this respect, dairy proteins are extensively required [15,16]. Other alternatives, as non-dairy proteins (i.e. soy protein), fruits (fruit pulps and dehydrated fruits), enzymes (microbial transglutaminases) and polysaccharides (partially hydrolyzed galactomannan, inulin, maltodextrin) have been studied to increase the total solid content in the fermented milk process (Table 1). Thus, these ingredients have been considered to improve the viscosity, gel strength and the ability to retain whey of fermented dairy products [30].

Soy proteins

Soybeans contain high-quality proteins with a capacity to form gels in an acidified medium. Silva, Abreu and Assumpção [20] observed that the supplementation of soy protein on goat milk yogurt provoke an increase in viscosity and water retention capacity and decrease the syneresis. This fact can be explained by the modification of the gel texture, which occurs due to an increase of the protein concentration. The same was detected by Martin-Diana et al. [31] using it on casein macro peptide and whey protein concentrates, which is an indicative that the soy protein can be used as an alternative to control the whey separation and to improve the texture in fermented goat products. In addition, Ribeiro et al. [32] demonstrated that higher soy protein content was related to decreased syneresis in grape-flavored goat milk's yogurt-like beverage.

Fruits

The addition of fruit and its products in yogurt holds an important position within the broad range of dairy products. Commercially the main fruits employed include strawberry, peach, plum, coconut, papaya and others. Among them, strawberry has been the most used for the elaboration of fermented milk. Goat's milk yogurts with fruit pulps, as strawberry, expressed better acceptance, considering the typical flavor and taste of goat's milk had not influenced the consumers' intention of acquisition [33]. Besides the yogurt's taste, one alternative to the low texture is the use of fruits pulps riches in fibers such as cupuassu [6,34]. Cupuassu is a fruit native to Brazil, which is composed of a large proportion of starch, pectin polysaccharides [35].

Moreover, another alternative is the use of dehydrated fruits. This preparation can be a promising way to increase the solids-non-fat (SNF) content of milk, which is crucial to the development of the milk's physical network. Posecion et al. [36] increased the goat milk yogurts firmness by the addition of dehydrated pineapple and banana cubes. However, the dehydrated fruit's treatments presented lower apparent viscosity than formulations with carrageenan. Thus, futures studies combining addition of dehydrated fruits and carrageenan should be encouraged.

Microbial transglutaminases

The microbial transglutaminases (mTGase) have cross-linking properties of casein, which result in the increase of the gel strength and the decrease of syneresis phenomena in dairy products. As result, this enzyme has been used to produce dairy derivatives, mostly in yogurt production [37]. Extensive research has been conducted to study the effects of mTGase treatment on cow milk yogurts properties. However, these researchers are more limited in the caprine milk [38].

The mTGase can be added at different stages of processing: prior to the fermentation process or simultaneously. In fermented goat products, the prior addition reached higher apparent viscosity, adhesiveness, and hardness and lower syneresis [38,39]. Ardelean and Rohm [40] demonstrated that mTGase pre-treatment accelerates the gel formation. Even that, fermented goat milk gels were three times weaker than fermented cow milk gels. Nonetheless, this enzyme might be successfully applied in the production of acidified fermented goat products.

Polysaccharides

Polysaccharides are very versatile polymers that can be found in nature in different forms performing different functions. In the food industry, polysaccharides have an important applicability, mainly due ability to thicken and to jellify solutions. Therefore, they have been used as thickeners, stabilizers, emulsifiers and jellifying agents [41]. The polysaccharides application as thickeners is associated with their capacity to increase the viscosity of a liquid by the formation of a gel, resulting in desirable texture characteristic in foods. This property can be very interesting to improve the texture and rheology of fermented goat products.

Galactomannans are the form of carbohydrate storage in plants, which are primarily used as a thickening and stabilizing agents for the industry. This polysaccharide has a neutral flavor and not affects final product palatability [42]. Studying goat dairy beverages, Buriti et al. [43] with the addition of partially hydrolyzed galactomannan (PHGM), these authors observed that PHGM can enhance the instrumental and sensory texture of guava and soursop goat dairy beverages. Based on the results the PHGM can be an alternative to enhance the texture of goat milk products.

Inulin is a polysaccharide, which provides a substrate for probiotic bacteria in the large intestine. This prebiotic is widely used in the food industry to obtain low-fat products since is a fat replacer [44]. In addition, inulin can form complexes with the protein aggregates, and it must be part of the structural network that is formed during fermentation and structuring of fermented products [45]. Costa et al. [6] results exhibited that inulin helped to increase apparent viscosity and consistency, however, no results were observed on firmness and cohesiveness of goat milk yogurt.

Maltodextrins are hydrolyzed starches produced by partial hydrolysis of starch with acid or enzymes, which was used in fat- and calorie-reduced products' development [46]. This polysaccharide can be obtained from different origins, as corn, potato, wheat, tapioca and oat. In non-fat cow's milk yogurt, Domagała et al. [47] reported the higher hardness and Casson's viscosity of oat-maltodextrin formulation. Moreover, a positive result for apparent viscosity of maltodextrin formulation in low-fat cupuassu goat's milk yogurt was also found by Costa et al. [48], when compared to skimmed formulation. Meanwhile, firmness and consistency were not significantly modified.

New Technologies on Goat's Fermented Milk Process

There are few studies about the use of new technologies such as high-pressure processing and ultrasound in fermented cow and goat products (Table 2). However, the use of these methodologies and filtration membranes are better elucidated in fermented cow products.

High-pressure processing

High hydrostatic pressure (HHP) treatment is an innovative technique for food preservation. This process can enhance the texture as well as inactivates harmful pathogenic and deteriorating microorganisms [48]. In cow milk the application of HHP evidenced that this method affects the rennet coagulation [49] and increased the water holding capacity, protein hydration index, gel rigidity, and gel breaking strength [50].

HHP treatment induces in milk the disruption and reformation of casein micelles into smaller particles and increases the amount of serum casein [51]. For whey proteins, HHP technology reduces the number of small polymers, possibly due to the formation of larger polymers, which are more readily precipitated at pH 4.6 [52]. Karlović et al. [53] achieved the optimal homogeneity of fat globules in goat milk at 200 MPa and 9 min of HHP treatment. Fat globules distribution size is an interesting measurement for homogenization and HHP control procedure because it influences the formation of clusters of fat globules and casein micelles. Despite the studies of HHP in cow milk, there is a lack of research on this methodology in fermented goat milk [54]. Therefore, further studies should be performed to determine the effect of HHP on fermented goat products.

Ultrasound

Ultrasound (US) is considered a non-toxic and sustainable. The US has several applications in the dairy industry, such as emulsification and homogenization [55-57]. The main physical effects of sonication for the dairy industry are cavitation, which is the growth and collapse of micro bubbles that produce high temperatures, localized pressure and turbulence [58] and shear force. High-power sonication (greater than 100 W) with low frequency (20 and 45 kHz) improves the viscosity and textural characteristics of fermented products [59]. US application also increases the soluble calcium and phosphorous contents of products, which is essential to produce a gel with suitable properties [60]. Therefore, the concentration of soluble calcium and phosphorous in milk is directly related to rheology and texture characteristics of fermented dairy products.

In addition, the use of US has obtained positive results in these proprieties of fermented cow milk [59,61-65]. However, to the best of our knowledge, this methodology has not been directly applied to fermented goat products. In fact, it was only evaluated in goat's milk [66]. These authors studied the effects of US pre-treatment on goat milk before rennet-induced coagulation. The results showed that the particles size became more homogeneous, smaller, and well-distributed, which was consistent with the decreasing polydispersity index (could characterize the size distribution of particle) after US pre-treatment. Thus, in this case, the US as a pre-treatment promoted an improvement in the coagulation process. As goat's milk has higher whey content

Classification	Ingredient	Effects		References
		Positive	Negative	
Soy protein	Water-soluble soybean extract	lower syneresis; higher viscosity and water holding retention	none	[31]
	Water-soluble soybean extract	lower syneresis; higher water holding capacity; influenced rheological properties (increased consistency index and decreased flow behavior index values)	none	[33]
Fruit	Strawberry pulp	improved sensory characteristics	none	[34]
	Cupuassu pulp	higher viscosity; cupuassu pulp and probiotic formulation increased firmness, consistency, and cohesiveness of goat's milk yogurt	none	[6]
		higher viscosity; improved sensory attributes of goat's milk yogurt (consistency and viscosity)	cupuassu pulp did not affect the instrumental texture	[35]
	Dehydrated pineapple and banana cubes	firmer curder than the control; higher preference by sensory panelists in terms of product preference and firmness	none	[37]
Microbial Transglutaminases	2 and 4 U/g protein	higher viscosity and texture parameters (firmness, adhesiveness and extrusion force); lower syneresis; improvement of yogurt gel's microstructure	none	[39]
	2 and 3 U/g protein	higher sensory scores; lower syneresis; protein matrix was more compact	none	[40]
	3 U/g protein	accelerated gelation; higher gel stiffness and water holding capacity; lower syneresis	none	[41]
Galactomannans	Partially hydrolyzed galactomannan	higher overall mean of all instrumental texture parameters (firmness, consistency, cohesiveness) and viscosity	none	[44]
Inulin	5% wt/vol	higher consistency at the end of the storage period when compared to another treatment; increased the viscosity	none	[6]
	5% wt/vol	increased viscosity	higher syneresis	[48]
Maltodextrin	Oat-maltodextrin	increased hardness, adhesiveness and Casson's viscosity	decreased the consistency coefficient and yield stress values	[45]
	Non-specified	increased viscosity	none	[48]

Table 1: Positive and negative effects of specific ingredients in fermented goat products.

Process	Conditions	Effects		References
		Positive	Negative	
High-Pressure	500 MPa; 25ºC or 50ºC; 10 min	reduced number of small polymers	none	[53]
	250 mL; 200 MPa; 3, 6 and 9 min	improved stability and quality of goat's milk emulsions	none	[54]
	65ºC/5 min+600 MPa/75ºC/15 min	improved consumers' acceptance of goat-cow milk's yogurt	none	[55]
Ultrasound (Pretreatment)	250 mL; 30 kHz; maximum nominal power of 100 W; 60% amplitude; full duty cycle; 3 and 6 min	enhanced homogeneity of fat globules; improved stability and quality of goat's milk emulsions	none	[54]
	800 W; 20 kHz; 0-20 min; cell disruptor; probe's diameter: 13 mm	improve goat milk coagulation properties; lower syneresis and gelation time; higher gel firmness, coagulum strength, final storage modulus, cohesiveness, water holding capacity	none	[67]
Filtration Membrane	Ultrafiltration: 1.5-, 2.0- and 2.5-fold (v/v) concentration degree	higher hardness, adhesiveness, extrusion force; lower syneresis;	consistency of cream cheese	[70]
	Ultrafiltration	higher hardness, adhesiveness and extrusion force; more compact protein matrix of goat's milk yogurt	none	[71]
	Ultrafiltration: volume concentration ration of 1.7	increased protein, Ca, P, Mg and Zn concentrations; increased Ca and Mg solubility	none	[72]
	Ultrafiltration, reverse osmosis and vacuum evaporation	better flavor, viscosity, curd tension, higher protein level	none	[73]
	Ultrafiltration: 2- and 3-fold (v/v) concentration degree using a type B module. Reverse osmosis: 2- and 3-fold (v/v) concentration degree; 40 bar (560 lb/in^2)	ultrafiltration had a better acidity and aroma than reverse osmosis; concentration by reverse osmosis resulted in an increase in protein, lactose, vitamins and salts; ultrafiltration only concentrated protein	reverse osmosis did not provide a useful method for fortification: Yogurts had slower coagulation and acidity, and poor aroma	[73]

Table 2: New technological processes conditions applied to goat products and their positive and negative effects.

than cow's milk, then the former has poorer coagulation [67]. The undenatured whey protein content of goat's milk decreased slightly after US pre-treatment. The denatured whey protein may easily interact with casein protein and promote the formation of aggregates. Although the degree of whey separation in goat milk was higher than in cow milk during coagulation process, US pre-treatment really made a great contribution to the promotion of the goat milk coagulation properties that had been considered inferior to those of cow milk.

Despite the positive results of US pre-treatment on goat's milk coagulation, the values of gel firmness, coagulum strength, cohesiveness decreased when the process time was excessively increased. A possible explanation is that smaller particle sizes were produced with excessive US pre-treatment time such that it became harder for the particles to aggregate and form gels [68]. Moreover, the US can be used combined with another homogenization technique, as HHP [53]. US processing (30 kHz; 100 W of nominal power; amplitude 60 and 100%; 3, 6 and 9 min) resulted in more homogeneous goat's milk fat globules while HHP (200 MPa) had a significant influence on the observed mean diameter of the particles. The both proceedings were used to improve the stability and quality of emulsions of goat's milk. Zhao et al. [66] and Karlović et al. [53] findings indicate a promising application of US techniques on fermented goat's milk production.

Filtration membranes

The membrane separation techniques, as ultrafiltration (UF) and reverse osmosis (RO), are been used to separate and concentrate substances of milk by the dairy industry. This technological process is also employed to increase the milk dry matter by, which favors the rheological and texture properties of dairy products. However, the efficiency of this practice is dependent on the type of migrant molecules. Similarly, the character of membrane used influences the composition and functional characteristics of milk concentrate [68].

In goat milk yogurts, the UF membrane increased the viscosity, hardness, and cohesiveness of coagulum, which can be related to the influence on the dry matter as well as the acidity of goat milk filtered. Furthermore, another very important factor is the degree of concentration [69]. At a higher concentration, the values of hardness, adhesiveness, and extrusion force increased, and the protein matrix of goat milk yogurt samples was more compact [70]. However, high milk's dry matter concentration can promote a consistency and structure more typical for cream cheese. In addition, greater concentrations of minerals (Ca, P, Mg and Zn) and proteins (caseins and whey proteins) were obtained. Ca and Mg solubility was also increased by UF, changing their distribution in milk [39].

The UF's provides better equilibrium of salts between the aqueous and dispersed milk's phase, which modify the mineral distribution with better post fermentation curd formation and affects the rennet coagulability and physical properties of the curd [71]. Furthermore, UF obtained better results than RO in goat milk when the both processes were compared [72]. According to Marshal and El-Bagoury [73], RO did not provide a useful method of fortification because goat's milk yogurts had slower coagulation and UF goat's milk had better acidity and aroma.

Conclusion

We conclude that although several technological strategies can be used to improve the rheological and texture of fermented products, as the inclusion of different ingredients and new technological processes, there are few studies of these alternatives application in fermented goat products. Therefore, further studies must be conducted to know better the effect of these methodologies in this matrix, besides even to guide the goat dairy industry.

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