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Effects of fat content, pasteurization method, homogenization pressure, and storage time on the mechanical and sensory properties of bovine milk

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ABSTRACT

Fluid milk may be pasteurized by high-temperature short-time pasteurization (HTST) or ultrapasteurization (UP). Literature suggests that UP increases milk astringency, but definitive studies have not demonstrated this effect. Thus, the objective of this study was to determine the effects of pasteurization method, fat content, homogenization pressure, and storage time on milk sensory and mechanical behaviors. Raw skim (<0.2% fat), 2%, and 5% fat milk was pasteurized in duplicate by indirect UP (140°C, 2.3 s) or by HTST pasteurization (78°C, 15 s), homogenized at 20.7 MPa, and stored at 4°C for 8 wk. Additionally, 2% fat milk was processed by indirect UP and homogenized at 13.8, 20.7, and 27.6 MPa and stored at 4°C for 8 wk. Sensory profiling, instrumental viscosity, and friction profiles of all milk were evaluated at 25°C after storage times of 1, 4, and 8 wk. Sodium dodecyl sulfate PAGE and confocal laser scanning microscopy were used to determine protein structural changes in milk at these time points. Fresh HTST milk was processed at wk 7 for wk 8 evaluations. Ultrapasteurization increased milk sensory and instrumental viscosity compared with HTST pasteurization. Increased fat content increased sensory and instrumental viscosity, and decreased astringency and friction profiles. Astringency, mixed regimen friction profiles, and sensory viscosity also increased for UP versus HTST. Increased storage time showed no effect on sensory viscosity or mechanical viscosity. However, increased storage time generally resulted in increased friction profiles and astringency. Sodium dodecyl sulfate PAGE and confocal laser scanning microscopy showed increased denatured whey protein in UP milk compared with HTST milk. The aggregates or network formed by these proteins and casein micelles likely caused the increase in viscosity and friction profiles during storage. Homogenization pressure did not significantly affect friction behaviors, mechanical viscosity, or astringency; however, samples homogenized at 13.8 MPa versus 20.7 and 27.6 MPa showed higher sensory viscosity. Astringency was positively correlated with the friction coefficient at 100 m/s sliding speed ($R^2 = 0.71$ for HTST milk and $R^2 = 0.74$ for UP milk), and sensory viscosity was positively correlated with the mechanical viscosity at a shear rate of 50 s^{-1} ($R^2 = 0.90$). Thus, instrumental testing can be used to indicate certain sensory behaviors of milk.

Key words: milk, sensory, rheology, tribology, pasteurization

INTRODUCTION

The oral texture of food is thought to be related closely to overall food liking (de Wijk and Prinz, 2006). Once placed in the mouth, food is subjected to a complex series of oral processes that are related to perceived texture (Lenfant et al., 2009). For solid food, physical deformation and breakdown properties are related to sensory attributes such as hardness, softness, plasticity, crispness, brittleness, and sponginess (Sherman, 1969, Agrawal et al., 1997). As oral processing continues, more saliva is added and attributes related to physical structure (e.g., smoothness, lumpiness, and pastiness), consistency (e.g., creaminess and wateriness), and adhesion to the palate (e.g., stickiness) are perceived (de Wijk and Prinz, 2006). Oral processing of liquid food is less complicated, which results in liquid food sensory attributes being dominated by flow behaviors (Engelen and de Wijk, 2012). However, some sensory attributes that persist after swallowing, termed after-feel, depend on thin-film tribology behaviors (Chen and Stokes, 2012).

Astringency, a common after-feel sensation, is related to food residue following consumption (Stokes et al., 2013). Substances that cause an astringent sensation,

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such as alum, tannins, and some polyphenols, are called astringent molecules (Green, 1993). The popular mechanism of astringency is believed to be the result of aggregation and precipitation of salivary proteins, which causes the loss of saliva lubrication ability (Jöbstl et al., 2004). The precipitation of salivary proteins caused by astringent molecules produces a dry feeling in the mouth through gritty feeling or interruption of the salivary film (Gibbins and Carpenter, 2013). However, Rossetti et al. (2009) found epicatechin was unable to precipitate saliva proteins but caused astringency mouthfeel similar to epigallocatechin gallate (**EGCG**), which did precipitate salivary proteins when used at the same concentration (Rossetti et al., 2009). On the other hand, semi-skimmed milk-EGCG solutions were perceived as less astringent than the EGCG solution alone, although both solutions induced loss of lubrication in saliva-coated surfaces (Rossetti et al., 2009). Thus, a direct relationship between precipitation of saliva proteins and astringency cannot be found for all astringent substances.

The specific mechanisms behind milk astringency have not received much attention in the literature. Increased astringency was also associated with increased particle size and heat-altered whey proteins (Josephson et al., 1967). On the other hand, milk astringency and the presence of γ-caseins were found to be related (Harwalkar et al., 1993). Withers et al. (2014) found that caseins bound more strongly to oral surfaces than β-lactoglobulin. However, several studies by these authors suggested that both casein and whey proteins contributed to milk astringency (Withers et al., 2013, 2014). Although milk astringency is clearly related to changes to milk proteins, a consensus has not been achieved on which specific proteins and changes contribute to milk astringency.

The presence of fat has a significant effect on perceived astringency. Astringent and friction-related sensations can be reduced by coating the oral surfaces with fat (de Wijk and Prinz, 2005, 2006; des Gachons et al., 2012). Perceived astringency in custards (de Wijk and Prinz, 2005, 2006), spreadable cheeses (Bayarri et al., 2011), and ice cream (Soukoulis et al., 2010) has been shown to decrease with increased fat content. On the other hand, fat content has not been shown to significantly affect milk astringency (Phillips et al., 1995; Campbell et al., 2003; Ares et al., 2009). However, these studies generally used samples with lower fat content (≤2%); a higher fat content may be needed to affect astringent sensations. One study did use milk with a fat content of 3.2% and showed that it had equal ability to reduce astringent sensation of antioxidant extracts as skim milk (Ares et al., 2009). Viscosity may play a role in the effect of fat on perceived astringency: studies that found that fat content affected astringency used foods with viscosities that were significantly higher than milk. In foods with lower viscosity, a higher fat content may be needed to achieve a reduction in perceived astringency because the lower viscosity food would be easier to remove from the oral surfaces and thus have reduced protection against astringent compounds.

Clearly, astringency is a complex sensory attribute and has multiple mechanisms. A significant number of studies have been done on astringency of wine and tea because they are commonly known to be astringent. Other astringent foods have received little attention in the literature. For example, ultrapasteurization (**UP**) of milk can increase the shelf life of milk compared with HTST pasteurization; however, UP milk is perceived as more astringent (Datta et al., 2002; Lee et al., 2017). The increase in astringency, as well as other sensory and physicochemical changes such as cooked flavor, and bitterness, color change, protein sediment, and age gelation, is due to the more severe thermal treatment in UP versus HTST (Datta et al., 2002). However, the published literature does not explain the astringency mechanism in UP milk. It is possible that the mechanism is related to increased whey protein denaturation from UP. Denatured whey proteins have an increased number of interactions with each other and caseins, and form large complexes that influence mouthfeel attributes (Morales et al., 2000). Thus, the objective of this study was to determine how fat content, pasteurization method, homogenization pressure, and storage time affect the sensory and mechanical properties of bovine milk.

MATERIALS AND METHODS

Experimental Design

Experiments were designed to determine the effect of different variables (fat content, storage time, pasteurization method, and homogenization pressure) on mechanical properties and sensory attributes and to determine how mechanical properties relate to sensory attributes in milk. Thus, skim (fat <0.2%), 2% fat, and 5% fat milk were used to study the influence of fat content on mechanical and sensory properties. Milk with different fat contents was pasteurized by HTST or UP-indirect method to determine the effect of pasteurization methods on mechanical and sensory properties. Three different homogenization pressure levels (13.8, 20.7, and 27.6 MPa) were used to study the effect of homogenization pressure on mechanical and sensory properties. Milk was stored at 4°C until tested for sen-