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The effect of storage conditions on the composition and functional properties of blended bulk tank milk

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ABSTRACT

The objective of this study was to investigate the effects of storage temperature and duration on the composition and functional properties of bulk tank milk when fresh milk was added to the bulk tank twice daily. The bulk tank milk temperature was set at each of 3 temperatures (2, 4, and 6°C) in each of 3 tanks on 2 occasions during two 6-wk periods. Period 1 was undertaken in August and September when all cows were in mid lactation, and period 2 was undertaken in October and November when all cows were in late lactation. Bulk tank milk stored at the 3 temperatures was sampled at 24-h intervals during storage periods of 0 to 96 h. Compositional parameters were measured for all bulk tank milk samples, including gross composition and quantification of nitrogen compounds, casein fractions, free amino acids, and Ca and P contents. The somatic cell count, heat stability, titratable acidity, and rennetability of bulk tank milk samples were also assessed. Almost all parameters differed between mid and late lactation; however, the interaction between lactation, storage temperature, and storage duration was significant for only 3 parameters: protein content and concentrations of free cysteic acid and free glutamic acid. The interaction between storage temperature and storage time was not significant for any parameter measured, and temperature had no effect on any parameter except lysine: lysine content was higher at 6°C than at 2°C. During 96 h of storage, the concentrations of some free amino acids (glutamic acid, lysine, and arginine) increased, which may indicate proteolytic activity during storage. Between 0 and 96 h, minimal deterioration was observed in functional properties (rennet coagulation time, curd firmness, and heat stability), which was most likely due to the dissociation of β-casein from the casein micelle, which can be reversed upon pasteurization. Thus, this study suggests that blended milk can be stored for up to 96 h at temperatures between 2°C and 6°C with little effect on its composition or functional properties.
Key words: raw milk, milk storage, storage temperature, proteolysis

INTRODUCTION

Due to ongoing expansion of the dairy industry in Ireland following the abolition of the milk quota system in the European Union in 2015, it is anticipated that on-farm storage of raw milk may be extended from 48 h to up to 96 h to improve logistical efficiency for milk processors. Current European Union legislation dictates that milk produced and stored on-farm must be cooled to at least 8°C when a daily milk collection regimen is in place, and to at least 6°C when collection is less frequent (Annex A, Directive 92/46; European Commission, 1992). However, many milk processors in Ireland request that milk be cooled to 2 to 4°C within 2 to 3 h after milking. There may be an economic incentive for farmers to store milk at higher temperatures (e.g., at 6°C compared with 2°C) when milk is stored for longer durations on-farm, as milk cooling is a significant operational expenditure at the farm level (Upton et al., 2013). However, cooling milk to higher temperatures, in conjunction with longer on-farm storage intervals, may have implications for milk quality, with possible deleterious effects on milk functionality at milk processing facilities.

Milk processing as a generic term covers the typical unit operations and processes applied to milk in an integrated milk processing facility. Such processes can include thermal processing—HTST pasteurization and UHT or high temperature treatments. Separation technologies can include centrifugal separation, microfiltration, ultrafiltration, nanofiltration, and reverse

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osmosis, whereas concentration technologies include evaporation and spray drying.

Ireland's established reputation for efficient production of high-quality products has allowed the Irish dairy industry to become a major exporter of premium dairy products. The manufacture of such products requires the supply of the highest quality raw milk, highlighting the importance of on-farm milk storage conditions as a critical point in the dairy supply chain. On-farm storage of raw milk provides conditions suitable for the growth of microorganisms, with refrigerated conditions preferentially selecting for psychrotrophic bacteria, which can deleteriously affect the quality of raw milk through production of heat-stable proteinases and lipases (Sorhaug and Stepaniak, 1997; Haryani et al., 2003; Hantsis-Zacharov and Halpern, 2007).

Proteolysis can reduce the economic value of milk by negatively affecting its performance within milk processing facilities. In particular, the hydrolysis of casein can reduce cheese yield (Barbano et al., 1991; Klei et al., 1998). Lipolysis is the enzymatic conversion of lipids into free fatty acids (**FFA**) and partial glycerides. An increase in FFA in milk can result in undesirable off-flavors and altered functionality (Ma et al., 2000; Deeth, 2006), such as increased churning time during the production of butter (Deeth and Fitzgerald, 1995).

Due to enzymatic and microbial activity, both the microbial and functional quality of raw milk deteriorates with time. After storing raw milk obtained from 2 milkings at 4°C for 6 d, Guinot-Thomas et al. (1995a) reported declines in pH, casein nitrogen, β-CN, and colloidal Ca and P contents, whereas levels of NPN and γ-CN increased. A reduction in the β-CN level of milk may also cause increased rennet coagulation time (**RCT**); de Moura Maciel et al. (2015) reported an increase in RCT after 24 h of storage of milk at 4°C. The concentration of FFA in milk has been shown to increase during storage (Wiking et al., 2002). Muir et al. (1978) observed a temperature-dependent increase in concentrations of FFA in milk after 96 h of storage, with higher concentrations linked to milk stored at 8°C compared with 6°C or 4°C.

Seasonal milk production is the dominant milk production system in Ireland (O'Connell et al., 2015), resulting in a large proportion of the national dairy cow population (1.127 million cows) approaching late lactation within the same period (during October and November). Due to adverse weather conditions and minimal grass growth during this period, cows are typically housed indoors. Consequently, cow's diets are altered from a pasture-based grazed grass to a grass silage system. During late lactation the total bacterial count (**TBC**) and SCC of milk also increase, often because of poorer environmental conditions and increased prevalence of subclinical mastitis within the herd (O'Connell et al., 2015). Alterations in diet, stage of lactation, and SCC can alter the composition of milk produced by cows. With a reduction in milk yield, the fat and protein contents of milk increase (Quinn et al., 2006); however, the β-CN and α_S-CN contents of milk decrease and the γ-CN content increases because of higher plasmin activity during late lactation (Lucey, 1996; O'Brien et al., 2001). Late-lactation milk used for cheese production is associated with longer coagulation times and weaker gel structures, reducing its suitability for use (Lucey, 1996). Due to the changes in milk composition in late lactation, the milk produced during this period may be particularly susceptible to compositional and functional changes related to extended storage conditions of raw milk on farms due to less-frequent milk collections from the farm.

Milk with high SCC is often associated with elevated indigenous enzyme activity, which contributes to increased proteolysis and lipolysis during storage (Bastian and Brown, 1996; Deeth, 2006). The 2 most significant indigenous enzymes for milk spoilage are plasmin and lipoprotein lipase. Plasmin cleaves polypeptide chains after a lysine or, to a lesser extent, an arginine residue (Ueshima et al., 1996); α_{S1}-, α_{S2}-, and β-CN are all susceptible to hydrolysis by plasmin (Andrews, 1983; Le Bars and Gripon, 1989; McSweeney et al., 1993a). Schroeder et al. (2008) showed that milk stored at lower temperatures (2.2°C compared with 4.4°C) for 24 h resulted in less plasmin-induced proteolysis. However, Leitner et al. (2008) reported a 4% loss in curd yield from milk sourced from an uninfected cow (SCC of 25,000 cells/mL) after 48 h of storage at 4°C. This loss in yield was likely linked to continued casein proteolysis during cold storage, resulting in impairment of curd formation (Crudden et al., 2005a). Although plasmin activity in raw milk stored at low temperature (5°C) is reduced due to autolysis and low temperature inhibition (Crudden et al., 2005b), the high thermal stability of the enzyme allows it to survive conventional pasteurization, which can limit the shelf life of resulting dairy products (Alichanidis et al., 1986). Lipoprotein lipase catalyzes the hydrolysis of ester bonds of triacylglycerols, resulting in the release of FFA, with the subsequent accumulation of short-chain FFA in milk and the development of off-flavors (Ma et al., 2000; Dickow et al., 2011). Lipoprotein lipase is relatively heat-sensitive and can be completely inactivated by pasteurization for 10 s at 85°C (Driessen, 1989).

On Irish farms, milk is stored in bulk milk tanks between milk collections, typically for 48 h, and fresh milk is added to the bulk tank at each milking. Given