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Effect of seasonal variation on the composition and properties of raw milk destined for processing in the UK

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ABSTRACT

The composition and physical properties of raw milk from a commercial herd were studied over a 1 year period in order to understand how best to utilise milk for processing throughout the year. Protein and fat levels demonstrated seasonal trends, while minerals and many physical properties displayed considerable variations, which were apparently unrelated to season. However, rennet clotting time, ethanol stability and foaming ability were subject to seasonal variation. Many significant interrelationships in physico-chemical properties were found. It is clear that the milk supply may be more suited to the manufacture of different products at different times of the year or even on a day to day basis. Subsequent studies will report on variation in production and quality of products manufactured from the same milk samples described in the current study and will thus highlight potential advantages of seasonal processing of raw milk.

1. Introduction

The composition of raw bulk milk is of prime importance for the manufacture of products in the UK, and there is significant interest in variations in the composition and physico-chemical properties of raw milk. In general, the composition of milk varies with season, stage of lactation, feeding, health status of the cow, milking interval, genetic factors and other day to day variation (Heck, Van Valenberg, Dijkstra, & Van Hooijdonk, 2009).

The effects of seasonal variation on milk composition have been reported by many researchers and it is clear that the concentrations of many constituents and the physico-chemical properties vary throughout the year to different extents (DairyCo, 2013). Heck et al. (2009) reported lower fat and protein contents in summer than in winter milk. This could be attributed to the different temperatures and feed composition, because cows consume more dry feed in winter, whereas in summer they eat grass and stay outside for longer (Fox & McSweeney, 2003). Some of this variation is well established and predictable. For example, DairyCo (2013) reported that in the years 2009–2013, fat levels from the UK national herd gradually decreased from January to July, followed by a sharp increase to more than 4.20% in August and September, and remained constant in October, November and December. Protein content followed a similar trend but with less variation. From November to April, protein content declined steadily from 3.35% to 3.23%, followed by a constant period from April to July, and finally increased slightly from July to November. While these trends are repeated annually, it is notable that there was significant year on year variation in the absolute values. Also it should be noted that these trends are the means of the national herd, and greater variation would be expected when considering individual milk supplies. Different regions and feeding regimes result in different seasonal effects on the main components of raw milk. Compared with the UK, the lowest protein content observed by O'Brien, Mehra, Connolly, and Harrington, (1999a) in Ireland was in March, which was probably due to lower intake of feed energy with indoor feeding.

These seasonal changes cause problems, but also allow opportunities for dairy manufacturers. For example, it is well established that butter spread ability is better when produced from summer fat compared with winter fat, due to the higher proportion of unsaturated fatty acids when cows are maintained on pasture in summer (Schmidt & Van Vleck, 1974). In the cheese industry, extended rennet clotting times can result in either disruption of production schedules or the failure to form a coagulum (Schmidt & Van Vleck, 1974). In addition to cheese manufacturing, seasonal variation in milk composition probably causes a range of problems in the manufacture of casein powder, whipping cream and liquid milk (Murphy & O'Brien, 1997).

Variation in raw milk properties, such as pH, Ca^{2+} and mineral content, can also have a pronounced effect on the manufacture of

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different dairy products (Faka, Lewis, Grandison, & Deeth, 2009). For example, according to Faka et al. (2009), higher Ca^{2+} and lower pH was generally correlated with poor heat stability in skim milk powder (SMP) and vice versa, and it is well known that calcium chloride addition can reduce the rennet coagulation time and increase the curd firmness in cheese-making (Tsioulpas, 2005). On-Nom, Grandison, and Lewis (2010) found that Ca^{2+} concentration increased as pH decreased, and both parameters decreased as temperature increased. Casein micelle size, buffering capacity, viscosity and foaming ability are other important physico-chemical properties, which are related to the natural and induced variations in the composition of milk (Fox & McSweeney, 2003; Salaun, Mietton, & Gaucheron, 2005).

The aim of this study was to determine the composition and physical properties of raw milk from a commercial herd over the period from August 2011 to October 2012. Although seasonal variation in milk composition and properties has been studied previously, the current study is focussed on the practical relationship of these variations to dairy product manufacture.

2. Materials and methods

2.1. Milk samples

Raw bulk milk was collected from the University of Reading Centre for Dairy Research. The herd consists of an average of 550 lactating Holstein cows and the milk is sold commercially. The animals are year-round calvers, and the majority are maintained indoors on total mixed rations, while approximately 30% spend the summer months on grass. The composition and physical properties were measured every 2 weeks. All analyses of raw milk were carried out in triplicate. pH, ionic calcium, lactose, protein, fat and total solids content, rennet clotting time (RCT), ethanol stability (ES), percentage of dry sediment, density, viscosity, buffering capacity (BC), casein micelle size, freezing point depression (FPD), foaming ability were measured at 20 °C within 24 h of milking. A total of 25 bulk milk samples were studied during the period August 2011 to October 2012.

2.2. Chemical analysis

The protein, fat, lactose, urea, somatic cell count (SCC) and total casein concentrations were measured in raw milk using a Lactoscope (Quadrachem Laboratories Ltd., London, UK).pH was measured using a Sentron 3001 pH meter (Sentron Europe BV, ZH Roden, Dutch), which was calibrated with standard buffer solutions of pH 4.0 and 7.0.

Ionic calcium (Ca^{2+}) was measured using a Ciba Corning 634 ISE Ca^{2+}/pH analyser (Ciba-Corning Diagnostic Limited). The instrument was calibrated in the millivolt (mV) output mode with solutions of 0.50, 1.00, 2.50 and 5.00 mM Ca^{2+} daily, prior to use. There was a linear relationship between log (ionic calcium) and mV output, with correlation coefficients greater than 0.99.

To determine total solids content (TS), raw milk samples (5 g) were accurately weighed and poured into stainless aluminium dishes and placed in an oven (100 °C) to constant weight. The residual dry weight of raw milk was considered as the total solids.

To measure buffering capacity (BC), 4.0 ml 0.1 M HCL solution was added to 25 ml raw milk sample and left for 1 h at room temperature. The pH difference before, and 1 h after, acid addition was considered to be the buffering capacity, and was expressed in pH units. The fall in pH accompanied by this procedure is similar to the fall in pH when milk is heated from 20 °C to 120 °C.

Ash content was measured using the AOAC method (2005) employing a Precisa 125A balance. Dry ashing was preferred to wet digestion. Results were expressed as % (w/v) percentage of ash in milk. Each sample was measured in triplicate.

Total calcium and magnesium concentration were determined according to the AOAC official method of analysis 991.25 (AOAC, 2005), employing a Pye Unicam SP9 Atomic Absorption Spectrophotometer (Atomic absorption Spectrometer novAA350, Analytik Jena AG, Germany) and using a calcium/magnesium lamp at a wavelength of 422.7 nm and 282.5 nm, respectively. This method involves dry ingestion of milk samples followed by dissolution of the resulting ash in concentrated nitric acid (69% HNO_3, Fisher Scientific, Loughborough, UK). The calcium in the samples (100 ml) reacts with the added lanthanum chloride solution, 1 ml (10%; Fisher Scientific, Loughborough, UK).

Total citrate concentration was determined by HPLC (High Performance Liquid Chromatography) according to Garnsworthy, Masson, Lock, and Mottram (2006).The HPLC apparatus consisted of an Agilent 1100 Isocratic Pump, an auto-sampler, a variable wavelength detector, and a Prevail™ Organic Acid, 5 μm Column (150 × 4.6 mm) (Alltech, Deerfield, USA). Data were analysed by ChemStation software.

Total phosphorus concentration was determined according to IDF standard 42B (International Dairy Federation, 1990).

2.3. Physical analysis

Dry sediment and ethanol stability (ES) were measured according to Chen, Grandison, and Lewis (2012).

A range of hydrometers (ranged from 1.000 to 1.050 g/ml) were used to determine the density of raw milk.

Kinematic viscosity was determined by a capillary BS/U tube viscometer (PoultenSelfe and Lee Ltd., Essex, UK). Raw milk was well shaken before the analysis. All measurements took place at room temperature (20 °C). The kinematic viscosity was calculated by multiplying the flow time by the instrument constant. Types B, C, and D BS/U tube viscometers were used. The nominal constants for each type are 0.01, 0.03 and 0.1 cSt s^{-1} (1 cSt s^{-1} = 10^{-6} m^2 s^{-1}), respectively.

Freezing point depression (FPD) was measured for milk samples by using an Advanced Milk Cryoscope 4L2 (Advance Instruments Inc., Metuchen, NJ, USA).

Rennet coagulation time (RCT) was measured according to Tsioulpas (2005).

The average casein micelle size of raw milk was measured with a Zeta Master (Malvern Instruments, Malvern, UK) according to Chen et al. (2012).

Foaming ability was determined at 65 °C by the air bubbling method developed by Huppertz (2010).

2.4. Statistical analysis

Statistical analysis of all data used Xlstat, 2012 and Statistical Package for the Social Sciences (SPSS 18) software. All variables were centred and normalised using SPSS 18 normality test (explore). The Spearman correlation method in Xlstat was used to establish whether the correlation coefficients between parameters were significant. Mean values, number of determinations, regression, univariate analysis and seasonal variations were calculated using SPSS 18 one-way ANOVA. The threshold levels of significance of $p < 0.05$, 0.01 and 0.001 were used in all analysis. Seasonal variations in raw milk were categorised into four groups as shown in Table 1.

Measurements were made in triplicate and inserted into the database. Principal component analysis (PCA) statistical method was performed with the Xlstat, 2012 software.