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Trend analysis and prediction of seasonal changes in milk composition from a pasture-based dairy research herd

E. Hayes,[1,3] D. Wallace,[2] C. O'Donnell,[3] D. Greene,[2] D. Hennessy,[4] N. O'Shea,[1] J. T. Tobin,[1] and M. A. Fenelon[1,3]*

[1]Teagasc Food Research Centre, Moorepark, Fermoy, Co. Cork, Ireland, P61C996
[2]School of Computer Science, University College Dublin, Ireland, D04V1W8
[3]School of Biosystems and Food Engineering, University College Dublin, Ireland, D04V1W8
[4]Teagasc Animal and Grassland Centre, Moorepark, Fermoy, Co. Cork, Ireland, P61C996

ABSTRACT

The composition of seasonal pasture-produced milk is influenced by stage of lactation, animal genetics, and nutrition, which affects milk nutritional profile and processing characteristics. The objective was to study the effect of lactation stage (early, mid, and late lactation) and diet on milk composition in an Irish spring calving dairy research herd from 2012 to 2020 using principal component and predictive analytics. Crude protein, casein, fat, and solids increased from 2012 to 2020, whereas lactose concentration peaked in 2017, then decreased. Based on seasonal data from 2013 to 2016, forecasting models were successfully created to predict milk composition for 2017 to 2020. The diet of cows in this study is dependent upon grass growth rates across the milk production season, which in turn, are influenced by weather patterns, whereby extreme weather conditions (rainfall and temperature) were correlated with decreasing grass growth and increasing nonprotein nitrogen levels in milk. The study demonstrates a significant change in milk composition since 2012 and highlights the effect that seasonal changes such as weather and grass growth have on milk composition of pasture-based systems. The potential to forecast milk composition at different stages of lactation benefits processers by facilitating the optimization of in-process and supply logistics of dairy products.
Key words: seasonality, milk trends, milk composition, lactation, forecasting

INTRODUCTION

World milk production is expected to grow by 1.6% per year over the next decade (OECD, 2020), with population growth in Asia projected to increase demand for dairy ingredients such as skim milk powder. In Europe, milk quotas were abolished in 2015, allowing farmers to expand their herds and increase milk production. For example, output in Ireland increased from 5.17 billion liters in 2010 to 7.15 billion liters in 2017 (Kelly et al., 2020). Moreover, it has increased in terms of total volume and milk components yield (fat and protein). Milk volume per cow increased by 14% from 2009 to 2018, with a 21% increase in fat and protein content over the same period (Kelly et al., 2020). The introduction of the Economic Breeding Index encouraged farmers to choose high-potential bulls based on specific traits to enhance the genetic merit of their daughters entering the dairy herd (Veerkamp et al., 2002). This resulted in a targeted increase in milk protein and fat. Other factors at the primary production level, including improvements in soil fertility and grassland management, have also contributed to increased milk production (Kennedy et al., 2005). Consequently, this has increased the yield of milk solids, with reports of milk solids increasing from 359 kg of fat plus protein per cow to 397 kg of fat plus protein per cow, from 2010 to 2017 (Kelly et al., 2020). In many countries, farmers are paid based on the yield of fat and protein in milk rather than volume. Thus, increasing TS is economically beneficial for the farmer and processor. Milk solids are converted into a diverse range of dairy products, for example, skim milk powder, whole milk powder, protein concentrates and isolates, and hydrolysates, caseinates, nutritional formulations, cheese, and butter.

Advances in analytical techniques for quantifying milk components may lead to changes in how milk payments are determined. Payments based on casein (**CN**) rather than total protein can benefit the cheese-making industry (Boland, 2010). In most cases, payments are based on CP, which includes NPN, and thus, are not an accurate indicator of the amount of true protein in milk. In addition, dairy processors may consider the end applications of whey proteins or other milk components, their nutritional benefits, and their functionality

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*Corresponding author: mark.fenelon@teagasc.ie

during processing in future cost models. The primary focus of producers has been to increase fat and protein, with less consideration given to lactose content. Lactose is recovered via a crystallization process typically from cheese whey and whey permeate. It can be used as an ingredient in infant formula or for standardizing the protein content in products such as skim milk or milk protein concentrate. A more refined and valuable form of lactose is used as an ingredient in the pharmaceutical industry.

In pasture-based farming systems, farmers rely on grazed grass and grass silage as the primary feed source for dairy cows, lowering input costs compared with indoor fed systems, thus improving profitability (Moscovici Joubran et al., 2021). The relationship between grass growth and weather is well known. Studies have shown that a year deficient in grass growth during the summer has significant implications for milk yield. For example, unusually hot and dry weather conditions in 2018 affected grass growth during the peak milk supply period and was reported to have cost the Irish dairy industry €500 million (McCaughren, 2018). Seasonal variations in milk composition have been well documented (O'Connell et al., 2015; Gulati et al., 2018; O'Brien et al., 1999), as have their effects on processing (Guinee et al., 1997; Guinee et al., 1999; Lin et al., 2017). New Zealand's pasture-based system has also documented seasonal changes (Auldist et al., 1998). However, changes in milk composition over time (sequential milking years) have not been well documented. The study by Sargeant et al. (1998) in Canada reported changes in milk composition from 1985 to 1994. The data were based on mean milk composition in the Ontario region and showed increased concentrations of fat (3.85 to 3.99%), whereas protein remained almost unchanged (3.30 to 3.32%). Another study looking at Australian Holstein-Friesian cattle also found that from 1993 to 2012, the percentage of fat in milk increased (Haile-Mariam and Pryce, 2015). However, contrary to the Canadian study, these authors reported an increase in protein.

Cows' diet affects milk composition, and multiple studies have indicated that it directly affects milk fat concentration (Palmquist et al., 1993; Kelly et al., 1998; Elgersma et al., 2004) concentration. Diet has also been shown to significantly affect cheese properties (Gulati et al., 2018). Although diet does not generally influence the composition of individual protein fractions in milk, it does affect protein concentration (Xie et al., 2015). In a pasture-based system, poor grass growth or bad weather can necessitate supplementation of concentrates or silage in cows' diet, leading to changes in milk composition. Increasing the addition of concentrates, which can contain high levels of CP, can lead to increased urea in milk due to cows' inability to utilize or store the excess protein in the diet and converts it to urea to be excreted. Although most urea is found in the blood, some passes into the milk, contributing to the NPN fraction, which can improve heat stability of milk; however, it reduces the true protein content of milk.

With the increased demand for functional foods (Vergari et al., 2010), including formulated beverages, understanding changes in milk composition is key to meeting nutrient specifications for complex foods such as infant formula. Data science has led to more advanced forecasting algorithms, and multivariate modeling is currently used for predicting milk composition. These digital tools provide the potential for milk forecasting, enabling the long-term prediction of composition over a lactation period. The dairy industry can use these forecasts to establish processing parameters and assist with the logistics of manufacturing products throughout a season. However, long-term forecasting can be inaccurate due to variability associated with factors influencing milk composition, such as animal genetics, stage of lactation (**SOL**) and nutrition. The incorporation of weather and grass data could potentially increase accuracy of short-term forecasting, providing processors with compositional predictions at the point of manufacture. Visentin et al. (2015) reported that milk composition (protein and CN) directly influenced processing traits such as rennet coagulation time and heat coagulation time, which are essential processing traits.

Little research is available on the correlation between temperature, rainfall and grass growth relative to changes in milk composition over time in pasture-based systems. The current study examines the effect of lactation stage (early, mid, and late) in a spring calving research herd on compositional changes in milk from 2012 to 2020 and correlates these changes with weather and grass growth to design a milk forecasting model.

MATERIALS AND METHODS

Experimental Design

No invasive techniques were used in this study. Milk was collected from a bulk tank, and there was no contact with animals. Milk samples were collected weekly between January 2012 and September 2020 from the bulk tank of a spring calving herd (mean calving date February 20) of predominantly Holstein-Friesian cows at Teagasc Animal and Grassland Research and Innovation Centre (Moorepark, Fermoy, Co. Cork, Ireland). All cows were fed a perennial ryegrass (pasture-based system)-based diet supplemented with concentrate as per Egan et al. (2018). Cows were kept outdoors for spring and summer months and housed during winter. During winter months (late November, December, and January), cows were fed a grass silage diet. In November and February, the diet consisted of grazed grass and sometimes grass silage, depending on weather conditions and grass availability. Cows were fed between 300 and 500 kg of concentrate feed per year. Compositional data from the milk samples were statistically analyzed to identify trends in milk composition throughout the lactation period and to identify changes in milk composition from 2012 to the present. Data for protein, casein, and NPN range from 2012 to 2020, whereas data for TS, fat, and lactose range from 2013 to 2020. The SOL was identified by 100-d intervals: early lactation (January to April), mid lactation (May to August), or late lactation (September to December).

Milk Sample Collection and Analyses

Each week, representative milk samples of 25 L were collected from the bulk tank, and 30 mL of a broad-spectrum preservative containing Bronopol and Natamycin was added. Samples collected comprised of a combination of both morning and evening milkings. Milk was subsequently divided into aliquots of 40 mL in plastic vials. A subsample (3 vials) was refrigerated at 4 ± 2°C. Fat (ISO, 2018c), TS (ISO, 2018a), protein (ISO, 2018d), CN (ISO, 2018b), and NPN (ISO, 2014) were analyzed. Lactose was measured by polarimetry as follows: zinc acetate, phosphotungstic acid and glacial acetic acid are used to make the clearing agent. The clearing agent was added to liquid milk. The filtrate was measured using a polarimeter. The percentage of lactose is calculated using the following equation:

$$\mathrm{C[g/100\ mL]} = \mathrm{A} - 0.18 \times [1.0609 - 0.0121 \times \mathrm{F}]1.053,$$

where C is concentration of lactose, A is the observed reading in a 2 DM sample cell and F is the percentage of fat. Milk composition (fat, total protein, lactose, TS, CN, and true protein) was also analyzed using a rapid Fourier-transform infrared spectroscopy (Bentley Dairy Spec FT, Bentley Instruments).

Meteorological Data

Temperature (°C) and rainfall (mm) data were obtained from the meteorological station established by Met Eireann at Teagasc (Moorepark, Fermoy, Co. Cork). Although daily meteorological data were available, this study used weekly data for average temperature and total rainfall for comparison with grass growth data.

Grass Growth Data

Weekly grass growth data (kg of DM/ha per d) was gathered from the ongoing long-term grass growth study at Teagasc Animal and Grassland Research and Innovation Centre (Moorepark, Fermoy, Co. Cork, Ireland), as described by Hurtado-Uria et al. (2013)

Prediction

Prediction models were developed using the Prophet forecasting algorithm for time series data (Taylor and Letham, 2018), which is based on an additive model to include seasonality effects for nonlinear data. An open source Python implementation for this forecasting procedure was used (Calamari et al., 2007). Data were split into separate temporal training and testing sets for evaluation purposes. For fat and lactose prediction, the training data used was for the time period 2013 to 2015, whereas for protein and ratio of protein to protein plus lactose (**P:P+L**) predictions, the training data used were for the time period 2013 to 2017.

Statistical Analysis

Analysis of variance was assessed using one-way ANOVA (Minitab 17, Minitab Ltd.). The variation of composition as influenced by SOL and year was measured. The level of significance was determined at $P < 0.05$. Mean, minimum, and maximum concentrations were measured using Unscrambler X (version 10.5.1, CamoSoftware, 2018). Principal component analysis (**PCA**) was carried out using Unscrambler X to observe the grouping of samples between early, mid, and late lactation. Python code was used to determine the mean absolute error (**MAE**) of the forecasting models.

RESULTS AND DISCUSSION

Variation in Milk Composition

Fat and Total Solids. The major milk components varied significantly between early, mid, and late lactation (Table 1). Mean percentage fat concentrations decreased from early to mid lactation and then increased again in late lactation as milk volume decreased. This trend was consistent for all years.

Concentrations for fat were not consistent throughout the season as shown by the high standard deviation in Table 1. Although fat increased numerically from

Table 1. Mean and SD of milk composition during early, mid, and late lactation from 2013 to 2020

	Early lactation			Mid lactation			Late lactation		
Composition	n	Mean	SD	n	Mean	SD	n	Mean	SD
Fat (%, wt/wt)									
2020	16	$4.50^{a,B}$	0.414	18	$4.05^{ab,C}$	0.259	16	$4.89^{abc,A}$	0.299
2019	16	$4.37^{ab,B}$	0.409	18	$4.15^{a,B}$	0.349	16	$4.98^{a,A}$	0.300
2018	16	$4.44^{ab,B}$	0.283	18	$3.95^{ab,C}$	0.367	17	$4.77^{abc,A}$	0.168
2017	16	$4.15^{b,B}$	0.320	18	$4.06^{ab,B}$	0.364	15	$4.92^{ab,A}$	0.175
2016	16	$4.22^{ab,B}$	0.309	18	$3.93^{ab,B}$	0.516	17	$4.97^{a,A}$	0.280
2015	16	$4.31^{ab,B}$	0.238	18	$4.14^{a,B}$	0.266	17	$4.83^{abc,A}$	0.258
2014	16	$4.27^{ab,B}$	0.287	18	$3.72^{b,C}$	0.515	16	$4.63^{bc,A}$	0.205
2013	16	$4.23^{ab,B}$	0.259	18	$3.82^{ab,C}$	0.137	17	$4.61^{c,A}$	0.361
Lactose (%, wt/wt)									
2020	16	$4.71^{c,A}$	0.160	18	$4.69^{d,A}$	0.099	16	$4.51^{de,B}$	0.090
2019	16	$4.78^{bc,A}$	0.129	18	$4.70^{d,A}$	0.104	16	$4.44^{e,B}$	0.064
2018	16	$4.92^{a,A}$	0.041	18	$4.77^{cd,B}$	0.062	17	$4.54^{cd,C}$	0.049
2017	16	$4.89^{a,A}$	0.320	18	$4.93^{a,A}$	0.061	15	$4.75^{a,B}$	0.052
2016	16	$4.90^{a,A}$	0.080	18	$4.87^{ab,A}$	0.083	17	$4.62^{bc,B}$	0.069
2015	16	$4.87^{ab,A}$	0.011	18	$4.81^{bc,A}$	0.081	17	$4.66^{b,B}$	0.098
2014	16	$4.88^{ab,A}$	0.042	18	$4.66^{d,B}$	0.125	16	$4.88^{b,B}$	0.060
2013	16	$4.70^{c,A}$	0.140	18	$4.71^{d,A}$	0.062	17	$4.48^{de,B}$	0.075
Protein (%, wt/wt)									
2020	16	$3.46^{ab,C}$	0.105	17	$3.66^{a,B}$	0.110	16	$4.07^{a,A}$	0.197
2019	16	$3.47^{a,C}$	0.157	18	$3.60^{ab,B}$	0.102	16	$4.03^{a,A}$	0.177
2018	15	$3.30^{cd,C}$	0.113	14	$3.47^{cd,B}$	0.122	17	$4.05^{a,A}$	0.215
2017	17	$3.33^{bcd,C}$	0.172	17	$3.56^{abc,B}$	0.109	16	$3.89^{ab,A}$	0.171
2016	16	$3.22^{d,C}$	0.169	16	$3.50^{bcd,B}$	0.128	17	$3.90^{ab,A}$	0.277
2015	17	$3.46^{ab,B}$	0.055	17	$3.60^{ab,B}$	0.112	17	$3.87^{ab,A}$	0.388
2014	17	$3.44^{abc,B}$	0.078	17	$3.52^{bc,B}$	0.092	16	$3.44^{b,A}$	0.188
2013	16	$3.35^{abcd,B}$	0.134	18	$3.39^{d,B}$	0.074	17	$3.84^{ab,A}$	0.225
2012	18	$3.42^{abc,B}$	0.102	17	$3.38^{d,B}$	0.084	16	$3.68^{b,A}$	0.186
Casein (%, wt/wt)									
2020	16	$2.72^{ab,C}$	0.091	17	$2.91^{ab,B}$	0.086	17	$3.19^{a,A}$	0.166
2019	16	$2.75^{a,C}$	0.116	18	$2.87^{a,B}$	0.078	16	$3.18^{ab,A}$	0.134
2018	15	$2.61^{cd,C}$	0.079	15	$2.78^{b,B}$	0.093	16	$3.26^{a,A}$	0.157
2017	17	$2.65^{abcd,C}$	0.130	17	$2.85^{ab,B}$	0.086	15	$3.08^{ab,A}$	0.143
2016	16	$2.56^{d,C}$	0.128	16	$2.78^{b,B}$	0.091	17	$3.07^{abc,A}$	0.204
2015	17	$2.74^{a,B}$	0.011	17	$2.85^{ab,B}$	0.086	17	$3.06^{abc,A}$	0.294
2014	17	$2.74^{a,B}$	0.080	17	$2.78^{b,B}$	0.071	16	$2.74^{c,A}$	0.148
2013	16	$2.63^{bcd,B}$	0.104	18	$2.68^{b,B}$	0.060	17	$2.99^{bc,A}$	0.152
2012	18	$2.67^{abc,A}$	0.076	17	$2.65^{b,B}$	0.071	16	$2.88^{c,A}$	0.141

[a–e]Values within a column for each nutrient not sharing a common lowercase superscripted letter differ significantly ($P < 0.05$).
[A–C]Values within a row not sharing a common uppercase superscripted letter differ significantly ($P < 0.05$).

2013 to 2019 for early and mid lactation, it significantly ($P < 0.05$) increased from 4.61 ± 0.36 (SD) to 4.98 ± 0.30 during late lactation. Milk fat can be influenced by changes in diet (O'Callaghan et al., 2016), whereas protein composition is primarily determined by animal genetics (Gaunt, 1973; McLean et al., 1984; O'Callaghan et al., 2016). O'Brien et al. (1999) reported mean fat concentrations of 3.4% from mid to late lactation, with a maximum value of 3.9% from a pasture-based feeding system. They also reported that the percentage of fat in milk increased from 1993 to 1994. Barbano and Sherbon (1984) reported concentrations for milk fat from 3.57 to 3.69% between d 30 and 85 of lactation. Jensen et al. (1991) reported an average milk fat value of 3.9%, consistent with O'Brien et al. (1999). More recently, Lin et al. (2017) recorded a mean fat value of 4.05 ± 0.30% over the lactation period, similar to the current study (Table 1). As discussed, the variations in fat concentration over the years is a result of improved breeding and feeding strategies.

Total solids followed a similar trend to fat concentration (i.e., increasing from a mean value of 13.26% in 2013 to 13.64% in 2020 over the entire lactation period). Within a lactation period, TS reduced from early to mid lactation and then increased from mid to late lactation for all years. In late lactation TS increased from 13.77% in 2013 to 14.3% in 2020. Total milk solids decreased during mid lactation in 2018 (13.1%) compared with the same period in 2017 (13.23%) and 2019 (13.4%); this reduction is most likely due to a lack of grass growth in 2018, which lowered the protein concentration during the summer months. Total solids remained higher in early and late lactation of 2018 compared with 2017.

Protein. Similar to results reported by Gulati et al. (2018), protein concentrations significantly ($P < 0.05$) increased in the order of early < mid < late lactation. This trend was consistent for all years except 2014, where protein was higher (3.52%) in mid compared with early (3.44%) or late lactation (3.44%). The mean protein (% wt/wt) concentrations in 2013 for early, mid, and late lactation were 3.35 ± 0.13, 3.39 ± 0.07, and 3.84 ± 0.23 compared with 3.46 ± 0.11, 3.66 ± 0.10, and 4.07 ± 0.19, respectively in 2020. These significant ($P < 0.05$) increases may be attributed to genomic selection (Sneddon et al., 2015) and better pasture management (Dineen et al., 2018).

Casein. Casein concentration followed a similar pattern to protein, increasing from early to late lactation. Li et al. (2019) reported on changes in protein fractions over 2 milking seasons and found that the proportion of CN relative to total protein did not vary within a season; however, it was lower in 2017–2018 than in 2016–2017. The authors also found that the whey protein, β-LG was higher across the season in 2017–2018 compared with 2016–2017. Other studies (Heck et al., 2009; Lindmark-Månsson et al., 2003) have noted that CN varies significantly over the lactation period, following the trend in protein. Lindmark-Månsson et al. (2003) reported that since the 1970s, CN in Swedish milk decreased from 2.61 to 2.56%, whereas whey proteins increased. The current study shows that CN increased significantly ($P < 0.05$) from 2012 to 2019, from 2.65 to 2.91% in mid lactation and from 2.88 to 3.19% in late lactation over the 8-yr period. Because CN is converted into curd during cheese making, its level in milk determines yield. This study showed a significant difference ($P < 0.001$) in CN between early and mid or late lactation milk in 2019, with a maximum value of 3.18% reported in late lactation. This result is similar to that of Mehra et al., (1999), who reported CN was highest in October with a value of 2.95%.). Donnelly et al. (1984) reported that CN micelles measured in late lactation had significantly higher mineral concentration (calcium and magnesium) than CN micelles in mid lactation ($P < 0.05$). The level of CN in milk affects its buffering capacity and interactions with minerals and other ionic species, ultimately affecting milk processing (Singh and Fox, 1985; Tsioulpas et al., 2007).

Nonprotein Nitrogen. The concentration of NPN does not follow the same trend as the macro milk components of protein, fat, and lactose. The yearly variation in NPN is likely due to factors such as diet, which influences the levels of milk urea nitrogen, as discussed by DePeters and Ferguson (1992), Baker et al. (1995), and Reid et al. (2015). Mean NPN levels decreased by 0.17 mg/g protein each year from 2012 to 2020 (Figure 1), with concentrations significantly higher ($P < 0.01$) in 2012 than in other years. The high level in 2012 is likely due to adverse weather conditions, particularly high rainfall in spring, leading to increased concentrate feeding resulting in excess dietary protein intake. During 2012 grass growth rates were low in the spring (Figure 2), resulting in a longer period of indoor feeding and thus higher levels of CP in the form of concentrate. The general decrease in NPN over the years is likely due to improved animal nutrition and genetics. It is also possible that environmental legislation to reduce the use of N fertilizer on pasture systems contributed to the lower NPN levels. If this is the case, then examining the effects of reduced-N fertilizer on milk protein and NPN is important as it may lead to changes that could affect processing. Interestingly, when expressed as %wt/wt, NPN was significantly higher in late lactation in 2013, 2014, 2016, and 2017. Lower levels of NPN has been associated with reduced heat stability of milk (Reid et al., 2015; Muir and Sweetsur, 1978).

Lactose. In contrast to protein and fat, the lactose concentration of milk decreases during lactation (O'Brien et al., 1999), which agrees with the trend observed for each year shown in Table 1. However, although the mean lactose (%, wt/wt) concentration for the entire lactation period significantly ($P < 0.05$) increased from 2013 to 2017, it decreased from 2017 to 2020, with a significant ($P < 0.05$) decrease observed in mid and late lactation. In 2013, there was a negative correlation between lactose and NPN ($r = -0.61$), whereas in 2019 this trend was not seen to the same extent ($r = -0.29$). However, the mean correlation value between lactose and NPN between 2014 and 2018 was $r = -0.50$.

A review by Costa et al. (2019) demonstrated that lactose levels can be used to indicate milk quality; thus, some milk payment schemes consider this in their calculations. Low lactose is associated with high SCC, which results in poor processing characteristics such as rennet coagulation (Geary et al., 2013). For example, a milk processor may penalize suppliers with lactose levels between 4.0 and 4.2%. Milk with less than 4.0% may be rejected (Glanbia, 2022), and an extended milking season after removal of the milk quota in 2015 could affect lactose levels during late lactation.

Protein-to-Lactose Ratio. Protein-to-lactose (**P:L**) ratio has implications for skim milk powder (or liquid concentrate) production, whereby standardization is required, for example, when used to manufacture infant formula. Changes in innate lactose levels caused by the seasonality of pasture-based systems need to be accounted for during formulation to adhere to label claim requirements and regulations. Small changes in P:L ratio in milk affect the level of lactose required for standardization of protein in skim milk powder. Sned-

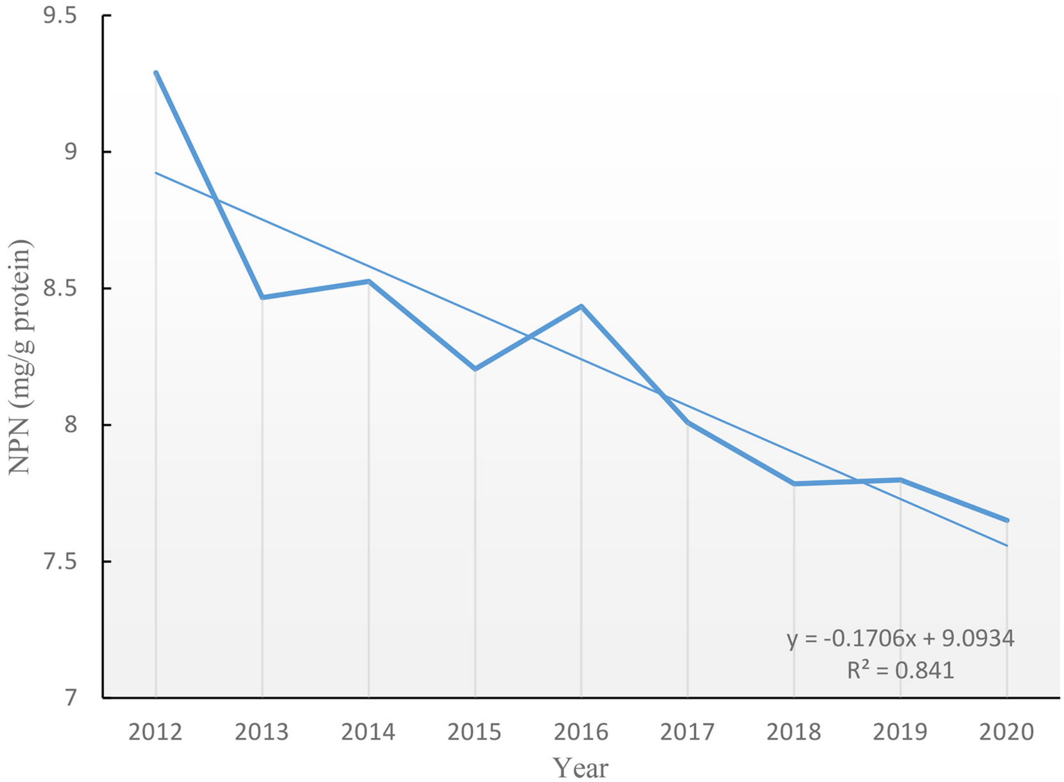

Figure 1. Changes of NPN expressed as milligrams per gram of protein from 2012 to 2020.

don et al. (2016) discuss the use of P:P+L as a tool to identify milk suitable for milk powder production. They noted that a small change in the ratio of P:P+L from 0.446 to 0.448 significantly affected large volumes of milk in New Zealand. Our study found significant ($P < 0.05$) changes in P:P+L from 2013 (0.432) to 2019 (0.443) over the lactation period (Figure 3). New Zealand farmers also breed cows for increased fat and protein concentration in milk. Sneddon et al. (2016) showed that including lactose in the selection process for breeding could reduce imported lactose by 6 to 11%. Significant variations in protein and fat levels confound the lactose concentration change in the late lactation period. Lactose did not change to the same extent as protein and fat over from 2012 to 2020; thus, as a percentage of milk solids, lactose decreased during the period 2017 to 2020 (Figure 4).

Relationship Between Rainfall, Temperature, Grass Growth, and Milk Composition

Rainfall and temperature directly influence grass growth (Hurtado-Uria et al., 2013), which indirectly affects milk composition. The relationship between grass growth, temperature and rainfall is shown in Figure 2. A decrease in grass growth coincided with an increase in NPN in both 2012 and 2016 (Figure 5); however, in 2018 when grass growth decreased, NPN levels did not change. Although the maximum NPN as percent of total N for years 2013 to 2015 and 2017 to 2019 was less than 7%, a maximum of 7.79% was seen in 2012 and 8.59% in 2016. The mean rainfall for June for 2013 to 2019 was 62.7 mm, compared with 215 mm in 2012. The spike in NPN in June of 2012 is likely due to the significantly higher rainfall during this period, resulting in feed supplementation with silage and concentrates (high in CP). Levels of NPN in mid lactation were generally lower than in early or late lactation, due to the grass-based diet of cows in the summer. The reason for the increase in NPN in September of 2016 is unknown; however, 2016 was the first year after abolition of the European Union milk quota, and a longer production season in late lactation was more prevalent, which may in part explain the higher NPN values. It is evident that the reduction in grass growth in 2018 between June and August is most likely due to lack of rainfall combined with warm temperatures (mean = 17.7°C). However, although diets may have had to be supplemented in 2018, there was no significant increase in NPN during this period. As mentioned previously, TS during mid lactation in 2018 were lower than 2017 and 2019, and this corresponds with the reduction in

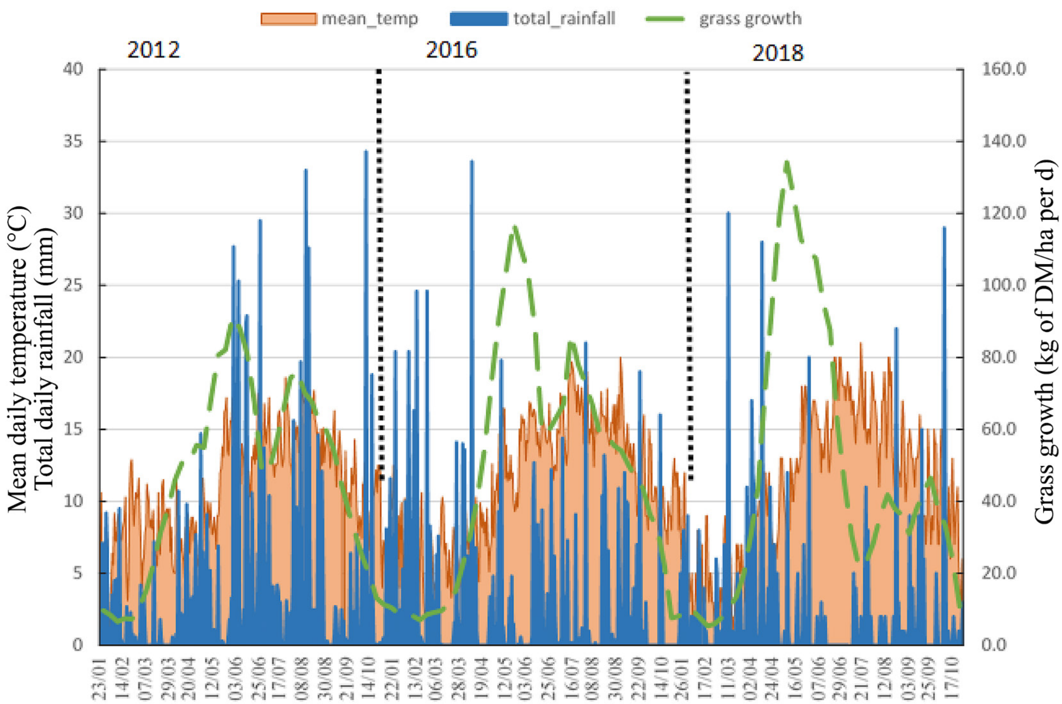

Figure 2. Seasonal variation of grass growth (dashed line), average temperature (orange), and total rainfall (blue) from January to October for 2012, 2016, and 2018.

grass growth during this period. This is also evident in Table 1, where mean protein and fat concentrations are lower in mid lactation for 2018 than 2017 or 2019. The TS did not reduce in either 2012 or 2016 when grass growth decreased indicating that overall milk solids was not affected by change in diet; however, excess protein did lead to increased NPN.

Milk Composition Forecasting

Due to the seasonality of milk production in pasture-based systems, milk yield and composition varies considerably over the year. Milk processors predict milk yield to aid manufacturing scheduling for each processing season. This study used the Prophet forecasting algorithm to predict fat, lactose, protein and P:P+L (Figure 4) and compare them against actual concentrations. Initially, the data from 2013 to 2016 was used for training and predictions were made using the 2017 to 2020 data. The forecasting model for protein did not accurately predict the 2016–2020 concentrations when trained on 2013–2016 data; predicted concentrations dropped toward the end of 2016, which was not observed in the measured concentrations. However, when the 2013 to 2017 data were used for training, the prediction improved significantly as shown in Figure 4. A similar trend was observed for P:P+L predictions (Figure 4) using the 2013 to 2016 and 2013 to 2017 data sets for training. The forecast is less accurate for the third year of its prediction and significantly overestimates the ratio of P:P+L for the fourth year of forecasting. The algorithm predicts concentrations for fat accurately (MAE = 0.24) over the period (Figure 4), increasing each year slightly, similar to that observed for actual concentrations. However, it failed to forecast minor dips and peaks throughout the season. These dips and peaks may be due to dietary influences and could be predicted better by incorporating diet or grass growth into the model. Protein was also reliably predicted (MAE = 0.15), particularly in mid and late lactation, whereas the model slightly overestimated concentrations in early lactation. Lactose was well predicted during mid lactation, but the algorithm failed to predict the decrease in late lactation. Lactose concentrations used for training increased year on year; however, after 2017 lactose decreased, especially in late lactation, and the predicted values were higher than observed values and thus was not reliable based on the training data set used. The model also overestimated lactose in early and mid lactation for 2020. As a result, the P:P+L prediction was also over estimated and followed the increasing trend of the predicted lactose. However, the MAE concentrations for the forecast model of protein and protein plus lactose was low at 0.026. This model

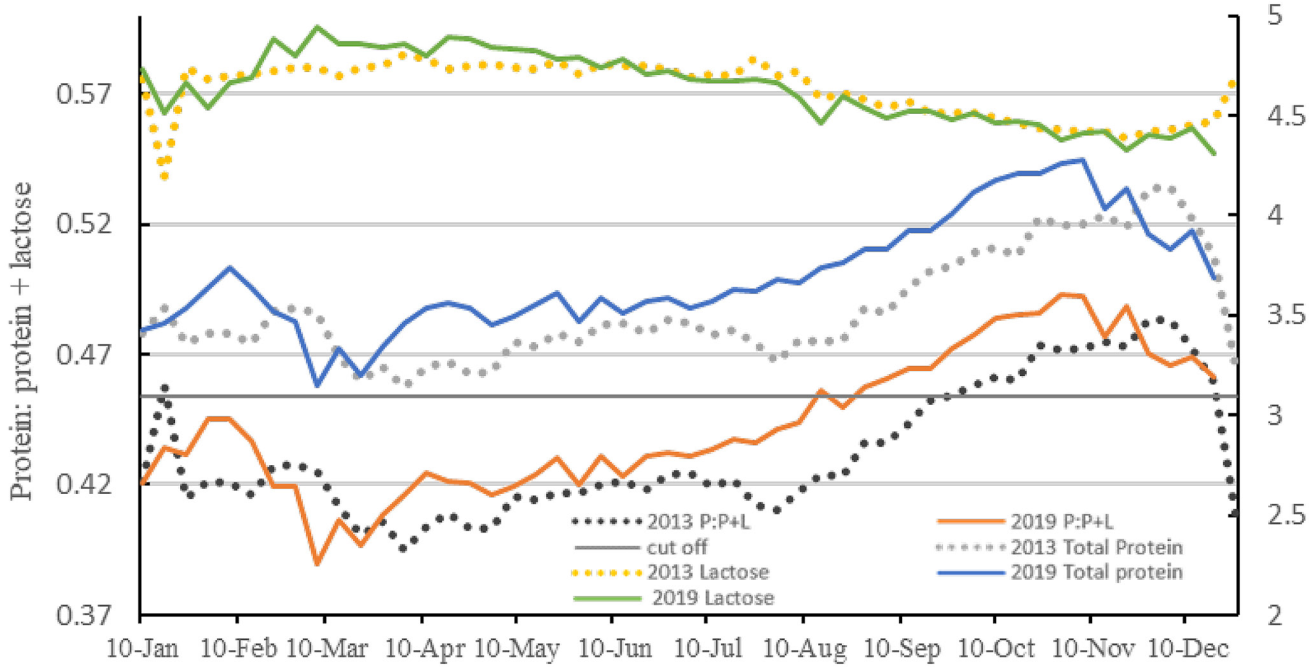

Figure 3. Total protein, lactose, and ratio of protein to protein plus lactose (P:P+L) for 2013 and 2019. The area above the gray cut-off line indicates the ratio that processors need to start standardizing milk powder with protein instead of lactose according to Sneddon et al. (2016).

had the lowest error; however, all error concentrations were low, suggesting that the forecasting model worked well. The findings demonstrate the potential of prediction models to facilitate management of product streams in dairy processing. Using the P:P+L ratio could be used to predict the volume of lactose required

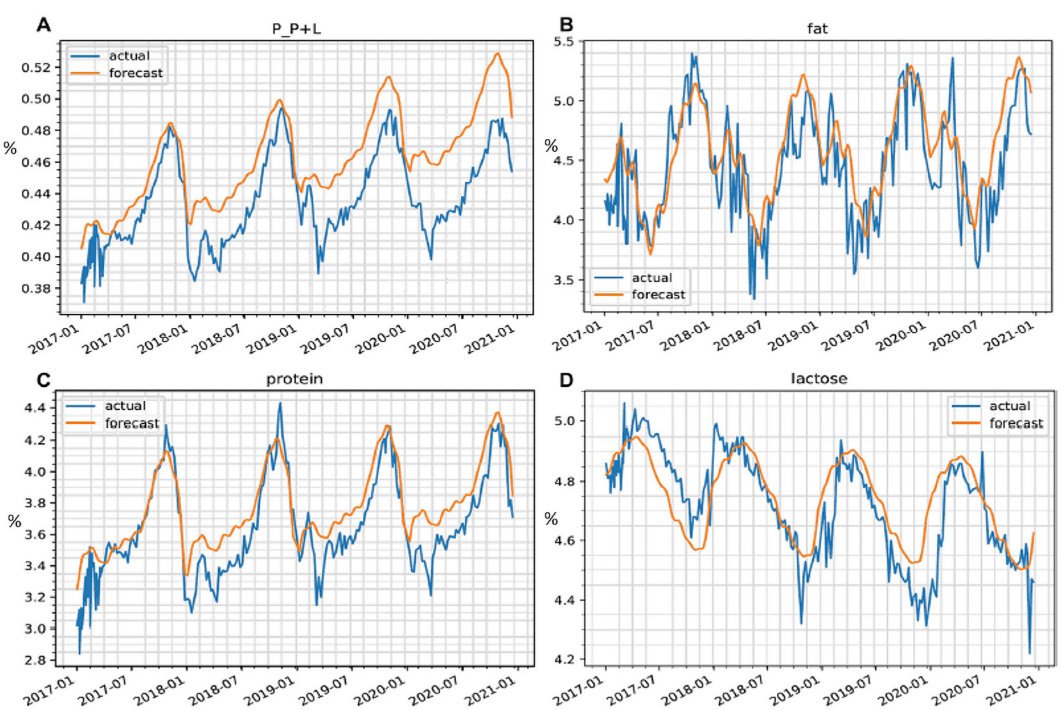

Figure 4. Actual and predicted values for (A) the ratio of protein to protein plus lactose (P_P+L), (B) fat, (C) protein, and (D) lactose from 2017 to 2021, based on time series forecasting models.

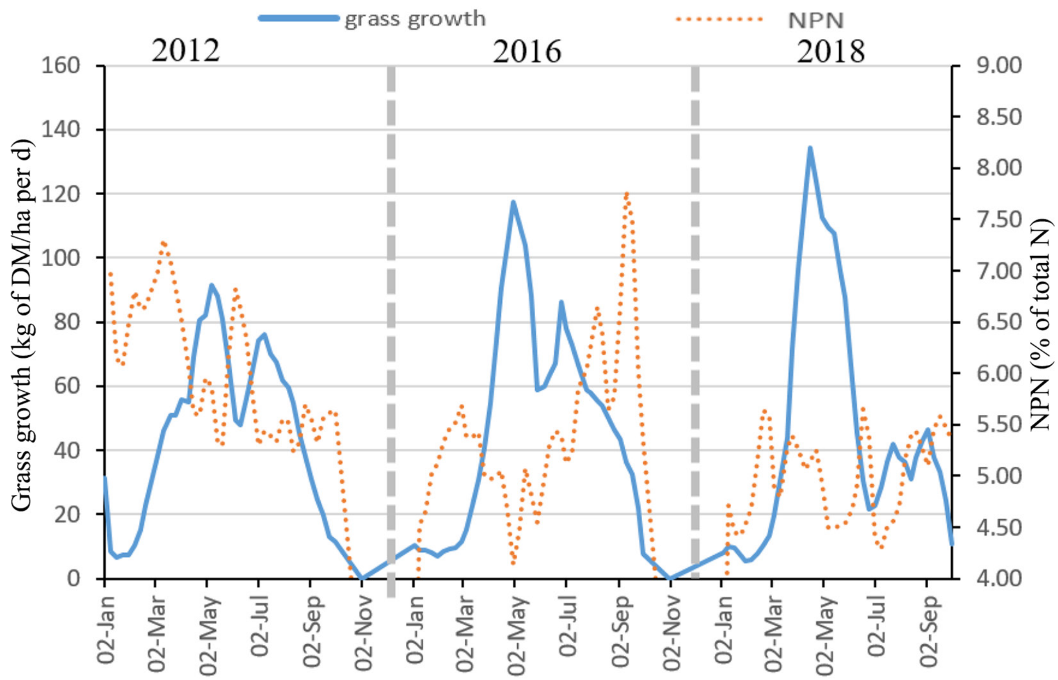

Figure 5. Nonprotein nitrogen as percentage of total N (orange dashed line) versus grass growth in kilograms of DM/hectare per day (blue line) over the lactation period from January to November for 2012, 2016, and 2018.

for standardization of milk powders at specific stages in lactation. However, the limitations of the prediction model demonstrate the need to monitor and update such algorithms regularly. Prediction accuracy could be further improved by incorporating additional variables such as diet, animal genetics, and weather in the models. This prediction model is based on Irish milk data; however, it could be utilized elsewhere by training the model on data from systems used in other countries, including indoor milking systems.

Principal Component Analysis

The PCA score plots were used to group milk samples based on the SOL (Figure 6). The score plot for fat shows little deviation from the mean in early, mid, or late lactation. There was one outlier in the late lactation stage, which corresponded to a value from 2014 that differed from other values within 2014 and from other years. Seasonal protein concentrations were separated into individual groups, increasing from early to late lactation (Figure 6). Less clear groupings were observed for lactose in early and mid lactation, indicating little variation between concentrations. However, it was observed that lactose during late lactation is grouped with lower concentrations than either early or mid lactation. These results show that PCA can be used to identify samples based on SOL and can detect outliers within a data set. Principal component analysis is a quick method that can be used to identify milk compositional trends. It can generate valuable tools for dairy processing companies to predict yearly milk composition trends, to inform processing strategies and screen milk based on processing quality parameters. For example, PCA could detect poor-coagulating milk by developing a classification algorithm, alerting processors to divert milk to liquid processing instead of cheese making. Although the forecasting models mentioned in the study provide more accurate predictions, they are complex and time-consuming. For increased process efficiency, PCA could offer a rapid screening prediction of milk composition that dairy manufacturers could exploit.

CONCLUSIONS

Milk composition from pasture-fed cows changed significantly between 2012 and 2020, primarily driven by increases in fat and protein concentration. Compositional changes, particularly P:P+L ratio, affect the level of standardization required to meet target specifications during the manufacture of skim milk powder. In addition, adverse weather conditions that correlated with a reduction in grass growth led to seasonal changes in milk composition. The higher milk solids concentration observed over the period of this study translates

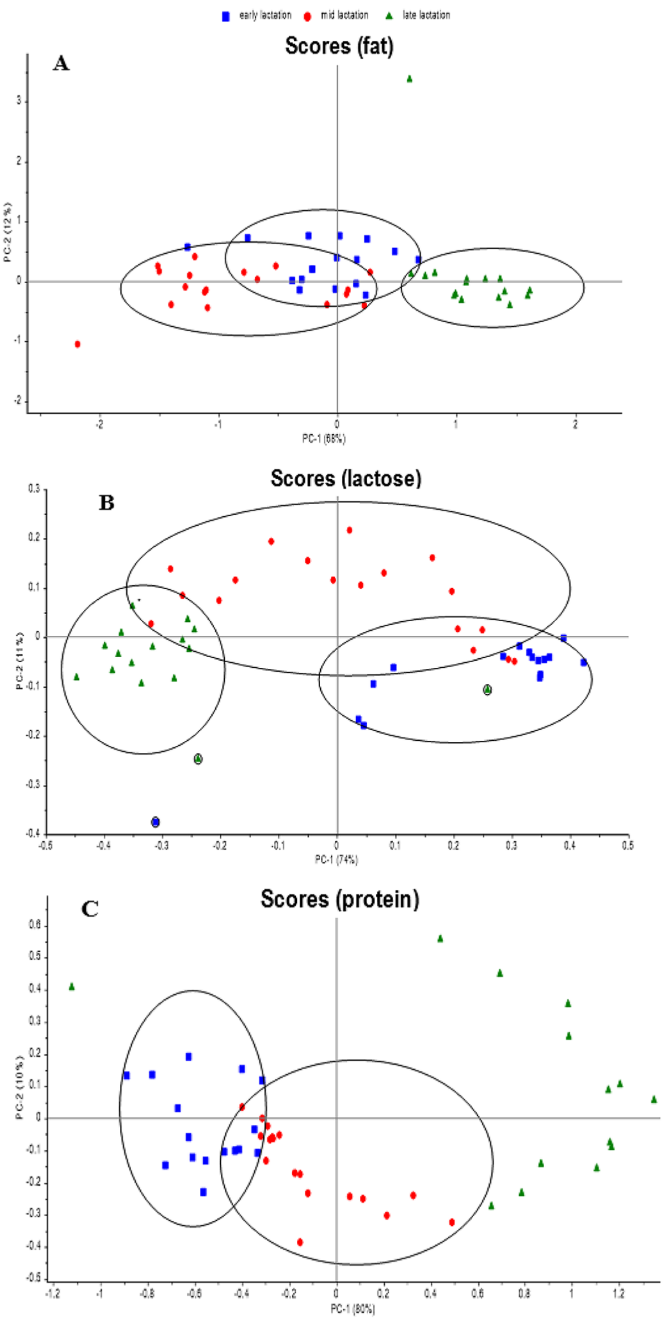

Figure 6. Principal component (PC) analysis score plot of (A) fat, (B) lactose, and (C) protein with sample grouping according to stage of lactation (early lactation = blue squares; mid lactation = red circles; and late lactation = green triangles).

into increased product yield (e.g., butter, cheese, milk protein powders, and coagulated acid products). Changes in composition can alter formulation dynamics of ingredients such as unstandardized skim milk powder when used in nutritional foods. The study suggests that future prediction algorithms can be developed to include grass growth and weather for short-term forecasting of milk composition and processability.

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ORCIDS

E. Hayes https://orcid.org/0000-0001-5211-4331
D. Greene https://orcid.org/0000-0001-8065-5418
D. Hennessy https://orcid.org/0000-0002-7375-3754
M. A. Fenelon https://orcid.org/0000-0002-4066-7075