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Impact of a total mixed ration or pasture/pasture silage-based feeding strategy in the initial stages of lactation of spring-calving dairy cows on milk production, composition and selected milk processability parameters

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Abstract

The objective of this experiment was to investigate the effect of feeding strategy on milk production, composition and selected processability parameters in the initial stages of lactation. Twenty Holstein Friesian cows were allocated to one of two dietary treatments (n = 10; 7 multiparous and 3 primiparous) in a randomised complete block design for 21 d from day 10 to day 31 post-calving. Treatment 1 (pasture-based system [PBS]) was a pasture/pasture silage-based diet where cows were offered ad libitum grazed pasture or pasture silage (when weather did not permit grazing) plus 3 kg DM/d or 5 kg DM/d concentrate supplementation, respectively. On average, cows grazed pasture for 7.5 d and were fed pasture silage indoors for 13.5 d. Treatment 2 (TMR) was a total mixed ration (TMR) diet made up of concentrate, plus maize silage, pasture silage, beet pulp, soya bean meal and straw. Multiparous cows were blocked on calving date and balanced for parity and milk yield. Primiparous cows were balanced for live weight. Milk attributes pertinent to composition and functionality (e.g., fatty acids and rennet coagulation time [RCT]) were examined over a 21-d experimental period from day 10 to day 31 post-calving. Cows offered PBS tended to have a lower test day milk yield (PBS = 24.2 kg/cow vs. TMR = 26.8 kg/cow, P = 0.09) and a greater milk urea nitrogen (MUN) content compared to TMR (PBS = 0.030 g/100 g milk vs. TMR = 0.013 g/100 g milk, P < 0.001). Most notably, PBS-derived milks had a greater (P < 0.001) concentration of cis-9 trans-11 conjugated linoleic acid (CLA) compared to TMR. In conclusion, milk produced during early lactation from both feeding strategies was suitable for processing. Feeding a TMR compared with ad libitum pasture/pasture silage had no impact on average milk pH, casein concentration or RCT. Cows fed a pasture/pasture silage-based diet produced milk with a desirable RCT for milk processing, while the higher MUN content from cows offered PBS did not impact the processability of milk. Furthermore, milk from cows offered PBS had greater concentrations of cis-9 trans-11 CLA, which may offer human health benefits.

Keywords

Dairy cow • early lactation • milk composition • processability

Introduction

The early lactation period has been defined as milk produced up to approximately 95 d in milk (DIM; Dillon *et al*., 2002). Milk produced during this period is characterised as being low in protein, particularly casein, which poses issues for dairy product manufacturers as the milk is of poor processability. Milk from early lactation cows has a reduced shelf life and poorer functional and rheological properties compared to mid-lactation milk (Phelan *et al*., 1982; Tsioulpas *et al*., 2007). Seasonal variation in milk composition and processability is driven by the physiology of lactation. However, nutrition and the interaction between stage of lactation and nutrition could also play a role (Downey & Doyle, 2007). In addition, milk compositional and processability issues are also affected by stage of lactation. As lactation advances, concentration of fat and protein increases, with a concurrent decrease in milk yield and lactose concentration after peak milk production (Walker *et al*., 2004; Downey & Doyle, 2007). In dairy systems where milk is produced in a seasonal system, issues with milk

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composition and processability are exacerbated as all cows are at the same stage of lactation at the same time (Downey & Doyle, 2007).

In Ireland, milk for manufacturing is produced primarily from a spring-calving pasture-based system (PBS) (Phelan *et al*., 1982; Dillon *et al*., 1995, 2002). As pasture is the cheapest feed source, an important focus in this system is to maximise the amount of pasture in the cow's diet (O'Brien *et al*., 1996) and to get cows out to pasture as early as possible post-calving. Due to its low cost and high nutritive value, maintaining high levels of pasture in the cow's diet can reduce the cost of milk production (O'Brien *et al*., 1999; Alothman *et al*., 2019). Thus, the typical diet for cows in the Irish dairy industry contains 95% pasture on a fresh matter basis (O'Brien *et al*., 2018). Furthermore, PBSs can improve milk composition (Dillon *et al*., 1995) as the nutrient profile of pasture contains the precursors required to produce milk constituents such as lactose, protein and fat (Jenkins and McGuire, 2006). However, inadequate pasture supply or difficult grazing conditions in spring, which coincides with early lactation, can result in reduced milk production and poor milk composition (Dillon *et al*., 1997). In contrast, in indoor dairy systems, farmers typically operate a total mixed ration (TMR) feeding strategy, where cows are housed indoors year-round, allowing for greater control over nutrient intake and protection from climatic extremes. Cows in these feeding systems produce more milk due to greater DM intake (DMI) and energy intake (Kolver & Muller, 1998); however, these systems also operate at a greater cost of production. There is, however, little information available on the impact of feeding strategy in the initial stages of early lactation (0–30 DIM) on milk production, composition and processability characteristics.

Nutritional management can affect the composition and processability of milk and milk products (O'Brien *et al*., 1999; O'Callaghan *et al*., 2016a). A high digestibility diet in terms of increasing DMI and total energy intake has been reported to improve the renneting parameters and casein concentration of early lactation milk (O'Brien *et al*., 1997; Dillon *et al*., 2002). Several authors have reported that milk from cows fed pasture has a greater curd firmness and improved coagulation properties than that from cows fed a TMR in an indoor system (Grandison *et al*., 1984; Macheboeuf *et al*., 1993). However, good quality spring pasture is a high-protein feed, and this can have a negative effect on the heat stability of milk (Reid *et al*., 2015). Results from these studies are often conflicting and experimental designs differed in diet type, stage of lactation and cow breed.

Early lactation is a challenging time in the lactation cycle (Veerkamp *et al*., 2003) as cows are in a state of negative energy balance (NEB) due to the imbalance between the energy demand for milk production and low DMI post-calving (Veenhuizen *et al*., 1991). Negative energy balance results in the mobilisation of fatty acids from body reserves, which has been reported to increase milk fat concentration with a negative influence on milk protein concentration (Miettinen & Setälä, 1993; Nir Markusfeld, 2003). In addition, under-feeding of dairy cows, particularly in early lactation, compromises milk production and processing characteristics (Downey & Doyle, 2007). Dillon *et al*. (1997) reported that feeding concentrates (2–4 kg DM/d) to pasture-fed cows during early lactation increases DMI, milk production and may also improve the processing characteristics of the milk compared with offering pasture only. Similarly, Dillon *et al*. (2002) reported that increasing total DMI in early lactation cows can improve the renneting properties of the milk.

The objective of this experiment was to investigate the effect of feeding a pasture/pasture silage-based diet compared with a TMR on milk production, composition and selected processability parameters in the initial weeks post-parturition. It was hypothesised that early lactation milk composition could be altered by feeding strategy, with a PBS having benefits on milk composition and fatty acid profile, while a TMR system may improve milk processability through reduced dietary protein intake.

Materials and methods

Cows, treatments and experimental design

Twenty dairy cows (*Bos taurus* strain Holstein Friesian; Linnaeus, 1758) were selected from the spring-calving dairy herd at UCD Lyons Research Farm, Naas, Co. Kildare, Ireland (53° 17′56″ N, 6° 32′ 18″ W). After calving (from 21 January to 16 March), cows (n = 10, 3 primiparous and 7 multiparous) were blocked on calving date (8 February; ±10.5 d) and balanced for parity (1.0 ± 0.8 lactation), body condition score (BCS; 3.2 ± 0.22) and predicted transmitting ability (PTA) for milk yield (44.8 ± 20.5 kg). Primiparous cows were also balanced for live weight (LWT; 605 ± 13.5 kg). From the date of calving, the experiment ran for a total of 31 d (3-d adaption period, where cows were managed the same, a 7-d dietary acclimatisation period and a 21-d experimental period). From 0 to 3 d post-calving, all cows were offered *ad libitum* pasture silage and 3 kg DM/d of a commercial concentrate through the milking parlour prior to starting their experimental treatments. Cows were then assigned to one of two dietary treatments in a randomised complete block design and began the experimental period at 4 DIM. Treatment 1 was a PBS where cows were offered *ad libitum* grazed pasture plus 3 kg DM/d of concentrate supplementation through the milking parlour. During unsuitable weather conditions (rain/snow), PBS cows were kept inside and offered high-quality pasture silage (81% DM digestibility [DMD]) for *ad libitum* intake plus 5 kg DM concentrate through the milking parlour until grazing conditions improved (Tables 1 and 2). It was planned that cows would be grazing for the majority of the experimental period (21 d) with pasture silage offered only when required; however, due to an unexpected snow storm, each cow grazed pasture for an average of 7.5 d and spent the remaining 13.5 d indoors on pasture silage and concentrates. Concentrates were manufactured by Gain Feeds (Portlaosie, Ireland). Cows were grazed in a single group and were offered fresh allocations of pasture twice daily when grazing. Cows had *ad libitum* access to fresh water.

Treatment 2 was a TMR system, where cows were managed indoors and offered a diet composed of concentrate, maize silage, pasture silage, beet pulp, soya bean meal and straw formulated to meet daily average cow production requirements for 33 kg milk, 4.3% fat and 3.3% protein (Tables 1 and 2). An additional 20% of TMR was offered to ensure cows were not restricted in intake. Diets were fed via a Keenan (Borris, Co. Carlow, Ireland) diet feeder into computerised feeding stations (RIC System, Insentec B.V., Marknesse, The Netherlands). All diet components were mixed in the diet feeder prior to feed out and fed directly into assigned feeders. Cows had *ad libitum* access to the TMR and water with the only restriction being during milking and feeding times.

Sample collection and analysis

All cows offered PBS were grazed together in a strip grazing system to enable fresh allocations of pasture twice daily. Pre-grazing herbage mass was measured daily before cows entered a new paddock using a rising plate meter (diameter 355 mm and 3.2 kg/m^2; Jenquip, Fielding, New Zealand) by walking in a W shape across the field. Cows offered PBS were allocated pasture every 12 h *ad libitum* and pasture allocations were closely monitored by pre-grazing and post-grazing measurements to ensure cows were not restricted. Reels and temporary posts were used to fence paddocks to ensure pasture was allocated correctly for the number of cows grazing each day. Body condition score was determined at the start and end of the trial for each cow, by the same pretrained operator, using a scale of 1–5 with 0.25 increments, according to Edmonson *et al*. (1989).

The quality of pasture offered was determined using the quadrat and shears method as described by Whelan *et al*. (2012). Quadrat samples of pasture were taken daily pre-grazing by taking two quadrat (0.5 × 0.5 m quadrat) cuts per allocation (two morning and two evening) and harvesting to 4 cm. This sample was then dried and pooled weekly for composition analysis. Pasture silage and TMR samples were also taken daily, dried and pooled weekly over the duration of the trial for composition analysis. Weekly samples of each compound feed offered to either PBS or TMR cows were collected, frozen and then pooled, respectively, for the duration of the trial for analysis. The pooled feed samples of

Table 1: Ingredient composition of experimental diets

	Dietary composition	
	PBS	**TMR**
Ingredient composition (g/kg)		
Grazed pasture[1]	*Ad libitum*	—
Grass silage[1]	*Ad libitum*	232.6
Maize silage	—	284.8
Beet pulp	—	68.8
Soya meal	—	46.0
Straw	—	38.0
Concentrate	—	329.8
Concentrate composition (g/kg)		
Barley	225	225
Maize	225	225
Maize distiller	100	100
Sugarbeet pulp pellets	94.6	150
Soya bean meal 47%	136.0	105
Soya hulls	—	87.0
Palm oil (mixer)	5.0	5.0
Palm oil (coater)	10.0	10.0
Sugarcane molasses	45.0	45.0
Mono DCP	45.9	8.0
Calcium carbonate	20.4	8.0
Acidbuff	26.7	10.0
Sodium chloride	26.3	9.0
Magnesium oxide	25.8	7.5
Alltech Lifeforce MinPlex Pack	1.34	0.5
Vitamin E 5% premix	1.34	0.5
Biotin 2% premix	0.35	0.125
Yea-sacc TS	0.67	0.25
Gain cattle premix[2]	10.7	4.0
Formulated composition (%)		
CP	—	15
NDF	—	22
Starch + sugar	—	26

[1] Where cows were offered *ad libitum* grazed pasture or grass silage plus 3 or 5 kg DM concentrate, respectively, dependent on weather conditions.

[2] Gain cattle premix consisted of the following: TMR concentrate: 1.19 g calcium, 0.5 g phosphorus, 0.4 g sodium, 0.88 g potassium, 0.75 g chlorine, 0.66 g magnesium, 0.06 g copper, 0.0008 g selenium, vitamin A 6,400 IU, vitamin D 1,600 IU, vitamin E 33 IU; Grass concentrate: 3.20 g calcium, 1.33 g phosphorus, 1.07 g sodium, 0.83 g potassium, 1.79 g chlorine, 1.60 g magnesium, 0.130 g copper, 0.002 g selenium, vitamin A 17,072 IU, vitamin D 4,268 IU, vitamin E 88.34 IU.

CP = crude protein; DCP = monocalcium phosphate; NDF = neutral detergent fibre; PBS = pasture-based system; TMR = total mixed ration.

Table 2: Chemical composition of experimental forages, total mixed ration and concentrate feedstuffs

	Dietary feedstuffs				
	Pasture	**Grass silage**	**TMR**	**Pasture concentrate**	**TMR concentrate**
Chemical composition (g/kg DM)					
Dry matter	203	311	417	871	881
Crude protein	243	143	158	150	148
Ash	82	102	88	184	99
NDF	476	470	304	144	207
ADF	206	306	186	65	113
WSC	110	63	—	—	—
Starch	—	—	267	172	274
Ether extract	25	11	17	17	17
Gross energy (MJ/kg)	17	16	16	15	16

ADF = acid detergent fibre; NDF = neutral detergent fibre; TMR = total mixed ration; WSC = water-soluble carbohydrates.

pasture, pasture silage, TMR and both concentrates were analysed for their fatty acid profile (Table 3).

The pasture, pasture silage, TMR and concentrate samples were dried in a forced air oven at 55°C and were ground in a hammer mill fitted with a 1-mm screen (Lab Mill; Christy Turner, Suffolk, UK). The DM content of feed samples was determined by drying at 105°C overnight (16 h minimum) (AOAC International, 2005c, 960.15). The nitrogen content of the samples was determined by combustion (FP 528 Analyzer, Leco Corp, St. Joseph, MI, USA; AOAC International, 2005b, 990.03). Gross energy was determined by bomb calorimetry (Parr 1281 bomb calorimeter, Parr Instrument Company, Moline, IL, USA) and ether extract content was determined using Soxtex instruments (Tecator, Hoganas, Sweden) and light petroleum ether. The ash content was determined following combustion in a muffle furnace (Nabertherm GMBH, Lilienthal, Germany) at 550°C for 5.5 h (AOAC International, 2005a, 942.05). Neutral detergent fibre and acid detergent fibre (ADF) were determined using the method of Van Soest *et al*. (1991) adapted for use in the Ankom™ 220 Fibre Analyser (Ankom™ Technology, Macedon, NY, USA). The concentration of water-soluble carbohydrates (WSC) was determined by the phenol–sulphuric acid method which involved the extraction of the soluble carbohydrates from herbage in water (Dubois *et al*., 1956). The fatty acid profile (BS EN ISO 5509:2001) of feed samples was analysed by gas chromatography in a commercial laboratory (ALS Carrigeen Business Park, Clonmel, Co. Tipperary, Ireland). The chemical composition of experimental feedstuffs is reported in Table 2.

Cows were milked twice daily at 0700 h and 1500 h. Milk sampling began when cows were 10 DIM (at the start of the experimental period) and continued weekly for 21 d (17, 24, 31 DIM). Samples were collected as close to 10, 17, 24 and 31 DIM (±1 d) as possible, with milk sampling carried out four times weekly (Mondays, Wednesdays, Fridays and Saturdays). Milk yield was measured, and milk samples collected from individual cows using the Weighall milk metering and sampling system (Dairymaster, Causeway, Kerry, Ireland). On these days, milk samples from individual cows were collected from one successive morning and evening milking and pooled on a per cow basis according to milk yield. The milk samples were sent for analysis of fat, protein, casein, lactose, somatic cell count (SCC), milk urea nitrogen (MUN) and basic milk fatty acids (total monounsaturated [MUFA], total polyunsaturated [PUFA], total saturated [SFA], total unsaturated [UnSFA], palmitic, stearic and oleic acid) at a commercial milk laboratory (National Milk Laboratories Ltd, Wolverhampton, UK) using mid-infrared (MIR) spectrometry (MilkoScan FT6000, FOSS, 2005; Soyeurt *et al*., 2006). A preservative tablet (Broad Spectrum Microtabs® II, D&F Control Inc., Norwood, MA, USA) was added to the samples to prevent spoilage. The full milk fatty acid profile (39 fatty acids) was analysed from milk samples collected on day 31 by gas chromatography in a commercial laboratory using a variation of the Bligh & Dyer (1959) method for total lipid extraction and purification (Agri-Food and Biosciences Institute, Belfast, UK). These samples were collected, frozen and upon trial completion, were sent to the lab for analysis.

Milk samples were analysed immediately after morning and evening collection for pH (Phoenix Instrument EC-25 pH/Conductivity Portable Meter, Heinkelstr 4 D-30827, Garbsen, Germany) and averaged per day. Fresh weekly milk samples from individual cows (10, 17, 24, 31 DIM) that were stored in the fridge overnight were analysed the day after collection for rennet coagulation time (RCT) and ethanol stability (ES). Milk RCT was determined by modification of the method by

Table 3: Fatty acid profile of experimental forages, total mixed ration and concentrate feedstuffs

	Dietary feedstuffs			
	Pasture	**Grass silage**	**Pasture conc.**[1]	**TMR conc.**[2]
Fatty acids (g/100 g feed)				
Total fat	2.4	2.5	1.1	1.3
Saturated	0.55	0.62	0.5	0.58
Monounsaturated	0.17	0.18	0.4	0.47
Polyunsaturated	1.58	1.59	0.15	0.2
Omega 3 (mg/100 g)	1275	1240	44	46
Fatty acid profile (g/100 g fat)				
Caproic acid (C6:0)	0.01	<0.01	2.24	2.26
Caprylic acid (C8:0)	0.01	<0.01	0.5	0.49
Capric acid (C10:0)	0.07	0.46	0.43	0.47
Lauric acid (C12:0)	1.29	0.13	1.26	0.98
Myristic acid (C14:0)	0.81	0.56	0.7	0.6
Myristoleic acid (C14:1)	1.13	1.14	0.34	0.39
Pentadecanoic acid (C15:0)	0.44	0.07	1.51	1.88
Pentadecenoic acid (C15:1)	1.56	1.66	0.01	0.01
Palmitic acid (C16:0)	16.13	19.88	33.04	31.59
Palmitoleic acid (C16:1)	1.28	1.13	0.11	0.13
Heptadecanoic acid (C17:0)	0.12	0.07	0.07	0.09
Heptadecenoic acid (C17:1)	0.68	0.23	0.04	0.03
Stearic acid (C18:0)	1.45	1.09	3.55	3.69
Oleic acid (C18:1)	1.91	1.94	25.58	25.39
Linoleic acid (C18:2)	11.87	12.92	9.05	10.81
Linolenic acid (omega 3 C18:3)	52.09	49.19	0.52	0.67
Linolenic acid (omega 6 C18:3)	0.08	0.01	0.01	0.01
Octadecatetraenoic acid (C18:4)	0.17	0.11	0.28	0.3
Arachidic acid (C20:0)	0.29	0.45	0.66	0.77
Gadoleic acid (C20:1)	0.08	0.07	4.54	4.99
Eicosadienoic acid (C20:2)	0.08	0.28	0.01	0.06
Eicosatrienoic acid (omega 3 C20:3)	0.09	0.1	0.01	0.01
Eicosatrienoic acid (omega 6 C20:3)	0.08	0.1	0.08	0.05
Eicosatetraenoic acid (omega 3 C20:4)	0.01	0.09	0.28	0.31
Arachidonic acid (omega 6 C20:4)	0.01	0.01	0.01	0.01
Eicosapentaenoic acid (C20:5)	0.07	0.01	0.37	0.35
Behenic acid (C22:0)	0.91	0.98	0.78	0.8
Cetoleic acid (C22:1)	0.45	1	6.14	5.31
Docosatetraenoic acid (C22.4)	0.43	0.7	0.5	0.59
Clupanodonic acid (C22.5)	0.46	<0.01	0.15	0.13
Docosahexaenoic acid (C22.6)	0.25	0.09	2.37	1.79
Lignoceric acid (C24:0)	1.34	1.15	0.53	0.67

[1] Concentrate offered to cows on pasture-based system.
[2] Concentrate included in the TMR diet.
TMR = total mixed ration.

Berridge (1952). Five millilitres of rennet was diluted to 100 mL with distilled water to give a 1/20 rennet dilution. For each milk sample, 5 mL was measured into a test tube and placed in a water bath to allow a 5-min equilibrium time to reach 30°C. Once the samples had reached 30°C, 0.5 mL of the rennet dilution was added, and the timer was started simultaneously. The sample was slowly inverted twice, attached to a rotating holder and immersed in water at a 30° angle with rotation set to maximum speed (4 rpm). The length of time taken for milk to coagulate was recorded. The ES of milk was determined by the method reported by Guo *et al*. (1998). Briefly, equal volumes of the milk were mixed with an ethanol solution (ranging in concentration from 63% to 76%, v/v) at room temperature. The ES of milk was determined at the maximum concentration of ethanol solution that did not cause milk coagulation. Additionally, ionic calcium was measured weekly from a subsample of cows from each treatment (n = 4) over the experimental period. The ionic calcium of milk was measured with a calcium-ion selective electrode (ISE 25 Ca; Radiometer Analytical, Mendes, France) and a reference electrode ("Red Rod" REF 251; Radiometer Analytical) attached to a pH meter as described by McIntyre *et al*. (2016).

Statistical analysis

Data were checked for adherence to the normal distribution and homogeneity of variance using histograms and formal statistical tests as part of the univariate procedure of SAS (9.3 2012). The natural logarithm transformation of milk SCC was used to normalise the distribution. The transformed data were used to calculate *P* values. However, the corresponding least squares means and standard errors of the non-transformed data are presented in the results for clarity (Al Ibrahim *et al*., 2010). Analysis of data was conducted using Proc Mixed of SAS (2012). The model included tests for the fixed effects of treatment, day, treatment × day and parity. Repeated measure (day) and random effect (cow) were also included in the model. With regard to the full milk fatty acid profile, BCS start and BCS end, as these were only analysed and measured at one timepoint, the model included tests for the fixed effects of treatment and parity. Random effect (cow) was also included in the model. Statistical significance was assumed at a value of $P < 0.05$ and a tendency toward significance assumed at a value of $P > 0.05$ but <0.10.

Results

In this experiment, there were minimal treatment × day interactions and therefore the results and discussion of this paper will focus on treatment effects. Average pasture pre-grazing herbage mass was 1,134 kg DM/ha and the post-grazing herbage mass was 152 kg DM/ha (post-grazing height of 3.9 cm) for cows offered PBS. The effect of feeding strategy on milk production and milk composition, averaged over the 21-d experimental period, is presented in Table 4.

Cows offered PBS tended to have a lower ($P = 0.09$) milk yield than cows offered TMR. Similarly, cows offered PBS tended to have lower milk lactose yield than TMR cows ($P = 0.08$). However, milk fat yield, milk protein yield, milk fat plus protein yield and milk casein yield were not significantly different between treatments ($P > 0.1$). Cows offered PBS had a greater MUN content compared to TMR ($P < 0.001$). However, milk fat concentration, milk protein concentration, milk casein concentration, milk casein as a % of total protein, milk lactose concentration and SCC were not significantly different between treatments ($P > 0.1$).

Milk from cows offered PBS (Table 4) had a greater ($P < 0.001$) proportion of fat as MUFA, PUFA and lower ($P < 0.001$) SFAs compared with cows offered TMR.

The effect of feeding strategy on milk processability parameters is also presented in Table 4. Average milk pH, RCT, ES (Figures 1 and 2) and ionic calcium were not significantly different between treatments ($P > 0.1$).

The full fatty acid profile was analysed from milk samples on day 31 (Table 5). For individual SFA, milk from cows offered PBS had lower ($P < 0.01$) concentrations of myristic (C14:0), palmitic (C16:0), arachidic (C20:0), behenic (C22:0), tricosanoic (C23:0) and lignoceric acid (C24:0) compared with milk from cows offered TMR. For MUFA and PUFA, cows offered PBS produced milk with greater ($P < 0.02$) oleic (C18:1 *cis 9*), vaccenic (C18:1 *trans 11*), α-linolenic acid (C18:3, 9, 12, 15) and conjugated linoleic acid (CLA; *cis 9*, *trans 11*) content compared to cows offered TMR.

Cows offered PBS produced milk with lower ($P < 0.004$) linoleic (C18:2 *cis 9 trans 12*), eicosadienoic (C20:2 *cis 11, cis 14*), dihomo-γ-linolenic (C20:3 *cis 8, 11, 14*), eruic (C22:1 *cis 13*), nervonic (C24:1 *cis 15*) and docosahexaenoic acid (C22:6 *cis 4, 7, 10, 13, 16, 19*) content, compared with cows offered TMR.

Cow BCS change (Table 6) was not different between treatments from the start to the end of the study ($P = 0.49$).

Discussion

Pasture-based systems are the most common in regions with a temperate climate such as Ireland, as they offer benefits such as lower cost of production (White *et al*., 2002; Dillon *et al*., 2005) and also a "more natural" environment for cows (Verkerk, 2003). In contrast, indoor systems aim to increase farm revenue by increasing milk yield per cow through a greater control of the quality and availability of feed intake (O'Brien *et al*., 2014; O'Brien & Hennessy, 2017). In the current study, milk yield tended to be lower in the PBS treatment.

Table 4: The effect of feeding strategy on milk production, composition and processability

	Treatment			***P* value**	
	PBS	**TMR**	**s.e.m.**	**Treatment**	**Treatment × day**
Milk production (kg/d)					
Milk yield	24.23	26.80	0.999	0.09	0.72
Fat	1.12	1.13	0.061	0.88	0.03
Protein	0.79	0.86	0.031	0.10	0.91
Fat + protein	1.94	1.99	0.089	0.67	0.37
Lactose	1.07	1.19	0.045	0.08	0.59
Casein	0.62	0.67	0.026	0.14	0.97
Milk composition (%)					
Fat	4.45	4.17	0.122	0.13	0.19
Protein	3.23	3.25	0.053	0.79	0.93
Casein	2.55	2.54	0.053	0.88	0.51
Casein as % of total protein	78	78	0.427	0.52	0.16
Lactose	4.40	4.44	0.026	0.32	0.12
Urea (MUN; g/100 g milk)	0.03	0.01	0.001	<0.001	0.08
SCC (cells/mL)[1]	32	55	9.47	0.10	0.57
Milk pH	6.61	6.60	0.019	0.64	0.25
Ionic calcium (mmol)	1.59	1.41	0.114	0.28	0.04
RCT (min)	3.43	4.25	0.453	0.22	0.57
Ethanol stability (%)	78	78	0.516	0.52	0.03
Milk fatty acids[2] (g/100 g fat)					
Monounsaturated fatty acids	31.19	26.67	0.473	<0.001	0.78
Polyunsaturated fatty acids	4.68	3.42	0.114	<0.001	0.37
Saturated fatty acids	56.94	62.69	0.706	<0.001	0.52
Unsaturated fatty acids	37.03	31.28	0.611	<0.001	0.31

[1] For SCC the natural logarithm transformation data were used to calculate *P* values. The corresponding least squares means and standard errors of the non-transformed data are presented in results for clarity.
[2] Milk fatty acids measured weekly by mid-infrared (MIR).
MUN = milk urea nitrogen; PBS = pasture-based system; RCT = rennet coagulation time; SCC = somatic cell count; TMR = total mixed ration.

Other studies (White *et al*., 2001; O'Callaghan *et al*., 2016a,b) have reported that cows offered a pasture-based diet had lower milk yields compared with TMR feeding, which is most probably due to the greater DMI and energy intake of cows fed a TMR (Kolver & Muller, 1998), and to a lesser extent the different nutrient profiles, particularly the higher starch content of a TMR compared with pasture and pasture silage. Feeding high-starch feeds increases glucose production, a precursor for milk lactose which regulates milk yield (Kolver & Muller, 1998; Shamay *et al*., 2003; Aschenbach *et al*., 2010).

In the current study, when PBS was compared to TMR, milk protein concentration was not altered by feeding strategy. Similarly, milk casein, as a % of total protein, was 78% from cows in both feeding strategies, approaching the optimum value for processing (Downey & Doyle, 2007). Similar values of casein as a % of total protein have been reported for mid-lactation milk when it reaches a maximum of 79%–80% in summer in seasonal systems (O'Brien *et al*., 1996; Downey & Doyle, 2007). However, the casein, as a % of total protein value from the current experiment, is greater than that reported by Dillon *et al*. (1997), who offered early lactation dairy cows pasture plus 2–4 kg DM concentrate supplementation. This difference may simply be as a result of the 21-yr gap between the two studies as in 2001 the Economic Breeding Index was introduced and, since then, there has been a greater focus on selection for milk fat and protein concentration (Berry *et al*.,

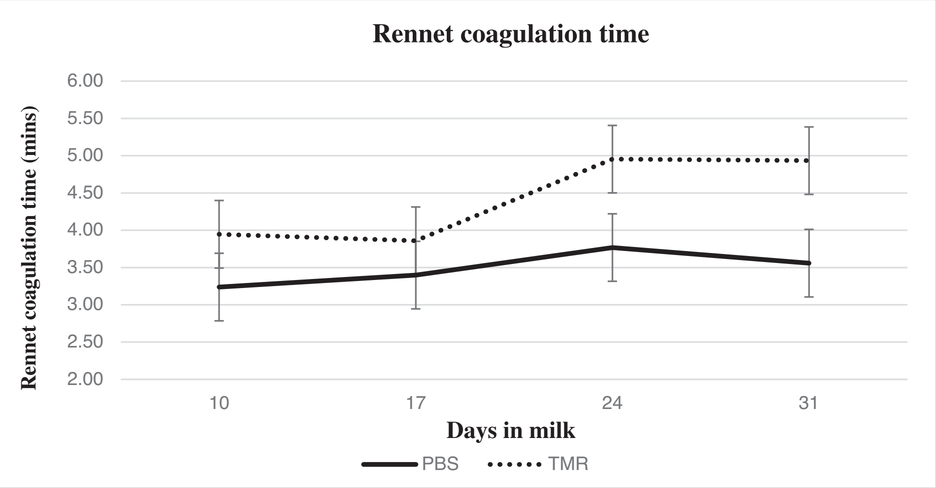

Figure 1. The effect of feeding strategy on the rennet coagulation time of milk over the experimental period in pasture-based system (PBS) where cows (n = 10) were offered *ad libitum* grazed pasture plus 3 kg DM concentrate or grass silage plus 5 kg DM concentration if weather conditions did not allow grazing. The total mixed ration (TMR) treatments were cows (n = 10) offered a mixed ration composed of 6.95 kg DM concentrate, plus maize silage, grass silage, beet pulp, soya bean meal and straw formulated to meet daily cow production requirements for 33 kg/milk, 4.3% fat and 3.3% protein.

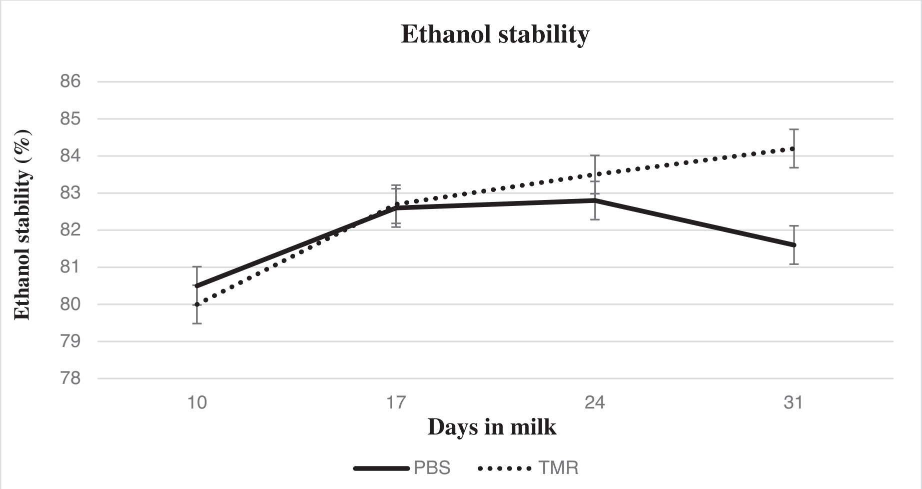

Figure 2. The effect of feeding strategy on the ethanol stability of milk over the experimental period in pasture-based system (PBS) where cows (n = 10) were offered *ad libitum* grazed pasture plus 3 kg DM concentrate or grass silage plus 5 kg DM concentration if weather conditions did not allow grazing. The total mixed ration (TMR) treatments were cows (n = 10) offered a mixed ration composed of 6.95 kg DM concentrate, plus maize silage, grass silage, beet pulp, soya bean meal and straw formulated to meet daily cow production requirements for 33 kg/milk, 4.3% fat and 3.3% protein.

2007; Coleman *et al*., 2010). With the index focusing on milk solids (fat + protein) and with the protein concentration of milk being made up of approximately 80% caseins (Jenkins and McGuire, 2006), this may have contributed to the greater casein, as a % of total protein, reported in the current study compared to the pre-2001 study by Dillon *et al*. (1997).

It was hypothesised in this experiment that early lactation milk composition could be altered by feeding strategy, with PBS having benefits on milk composition and fatty acid profile, while TMR may improve milk processability through reduced dietary protein intake. However, due to adverse weather conditions in spring 2018, cows only grazed pasture and consumed 3 kg

Table 5: The effect of feeding strategy on milk fatty acid profile[1]

	Treatment			
	PBS	**TMR**	**s.e.m.**	***P* value**
Milk fatty acids (g/100 g milk fat)				
SFA				
Butyric acid (C4:0)	2.42	2.51	0.064	0.33
Caproic acid (C6:0)	1.68	1.84	0.062	0.08
Caprylic acid (C8:0)	1.00	1.14	0.055	0.10
Capric acid (C10:0)	2.35	2.72	0.166	0.14
Undecanoic acid (C11:0)	0.06	0.06	0.008	0.78
Lauric acid (C12:0)	2.68	3.17	0.194	0.10
Tridecanoic acid (C13:0)	0.11	0.12	0.011	0.55
Myristic acid (C14:0)	9.36	11.00	0.396	0.01
Pentadecanoic acid (C15:0)	1.07	1.05	0.055	0.76
Palmitic acid (C16:0)	28.02	31.21	0.486	<0.001
Heptadecanoic acid (C17:0)	0.77	0.79	0.0009	0.27
Stearic acid (C18:0)	11.75	12.15	0.315	0.38
Arachidic acid (C20:0)	0.15	0.19	0.003	<0.001
Henicosanoic acid (C21:0)	0.06	0.06	0.002	0.64
Behenic acid (C22:0)	0.07	0.09	0.003	<0.0001
Tricosanoic acid (C23:0)	0.02	0.03	0.001	0.03
Lignoceric acid (C24:0)	0.04	0.05	0.002	0.004
MUFA				
Myristoleic acid (C14:1)	0.59	0.66	0.031	0.11
Palmitoleic acid (C16:1)	2.15	2.14	0.100	1.0
Oleic acid (C18:1 cis 9)	26.12	22.39	1.009	0.02
Elaidic acid (C18:1 trans 9)	0.21	0.20	0.006	0.58
Vaccenic acid (C18:1 trans 11)	3.89	1.57	0.250	<0.0001
Octadecenoic acid (C18:1 cis 11)	0.68	0.75	0.032	0.12
PUFA				
Linoelaidic acid (C18:2 trans)	0.01	0.01	0.001	0.94
Linoleic acid (C18:2 c9 t12)	1.59	2.08	0.067	<0.0001
γ-Linolenic acid (C18:3 c6, 9, 12)	0.02	0.02	0.002	0.62
Paullinic acid (C20:1 c11)	0.09	0.10	0.005	0.07
α-Linolenic acid (C18:3 9,12,15)	0.97	0.60	0.041	<0.001
CLA (c9, t11)	1.42	0.66	0.087	<0.0001
CLA (t10, c12)	0.02	0.02	0.004	0.61
Eicosadienoic acid (C20:2 c11 c14)	0.01	0.02	0.002	0.0003
Dihomo-γ-linolenic acid (C20:3c8,11, 14)	0.04	0.06	0.003	0.004
Erucic acid (C22:1 c13)	0.101	0.188	0.007	<0.001
Eicosatrienoic acid (C20:3 c11,14,17)	0.02	0.02	0.001	0.56
Arachidonic acid (C20:4 c5,8,11,14)	0.09	0.09	0.004	0.46
Eicosapentaenoic acid (C20:5 c5,8,11,14,17)	0.09	0.08	0.004	0.112

Table 5 (continued)

	Treatment			
	PBS	**TMR**	**s.e.m.**	***P* value**
Nervonic acid (C24:1c15)	0.02	0.03	0.001	<0.001
Docosapentaenoic acid (C22:5 cn3 7, 10, 13, 16,19)	0.12	0.12	0.004	0.61
Docosahexaenoic acid (C22:6 c4,7,10,13,16,19)	0.020	0.024	0.001	0.004
Omega 3 (N3)	0.93	1.13	0.077	0.08
Omega 6 (N6)	1.98	2.03	0.100	0.71
Omega 7 (N7)	3.11	2.70	0.149	0.07
Omega 9 (N9)	24.13	27.73	1.305	0.75
Total omegas	30.14	30.60	2.021	0.82

[1]The full milk fatty acid profile was analysed from samples collected on day 31 (31 d in milk [DIM]).
PBS = pasture-based system; TMR = total mixed ration; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFA = polyunsaturated fatty acids.

Table 6: The effect of feeding strategy on cow body condition score (BCS)

	Treatment			
	PBS	**TMR**	**s.e.m.**	***P* value**
Start BCS[1]	3.03	2.93	0.08238	0.43
End BCS	2.85	2.76	0.04097	0.16
BCS change	0.17	0.08	0.09476	0.49

[1]BCS was measured according to the method described by Edmonson *et al*. (1989) using a scale of 1–5 with 0.25 increments.
PBS = pasture-based system; TMR = total mixed ration.

DM concentrate for an average of 7.5 d and consumed pasture silage and 5 kg DM concentrate for 13.5 d, thereby reducing the protein intake of cows offered PBS. Despite this, cows offered PBS had a greater average MUN content compared with TMR, reflecting the greater protein content of pasture (24.3% crude protein [CP]/kg DM) when grazing. In addition, the PBS treatment likely supplied greater rumen degradable protein (RDP) compared to the TMR, which was formulated to meet the protein requirements of the cow. The additional RDP in pasture and pasture silage was likely converted to urea and excreted via milk (McDonald *et al*., 2001). Reid *et al*. (2015) reported that high levels of dietary CP, such as that found in high-quality pasture, can affect the heat stability and the suitability of milk for processing. However, in line with the PBS implemented in the present experiment, where pasture silage and concentrate were fed for 13.5 d out of 21 d, there were similar milk protein and casein concentrations. Thus, the milk from both feeding strategies was heat stable, as indicated by the high ES values, which were greater than the standard value of 68%–72% (Guo *et al*., 1998). The greater the ES value, the greater the heat stability of the milk as identified by its ability to withstand exposure to a greater level of ethanol before the milk coagulates.

For milk to be efficiently processed into dairy products such as cheese, short to medium RCTs (3–5 min) are desirable, as they are associated with a higher yield of cheese (Formaggioni *et al*., 2008; Pretto *et al*., 2013). Dillon *et al*. (1997) reported RCT values within this range (4–5 min) for milk from cows fed pasture plus 2 or 4 kg DM concentrate in the first 5 wk of lactation. Both RCT and ES are influenced largely by milk pH, which typically ranges from 6.53 in January to 6.81 in November, for milk from spring-calving cows that are pasture-fed (Phelan *et al*., 1982). Issues with milk processability are most pronounced when cows are underfed (in a grazing scenario this could be due to inadequate pasture supply or difficult grazing conditions) and diets do not meet the nutritional requirements for production (O'Brien *et al*., 1996). The casein content, RCT, ES, ionic calcium and pH of the milk samples in the present study indicate milk was of a suitable composition for processing, despite all cows being in the natural state of NEB in early lactation. Dillon *et al*. (1997) offered early lactation dairy cows a pasture-only diet and observed a lower total DMI, milk yield, lactose concentration and greater free fatty acids compared to cows offered pasture plus 2 or 4 kg supplementary concentrate. For dairy cows in early lactation in a seasonal system, where pasture supply may be inadequate or grazing conditions may be difficult, concentrate supplementation could be offered to increase DMI and milk production, and to improve milk processing qualities (Dillon *et al*., 1997).

Milk fatty acids are derived from the diet, rumen microorganisms, mobilisation of body tissue and *de novo* synthesis in the mammary gland (Palmquist & Jenkins, 1980), and are consequently influenced by both the nutritional and metabolic status of the cow (O' Callaghan *et al.*, 2016a,b; Dórea *et al.*, 2017). As cows in the current study were in the initial stages of lactation and therefore in NEB, this would affect the milk fatty acid profiles (Jorjong *et al.*, 2015; Dórea *et al.*, 2017). The fat content of milk in this study was not significantly different (PBS: 4.45% vs. TMR: 4.17%) between treatments, which may be due to insufficient statistical power for that particular parameter. O'Callaghan *et al.* (2016a,b) reported milk fat contents of 4.48% and 4.36% for pasture and TMR feeding, respectively.

There is a wealth of research supporting the concept that feeding strategy affects the fatty acid profile of milk throughout lactation (White *et al.*, 2001; Couvreur *et al.*, 2006; O'Callaghan *et al.*, 2016a). Cows consuming large quantities of grazed pasture produce milk with greater proportions of UnSFA and CLA compared to diets comprising concentrates and conserved forages (Kelly *et al.*, 1998; O'Callaghan *et al.*, 2016a). Pasture contains high levels of linolenic acid, which through the process of rumen biohydrogenation, is converted to vaccenic acid, a precursor for endogenous synthesis of *cis-9, trans-11* CLA, via Δ^9-desaturase in the mammary gland (Harfoot & Hazlewood, 1988; Griinari *et al.*, 2000; Kay *et al.*, 2004, 2005; Harstad *et al.*, 2010). This process produces the majority of milk CLA, approximately 90% in pasture-fed cows. The remaining CLA is produced in the rumen from the biohydrogenation of linoleic acid. There are other CLA isomers apart from cis-9 trans-11 CLA, and the CLA isomer produced is dependent on the rumen environment (Griinari & Bauman, 1999). In agreement with Baltušnikienơ *et al.* (2008), cows offered PBS in the current study had greater total UnSFA, including greater PUFA, in milk compared with cows offered TMR. Multiple studies have reported that pasture-fed cows in both early and mid-lactation produce milk with a greater concentration of *cis-9 trans-11* CLA than cows offered TMR (Kelly *et al.*, 1998; White *et al.*, 2001; Couvreur *et al.*, 2006; O'Callaghan *et al.*, 2016a). This is also reflected in the current study, where milk from PBS cows contained 1.42 g *cis-9 trans-11* CLA/100 g milk fat, compared with 0.66 g *cis-9 trans-11* CLA/100 g milk fat in milk from cows offered TMR. As previously reported, increasing *cis-9 trans-11* CLA in milk may offer human health benefits, as *cis-9 trans-11* CLA has antiobesity, antidiabetic and anticarcinogenic properties (Kelly *et al.*, 1998; Corl *et al.*, 2003; Koba & Yanagita, 2014). However, it is important to note that excess PUFA in the diet of dairy cows, in conjunction with poor rumen function and low rumen pH, can cause milk fat depression due to incomplete biohydrogenation and the subsequent production of trans-10, cis-12 CLA, which inhibits the production of milk fat (Peterson *et al.*, 2003; Rico *et al.*, 2015).

Significant research exists on the potential negative human health aspects of milk fatty acids with a particular focus on the link between high consumption of SFA and cardiac issues (Pfeuffer & Schrezenmeir, 2000; Briggs *et al.*, 2017). In the current study, cows offered PBS produced milk with lower total SFA compared with cows offered TMR. Baltušnikienơ *et al.* (2008) and O'Callaghan *et al.* (2016a) also reported that pasture-derived milk had lower, although not significantly, concentrations of SFA compared to milk from TMR-fed cows. Reducing SFA in milk may be beneficial in preventing cardiovascular disease (Pfeuffer & Schrezenmeir, 2000), although research findings are variable (Siri-Tarino *et al.*, 2015). In addition to improving the health properties of milk and dairy products, altering the fatty acid profile to contain less SFAs improves the properties (e.g., texture and softness) of butter (O'Callaghan *et al.*, 2016b).

Conclusion

Milk produced in the initial stages of lactation from cows fed TMR or pasture/pasture silage (grazed pasture for 7.5 d and pasture silage indoors for 13.5 d) and concentrate diet (PBS) was of good composition and suitable for processing. Although feeding strategy had no overall impact on the processability parameters measured (pH, casein concentration or RCT), cows offered the PBS treatment produced milk with an RCT suitable for milk processing, despite having a greater MUN content. In the first 5 wk of lactation, cows offered PBS produced less milk with a lower SFA and higher content of *cis-9 trans-11* CLA, which may offer human health benefits.

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Conflicts of interest

The authors declare that they do not have conflicts of interest.

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