The effects of cereal type and α -tocopherol level on milk production, milk composition, rumen fermentation, and nitrogen excretion of spring-calving dairy cows in late lactation

Z. C. McKay,¹ F. J. Mulligan,² M. B. Lynch,¹ G. Rajauria,¹ C. Miller,³ and K. M. Pierce^{1*}

¹School of Agriculture and Food Science, University College Dublin, Lyons Research Farm, Lyons Estate, Celbridge, Naas, Co. Kildare, Ireland W23 ENY2

²School of Veterinary Medicine, University College Dublin, Belfield, Dublin 4, Ireland D04 W6F6

³Gain Feeds, Glanbia Plc, Bridge Street, Portlaoise, Ireland R32 ND7A

ABSTRACT

Grass-based production systems use concentrate supplementation primarily when pasture quality and availability have declined. Barley is a common concentrate ingredient; however, oat grain grows well in Ireland, is a source of lipids and fiber, and may provide an alternative to barley. The antioxidant α -tocopherol (α -TOC) plays a role in cell membrane structure, and it has the potential to improve tight junction structures of the mammary gland that deteriorate in late lactation. The objective of this research was to investigate the effect of cereal type and α -TOC level on milk yield, milk composition, rumen fermentation, and N excretion in late-lactation dairy cows at pasture and when housed indoors on grass silage. Forty-eight Holstein Friesian dairy cows were blocked on days in milk (+185 d in milk) and balanced for parity, pre-experimental milk yield, milk composition, and body condition score and assigned to 1 of 4 dietary treatments in a randomized complete block design ($n = 12$). The dietary treatments were control (C) base diet; base diet + barley-based concentrate + low α -TOC (350 IU/kg) (B); base diet + oat-based concentrate + low α -TOC (350 IU/kg) (O); and base diet + oat-based concentrate + high α -TOC (1,050 IU/kg) (O+T). Following a 14-d acclimation period, diets were offered for a 49-d experimental period at pasture (P1) and a 21-d experimental period indoors (P2). The base diet was grazed grass in P1 and grass silage in P2. In P2, cows on C also received 2.65 kg (dry matter) of a standard concentrate. In P1, supplementation increased milk and milk solids yield (B: 20.7 kg/d, 1.74 kg/d; O: 20.6 kg/d, 1.81 kg/d; O+T: 20.5

kg/d, 1.77 kg/d, respectively) compared with C (17.8 kg/d, 1.60 kg/d). Cows offered B had a lower milk fat (4.60%) concentration than C (5.00%) and O (4.90%). In P2, cereal type and α -TOC level did not alter milk production. In conclusion, concentrate supplementation increased milk and milk solids yield and cows offered O had a higher milk fat concentration than cows offered B. Increasing the level of α -TOC had no major effect on production parameters measured in P1 or in P2.

Key words: dairy cow, concentrate supplementation, late lactation, oat grain, α -tocopherol

INTRODUCTION

Milk production in Ireland is produced primarily from a low-cost pasture-based system aimed at maximizing the amount of grazed grass in the cow's diet (McEvoy et al., 2008; Hanrahan et al., 2017). However, because grass growth is seasonal, grass quality and availability can be poor in the autumn (McEvoy et al., 2008), which can reduce milk production and negatively alter milk composition (Burke et al., 2008). Additionally, following the abolition of the European Union's milk quota, cow numbers in Ireland have increased (CSO, 2017) and cows are milking later into lactation (CSO, 2015), exacerbating the issues that arise with late-lactation milk production and quality (Phelan et al., 1982; Downey and Doyle, 2007). Subsequently, interest has increased in supplementation at pasture in the autumn as a means of supporting milk production and negating issues of milk quality at that time.

Concentrate supplementation can be offered at pasture in autumn to increase milk production, improve milk composition, and increase lactation length (Kellaway and Porta, 1993; Kennedy et al., 2005) as well as improve nitrogen utilization efficiency compared with pasture-only diets (Reid et al., 2015). However, research to date has focused on barley (Reid et al., 2015), which is a common high-energy cereal grown in

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*Corresponding author: karina.pierce@ucd.ie

Ireland (Theurer, 1986). Corn grain is also a common energy source included in concentrate feeds in Ireland; however, McKay et al. (2017) observed increased milk and milk solids yield from late-lactation grazing dairy cows offered a barley-based concentrate compared with a corn grain-based concentrate. Oat grain is a cereal crop that is suited to growing in Ireland's temperate climate (Hackett, 2018). Oat grain is higher in lipids and fiber, which makes it a potential complementary feed for dairy cows offered autumn pasture (Ekern et al., 2003; Hackett, 2018) to improve milk yield and milk composition, particularly milk fat concentration, which is known to decline with increasing cereal-based concentrate supplementation (O'Brien et al., 1996; Bargo et al., 2003). Offering an oat-based supplement to dairy cows as a supplement to grass silage-based and complete diets has been found to increase milk yield, milk protein yield (Ekern et al., 2003), and milk fat concentration (Moran, 1986); however, little research has been completed on the use of oats in grazing systems.

In late lactation, milk yield naturally begins to decline, with a reduction in secretory epithelial cell numbers due to apoptotic cell death in the mammary gland (Wilde and Knight, 1989; Stefanon et al., 2002). During this process, tight junctions between epithelial cells start to become leaky, which allows the passage of water, small molecules, and ions between milk and interstitial fluid (Nguyen and Neville, 1998; Matter and Balda, 2003). Consequences include reduced milk yield, milk lactose, and milk casein concentration and an increase in milk SCC of cows in late lactation (Stelwagen et al., 1997; Politis et al., 2004). One of the main functions of α -tocopherol (α -TOC) centers on its antioxidant properties, but it also has a role in cell membrane structure (Charmley et al., 1993). Cell membranes are composed of lipid bilayers, particularly PUFA, and it has been reported that α -TOC protects the PUFA in cell membranes from reactive oxygen species (Putnam and Comben, 1987; Rice and Kennedy, 1988). Studies have found that α -TOC improved the structure and function of renal and kidney tight junctions in rats and dogs, respectively (Arreola-Mendoza et al., 2009; Fusi et al., 2018), while research carried out in pigs (Monahan et al., 1989) and beef cattle (Liu et al., 1995) revealed that dietary vitamin E supplementation significantly increased the α -TOC concentration in muscles and suggested that α -TOC has a role in protecting cell membranes from oxidation.

The objective of this research was to investigate the effect of cereal type and α -TOC level on milk yield, milk composition, rumen fermentation, and N excretion in late-lactation dairy cows at pasture and when housed indoors on grass silage.

MATERIALS AND METHODS

Cows, Treatments, and Experimental Design

The Animal Research Ethics Committee at University College Dublin (UCD) approved all the procedures described in this experiment. These procedures were conducted under experimental license (AE189821/P106) from the Health Products Regulatory Authority under the European directive 2010/63/EU and S.I. No. 543 of 2012. Each person who carried out procedures on experimental animals during the course of this experiment was licensed to do so by means of individual authorization from the Health Products Regulatory Authority.

Forty-eight dairy cows (*Bos taurus* strain Holstein Friesian) were selected from the spring-calving dairy herd at UCD Lyons Research Farm, Lyons Estate, Celbridge, Naas, Ireland (53°17'56" N, 6°32'18" W). The cows were blocked on DIM and balanced for parity, milk yield, milk composition (fat content, protein content, and fat and protein in kilograms) and BCS. The study was divided into 2 periods. Period 1 (P1) was a 49-d grazing period with cows (212–261 DIM) assigned to 1 of 4 dietary treatments in a randomized complete block design ($n = 12$) with a base diet of grazed grass. The dietary treatments (Table 1) were the control base diet (C); base diet + barley-based concentrate + low α -TOC (350 IU/kg)(B); base diet + oat-based concentrate + low α -TOC (350 IU/kg)(O); and base diet + oat-based concentrate + high α -TOC (1,050 IU/kg) (O+T). The formulated supplemented levels of α -TOC (not including base diet α -TOC) resulted in a total dietary intake of 1,050 IU of α -TOC/d for B and O and a higher level of 3,150 IU of α -TOC/d for O+T. The type of α -TOC offered was all-*rac* α -tocopheryl acetate from DSM Nutritional Products (Heerlen, the Netherlands).

Milk yield, milk composition, BCS, rumen fermentation parameters, and BW measurements were taken before treatment for use as covariates in the statistical model if required. Cows had a 14-d dietary acclimation period before starting P1. Measurements were then taken weekly for 8 wk (September 12 to October 31) for BCS, milk production, milk composition, blood glucose, BW, and rumen health parameters, such as rumen pH, VFA, and NH_3 concentration, and during wk 3 for pasture DMI and N partitioning.

At the end of the grazing season (November 1, 2017), cows were housed and offered a base diet of grass silage (P2) for 21 d. Period 2 allowed for further investigation into the effect of dietary treatment on milk production and composition and rumen fermentation when cows were later in lactation (275–289 DIM) and were

offered a typical grass silage-based diet. During P2, when cows finished grazing, cows remained on the same dietary treatments ($n = 12$) except that cows on C received 2.65 kg DM of a standard concentrate (Table 1) composed of corn and barley with ad libitum grass silage to meet production requirements. Despite being high quality, grass silage alone would not have met the production requirements of the cows. Following a 14-d dietary acclimation period after housing, measurements were taken weekly for 3 wk for BCS, DMI (RIC System, Insentec B.V., Marknesse, the Netherlands), milk production, and milk composition and weekly for 2 wk for blood glucose and rumen fermentation parameters (rumen pH, VFA, and NH_3).

Cows were offered the supplementary concentrate twice daily through the milking parlor (Feedrite automatic system, Dairymaster, Causeway, Ireland) at a rate of 2.65 kg of DM/cow per day (3 kg of fresh weight/cow per day). Concentrates were formulated to be isonitrogenous (16% CP) and were manufactured by Gain Feeds (Portlaoise, Ireland). The ingredient

composition of the concentrates offered is presented in Table 1. Cows were managed in a single group both at pasture and when housed and had ad libitum access to fresh water. When housed, cows had ad libitum access to grass silage through automated feeders (RIC System), which allowed measurement of individual cow intakes.

Data and Sample Collection

Pasture and Feed Collection. All cows were grazed together in a strip grazing system to enable fresh allocation of pasture twice daily (17 kg of DM/d; above 4 cm). The pregrazing herbage mass was measured daily and before cows entered a new paddock using a rising plate meter (diameter 355 mm and 3.2 kg/m²; Jenquip, Feilding, New Zealand) by walking in a W shape across the field. The AgriNet grass software system (Irish Farm Computers Ltd., Kells, Ireland) was used to monitor pasture growth and ensure correct allocation of 17 kg of DM/head per day was achieved. The aver-

Table 1. Ingredient composition (g/kg of DM) of experimental concentrates

Ingredient composition	Experimental concentrate			
	Barley ¹	Oats ²	α -TOC ³	Standard ⁴
Barley	420	—	—	180
Oats	—	420	420	—
Maize	—	—	—	180
Maize distiller	117	117	117	150
Sugarbeet pulp pellets 8 mm	—	—	—	95
Soybean meal 47%	115	115	115	200
Soy hulls	117	117	117	95
Palm kernel expeller	117	117	117	—
Palm oil	4	6	6	10
Soybean oil	—	—	—	5
Sugarcane molasses	50	50	50	45
Mono- and dicalcium phosphate	4	4	4	6
Calcium carbonate	14	14	—	8
Sodium chloride	7	7	7	8
Magnesium oxide	20	20	20	8
Alltech Lifeorce MinPlex Pack ⁵	—	—	—	0.5
Vitamin E premix ⁶	7	7	21	—
Biotin 2% premix	—	—	—	0.4
Gain cattle premix ⁷	8	8	8	10

¹Barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg.

²Oat-based concentrate + 350 IU of α -TOC/kg.

³Oat-based concentrate + 1,050 IU of α -TOC/kg.

⁴Standard concentrate offered to control cows in P2.

⁵Alltech (Lexington, KY)

⁶DSM Rovimix E adsorbate (DL- α -tocopheryl acetate; DSM Nutritional Products, Heerlen, the Netherlands).

⁷Gain cattle premix (Gain Feeds, Glanbia Plc, Portlaoise, Ireland) consisted of the following (all values per kg): Barley: 1.38 g of Ca, 0.51 g of P, 0.31 g of Na, 1.02 g of K, 0.66 g of Cl, 1.20 g of Mg, 0.07 g of Cu, 0.02 g of I, 0.12 g of Mn, 0.001 g of Se, 0.23 g of S, 0.22 g of Zn, 12,000 IU of vitamin A, 3,000 IU of vitamin D. Oats and α -tocopherol: 1.40 g of Ca, 0.51 g of P, 0.31 g of Na, 0.99 g of K, 0.65 g of Cl, 1.22 g of Mg, 0.07 g of Cu, 0.02 g of I, 0.13 g of Mn, 0.001 g of Se, 0.24 g of S, 0.23 g of Zn, 12,000 IU of vitamin A, 3,000 IU of vitamin D. Standard concentrate: 1.02 g of Ca, 0.54 g of P, 0.36 g of Na, 1.11 g of K, 0.69 g of Cl, 0.58 g of Mg, 0.1 g of Cu, 0.3 g of Zn, 16,000 IU of vitamin A, 4,000 IU of vitamin D, 20 IU of vitamin E.

Table 2. Chemical composition (g/kg of DM unless otherwise noted) of experimental feedstuffs offered in periods 1 and 2

Chemical composition	Experimental feedstuff					
	Pasture ¹	Barley ^{1,2,3}	Oats ^{1,2,4}	α -TOC ^{1,2,5}	Grass silage ²	Standard concentrate ²
DM	135	870	876	874	249	846
CP	217	172	169	171	170	199
Ash	93	98	95	105	87	73
NDF	499	314	349	361	427	223
ADF	238	160	187	199	260	109
Ether extract	18	13	12	13	18	17
Water-soluble carbohydrates	139	—	—	—	138	—
Starch	—	211	181	170	—	233
Gross energy (MJ/kg)	17.4	17.1	17.4	17.3	17.9	17.5
α -TOC (IU/kg)	44	259	246	977	31	20

¹Period 1 = 49-d period at pasture.²Period 2 = 21-d period indoors on grass silage.³Barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg.⁴Oat-based concentrate + 350 IU of α -TOC/kg.⁵Oat-based concentrate + 1,050 IU of α -TOC/kg.

age pregrazing herbage mass was 1,646 kg of DM/ha (above 4 cm), with an average pregrazing compressed sward height of 10 cm (above ground level). The average postgrazing mass was 441 kg of DM/ha with an average postgrazing compressed sward height of 5 cm. Grass chemical composition was determined using the quadrat and shears method as described by Whelan et al. (2012a). Pregrazing quadrat samples were collected by taking 2 quadrat (0.5 × 0.5 m quadrat) cuts per allocation (twice per day) and harvesting to 4 cm to determine chemical composition. These samples were pooled weekly for analysis (DM, gross energy, ether extract, ash, and CP), NDF, ADF, and water-soluble carbohydrates (WSC), and the results are shown in Table 2 and Figure 1. Weekly concentrate samples were taken and pooled for the duration of the trial to determine DM and then ground for use in proximate analysis, NDF, ADF, and starch (Table 2). During P2, silage samples were taken daily and pooled weekly for proximate analysis, NDF, ADF, and WSC (Table 2).

Cow Measurements. Cows were milked twice daily at 0700 and 1500 h (a.m. and p.m. milkings, respectively). Milk yield measurement and composite milk sample collection was facilitated using the Weighall milk metering and sampling system (Dairymaster). Milk samples were taken once weekly from successive a.m. and p.m. milkings and pooled on a per-cow basis according to milk yield (Figure 2). Milk samples were sent for analysis of fat, protein, casein, lactose, SCC, and urea to a commercial milk laboratory (National Milk Laboratories Ltd., Wolverhampton, UK).

Cows were weighed twice daily after milking using an electronic scales as they left the parlor through the automatic drafting unit (Dairymaster) and averaged per

day. Body condition score was determined once weekly, by the same pretrained operator, using a scale of 1 to 5 with 0.25 increments according to Edmonson et al. (1989).

Blood samples were collected by jugular venipuncture once weekly following the p.m. milking to coincide with milk sampling, rumen fluid sampling, and BCS. Blood samples for glucose analysis were harvested into 4-mL glucose Vacutainer tubes (368921; BD, Plymouth, UK), which were stored on ice and centrifuged at 2,100 × *g* for 20 min at 4°C for extraction of blood plasma. The blood plasma was drained off and frozen at −20°C pending further analysis.

Rumen fluid samples were harvested by Flora Rumen scoop oral esophageal sampler (Prof-Products, Guelph, ON, Canada) once weekly. Sampling was carried out after the p.m. (1500 h) milking, at 1600 h. Rumen fluid samples were analyzed immediately for pH (Phoenix Instrument EC-25 pH/Conductivity Portable Meter). Samples were strained through 4 layers of cheese cloth; then, a 4-mL aliquot was taken using an automatic pipette, mixed with 1 mL of trichloroacetic acid (500 g/L), cooled on ice, and then stored (−20°C) pending analysis for VFA and NH₃.

Nitrogen Partitioning Study. Nitrogen partitioning was determined during wk 2 to 3 of the study (average 226 DIM). Pasture DMI and N excretion were estimated over a 6-d period. Based on the method of Dove and Mayes (2006), cows were dosed with a paper bolus impregnated with 500 mg of the *n*-alkane *n*-dotriacontane (C32), for a period of 12 d following a.m. and p.m. milkings. From d 6 to 12, samples of the concentrates, pasture, milk, and feces were collected. Daily concentrate samples were collected and pooled for

the 6-d period and stored at -20°C pending proximate analysis. Pasture samples were collected every morning and evening using a quadrat and handheld shears. These samples were immediately dried at 55°C for 48 h. Fecal samples were collected during observation periods as cows naturally defecated and if not, samples were collected per rectum and immediately placed in a forced air oven at 55°C for 72 h or until dry. To determine N partitioning, samples of milk were collected during a.m. and p.m. milkings and pooled according to milk yield. Milk samples were sent for analysis of fat,

protein, casein, lactose, SCC, and urea to a commercial milk laboratory (National Milk Laboratories Ltd.).

Sample Analysis

Feed and Fecal Sample Analysis. Pasture, silage, concentrate, and fecal (Whelan et al., 2012a) 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 samples was determined by drying at 105°C overnight

Figure 1. Changes in autumn pasture quality offered to dairy cows in period 1 (wk 1 = September 12 and wk 8 = October 31). Standard deviations across the 8-wk experimental period were ± 9.5 g/kg of DM, ± 10.7 g/kg of CP, ± 20.2 g/kg of water-soluble carbohydrate, ± 14.7 g/kg of NDF, ± 10.9 g/kg of ADF, and ± 8.8 g/kg of ash.

Figure 2. Changes in milk yield from the acclimation period (wk -2) over the 8-wk grazing period (wk 1–8: September 12 to October 31) followed by the second acclimation period (wk 8–9) and a 3-wk indoor period (wk 10–12: November 14–28). Control, pasture only (C); pasture + 2.65 kg (DM) of barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg (B); pasture + 2.65 kg (DM) of oat-based concentrate + 350 IU of α -TOC/kg (O); pasture + 2.65 kg (DM) of oat-based concentrate + 1,050 IU of α -TOC/kg (O+T). Error bars detail SEM.

(16 h minimum; method 930.15, AOAC International, 2005). Ash was determined following combustion in a muffle furnace (Nabertherm GmbH, Lilienthal, Germany) at 550°C for 5.5 h (method 942.05, AOAC International, 2005). The CP content of the pasture, concentrate, and fecal samples was determined by combustion (FP 528 Analyzer, Leco Corp., St. Joseph, MI; method 990.03, AOAC International, 2005). Gross energy was determined by bomb calorimetry (Parr 1281 bomb calorimeter, Parr Instrument Company, Moline, IL), and ether extract content was determined using Soxtec instruments (Tecator, Höganäs, Sweden) and light petroleum ether. Neutral detergent fiber and ADF were determined using the method of Van Soest et al. (1991) adopted for use in the Ankom 220 Fiber Analyzer (Ankom Technology, Macedon, NY). This method included a thermostable α -amylase and sodium sulfide, but residual ash was not determined. Starch content of feed samples was analyzed using the Megazyme Total Starch Assay Procedure (product no: K-TSTA; Megazyme International Ireland Ltd., Wicklow, Ireland). The concentration of WSC was determined as described by Dubois et al. (1956). The DL- α -tocopherol acetate content of feed samples was analyzed by ALS Global (Clonmel, Ireland) using the United Kingdom Accreditation Service method of extracting DL- α -tocopherol acetate from the feed using an ammonia/methanol solution at 60°C, shaking with chloroform, and then filtering. The diluted extract was tested by reverse-phase HPLC with fluorescence detection. Following chemical analysis, the

actual levels of DL- α -tocopherol acetate supplemented in the concentrates offered were 777, 738, and 2,931 IU/d for B, O, and O+T, respectively. One milligram of feed DL- α -tocopherol acetate is the same as 1 IU of DL- α -tocopherol acetate, which is accepted as the international standard (McDowell, 2000).

Cow Measurement Analysis. Concentrations of milk fat, protein, lactose, casein, urea, and SCC were determined in a commercial milk laboratory (National Milk Laboratories Ltd.) using mid-infrared spectrometry (MilkoScan FT6000, Foss Analytical A/S, Hillerød, Denmark; Soyeurt et al., 2006). The DL- α -tocopherol acetate content of milk samples was also analyzed by ALS Global by the same method used for the feed samples. Values for ECM, 40 g/kg FCM, and fat- and protein-corrected milk (**FPCM**) were calculated as follows: ECM = $(0.03273 \times \text{milk yield, kg}) + (7.65 \times \text{milk protein, kg}) + (12.97 \times \text{milk fat, kg})$ (Tyrrell and Reid, 1965); 40 g/kg FCM = $(0.4 \times \text{milk yield, kg}) + (15 \times \text{fat yield, kg})$ (Gaines and Davidson, 1923); FPCM = $(0.337 + 0.116 \times \text{milk fat, \%} + 0.06 \times \text{milk protein, \%}) \times \text{milk yield, kg}$ (Sjaunja et al., 1990).

Blood samples were analyzed for glucose in the UCD veterinary clinical pathology laboratory (School of Veterinary Medicine, UCD, Belfield, Dublin, Ireland) using Randox Kits according to the manufacturer's instructions and an RX Imola analyzer (Randox Laboratories, Crumlin, UK).

Rumen fluid was allowed to thaw for 16 h at 4°C and was centrifuged at $2,100 \times g$ for 10 min at 4°C.

One milliliter of supernatant was diluted 1:5 with distilled H₂O and then centrifuged at $1,600 \times g$ for 15 min at 4°C. Two hundred microliters of supernatant was combined with 3 reagents and then used to determine NH₃ concentrations using a spectrophotometer. Rumen fluid was prepared for VFA analysis by mixing 250 µL of rumen fluid with 3.75 mL of distilled H₂O and then adding 1 mL of internal standard solution (0.5 g 3-methylvaleric acid in 1,000 mL of 0.15 M oxalic acid). The resulting solution was centrifuged at $1,600 \times g$ and filtered through a syringe tip filter (polytetrafluoroethylene, 13-mm diameter, 0.45 µm) into 2-mL GC vials. Concentrations of VFA were determined using GC (Varian 3800 GCL; Varian Inc., Palo Alto, CA) fitted with a 15-m capillary column with an i.d. of 0.53 mm coated with 1.20 µm of acid-modified polyethylene glycol (EC-1000; Grace Davison Discovery Sciences, Lancashire, UK).

Nitrogen Partitioning Study. Pasture DMI was estimated by extracting *n*-alkanes from pasture, concentrate, and feces samples according to the method of Dove and Mayes (2006). Following extraction, samples were analyzed for concentrations of *n*-alkanes by GC using a Varian 3800 GLC (Varian Inc., Palo Alto, CA) fitted with a 30-m capillary column with an i.d. of 0.53 mm coated with 0.5 µm of dimethyl polysiloxane (SGE Analytical Science Pty Ltd., Ringwood, Victoria, Australia). These data were used to calculate N partitioning as follows: N intake (g) = (kg of pasture DMI × g of N/kg of DM pasture) + (kg of concentrate DMI × g of N/kg of DM concentrate); fecal N (g) = kg of fecal DM excretion × g of N/kg of DM feces; milk N (g) = kg of milk yield × g of N/kg of milk; and urine N (g) = N intake (g) – fecal N (g) – milk N (g) (van Vuuren et al., 1993).

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 version 9.3 (2012; SAS Institute Inc., Cary, NC). The natural logarithm transformation of milk SCC was used to normalize the distribution. The transformed data were used to calculate *P*-values. However, the corresponding least squares means and standard errors of the untransformed data are presented in results for clarity (Al Ibrahim et al., 2010). Analysis of data was conducted using Proc Mixed of SAS (SAS Institute Inc., 2012). The model included the fixed effects of treatment and time and their interaction. The interaction treatment × time was nonsignificant in the model and is therefore not reported here. Cow BW

recorded at the start of the study was included as a covariate in the model. Statistically significant differences between least squares means were tested using the PDIF command incorporating the Tukey test for pairwise comparison of treatment means. The model was adjusted for multicomparisons using Bonferroni correction. Repeated measures (week) and random effects (cow) were also included in the model. Statistical significance was assumed at $P < 0.05$, and a tendency toward significance was assumed at $P > 0.05$ but $P < 0.10$.

RESULTS

DMI, Feed Efficiency, Milk Production, Milk Composition, and BCS

Period 1. Table 3 shows the effect of treatment on DMI, feed efficiency, milk production, milk composition, and BCS of cows. Pasture DMI was not affected by treatment; however, total DMI was increased by offering B ($P = 0.001$), O ($P < 0.001$), or O+T ($P < 0.001$) compared with C. Offering B, O, or O+T reduced feed efficiency (kg of ECM/kg of total DMI) compared with C ($P < 0.02$).

Cows on C had a lower milk yield than those on B ($P < 0.001$), O ($P < 0.001$), or O+T ($P < 0.001$). Milk fat yield was also lower for C than for B ($P = 0.03$), O ($P < 0.001$), or O+T ($P = 0.001$), and O was associated with a higher milk fat yield compared with B ($P = 0.01$; Figure 2). The C treatment had lower milk protein, milk casein, and milk lactose yields than B ($P < 0.001$), O ($P < 0.001$), or O+T ($P < 0.001$). Milk fat + protein yield was lower for C than for B ($P < 0.001$), O ($P < 0.001$), or O+T ($P < 0.001$), and O tended to have higher milk fat + protein yield than B ($P = 0.08$; Figure 3).

Cows offered C and O had a higher milk fat concentration compared with B ($P = 0.001$), and O tended to have a higher milk fat concentration than O+T ($P = 0.05$). Milk lactose concentration of C and B was lower than that of O and O+T ($P < 0.002$). The B treatment had higher MUN than C ($P = 0.006$), O ($P = 0.003$), or O+T ($P = 0.04$; Figure 4). Energy-corrected milk, FCM, and FPCM yields were lower for C compared with B ($P < 0.001$), O ($P < 0.001$), and O+T ($P < 0.001$).

Period 2. The effects of treatment on DMI, feed efficiency, milk production, milk composition, and BCS of cows in P2, as shown in Table 4, were minimal. Cows offered O+T had a higher milk lactose concentration than those offered C ($P = 0.005$) or B ($P = 0.01$). Cows offered O had higher milk fat concentration than cows

Table 3. The effect of treatment on DMI, feed efficiency, milk production, milk composition, and BCS of cows in period 1¹

Item	Treatment				SEM	P-value
	Control ²	Barley ³	Oat ⁴	α-TOC ⁵		
DMI (kg/d)						
Pasture	14.3	15.1	15.5	15.3	0.92	0.64
Total	14.3 ^a	17.7 ^b	18.1 ^b	17.9 ^b	0.92	<0.001
Feed efficiency ⁶	1.60 ^a	1.31 ^b	1.37 ^b	1.38 ^b	0.077	0.02
Start BCS	2.66	2.57	2.74	2.57	0.130	0.49
End BCS	2.69	2.61	2.68	2.58	0.100	0.77
BCS change	0.02	0.04	-0.06	0.00	0.039	0.28
Start BW (kg)	669	658	667	657	21.6	0.92
End BW (kg)	688	676	684	678	19.5	0.93
BW change (kg)	17	24	25	27	10.0	0.81
Milk production (kg/d)						
Milk yield	17.8 ^a	20.7 ^b	20.6 ^b	20.5 ^b	0.57	<0.001
Fat	0.90 ^a	0.95 ^b	1.00 ^c	0.98 ^{bc}	0.024	<0.001
Protein	0.70 ^a	0.79 ^b	0.81 ^b	0.79 ^b	0.018	<0.001
Milk solids	1.60 ^a	1.74 ^b	1.81 ^b	1.77 ^b	0.040	<0.001
Lactose	0.72 ^a	0.85 ^b	0.85 ^b	0.85 ^b	0.023	<0.001
Casein	0.56 ^a	0.63 ^b	0.64 ^b	0.63 ^b	0.015	<0.001
Milk quality (%)						
Fat	5.00 ^a	4.60 ^b	4.90 ^{ac}	4.73 ^{bc}	0.076	<0.001
Protein	3.95	3.88	3.94	3.94	0.032	0.40
Casein	3.15	3.10	3.16	3.16	0.029	0.35
Lactose	4.07 ^a	4.08 ^a	4.15 ^b	4.16 ^b	0.024	<0.001
Urea (mg/dL)	33 ^a	35 ^b	32 ^a	33 ^a	0.100	0.01
SCC ⁷ (1,000 cells/mL)	93	98	92	91	7.704	0.92
α-TOC (mg/100 g of milk)	0.19	0.20	0.20	0.20	0.007	0.75
α-TOC (mg/100 g of fat)	3.93	4.53	4.22	4.18	0.160	0.11
ECM (kg)	22.82 ^a	25.15 ^b	25.96 ^b	25.40 ^b	0.597	<0.001
4% FCM (kg)	20.56 ^a	22.49 ^b	23.33 ^b	22.79 ^b	0.555	<0.001
FPCM ⁸ (kg)	16.81 ^a	18.44 ^b	19.10 ^b	18.67 ^b	0.453	<0.001

^{a-c}Within a row, means with different superscripts differ ($P < 0.05$).

¹Period 1 = cows at pasture for 49 d.

²Base diet of 17 kg of DM pasture allocation per day.

³Base diet + 2.65 kg of DM of barley-based concentrate + 350 IU of α-tocopherol (α-TOC/kg).

⁴Base diet + 2.65 kg of DM of oat-based concentrate + 350 IU of α-TOC/kg.

⁵Base diet + 2.65 kg of DM of oat-based concentrate + 1,050 IU of α-TOC/kg.

⁶Feed efficiency = kg of ECM/kg of total DMI.

⁷For 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.

⁸Fat- and protein-corrected milk.

on C ($P = 0.02$) and tended to have a higher milk fat concentration than those on O+T ($P = 0.05$). Cows offered B tended to have a higher milk fat concentration than those on C ($P = 0.05$).

Rumen Fermentation and Blood Glucose

Period 1. Concentrate supplementation reduced rumen pH (Table 5) compared with C ($P = 0.001$), whereas O+T led to a higher ruminal pH and lower rumen NH_3 concentration compared with O ($P = 0.04$, $P = 0.01$, respectively). Treatment O+T also had a lower rumen NH_3 compared with C ($P = 0.002$). The C treatment had lower total VFA concentration compared with B ($P = 0.002$) and O ($P = 0.006$) and a higher acetic-to-propionic acid ratio compared with B

($P = 0.03$). Rumen acetic acid and propionic acid concentrations were increased by B ($P = 0.004$, $P = 0.002$, respectively) and O ($P = 0.01$, $P = 0.007$, respectively) compared with C. Cows offered O had a higher concentration of butyric acid than those offered C ($P < 0.001$) and O+T ($P = 0.03$). However, rumen fermentation parameters did not differ between O and B ($P > 0.13$). When propionic acid was expressed as a proportion of total VFA, propionic acid of cows offered B was higher than in cows offered C ($P = 0.01$).

Period 2. Treatment had minimal effects on blood glucose concentration and rumen fermentation parameters of cows in P2. Cows offered O+T had a higher ruminal pH compared with C ($P = 0.04$) and B ($P = 0.001$), and O led to a higher ruminal pH compared with B ($P = 0.02$; Table 6).

Figure 3. Changes in milk solids yield from the acclimation period (wk -2) over the 8 wk of period 1 (P1; wk 1-8: September 12 to October 31, 2017), acclimation (wk 9 when milk samples were not taken), and 3 wk of period 2 (P2; wk 10-12: November 14-27, 2017). Control, pasture only (C); pasture + 2.65 kg (DM) of barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg (B); pasture + 2.65 kg (DM) of oat-based concentrate + 350 IU of α -TOC/kg (O); pasture + 2.65 kg (DM) of oat-based concentrate + 1,050 IU of α -TOC/kg (O+T). Error bars detail SEM.

Nitrogen Partitioning Study

Feed N intake (Table 7) was increased by offering B ($P = 0.005$), O ($P = 0.002$), or O+T ($P = 0.003$) compared with C. Offering B ($P = 0.003$), O ($P = 0.001$), or O+T ($P = 0.002$) increased urinary N excretion compared with C. The proportion of ingested N excreted into urine was increased by offering B ($P = 0.04$), O ($P = 0.02$), and O+T ($P = 0.04$) compared with C.

DISCUSSION

The objective of this research was to investigate the effect of cereal type and α -TOC level on milk yield, milk composition, rumen fermentation, and N excretion in late-lactation dairy cows at pasture and when housed indoors on grass silage. Therefore, the α -TOC intake levels (738 and 2,931 IU of α -TOC/d) were selected based on multiple studies in which similar supplemented levels were offered, ranging from 700 to 3,000 IU/d,

Figure 4. Changes in MUN from the acclimation period (wk -2) over the 8 wk of period 1 (P1; wk 1-8: September 12 to October 31), acclimation (wk 9 when milk samples were not taken), and 3 wk of period 2 (P2; wk 10-12: November 14-27, 2017). Control, pasture only (C); pasture + 2.65 kg (DM) of barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg (B); pasture + 2.65 kg (DM) of oat-based concentrate + 350 IU of α -TOC/kg (O); pasture + 2.65 kg (DM) of oat-based concentrate + 1,050 IU of α -TOC/kg (O+T). Error bars detail SEM.

Table 4. The effect of treatment on DMI, feed efficiency, milk production, milk composition, and BCS of cows in period 2¹

Item	Treatment				SEM	P-value
	Control ²	Barley ³	Oat ⁴	α -TOC ⁵		
DMI (kg/d)						
Grass silage	17.15	17.49	17.56	18.01	0.586	0.51
Total	19.80	20.14	20.21	20.66	0.586	0.51
Feed efficiency ⁶	0.74	0.82	0.79	0.75	0.029	0.25
Start BCS	2.69	2.61	2.68	2.58	0.100	0.77
End BCS	2.72	2.70	2.69	2.64	0.118	0.93
BCS change	-0.02	0.04	-0.04	0.02	0.064	0.64
BW start (kg)	688	676	684	678	19.5	0.93
BW end (kg)	767	727	748	732	17.8	0.1
BW change (kg)	72	44	56	47	12.6	0.14
Milk production (kg/d)						
Milk yield	11.57	13.25	12.27	12.74	0.621	0.30
Fat	0.53	0.62	0.59	0.57	0.028	0.93
Protein	0.45	0.49	0.47	0.48	0.024	0.49
Milk solids	0.98	1.11	1.06	1.05	0.053	0.23
Lactose	0.47	0.54	0.51	0.53	0.027	0.31
Casein	0.34	0.38	0.36	0.36	0.017	0.22
Milk quality (%)						
Fat	4.47	4.77	4.81	4.53	0.103	0.05
Protein	3.78	3.71	3.81	3.73	0.065	0.72
Casein	2.95	2.89	2.98	2.90	0.059	0.71
Lactose	3.87 ^a	3.89 ^a	3.96 ^{ab}	4.01 ^b	0.051	0.01
Urea (mg/dL)	30	32	30	32	1	0.28
SCC ⁷ (1,000 cells/mL)	75	74	83	82	16.18	0.26
ECM (kg)	14.10	16.11	15.23	15.14	0.730	0.22
4% FCM (kg)	12.56	14.54	13.67	13.55	0.623	0.18
FPCM ⁸ (kg)	10.05	11.63	10.93	10.86	0.496	0.18

^{a,b}Within a row, means with different superscripts differ ($P < 0.05$).

¹Period 2 = cows indoors for 21 d offered grass silage.

²Base diet, grass silage + 2.65 kg of DM of standard concentrate.

³Base diet + 2.65 kg of DM of barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg.

⁴Base diet + 2.65 kg of DM of oat-based concentrate + 350 IU of α -TOC/kg.

⁵Base diet + 2.65 kg of DM of oat-based concentrate + 1,050 IU of α -TOC/kg.

⁶Feed efficiency = kg of ECM/kg of total DMI.

⁷For 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.

⁸Fat- and protein-corrected milk.

and benefits were observed in terms of reduced SCC (Baldi et al., 2000; Politis et al., 2004), increased milk fat concentration (Charmley and Nicholson, 1993), reduced oxidized flavor (Charmley and Nicholson, 1993), increased milk α -TOC concentration (St-Laurent et al., 1990; Charmley and Nicholson, 1993; Baldi et al., 2000), and reduced plasmin activity (Politis et al., 2004). Furthermore, benefits of α -TOC supplementation on mammary gland health have been reported for both lactating and nonlactating cows at a minimum of 1,000 IU/d (Hogan et al., 1993, 1996; Smith et al., 1997). It is, however, important to note that grazing dairy cows had a higher basal level of α -TOC compared with cows offered hay or silage as in the aforementioned studies. In the current study, supplemental α -TOC was provided in a grazing system. The actual levels of α -TOC tested in the concentrate feed were lower than

those formulated at 259, 246, and 977 IU of α -TOC/kg, which amounted to 777, 738, and 2,931 IU of α -TOC/d for barley, oats, and α -TOC, respectively.

DMI, Milk Production, and Milk Composition

Some studies have shown a reduction in pasture DMI with concentrate feeding (Walker et al., 2001; Bargo et al., 2002); however, we did not observe such a reduction in this research, which may have been due to the low pasture DMI observed. Despite cows being offered 17 kg of DM/d, pasture DMI was significantly lower across all treatments, with the pasture-only cows consuming just 14.3 kg/d during the measurement period. Based on the high postgrazing residuals, the intake of cows was clearly not restricted (Macdonald et al., 2008; Roche et al., 2009). Voluntary feed intake has been well

Table 5. The effect of treatment on blood glucose concentration and rumen fermentation parameters of cows in period 1¹

Item	Treatment				SEM	P-value
	Control ²	Barley ³	Oat ⁴	α -TOC ⁵		
Blood glucose (mmol/L)	3.32	3.27	3.27	3.27	0.034	0.52
Rumen pH	6.70 ^a	6.55 ^{bc}	6.50 ^b	6.58 ^c	0.037	<0.001
NH ₃ ⁶ (mmol/L)	5.83 ^a	5.52 ^{ab}	5.71 ^a	5.28 ^b	0.138	0.01
VFA (mmol/L)						
Total VFA	140 ^a	151 ^b	150 ^b	144 ^{ab}	2.63	0.007
Acetate:propionate	4.33 ^a	4.11 ^b	4.18 ^{ab}	4.09 ^b	0.096	0.08
Acetate	95.94 ^a	103.33 ^b	102.25 ^b	98.25 ^{ab}	1.813	0.01
Propionate	22.97 ^a	25.22 ^b	24.96 ^b	24.37 ^{ab}	0.520	0.01
Butyrate	16.34 ^a	17.62 ^{bc}	18.03 ^b	16.97 ^{ac}	0.337	0.003
Iso-butyrate	1.34	1.34	1.39	1.30	0.040	0.43
Valerate	1.65	1.74	1.72	1.64	0.038	0.19
Iso-valerate	1.67	1.73	1.72	1.67	0.071	0.50
VFA proportions						
Acetate	0.686	0.681	0.680	0.679	0.0029	0.18
Propionate	0.163 ^a	0.169 ^b	0.166 ^{ab}	0.169 ^b	0.002	0.04
Butyrate	0.117	0.117	0.121	0.118	0.0012	0.10
Iso-butyrate	0.010	0.009	0.009	0.009	0.0002	0.14
Valerate	0.012	0.012	0.011	0.011	0.0002	0.30
Iso-valerate	0.012	0.012	0.012	0.012	0.0002	0.83

^{a-c}Within a row, means with different superscripts differ ($P < 0.05$).

¹Period 1 = cows at pasture for 49 d.

²Base diet of 17 kg of DM pasture allocation per day.

³Base diet + 2.65 kg of DM of barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg.

⁴Base diet + 2.65 kg of DM of oat-based concentrate + 350 IU of α -TOC/kg.

⁵Base diet + 2.65 kg of DM of oat-based concentrate + 1,050 IU of α -TOC/kg.

⁶Rumen NH₃.

Table 6. The effect of treatment on blood glucose concentration and rumen fermentation parameters of cows in period 2¹

Item	Treatment				SEM	P-value
	Control ²	Barley ³	Oats ⁴	α -TOC ⁵		
Blood glucose (mmol/L)	3.60	3.47	3.52	3.44	0.070	0.43
Rumen pH	6.58 ^{ac}	6.51 ^a	6.67 ^{bc}	6.72 ^b	0.045	0.008
NH ₃ ⁶ (mmol/L)	2.68	2.58	2.87	2.79	0.269	0.87
VFA (mmol/L)						
Total VFA	125	134	126	130	4.9	0.48
Acetate:propionate	7.09	7.29	7.35	7.22	0.134	0.56
Acetate	89.23	97.10	91.54	94.37	3.396	0.38
Propionate	12.77	13.43	12.65	13.16	0.575	0.77
Butyrate	18.09	19.06	17.36	17.53	0.847	0.48
Iso-butyrate	1.39	1.47	1.34	1.47	0.089	0.46
Valerate	2.29	2.45	2.22	2.38	0.141	0.17
Iso-valerate	1.06	1.01	0.78	0.97	0.121	0.17
VFA proportions						
Acetate	0.718	0.723	0.727	0.726	0.004	0.36
Propionate	0.102	0.100	0.100	0.101	0.002	0.76
Butyrate	0.141	0.137	0.134	0.131	0.005	0.21
Iso-butyrate	0.012	0.012	0.011	0.012	0.0005	0.73
Valerate	0.018	0.018	0.018	0.019	0.0007	0.83
Iso-valerate	0.011	0.010	0.011	0.012	0.0014	0.44

^{a-c}Within a row, means with different superscripts differ ($P < 0.05$).

¹Period 2 = cows indoors for 21 d offered grass silage.

²Base diet, grass silage + 2.65 kg of DM of standard concentrate.

³Base diet + 2.65 kg of DM of barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg.

⁴Base diet + 2.65 kg of DM of oat-based concentrate + 350 IU of α -TOC/kg.

⁵Base diet + 2.65 kg of DM of oat-based concentrate + 1,050 IU of α -TOC/kg.

⁶Rumen NH₃.

documented to be influenced by several feed characteristics such as dietary NDF and CP content (McDonald et al., 2001). In a study similar to ours, Reid et al. (2015) allocated late-lactation dairy cows 14 kg DM/d of autumn pasture and observed a higher pasture DMI of 16.5 kg of DM/d. A potential explanation for the difference in pasture DMI between the studies may be related to the difference in autumn pasture quality in the current study (135 g/kg DM, 217 g/kg CP, and 499 g/kg DM NDF) compared with that of Reid et al. (2015), who reported a higher DM, CP, and lower NDF content (141 g/kg DM, 274 g/kg CP, and 377 g/kg DM NDF). The combined effect of a lower NDF and a high CP content in Reid et al. (2015) possibly increased the rate of NDF degradability and rumen passage (Costa et al., 2008) and therefore may have resulted in an increased pasture DMI compared with the current study.

When pasture DMI is reduced as a result of concentrate feeding, it is referred to as substitution rate (kg reduction in pasture DMI per kg of DMI of concentrate; Kellaway and Harrington, 2004). However, with pasture DMI being low in the pasture-only treatment in this study, no substitution rate was observed. When concentrate supplementation was subsequently offered, total DMI was increased significantly. Other studies have also reported no substitution rate with low pasture allowances of 13 to 14 kg of DM/cow per day and concentrate supplementation of approximately 3 kg of DM/d in early lactation (McEvoy et al., 2008) and late

lactation (Reid et al., 2015). Substitution rate is a major factor that contributes to milk response to concentrate supplementation (the difference in milk produced between unsupplemented and supplemented treatment divided by concentrate DMI), with milk response and concentrate supplementation being negatively correlated (Kellaway and Porta, 1993). Therefore, with no substitution rate observed, an average milk response of 1.06 kg of milk/kg of concentrate supplemented was calculated, which is within the range of 0.5 to 1.18 kg of milk/kg of concentrate reported in other studies for late-lactation cows (Gleeson, 1981; Mackle et al., 1999; Lovett et al., 2005).

Different concentrate types can influence milk production and composition (Sutton, 1989), as seen in the current study, with oat grain supplementation maintaining milk production and increasing milk fat concentration compared with barley for late-lactation cows at pasture. Milk yield, FCM yield, and milk solids yield of cows at pasture were increased by both barley and oats compared with those of cows offered pasture only, as might be expected due to the increased energy intake (Jeffery et al., 1976; Kellaway and Porta, 1993; Reid et al., 2015). However, little information is available on oat supplementation at pasture. An early study by Jeffery et al. (1976) also observed no difference in FCM yield between cows supplemented with 3 kg/d of barley or oat grain, but differences in the study duration time (14 d), pasture species (tropical grasses and legumes),

Table 7. The effect of treatment on partitioning of nitrogen (N) in period 1¹

Item	Treatment				SEM	P-value
	Control ²	Barley ³	Oats ⁴	α -TOC ⁵		
Intake (kg/d)						
Feed N	0.501 ^a	0.597 ^b	0.607 ^b	0.602 ^b	0.032	0.005
N output (kg/d)						
Milk	0.108	0.126	0.125	0.123	0.006	0.11
Feces	0.188	0.200	0.201	0.204	0.009	0.61
Urine	0.202 ^a	0.268 ^b	0.279 ^b	0.272 ^b	0.022	0.002
N partitioning ⁶						
Milk	0.230	0.216	0.213	0.211	0.011	0.44
Feces	0.394	0.353	0.350	0.359	0.012	0.06
Urine	0.386	0.433	0.440	0.433	0.018	0.07
N excreted ⁷ (%)	77.05	78.44	78.72	78.88	1.080	0.44
NUE ⁸ (%)	22.95	21.56	21.28	21.12	1.080	0.44

^{a,b}Within a row, means with different superscripts differ ($P < 0.05$).

¹Period 1 = cows at pasture for 49 d.

²Base diet of 17 kg of DM pasture allocation per day.

³Base diet + 2.65 kg of DM of barley-based concentrate + 350 IU of α -tocopherol (α -TOC)/kg.

⁴Base diet + 2.65 kg of DM of oat-based concentrate + 350 IU of α -TOC/kg.

⁵Base diet + 2.65 kg of DM of oat-based concentrate + 1,050 IU of α -TOC/kg.

⁶N partitioning = N out [feces, urine, milk (kg/d)]/N intake (kg/d).

⁷N excreted = [feces + urine output (kg/d)]/N intake (kg/d) $\times$ 100.

⁸NUE = [milk output (kg/d)]/N intake (kg/d) $\times$ 100.

and breed of cow (Jersey and Australian shorthorn) exist between the studies. Although barley is a higher energy cereal than oats (Ewing, 1997), at the inclusion level in the concentrate (42%) of the current study, the starch intake of cows offered barley or oats only differed by 80 g/d, which is likely not enough to affect milk production. Increasing the starch intake of cows drives the production of propionic acid, a precursor of milk lactose, and subsequently, milk yield (Shamay et al., 2003; Aschenbach et al., 2010). The higher starch intake of cows offered concentrate supplementation (approximately 500 g/d) increased propionate concentration and subsequently milk yield compared with cows offered pasture only.

In pasture-based systems, as concentrate level increases from approximately 2 kg of DM/d up to 10 kg of DM/d, milk fat concentration is reduced compared with pasture-only diets (O'Brien et al., 1996; Bargo et al., 2003). In agreement, the present experiment observed a reduction in milk fat concentration with the barley-based supplement. However, the oat-based supplement maintained milk fat concentration similar to that of milk from cows offered pasture only and is supported by the similar acetate-to-propionate ratio. This may be due to the higher NDF content of the oat-based supplement (349 g/kg) compared with barley (314 g/kg). Lactose levels observed in this study were very low, however, that is not uncommon for spring calving grass-based systems in which milk yield can also be very low.

The majority of research into supplementation with oats has been carried out in confinement systems, with variable milk production responses for oats compared with barley (Moran, 1986). Tommervik and Waldern (1969) observed similar milk production for oats and barley when offered as part of a complete diet. However, other studies have found that dairy cows offered an oat-based concentrate as part of a complete diet had increased milk production compared with a barley-based diet (Moss and Prier, 1981; Moran, 1986; Ekern et al., 2003). When cows were housed and offered grass silage in the present experiment, we observed no difference between the barley and oat treatments, and this finding may be due to the similar energy content of the concentrates offered. Additionally, the silage offered was of high quality (122 g/kg of ME); a greater difference may have been observed between barley and oats with lower quality silage, such as in Ekern et al. (2003) (93.2 g/kg of ME). Multiple differences exist, however, between the current study and the confinement studies in the literature in terms of basal diets, stage of lactation, concentrate levels, and ingredient inclusion levels, making comparison difficult (Moran, 1986; Ekern et al., 2003).

α -Tocopherol plays an important role in cell structure and has been previously reported in other species to improve epithelial cell tight junctions (Charmley et al., 1993; Arreola-Mendoza et al., 2009; Fusi et al., 2018). In dairy cows, as lactation progresses, a reduction occurs in mammary secretory epithelial cells and tight junction structures become leaky, which negatively affects milk yield and alters milk composition (Wilde and Knight, 1989; Nguyen and Neville, 1998; Stefanon et al., 2002; Matter and Balda, 2003). We offered 2 different levels of α -TOC (treatment O = 738 IU of α -TOC/d and treatment O+T = 2,931 IU of α -TOC/d) but observed no difference between the 2 treatments for milk yield, SCC, or milk casein concentration, which suggests that cell structure was not affected by the higher level offered. The high quality of the milk suggests pasture quality and availability were adequate to meet the nutritional requirements of the cows and that tight junction leakiness, which is expected in late lactation, was not an issue for cows in this study.

Rumen Fermentation and Blood Glucose

Offering concentrate supplementation to dairy cows at pasture increases the starch and subsequent energy intake of cows (Bargo et al., 2002). The reported increase in milk yield from cows offered barley and oats compared with pasture only in this study is likely driven by the increase in propionic acid concentration, a precursor of milk lactose and, therefore, milk yield (Shamay et al., 2003; Aschenbach et al., 2010). In line with the increase in propionate and total VFA concentrations for all supplemented treatments, rumen pH was reduced as might be expected; however, rumen pH was above 6.2, which is considered optimal for fiber digestion (Ørskov, 1999).

The high α -TOC (2,931 IU of α -TOC/d) level during the grazing stage of this study altered some of the rumen fermentation parameters measured, namely NH_3 and rumen pH. Although these differences are statistically significant, they are not considered biologically significant given the similar level of milk production and composition from cows offered high and low levels of α -TOC. However, Kay et al. (2005) offered a high level of α -TOC to dairy cows (10,000 IU of α -TOC/d) in late lactation as part of a TMR diet and reported reduced plasma urea levels, which suggested a possible reduction in rumen NH_3 concentration or a greater utilization of NH_3 in the rumen similar to that observed in the current study. Kay et al. (2005) suggested that α -TOC may have altered rumen biohydrogenation although the exact mechanisms are not known. High α -TOC did alter the milk fatty acid profile in this study

(data not shown), which would support the suggestion of Kay et al. (2005).

Nitrogen Partitioning Study

Grazing dairy cows and cows offered fresh or ensiled ryegrass, which is high in N, are particularly inefficient at utilizing ingested N (Vérité and Delaby, 2000). Previous research has found that supplementation at pasture can reduce N excretion because high N grass is usually replaced by a lower N supplement (Whelan et al., 2012b; Reid et al., 2015). However, in this research, with pasture intake being similar across all treatments, dietary N intake was increased in the supplemented treatments. Although the total N excreted was not affected by treatment and was within the reference range of 70 to 80% of ingested N (Ryan et al., 2011), concentrate supplementation increased urinary N excretion. However, error may have occurred in the measurement of urinary N because it is calculated by difference: urinary N = N intake (g) – fecal N (g) – milk N (g). From an environmental perspective, however, increased urinary N from increased N intake is not desirable because urinary N can be volatilized into the atmosphere as NH₃ or lost through leaching in the soil (Castillo, 2001; Ryan et al., 2011).

CONCLUSIONS

Concentrate supplementation increased milk yield and milk solids yield. Oat-based supplementation had a similar milk yield and a higher milk fat concentration in comparison to the barley-based supplement offered at pasture. Increasing the level of α -TOC did not alter milk yield or milk composition parameters; however, a reduction in rumen NH₃ concentration was observed for grazing dairy cows. Cereal type and α -TOC level did not affect milk production or composition when cows were offered grass silage.

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