A comparison of serum metabolic and production profiles of dairy cows that maintained or lost body condition 15 days before calving

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ABSTRACT

Body condition score (BCS) change is an indirect measure of energy balance. Energy balance before calving may affect production and health in the following lactation. It is likely that cows may experience BCS loss before calving due to negative energy balance. The objective of this study was to determine if loss of BCS 15 d before calving affected milk production, BCS profile, and metabolic status during the transition period and early lactation. On d –15 to d 0 relative to calving, BCS was assessed (1 = emaciated, 5 = obese) for 98 Holstein-Friesian cows. The cows were divided into 2 groups: those that did not lose BCS between d –15 and d 0 (maintained, BCS-M, $n = 55$) and those that lost BCS from d –15 to d 0 (lost, BCS-L, $n = 43$, average loss of 0.29 ± 0.11 BCS). The fixed effects of BCS group, parity, week (day when analyzing milk production records), their interactions, and a random effect of cow were analyzed using PROC MIXED of SAS (SAS Institute Inc., Cary, NC). Before calving, BCS-L cows tended to have higher concentrations of nonesterified fatty acids than BCS-M cows (0.88 vs. 0.78 mmol/L). After calving, BCS-L cows had higher nonesterified fatty acid concentrations in wk 1 (0.93 vs. 0.71 mmol/L), wk 2 (0.84 vs. 0.69 mmol/L), and wk 4 (0.81 vs. 0.63 mmol/L) than BCS-M cows. The BCS-L cows had higher concentrations of β -hydroxybutyrate (BHB) in wk 1 (0.72 vs. 0.57 mmol/L), wk 2 (0.97 vs. 0.70 mmol/L), and wk 4 (0.94 vs. 0.67 mmol/L) compared with BCS-M cows. We detected significant reductions in insulin concentrations in BCS-L cows from wk –1 (2.23 vs. 1.37 μ IU/mL) to wk 2 (1.68 vs. 0.89 μ IU/mL) and wk 4 (2.21 vs. 1.59 μ IU/mL) compared with BCS-M cows. Prevalence of subclinical ketosis increased in BCS-L cows in wk 3 and 4 when BHB was ≥ 1.4 mmol/L and in wk 1, 3, and 4 when BHB was ≥ 1.2 mmol/L. In wk 1, BCS-L cows

tended to have lower levels of calcium than BCS-M cows (2.33 vs. 2.27 mmol/L). We found no differences between the groups of cows for milk yield and energy-corrected milk. The BCS-L cows had lower BCS up to 75 d in lactation. Overall, BCS-L cows had higher somatic cell scores with an elevated somatic cell score on d 45, d 60, and d 75. There was an overall tendency for BCS-L cows to have higher fat yield and an overall significant increase in fat percentage. Overall, BCS-L cows had lower lactose percentage, with a reduction on d 60. This work shows that BCS loss before calving may have significant consequences for metabolic status, milk composition, somatic cell score, and BCS profile in dairy cows.

Key words: transition period, body condition score, milk production, dry cow nutrition, metabolic status

INTRODUCTION

The transition period for dairy cows has been defined as the period from 3 wk prepartum to 3 wk postpartum (Grummer, 1995; Drackley, 1999). This period is considered the most critical period in the lactation cycle (Grummer, 1995; Huzzey et al., 2005) because 50% of transition cows may be affected by disease (LeBlanc, 2010). These diseases can be of a metabolic, nutritional, or infectious nature (Mulligan and Doherty, 2008). During the prepartum close-up period, which is 3 wk before the expected calving date (Dann et al., 2006), cows may experience reduced feed intake, resulting in negative energy balance. It is generally accepted that a detrimentally altered metabolic status is a consequence of negative energy balance in the prepartum or postpartum period. An adverse metabolic status in this period is generally associated with poor health and reduced reproductive outcomes. Studies have shown that if prepartum nonesterified fatty acids (NEFA) concentrations increase above 0.5 mmol/L, there is an increased risk of retained placenta, increased time to pregnancy, reduced milk production, metritis (Ospina et al., 2010a,b; Chapinal et al., 2011, 2012a), and increased risk of displaced abomasum (LeBlanc et al.,

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2005). Prepartum BHB concentrations ≥ 0.8 mmol/L were associated with reduced milk production and increased risk of displaced abomasum (Chapinal et al., 2012b). Negative energy status in the close-up period also appears to be associated with exacerbated immune system suppression due to impaired neutrophil function in the periparturient period (Hammon et al., 2006).

High concentrations of NEFA and BHB indicating negative energy balance are associated with hypocalcemia in early lactation (Martinez et al., 2012; Ribeiro et al., 2013). It is imperative that nutritional strategies used for transition cows do not result in negatively altered calcium status. Several studies have highlighted that calcium concentrations are important for cow health. Concentrations lower than 2.0 mmol/L are associated with metritis, displaced abomasum, reduced milk production and reduced pregnancy rates to first service (Chapinal et al., 2011, 2012b; Martinez et al., 2012). Furthermore, negatively altered calcium status in dairy cattle has been shown to have a detrimental effect on neutrophil function (Martinez et al., 2014).

Several nutritional strategies have been advocated internationally with the aim of optimizing transition cow nutritional status, health, and productivity. One such nutritional strategy involves controlled or restricted energy feeding during the dry period (Dann et al., 2005; Cardoso et al., 2013; Roche et al., 2013). Some of the research with this controlled energy nutritional strategy for late gestation cows indicates favorable changes in some but not all metabolic and production parameters in the periparturient period (Keogh et al., 2009; Cardoso et al., 2013). However, it remains to be seen whether this restricted-energy dry-cow feeding strategy is suited to all cow types, production systems, prior nutritional conditioning strategies, dry-cow BCS, and dry-period lengths, and whether any prepartum BCS loss caused by such a strategy has a positive or negative influence on metabolic status. The application of the controlled energy feeding strategy, whether by accident or design, in the close-up dry period only may not be advantageous (Cardoso et al., 2013). In addition to cases where restricted energy allowance precalving is planned, there are many cases of negatively altered metabolic status and negative energy balance prepartum that arise

because of inadequate nutrition and management at farm level. These cases may have a greater effect on the health and productivity of cows as the degree of restriction may be more severe. However, severe under-feeding prepartum is not often documented as a result of controlled research but is generally identified through herd health investigations.

The consequences of BCS loss and negatively altered metabolic status prepartum for the metabolic status and BCS profile of postpartum cows are not commonly reported in the literature. Therefore, the objective of this study was to evaluate the effect of BCS loss 15 d before calving on serum metabolic compounds, mineral compounds, and milk production and composition. These cows consumed a diet that met their prepartum energy requirements (AFRC, 1993).

MATERIALS AND METHODS

This study involved a retrospective analysis of BCS and lactation records. The study was approved by the Animal Research Ethics Committee of University College Dublin (Ireland) and was licensed by the Department of Health and Children, Ireland, in accordance with the Cruelty to Animals Act (Ireland 1876) and European Union Directive 86/609/EC.

Experimental Dairy Cows

This study was conducted using a commercial dairy farm supplying milk for liquid consumption in Ireland. There were a total of 220 Holstein-Friesian dairy cows on the farm, and cows with lameness and health issues were removed to reduce confounding. After removing these cows, 98 Holstein-Friesian spring-calving animals were monitored in this study. The calving period occurred from January to May with a mean calving date of March 4 (Table 1). The average 305-d milk yield of the previous lactations for the 67 multiparous cows was $8,800 \pm 154$ kg.

Cows were divided into 2 groups based on BCS change between d $-15 (\pm 2$ d) and d 0 relative to calving. Cows that maintained their BCS were allocated to the **BCS-M** group, and cows that lost BCS in the same period

Table 1. Frequency of calving of cows that maintained (BCS-M) and cows that lost (BCS-L) body condition in the 15 d before calving for each month within parity

Group	Parity 1			Parity 2			Parity 3+			Total
	January	February	March	January	February	March	January	February	March	
BCS-M	13	2	8	3	2	7	2	7	11	55
BCS-L	2	2	4	2	4	9	4	4	12	43
Total	15	4	12	5	6	16	6	11	23	98

were allocated to the **BCS-L** group (Table 2). Before calving, all cows were blood sampled every 3 d and the relevant blood samples were retained to ensure samples were collected for d -7 and -14 relative to calving after retrospective confirmation of the calving date. None of the cows had an increase in BCS during this period. The study included first-, second-, and third- or later-parity cows. The management protocol followed on this farm was to dry off cows 60 ± 3 d (for both BCS-M and BCS-L groups) before the expected calving date. Cows in the BCS-M group were dry for 59.7 ± 6 d and cows in the BCS-L group were dry for 60.1 ± 5 d relative to actual calving dates. First-parity animals were grouped with the dry cows at the beginning of the dry period (i.e., 60 d before expected calving).

Diets

In the first 30 d of the dry period, all cows were fed a far-off (60 to 30 d before parturition) dry-cow TMR (Table 3) and housed in a cubicle freestall system. During the final 30 d before calving, the cows were fed a close-up dry-cow diet (Table 3) and housed together on straw bedding. During the appropriate period, cows had ad libitum access to the far-off or close-up diet and each cow had access to 0.7 m of feedbunk space. At calving, cows entered a maternity group (straw-bedded) for 7 d and subsequently went into a high-yielding group (cubicle freestall system) and remained indoors. In late March, cows were allowed ad libitum access to perennial ryegrass-based grazed grass (3 cows/ha) for 4 h/d. In April, the length of time allowed for grazing was gradually increased until cows were grazed full time by April 27. From April to August, cows had access to a blended ration of TMR, concentrates, and forages fed twice daily at milking time, as outlined in Table 3, as supplements to grazed pasture.

Body Condition Scoring

Body condition score was determined using a 5-point scale (1 = emaciated; 5 = obese) with quarter-point increments and evaluated by the same trained researcher. The reproducibility of the researcher was assessed by having the researcher score a set of 60 cows in one day after the morning and evening milkings before the trial began. A weighted kappa coefficient of 0.91 was calculated for this exercise, which implies excellent reproducibility (Woodward, 1999). Body condition score was evaluated by palpating and assessing the spinal column (chine, loin, and rump), the cranial coccygeal vertebrae (tail head), the tuber ischia (pin bones), the tuber sacral (hip or hook bones), and the thigh region, as described by Edmonson et al. (1989). Cows were

Table 2. Body condition score (mean $\pm$ SD) at 15 d precalving (d -15) and calving (d 0) and average change in BCS (Δ BCS) for cows that maintained (BCS-M) or lost (BCS-L) body condition precalving

Item	BCS-M (n = 55)	BCS-L (n = 43)
d -15	3.04 $\pm$ 0.25	3.07 $\pm$ 0.31
d 0	3.04 $\pm$ 0.25	2.78 $\pm$ 0.32
Δ BCS ¹	0 $\pm$ 0	0.29 $\pm$ 0.11

¹ Δ BCS = d -15 - d 0.

body condition scored every 14 d commencing from drying-off (d-60) to calving and up to mid lactation and the researcher was blind to the previous BCS.

Blood Sampling

Cows were blood sampled every 3 d prepartum, on the day of calving and in wk 1, 2, 3, and 4 postpartum. Blood samples for NEFA, BHB, insulin, IGF-I, calcium, and magnesium analysis were collected into 10-mL Vacutainers (Ref. No. 8303209; BD, Plymouth, UK) and allowed to clot for 16 h at 4°C before centrifuging at $2,100 \times g$ for 20 min at 4°C for extraction of serum. Stokol and Nydam (2005) showed that blood NEFA and BHB remained stable for 24 h when stored at 4°C. These samples were stored at -20°C pending analysis. Concentrations of NEFA and BHB were analyzed using enzymatic colorimetry and a clinical blood analyzer (RX imola, Randox Laboratories Ltd., Antrim, UK). Insulin was determined using a solid-phase fluoroimmunoassay (AutoDelfia, PerkinElmer Life, Turku, Finland; coefficient of variation <4.5%; Al Ibrahim et al., 2010a). Concentrations of IGF-I were determined using a RIA that followed ethanol:acetone:acetic acid extraction (at a ratio of >60:30:10, as described by Beltman et al., 2010) with recombinant iodinated IGF-I (Upstate, Millipore, Temecula, CA) as the standard and 50 μ L of anti-human IGF-I (NHPP-NIDDK AFP4892898; National Hormone and Peptide Program, Torrance, CA; dilution 1:750,000) as the primary antibody. Similar to Al Ibrahim et al. (2013), calcium and magnesium were analyzed using a biochemical assay kit (Boehringer Mannheim, Mannheim, Germany) using an automated biochemical analyzer (ABX Mira; Horiba, ABX SAS, Montpellier, France).

Feed Analysis

Feed was collected weekly and stored at -20°C for analysis following the procedure described by Whelan et al. (2012). Corn and grass silage DM was determined by drying in an oven for 72 h at 55°C. Dried corn, concentrates, and grass silage samples were milled

Table 3. Composition and analyses of diets for all categories of dairy cows enrolled in the study during the dry and lactating periods

Item	Dry cows (indoors)			Lactation (January–August)						
	Far off	Close up	January to mid-March	Late March	Early April	Late April	May	June	July	August
Composition (kg/cow per day, fresh wt)										
Grass silage	47.0	39.0	20.0	6.0	—	—	—	—	—	—
Corn silage	—	—	15.0	12.0	—	5.0	—	5.0	—	—
Wheat straw	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5	0.5	0.5
Brewers grain	—	—	10.0	10.0	8.0	8.0	8.0	8.0	8.0	8.0
Dairy blend 20% CP ¹	—	1.0	10.0	—	—	—	—	—	—	—
Dairy blend 16% CP ²	—	—	—	10.0	9.0	7.0	5.5	5.5	5.5	5.5
Pelleted concentrate 15% CP ³	—	—	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Hi Pro Soya ⁴	—	1.0	—	—	—	—	—	—	—	—
Dry cow mineral	0.15	0.15	—	—	—	—	—	—	—	—
Grazed grass (DMI) estimated	—	—	—	6.0	10.0	13.0	15.0	16.0	16.0	16.0
Total DMI (kg/cow per day)	12.2	11.9	24.7	24.9	24.2	24.6	24.8	24.4	24.4	24.4
ME intake (MJ/cow per d)	114.0	117.0	284.0	297.0	302.0	312.0	298.0	317.0	297.0	305.0
Analyses										
DM (g/kg)	25.3	28.3	43.4	38.5	27.9	24.6	20.9	20.0	22.9	21.0
ME (MJ/kg of DM)	9.3	9.8	11.5	11.9	12.6	12.7	12.0	13.0	12.2	12.5
NDF (g/kg of DM)	534.0	488.0	435.0	411.0	385.0	388.0	386.0	378.0	378.0	411.0
Starch (g/kg of DM)	—	22.0	143.0	135.0	119.0	91.0	75.0	65.0	65.0	65.0
Sugars (g/kg of DM)	19.0	28.0	42.0	65.0	80.0	88.0	92.0	99.0	99.0	99.0
Oil (g/kg of DM)	36.0	36.0	42.0	43.0	43.0	42.0	42.0	42.0	42.0	42.0
CP (g/kg of DM)	105.0	140.0	166.0	179.0	219.0	235.0	195.0	259.0	196.0	233.0

¹Dairy blend 20% CP (C. R. Wynne Ltd., Moone, Kildare, Ireland). Ingredients in descending order were soybean meal, corn, soy hulls, citrus pulp, rapeseed meal, molasses, mineral/vitamin premix, Megalac (Volac UK, Royston, UK), sodium bicarbonate, calcined magnesite. Analytical composition per kilogram of fresh weight: 20% CP, 4.6% oil acid hydrolysis, 15.4% starch, 9.51% sugars, 11.57 MJ as fed.

²Dairy blend 16% CP (C. R. Wynne Ltd.). Ingredients in descending order were corn, soy hulls, rapeseed meal, soybean meal, molasses, mineral/vitamin premix, Megalac (Volac UK), sodium bicarbonate, calcined magnesite. Analytical composition per kilogram of fresh weight: 16% CP, 4.8% oil A.H., 17.9% starch, 8.7% sugars, 11.4 MJ as fed.

³Pelleted concentrate 15% CP (C. R. Wynne Ltd.). Ingredients in descending order were wheat, corn, soy hulls, citrus pulp, rapeseed meal, barley, soybean meal, molasses, mineral/vitamin premix, calcined magnesite. Analytical composition per kilogram of fresh weight: 15% CP, 2.6% oil A.H., 23.3% starch, 9.5% sugars, 10.81 MJ as fed.

⁴Hi Pro Soya (C. R. Wynne Ltd.); 48% soybean meal.

through a 1-mm screen using a hammer mill (Christy and Norris Process Engineers Ltd., Chelmsford, UK), dried at 105°C for a minimum of 106 h to determine the residual DM, and ashed at 550°C for 4 h in a muffle furnace (Nabertherm, Bremen, Germany) to determine the ash component. Crude protein was calculated as $N \times 6.25$ using the Leco FP 528 instrument (Leco Instruments UK Ltd., Stockport, UK). The NDF and ADF contents of feed were measured according to the procedures of Van Soest et al. (1991) using a Fibertec extraction unit (Tecator, Hoganas, Sweden) and heat-stable α -amylase (Ankom Technology, Macedon, NY) to degrade the starch in the concentrate samples. Gross energy content of the concentrate was determined using a Parr 12001 oxygen bomb calorimeter (Parr, Moline, IL). The ether extract was measured using a Soxtec instrument (Tecator). Fresh silage sample pH was measured using a Mettler Toledo MP 200 pH meter (Mettler Toledo Ltd., Essex, UK). In vitro grass silage DM digestibility was calculated using the procedure of Tilley and Terry (1963). Starch in the corn silage was determined using the Megazyme total starch assay kit (Megazyme International Ireland Ltd., Bray, Co. Wicklow, Ireland). Ammonia nitrogen ($\text{NH}_3\text{-N}$) in grass silage was determined by modification of the phenol/hypochlorite technique described by O'Keefe and Sherrington (1983).

Milk Collection and Analysis

Milk and component yields were recorded for individual cows every 2 wk. Milk samples were collected at consecutive a.m. and p.m. milkings by a commercial milk recording company (Progressive Genetic, Bluebell, Dublin, Ireland) using the on-farm milk recording jars, and the samples were pooled in proportion to their a.m. and p.m. yields. These composite milk samples were preserved in bronopol (Broad Spectrum Microtabs, D&F Control Systems Inc., Dublin, CA) and refrigerated until they were analyzed for fat, protein, and lactose concentrations by mid-infrared reflectance spectrophotometry (Foss Electric, Hillerød, Denmark). Total milk, fat, and protein yields and lactose percentages and yields and SCC were also recorded. The 305-d yields were obtained after the cows had reached 305 d in lactation. Energy-corrected milk was calculated as $(0.3246 \times \text{kg of milk}) + (12.86 \times \text{kg of fat}) + (7.04 \text{ kg of protein})$ (Tyrrell and Reid, 1965).

Statistical Analysis

Diagnostic tests were conducted using the UNIVARI-ATE procedure in SAS (version 9.4, SAS Institute Inc., Cary, NC) to determine whether residuals of the data

had normal distributions. Data that were not normal were transformed using a Box-Cox transformation as previously described by Fahey et al. (2007). Somatic cell count was transformed to SCS using the formula $\text{SCS} = \log_2(\text{SCC}/100,000) + 3$ (Schutz, 1994). Data were analyzed as a randomized complete block design with repeated measures. Cow was considered the experimental unit. The model included fixed effects for group (BCS-L or BCS-M), time, parity (1, 2, ≥ 3), calving month (January, February, March), and their interactions. Time was measured as wk relative to calving (-2, -1, 0, 1, 2, 3, 4) for NEFA, BHB, insulin, IGF-1, calcium, and magnesium. Time was measured as days relative to calving (d 15, 30, 45, 60, and 75) for milk yield, ECM, and milk components, and SCS was measured as days relative to calving (d 0, 15, 30, 45, 60, and 75). The repeated-measures analysis was based on time, with the most appropriate covariance structure selected using the lowest Bayesian information criterion. Compound symmetry was used when analyzing lactose yield, lactose percentage, milk yield, fat yield, fat percentage, protein percentage, SCS, and calcium. Compound symmetry heterogeneous was used when analyzing fat:protein ratio, NEFA, BHB, insulin, and IGF-1. Toeplitz and first-order autoregressive were used when analyzing protein yield and magnesium, respectively. Cow within group was included as a random effect. A Bonferroni multiple comparison adjustment was used. Results for the fixed effects and their interactions that had an adjusted P -value ≤ 0.10 were considered statistical tendencies, and an adjusted P -value ≤ 0.05 was considered statistically significant. Multinomial ordinal logistic regression using the GENMOD procedure of SAS was used to analyze postpartum BCS for up to 75 DIM with the fixed effects of group (BCS-M or BCS-L), day (d 0, 15, 30, 45, 60, and 75), and the group $\times$ day interaction. Results for the fixed effects and their interactions that had a P -value ≤ 0.10 were considered a statistical tendency, and P -values ≤ 0.05 were considered statistically significant. A Bonferroni multiple comparison adjustment was used. Chi-squared analysis was used to determine if a significant difference existed for the proportion of cows exceeding BHB levels of 1.2 and 1.4 mmol/L.

RESULTS

We detected significant group effects for NEFA, BHB, and insulin ($P < 0.01$), effects of week for NEFA, BHB, insulin, and IGF-I, and group $\times$ week interactions for BHB ($P < 0.01$) and insulin ($P < 0.10$). Cows in the BCS-L group had a tendency to have increased serum NEFA concentrations 1 wk before parturition ($P < 0.10$) and increased serum NEFA concentrations in

Figure 1. Least squares means ($\pm$ SEM) for nonesterified fatty acids (NEFA), BHB, insulin, and IGF-1 serum concentrations from -2 to 4 wk relative to parturition for cows that lost (BCS-L, —) and maintained (BCS-M, - - -) BCS 15 d before calving. † $P < 0.10$, * $P < 0.05$, ** $P < 0.01$. Grp = group.

wk 1, 2 ($P < 0.01$), and 4 ($P < 0.05$) after parturition compared with BCS-M cows (Figure 1). Concentration of BHB did not differ between the BCS-L and BCS-M cows from -2 to 0 wk relative to calving (Figure 1) but did increase in BCS-L cows in wk 1 ($P < 0.05$), wk 2 ($P < 0.10$), and wk 4 ($P < 0.05$) compared with BCS-M cows. Cows in the BCS-M group had higher insulin concentrations in wk -2 ($P < 0.10$) and wk -1 , 1, 2, and 4 ($P < 0.01$) relative to calving than BCS-L cows (Figure 1). Both BCS-M and BCS-L groups had similar concentrations of IGF-I except in wk 1 after calving, when the BCS-M cows tended to have higher concentrations of IGF-I ($P < 0.10$, Figure 1).

The data in Figure 2a indicate that a greater percentage of cows in the BCS-L group had concentrations of BHB ≥ 1.4 mmol/L in wk 3 ($P < 0.05$) and wk 4 ($P < 0.001$) compared with BCS-M cows. Similarly, a greater percentage of BCS-L cows had serum concentrations of BHB ≥ 1.2 mmol/L in wk 1 ($P < 0.05$), wk 3 ($P < 0.01$), and wk 4 ($P < 0.001$) compared with the BCS-M cows (Figure 2b).

We detected a tendency for a group effect for calcium ($P < 0.10$), a week effect ($P < 0.01$) for calcium and magnesium, and a tendency for a group $\times$ week interaction for magnesium ($P < 0.10$, Figure 2). Magnesium

serum concentrations were similar for both groups of cows from -2 to 4 wk relative to parturition. However, BCS-L cows had higher magnesium serum concentrations in wk 0 ($P < 0.10$, Figure 3). Calcium serum concentrations were similar for BCS-L and BCS-M cows -2 to 4 wk relative to parturition with the exception of wk 1, where BCS-L cows tended to have lower serum concentrations of calcium ($P < 0.10$, Figure 3).

We detected no significant group or group $\times$ day interactions but there was a significant day effect ($P < 0.001$) for milk yield and ECM (Figure 4). We found no differences within day between BCS-M and BCS-L cows for milk yield and ECM, but we found a significant group ($P < 0.01$) and day ($P < 0.0001$) effects for BCS and a group effect for SCS ($P < 0.01$). Cows in the BCS-L group had higher SCS on d 45 ($P < 0.05$), d 60 ($P < 0.01$), and d 75 ($P < 0.05$).

We detected a group effect for fat yield, with BCS-L cows tending to have higher fat yield ($P < 0.10$) and a higher fat percentage ($P < 0.05$) than BCS-M cows. We also found a day effect for fat yield ($P < 0.01$) and fat percentage ($P < 0.001$, Figure 5), but detected no differences within day between groups for fat yield or percentage. There was a significant day effect for protein yield ($P < 0.10$) and percentage ($P < 0.001$).

Figure 2. Percentages ($\pm$ SEM) of cows exceeding (a) 1.4 mmol and (b) 1.2 mmol of BHB from -2 to 4 wk relative to parturition for cows that lost (BCS-L, black bars) and maintained (BCS-M, gray bars) BCS 15 d before calving. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

We detected no differences within day between groups of cows for protein yield or percentage. A significant group effect ($P < 0.01$) was found for lactose percentage, with cows in the BCS-M group having a higher lactose percentage over the 75 d of the trial. On d 60, BCS-M cows had a higher lactose percentage ($P < 0.01$) than BCS-L cows.

DISCUSSION

This study had several limitations, the first being that this study was carried out a single commercial dairy farm. The effect of BCS loss prepartum may vary from farm to farm, depending on cow genotype and farm management system as well as other factors. The average BCS loss in the BCS-L group ($n = 43$) was 0.29 units, which is similar to the resolution of the scoring system used (0.25 units).

To the best of our knowledge, there are no reports in the international scientific literature describing the metabolic status and early-lactation productivity of cows with BCS loss in the close-up dry period. Loss of BCS during this time may occur because of inadequate nutrition or poor management or because of a controlled

Figure 3. Least squares means ($\pm$ SEM) for magnesium and calcium concentrations from -2 to 4 wk relative to parturition for cows that lost (BCS-L, —) and maintained (BCS-M, - - -) BCS 15 d before calving. † $P < 0.10$. Grp = group.

energy feeding strategy applied in the close-up dry period (Dann et al., 2006; Roche, 2006; Cardoso et al., 2013). The consequences of BCS loss in the prepartum transition period on metabolic status and production parameters both pre- and postpartum are not known. In our study, both groups of cows in the close-up period were fed to energy requirements, which were estimated to be 120 MJ/cow per day based on the AFRC (1993) UK standard for a 600-kg cow at 38 wk of pregnancy.

Nonesterified Fatty Acids

Interestingly, in this study, we observed a greater consequence of prepartum BCS loss on metabolic status in the postpartum period compared with the prepartum period. We found no significant differences in serum NEFA concentrations between the BCS-M and BCS-L groups in wk -2 or at calving, and a statistical tendency for increased serum NEFA concentrations at wk -1 ($P < 0.10$). However, in the postpartum period, highly significant differences were observed between the

groups at wk 1, 2, and 4 postpartum ($P < 0.01$). Given that there are several reports in the literature relating high postpartum NEFA to negative consequences for production (McArt et al., 2013), reproduction (Leroy et al., 2008), and health (Hammon et al., 2006), this consequence of BCS loss in the prepartum period is particularly noteworthy.

It is also interesting that a controlled energy feeding strategy in the far-off dry period (80 to 100% of daily requirements) caused a significant reducing effect on serum NEFA concentrations in the postpartum period but controlled energy diets fed in the close-up period elevated serum NEFA concentrations before calving (Cardoso et al., 2013; Drackley and Cardoso, 2014). Similarly, Keogh et al. (2009) found no differences in the prepartum serum NEFA concentrations for cows fed a low or high energy allowance in late gestation but significant differences were noted for serum NEFA concentrations in the postpartum period. Furthermore, we detected no group differences in serum NEFA concentration in the week of calving. This is a factor of the large within-group variation found at that point.

Prepartum serum NEFA concentrations for both groups exceeded the threshold of 0.4 mmol/L proposed by Mulligan et al. (2006) as indicating prepartum nega-

tively altered metabolic status and the serum concentration (0.7 mmol/L) proposed to indicate postpartum negatively altered metabolic status. As has been reported previously, serum NEFA concentrations for both groups peaked at or very close to parturition and then declined in wk 1 but remained higher than prepartum values during the early weeks of lactation.

β -Hydroxybutyrate

As with NEFA, we observed no significant differences between the groups for serum BHB concentration in the prepartum period. However, in the postpartum period, cows that lost BCS 15 d precalving had significantly higher serum BHB in wk 1 and 4. High serum concentrations of BHB have been associated with reduced immune system functionality (Ingvarsen and Moyes, 2013), displaced abomasum (Le Blanc et al., 2005; Ospina et al., 2013), reduced reproductive parameters (Leroy et al., 2005, 2006), and many other transition and early lactation cow disorders (Mulligan et al., 2006).

Previous reports from this research group (Al-Ibrahim et al., 2010a) have indicated that higher prepartum conditioning (BCS of 3.75 at calving) can significantly

Figure 4. Least squares means ($\pm$ SEM) for milk yield, ECM, BCS, and SCS for cows that lost (BCS-L, —) maintained (BCS-M, - - -) BCS 15 d before calving. * $P < 0.05$, ** $P < 0.01$. Grp = group.

Figure 5. Least squares means ($\pm$ SEM) for fat yield and percentage, protein yield and percentage, and lactose yield and percentage for cows that lost (BCS-L, —) maintained (BCS-M, - - -) BCS 15 d before calving. ** $P < 0.01$. Grp = group.

elevate serum BHB and NEFA concentrations in early lactation. However, for dry cows offered a high and a low feed allowance, there were no effects on pre- or postpartum serum BHB concentrations (Keogh et al., 2009).

In terms of monitoring metabolic status, it is interesting to note that BCS-L cows had higher serum BHB concentrations at wk 1 and 4 postpartum. Making a decision on the correct timing for BHB screening in early lactation is an important part of using BHB in a monitoring strategy. Data from this study support the practice of taking blood samples for BHB within the first 4 wk postpartum, which is within the period proposed by Mulligan et al. (2006). Interestingly, in the data of Al Ibrahim et al. (2010b), large differences in metabolic profile because of differing BCS at calving only yielded significant group differences for BHB at wk 5 postpartum, even though large numerical differences between the groups existed at d 25 postpartum. The timing of the highest BHB serum concentration in the current study was at wk 2 postpartum, which is earlier than the timing of the highest BHB serum concentration of 25 d postpartum (Al-Ibrahim et al.,

2010a) and later than 10 d postpartum reported by Cavestany et al. (2005).

McArt et al. (2013) summarized several studies and found that the range of prevalence (at the cow level) of BHB ≥ 1.2 mmol/L was between 18 and 25% in the first 2 wk of lactation and the prevalence of BHB ≥ 1.4 mmol/L was 12% in the first week of lactation. These prevalence rates were similar to the cows in the BCS-L group, where the prevalence rates ranged from 14 to 21% for cows with BHB ≥ 1.2 mmol/L, and from 9 to 16% for cows with BHB ≥ 1.4 mmol/L in the first 4 wk of lactation. However, cows in the BCS-M group had lower prevalences of between 3.6 and 7.2% and 2.6 and 5.5% for BHB serum concentrations ≥ 1.2 and ≥ 1.4 mmol/L, respectively. Furthermore, serum concentrations of BHB observed in the prepartum period were below the thresholds often used to screen for negatively altered metabolic status (0.6 mmol/L; Mulligan et al., 2006).

Type II ketosis occurs between 1 and 2 wk postpartum and is associated with fatty liver before calving. Type I ketosis occurs 3 to 6 wk postpartum and is associated with low blood glucose concentrations and

no fatty liver (LeBlanc, 2010). When we looked at the frequency of cows in the BCS-M and BCS-L groups, our results indicate that the BCS-L cows had a greater risk of type I and type II ketosis due to the higher frequency of BCS-L cows exceeding 1.2 mmol/L of BHB. However, if we used a threshold of 1.4 mmol/L of BHB, BCS-L cows would have a higher risk of type II ketosis. This may have implications at the farm level when deciding on what serum BHB threshold to use as a preventative herd health strategy.

Insulin and IGF-I

Insulin status in early lactation has been related to some important aspects of reproductive performance, including days to first ovulation and conception rate (Gong et al., 2002). In this study, cows experiencing BCS loss prepartum had lower concentrations of insulin in circulation in the pre- and postpartum periods. Previous early lactation studies in this group have indicated that over-conditioned prepartum cows experience more BCS loss, higher serum concentrations of BHB and NEFA, and lower serum concentrations of insulin in the postpartum period (Al Ibrahim et al., 2010a,b). Feeding a controlled energy diet in the far-off dry period significantly increased serum insulin concentration postpartum. However, feeding a controlled energy diet in the close-up dry period significantly reduced serum insulin concentrations both pre- and postpartum (Cardoso et al., 2013). In early lactation, the diet used has been found to significantly increase serum insulin concentration status in response to a better metabolic status, as seen through lower NEFA and BHB serum concentrations (Al Ibrahim et al., 2013). Taken together, the observations here for cows with BCS loss in the last 15 d prepartum and those of Cardoso et al. (2013), where cows were fed a controlled energy diet in the close-up dry period, indicate that nutritional restrictions in the immediate prepartum period may have negative consequences for the insulin status of dairy cows both pre- and postpartum.

During negative energy balance, the liver becomes resistant to growth hormone (GH) due to the reduction in the expression of GH type 1A receptor, reducing the hepatic synthesis of IGF-I (Thissen et al., 1994). This reduction in serum IGF-I concentration can have negative implications for the dairy cow, particularly in the areas of fertility (Taylor et al., 2004) and embryo survival (Heyner, 1997). Thus, our observations of the tendency to have reduced serum concentrations of IGF-I in wk 1 postcalving for BCS-L cows ($P < 0.10$) is yet another detrimental consequence of prepartum BCS loss.

Calcium

Cows in the BCS-L group had reduced BCS and elevated serum concentrations of NEFA and BHB. Furthermore, these cows had a tendency for reduced calcium at wk 0 relative to calving ($P < 0.10$). This is in agreement with previous studies that demonstrated that cows with hypocalcemia also had increased serum concentrations of NEFA (Reinhardt et al., 2011; Martinez et al., 2014). Results from this and previous studies show that serum calcium concentration at the time of calving could be used as a biomarker for the energy status of the cow as well as an indicator for the risk of milk fever (Østergaard et al., 2003).

Cows with BCS loss prepartum may have had lower feed intake, which may have influenced serum calcium concentration. However, it would be difficult to attach any certainty to the reasons behind these observations. This study presents interesting results on the effects of the loss of BCS 15 d before calving. However, because this study was conducted on one commercial farm, further research is required on a greater number of farms across different environments.

CONCLUSIONS

The transition period is an important part of the cows' production cycle. This study showed that cows that lost body condition in the 15 d before calving had an adverse metabolic reaction, with increased serum concentrations of NEFA and BHB and reduced serum concentrations of insulin and IGF-I. Although we found no differences in milk production, the cows that lost BCS 15 d before calving had increased fat yield and percentage, increased SCS, and reduced lactose percentage. In addition, a greater percentage of these cows had BHB profiles that suggested they had a higher risk of subclinical ketosis. Overall, our results indicate that cows that lost BCS 15 d before calving have reduced production potential and poorer health status.

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