J. Dairy Sci. 101:4595–4614
https://doi.org/10.3168/jds.2017-13732

Association between body condition score change during the dry period and postpartum health and performance

Ricardo C. Chebel,*†[1] Luís G. D. Mendonça,‡ and Pietro S. Baruselli§
*Department of Large Animal Clinical Sciences, and
†Department of Animal Sciences, University of Florida, Gainesville 32611
‡Department of Animal Sciences and Industry, Kansas State University, Manhattan 66506
§Departamento de Reprodução Animal, Universidade de São Paulo, São Paulo, Brazil 03178-200

ABSTRACT

The objectives of the current study were to determine the association between body condition score change during the dry period (ΔBCS) and postpartum health and reproductive and productive performance of Holstein cows. Data from 16,104 lactations from 9,950 parous cows from 2 dairies located in the San Joaquin Valley of California were used. Within dairy, cows were scored for body condition at dry off and parturition by the same herd workers, who were trained by veterinarians from the Veterinary Medicine Teaching and Research Center of the University of California Davis. Cows were classified as having excessive loss of BCS (ΔBCS ≤ -0.75; n = 1,604), moderate loss of BCS (ΔBCS = −0.5 to −0.25; n = 6,430), no change in BCS (ΔBCS = 0; n = 4,819), and gained BCS (ΔBCS ≥ 0.25; n = 3,251). Data regarding morbidity, mortality, and reproductive and productive performance were recorded until 305 d postpartum or until cows were dried off or left the herd. Loss of BCS during the dry period was associated with greater incidence of uterine disease and indigestion. Additionally, loss of BCS during the dry period was associated with greater likelihood of treatment with antimicrobials, anti-inflammatories, and supportive therapy. Loss of BCS during the dry period was associated with reduced likelihood of pregnancy after the first and second postpartum inseminations. Cows that gained BCS during the dry period had greater yield of milk, fat, and protein and had reduced somatic cell linear score in the subsequent lactation. In the current study, loss of BCS during the dry period was a predisposing factor associated with health disorders and reduced productive and reproductive performance in Holstein cows.
Key words: body condition score, dry period, lactating dairy cows, performance

Received August 23, 2017.
Accepted December 13, 2017.
[1]Corresponding author: rcchebel@ufl.edu

INTRODUCTION

The prepartum period has been identified as critical to the health and performance of lactating dairy cows. Cows that have decreased DMI during the prepartum period and that have greater decrease in DMI in the last days of gestation are more likely to have impaired innate immunity (Hammon et al., 2006) and are more likely to have health disorders (Huzzey et al., 2007). Although not completely understood, the association between reduced DMI peripartum and impaired innate immunity is likely a consequence of several factors, such as reduced IGF-I concentrations (Inoue et al., 1998; Wathes et al., 2009; Sander et al., 2011), increased concentrations of nonesterified fatty acid peripartum (Klucinski et al., 1988; Rukkwamsuk et al., 1999; Hammon et al., 2006), and increased BHB concentrations postpartum (Erb and Grohn, 1988; Gröhn et al., 1989; Correa et al., 1993). A strong positive correlation exists between prepartum and postpartum DMI (Grummer et al., 2004), suggesting that greater milk yield and improved performance should be obtained by minimizing the decline in DMI prepartum. Others have suggested that improvements in metabolic parameters may be achieved by restricting energy intake during the last weeks of gestations, with positive effects on reproductive performance (Cardoso et al., 2013); but questions remain regarding the effects of restricted energy intake prepartum on subsequent milk yield. In large dairy herds, monitoring individual DMI is not possible, and herds that attempt to measure it evaluate DMI of a group and not individuals. Body condition score and BCS change may, however, be used as indirect measures of fatness and energy balance, respectively, for individual cows (Roche et al., 2009).

Reduced BCS at calving is associated with lower milk yield and reduced likelihood of pregnancy, whereas elevated BCS at calving is associated with greater likelihood of postpartum metabolic diseases (reviewed by Roche et al., 2009). North American Holstein cows with BCS >4 in the prepartum period tend to have a more dramatic decrease in peripartum DMI and more pronounced and prolonged negative energy balance postpartum compared with thinner cows (reviewed by Grummer et al., 2004). As such, cows with elevated BCS at parturition are more likely to have hepatic lipidosis, ketosis, and displacement of abomasum (Roche et al., 2009; Ospina et al., 2010). Little is known, however, regarding the association between BCS change during the dry period (**ΔBCS**) and postpartum health of dairy cows. Contreras et al. (2004) demonstrated that cows with BCS ≤3 at dry off gained BCS during the dry period and were less likely to have retained fetal membranes compared with cows with BCS ≥3.25 at dry off. Cows managed from late gestation to 21 d before the expected calving date to be thinner (2.75 vs. 3.25) had neutrophils with reduced inflammatory state and an enhanced capacity for microbial destruction (Crookenden et al., 2017). Kadivar et al. (2014) suggested, however, that reduced BCS 2 wk prepartum was associated with increased incidence of clinical endometritis, but change in BCS from 2 wk prepartum to 2 or 4 wk postpartum was not associated with clinical endometritis.

The hypothesis of the current study was that ΔBCS is associated with incidence of postpartum health disorders, yield of milk and milk components, and reproductive performance. Furthermore, we hypothesized that ΔBCS is mainly explained by BCS at dry off (**BCSD**) and that BCSD is a consequence of reproductive and productive performance. The objectives of the current study were to evaluate the associations between ΔBCS and postpartum health and performance of lactating Holstein cows. Additionally, the current study aimed to determine factors associated with ΔBCS in the dry period and BCSD.

MATERIALS AND METHODS

Animals, Facilities, and Management

Holstein cows from 2 commercial dairies located in the San Joaquin Valley of California (Kings County), within 16 km of the city of Hanford, were used in this retrospective observational study. Only data from parous cows (≥1st lactation at dry off) that had gestation length of 256 to 296 d (Vieira-Neto et al., 2017) and that remained in the dry period for 22 to 100 d were used. A total of 5,263 lactations from 3,026 cows from dairy A and 10,841 lactations from 6,924 cows from dairy B met the enrollment criteria and were used in the current study. During the study period, the rolling herd average was 11,329 kg/cow in dairy A and 10,691 kg/cow in dairy B. Lactating cows in dairy A were housed in open lot corrals with capacity for 140 cows. Lactating cows in dairy B were housed in freestall pens with capacity for 160 or 350 cows. During lactation, cows were fed diets formulated to meet or exceed nutrient requirements for lactating Holstein cows weighing 650 kg and producing 45 kg of 3.5% FCM (NRC, 2001). During the dry period, cows were fed 2 diets, one from 60 to 25 d before the expected calving date and the other from 24 d before the expected calving date to calving, formulated to meet the requirements of nonlactating Holstein cows weighing 725 kg, with conceptus gaining approximately 0.6 to 0.7 kg/d, and DMI between 15 (60 to 25 d before the expected calving date) and 10 kg/d (24 d before the expected calving date to calving; NRC, 2001).

Cows were dried off at approximately 220 d of gestation. At dry off, cows received an intramammary treatment with a long-acting antimicrobial for the prevention of mastitis. In dairy A, cows were housed in open lot corrals during the entire dry period. In dairy B, far-off (60 to 25 d before the expected date of parturition) cows were housed in either open lot corrals or freestall pens, and close-up (24 d before the calving date to parturition) cows were housed in open lot corrals.

BCS and Classification

Body condition score was assessed on the day cows were dried off and at the maternity pen immediately after parturition. The herd personnel was trained by veterinarians of the Veterinary Medicine Teaching and Research Center of the University of California Davis to use the visual technique to determine the BCS on a scale of 1 (severe underconditioning) to 5 (severe overconditioning) in 0.25 increments (Ferguson et al., 1994). Cows were classified according to ΔBCS as excessive loss (**ELBCS**; ΔBCS ≤−0.75 unit), moderate loss (**MLBCS**; ΔBCS = −0.50 to −0.25), no change (**NCBCS**; ΔBCS = 0), and gained BCS (**GBCS**; ΔBCS ≥0.25) during the dry period. Moderate loss of BCS included cows with ΔBCS −0.50 and −0.25 because, in a preliminary analysis of pregnancy to first postpartum AI and mean milk yield in the first 60 DIM, no differences were observed between these cows, but cows with ΔBCS of −0.50 and cows with ΔBCS of −0.25 were different compared with NCBCS and GBCS cows.

Data Collection

Data regarding parity at dry off (primiparous vs. multiparous), length of the dry period, length of gestation, date of calving, calf sex (female vs. male), and number of calves born (singleton vs. twins) were collected from the on-farm computer software (Dairy

Comp 305; Valley Ag Software, Tulare, CA). Gestation length was classified as short (**SGL**; ≤273 d), normal (**NGL**; 274–283 d), and long (**LGL**; ≥284 d). Length of the dry period was classified as short (**SDP**; ≤47 d), normal (**NDP**; 48–69 d), and long (**LDP**; ≥70 d). The classification of gestation and dry period lengths were determined by subtracting or adding 1 standard deviation to the mean of the population. Weather data were collected from the weather station at the Visalia airport, which was located approximately 24 km from each of the dairies. Daily temperature-humidity index (**THI**) was calculated. Percentages of days with THI ≥72 during the 60 d before dry off and during the dry period were recorded. Cows were classified as exposed to no heat stress (**NHS**) when <35% of days had THI ≥72, whereas cows were classified as being exposed to heat stress (**HS**) when ≥35% of days had THI ≥72. The classification of exposure to heat stress was determined by adding 1 standard deviation to the mean of percentage of days with THI ≥72 for the study population.

Disease Definition

Disease diagnosis and treatment and data collection and input into the on-farm software (Dairy Comp 305; Valley Ag Software, Tulare, CA) was performed by dairy personnel trained and supervised by veterinarians of the Veterinary Medicine Teaching and Research Center of the University of California Davis. Cows were observed daily from parturition to 21 d postpartum for milk fever, retained fetal membranes, and metritis. A case of milk fever was defined as a prostrated cow with minimal rumen contractions that responded to intravenous calcium treatment within 30 min. Retained fetal membranes was defined as the failure to detach the fetal membranes within 24 h postpartum. Metritis was characterized by the presence of fetid, watery, red or pink uterine discharge within the first 21 d postpartum. From parturition to 60 d postpartum, occurrence of ketosis, displacement of the abomasum, mastitis, indigestion, respiratory disease, lameness, and prostration without a confirmed diagnosis were recorded. Cows with decreased appetite and altered pattern of milk production had urine tested for ketone bodies (Keto-Stix, Bayer Diagnostics, Tarrytown, NY) and those that tested at or above moderate were classified as ketotic. Cows with a metallic ("ping") sound at percussion-auscultation of the left or right abdomen (between the 4th and 13th rib) were diagnosed with displacement of the abomasum, which was confirmed by laparotomy to correct the displacement of the abomasum. Cows with scant manure, lack of appetite, and rumen stasis were diagnosed with indigestion. Respiratory disease was characterized by panting, rectal temperature >39.5°C, and crackling, rales, or percussion dullness when auscultating the lungs. Cows presenting prostration, fever (rectal temperature >39.5°C), anorexia, dehydration, and depressed without a confirmed diagnosis for the diseases described previously within 0 ± 7 d were recorded as undefined sickness. Occurrence of retained fetal membranes and metritis were grouped into 1 variable, uterine disease. Milk fever, ketosis, and displacement of the abomasum were grouped into 1 variable, metabolic disease. Cows with a diagnosis of respiratory disease and cows with undefined sickness were grouped into other diseases.

Additionally, all treatments from parturition to 60 d postpartum were recorded and were grouped into parenteral (except for intramammary) antimicrobials, oral and parenteral anti-inflammatories, and supportive therapy (e.g., oral drench, intravenous fluids).

Cows with traumatic events (e.g., cesarean section, udder/teat cuts, broken limb) were excluded from the study (n = 640). Health records of all lactations were inspected and cows with clinical diseases (e.g., mastitis, indigestion, lameness, and so on) and cows receiving antimicrobial, anti-inflammatory, and supportive therapies during the last 150 d of gestation were excluded from the study (n = 1,605).

Reproductive Management and Performance

Cows had their estrous cycle presynchronized with 2 injections of $PGF_{2\alpha}$ given 14 d apart. Cows not observed in estrus within 12 to 14 d after the second $PGF_{2\alpha}$ of the presynchronization protocol were submitted to an ovulation synchronization protocol (e.g., Ovsynch56, Ovsynch48, Cosynch72, 5dCosynch72; http://www.dcrcouncil.org/wp-content/uploads/2017/03/Dairy_Cow_Reproduction_Protocols_Final09302015.pdf). Cows observed in estrus after AI were reinseminated in the same morning. Daily, cows were observed for signs of estrus, which included removal of tail paint, vaginal mucous discharge, increased nervousness and activity, swelling and reddening of the vulva, or standing to be mounted. Cows were examined for pregnancy between 35 ± 7 d after AI, with pregnancy exams between 28 and 34 d after AI conducted by transrectal ultrasound and pregnancy exams between 35 and 42 d after AI conducted by transrectal manual palpation of the reproductive organs. Cows diagnosed pregnant were re-examined for pregnancy 67 ± 3 d after AI by transrectal manual palpation of the reproductive organs. Cows diagnosed not pregnant at pregnancy exam were submitted to an ovulation synchronization protocol.

Pregnancies per AI (**P/AI**) 35 ± 7 and 67 ± 3 d after the first and second postpartum AI were calculated and the percentages of pregnant cows that had pregnancy loss between 35 ± 7 and 67 ± 3 d after the first and second postpartum inseminations were calculated. Hazard of pregnancy was calculated for all cows up to 305 d postpartum, and cows were censored when they left the herd or were deemed ineligible for insemination by farm personnel.

Milk Production Data Collection

In both herds, cows were milked thrice daily. Herds were enrolled in the regular DHIA program for approximately 66% of the study period, and monthly yield of milk, milk components, and SCC were recorded for individual cows. Data regarding milk fat and protein content, 3.5% FCM yield, and somatic cell linear score were available for approximately 68.3% of milk records. In the current study, the first milk test in the lactation was between 5 and 34 DIM and milk yield records before 5 DIM were not used. Milk yield data were collected up to 305 d postpartum or until the cow was dried off or left the herd. Somatic cell linear score within 60 d before dry off from 9,837 lactations was evaluated to determine whether differences in somatic cell linear score postpartum could result from a carryover effect of the previous lactation. Cows from both dairies were treated with bST (Posilac, sometribove zinc suspension for injection, Elanco Animal Health, Greenfield, IN) every 14 d from 70 ± 3 DIM to 14 d before the expected dry off date.

Statistical Analysis

This was a retrospective observational study. Body condition score at dry off and ΔBCS were analyzed by ANOVA using the MIXED procedure of SAS (version 9.3, SAS Institute Inc., Cary, NC). Independent variables included in the analysis of factors associated with BCSD included dairy, parity (primiparous vs. multiparous), calf sex (female vs. male), number of calves born (singleton vs. twins), 305-d mature equivalent milk yield at the end of the lactation, interval from calving to conception, and exposure to heat stress 60 d before dry off. The statistical model for analysis of factors associated with ΔBCS included dairy, parity, calf sex, number of calves born, dry period length, gestation length, exposure to heat stress during the dry period, and BCSD. Cow was included in the model as a random effect. The likelihood of GBCS during the dry period was analyzed by logistic regression using the GLIMMIX procedure of SAS with the logit function and binomial distribution. The statistical model for analysis of factors associated with the likelihood of GBCS during the dry period included dairy, parity, calf sex, number of calves born, dry period length, gestation length, exposure to heat stress during the dry period, and BCSD (continuous: linear, quadratic, cubic). Cow was included in the model as a random effect. Independent variables with $P > 0.05$ were manually removed until all variables left had $P \leq 0.05$. Receiver operator characteristics was used to determine the BCSD that predicted GBCS with the highest sensitivity and specificity (Medcalc, Ostend, Belgium).

Binomial data (e.g., likelihood of disease, likelihood of treatment, likelihood of pregnancy) were analyzed by logistic regression using the GLIMMIX procedure of SAS with the logit function and binomial distribution. Time-dependent variables (e.g., hazard of removal from the herd and hazard of pregnancy) were analyzed by Cox proportional hazard regression analysis using the PHREG procedure of SAS. The statistical models included ΔBCS, dairy, parity, calf sex, number of calves born, gestation length, dry period length, exposure to heat stress, and the interactions between ΔBCS and dairy, ΔBCS and parity, ΔBCS and gestation length, ΔBCS and length of the dry period, and ΔBCS and exposure to heat stress. The statistical models to evaluate the association between ΔBCS and P/AI and pregnancy loss also included insemination code (estrus vs. fixed time). Cow was included in the model as a random effect. Independent variables with $P > 0.05$ were manually removed from the logistic regression models until all variables left had $P \leq 0.05$. The Cox proportional hazard regression models removed independent variables by a backward elimination based on the Wald's statistics criterion when $P > 0.05$. The associations between ΔBCS and the interval from parturition to removal from the herd and from parturition to establishment of pregnancy were analyzed by survival analysis using the product limit method of the Kaplan-Meier model by the LIFETEST procedure of the SAS.

Continuous data with repeated measures such as milk yield, yield of milk components, and somatic cell linear score were analyzed by ANOVA using the MIXED procedure of SAS using the repeated statement. The statistical models included ΔBCS, dairy, parity, calf sex, number of calves born, gestation length, dry period length, exposure to heat stress, month of lactation, and the interactions between ΔBCS and dairy, ΔBCS and parity, ΔBCS and gestation length, ΔBCS and length of the dry period, ΔBCS and exposure heat stress, and between ΔBCS and month of lactation. Cow was included in the model as a random effect. Independent variables with $P > 0.05$ were manually removed from the logistic regression models until all variables left had $P \leq 0.05$.

For each of the statistical models, collinearity was tested using the REG procedure of SAS with the "collin" and "VIF" functions. Variables with variance inflation factors ≥1.5 were considered collinear. In such cases, each variable was added to the model separately and the variable with the smallest P-value was retained. Statistical significance was defined as $P \leq 0.01$ and statistical tendencies as $0.01 < P \leq 0.05$. The Tukey-Kramer adjustment for multiple comparisons was applied when independent variables had more than 2 levels.

RESULTS

The mean BCSD (±SEM) were 4.08 ± 0.006, 3.75 ± 0.004, 3.51 ± 0.004, and 3.29 ± 0.005 for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively, and the mean BCS (±SEM) at calving were 3.19 ± 0.007, 3.37 ± 0.005, 3.47 ± 0.005, and 3.58 ± 0.006 for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively (Figure 1).

Factors associated with BCSD were dairy ($P < 0.001$), parity ($P < 0.001$), 305-d mature equivalent milk yield ($P < 0.001$), interval from calving to conception ($P < 0.001$), and exposure to heat stress in the last 60 d before dry off ($P = 0.003$). Individual cow explained 54.0% of the variability in BCSD, whereas the independent variables explained only 6.9% of the variability in BCSD. Parity, dairy, and 305-d mature equivalent milk yield made the greatest contributions to the variability in BCSD explained by the model (Figure 2 A). Factors associated with ΔBCS were BCSD ($P < 0.001$), dairy ($P < 0.001$), parity ($P < 0.001$), gestation length ($P < 0.001$), dry period length ($P < 0.001$), 305-d mature equivalent milk yield ($P < 0.001$), calf sex ($P < 0.001$), and number of calves born ($P < 0.001$). Individual cow explained 22.4% of the variability in ΔBCS, but the independent variables explained 57.4% of the variability in ΔBCS. Body condition score at dry off made the greatest contribution to the variability in ΔBCS explained by the model (Figure 2 B).

The probability of GBCS was dependent on dairy ($P < 0.001$), parity ($P < 0.001$), BCSD (linear, $P = 0.02$; quadratic, $P < 0.001$; Figure 3), length of the dry period ($P < 0.001$), and number of calves born ($P < 0.001$). The adjusted odds ratio (**AOR**) and 95% CI for factors associated with GBCS were dairy [A = 1.47 (1.32, 1.63), B = referent]; parity [primiparous = 0.53 (0.48, 0.58), multiparous = referent]; length of the dry period [SDP = 0.70 (0.60, 0.82), NDP = referent, LDP = 1.33 (1.14, 1.54)]; and number of calves born [singleton = 3.23 (2.52, 4.14), twins = referent]. The receiver operator characteristics analysis indicated that the BCSD that most accurately predicted the likelihood of GBCS was BCSD ≤3.25 (sensitivity = 70.0%, specificity = 85.1%; area under the curve = 0.86, 95% CI = 0.85–0.86; $P < 0.001$).

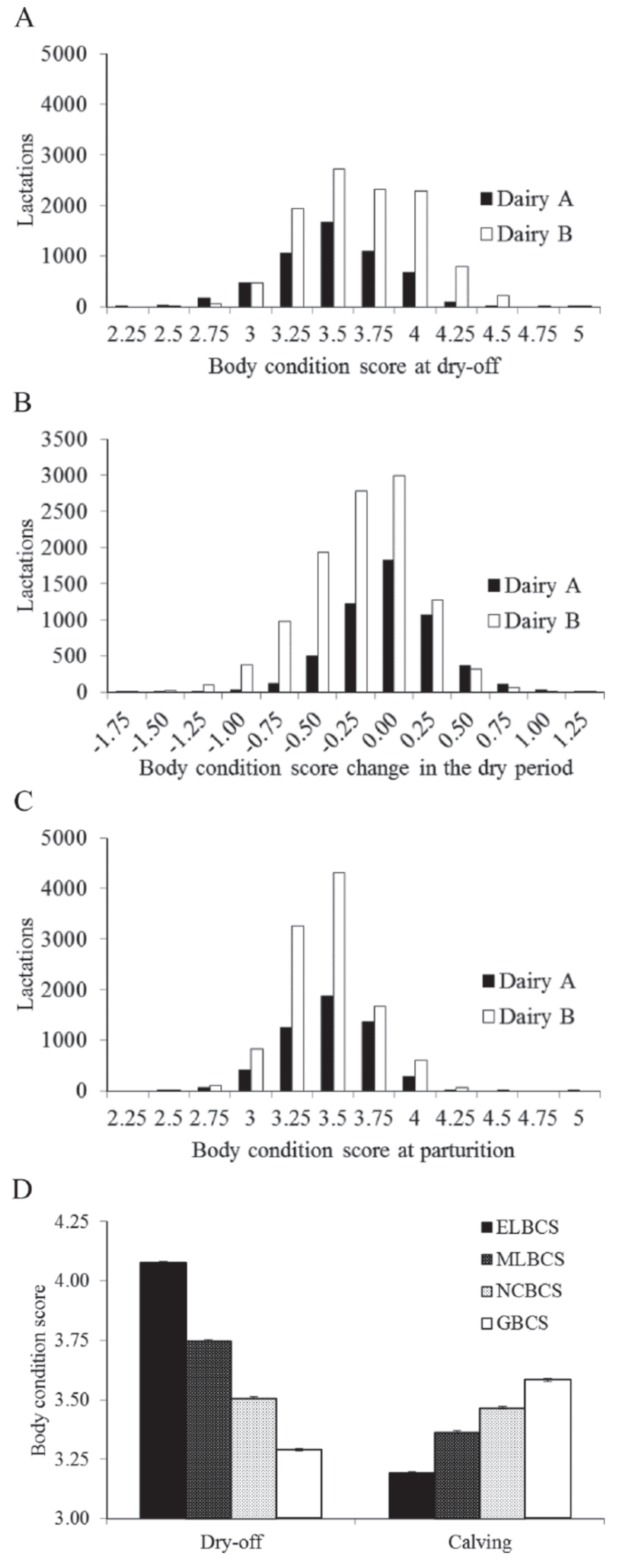

Figure 1. Distribution of BCS at dry off (A), BCS change during the dry period (B), and BCS at calving (C) according to dairy, and mean (±SEM) BCS at dry off and BCS at calving according to change in BCS during the dry period (ΔBCS; D). ELBCS = cows with ΔBCS ≤−0.75; MLBCS = cows with ΔBCS of −0.5 to −0.25; NCBCS = cows with ΔBCS of 0; GBCS = cows with ΔBCS ≥0.25.

Association Between ΔBCS and Health Outcomes

We noted a tendency (P = 0.04) for the interaction between ΔBCS and length of the dry period to be associated with the likelihood of stillbirth. Among cows with NDP, incidence of stillbirth was relatively constant according to ΔBCS (ELBCS = 3.60, MLBCS = 4.15, NCBCS = 4.23, GBCS = 3.22%). Among cows with SDP, incidence of stillbirth was slightly higher for NCBCS cows (ELBCS = 5.80, MLBCS = 5.13, NCBCS = 6.99, GBCS = 4.85%), whereas the incidence of stillbirth among cows with LDP was higher for ELBCS and MLBCS cows (ELBCS = 7.14, MLBCS = 7.34, NCBCS = 3.31, GBCS = 4.31%). We observed a tendency (P = 0.04) for primiparous cows (AOR = 0.84, 95% CI = 0.71–0.99) to be less likely to have stillbirths than multiparous cows. Additionally, cows that delivered female (AOR = 0.55, 95% CI = 0.47–0.66; P < 0.001) and singleton (AOR = 0.17, 95% CI = 0.14–0.21; P < 0.001) calves were less likely to have stillbirths than cows that delivered male and twin calves, respectively. Gestation length was (P < 0.001) associated with the likelihood of stillbirth because cows with SGL were (AOR = 2.32, 95% CI = 1.89–2.86) more likely to have stillborn calves compared with NGL (referent) and LGL (AOR = 1.20, 95% CI = 0.94–1.53). Cows that were not exposed to heat stress during the dry period were (AOR = 0.78, 95% CI = 0.84–0.93; P = 0.007) less likely to deliver stillborn calves.

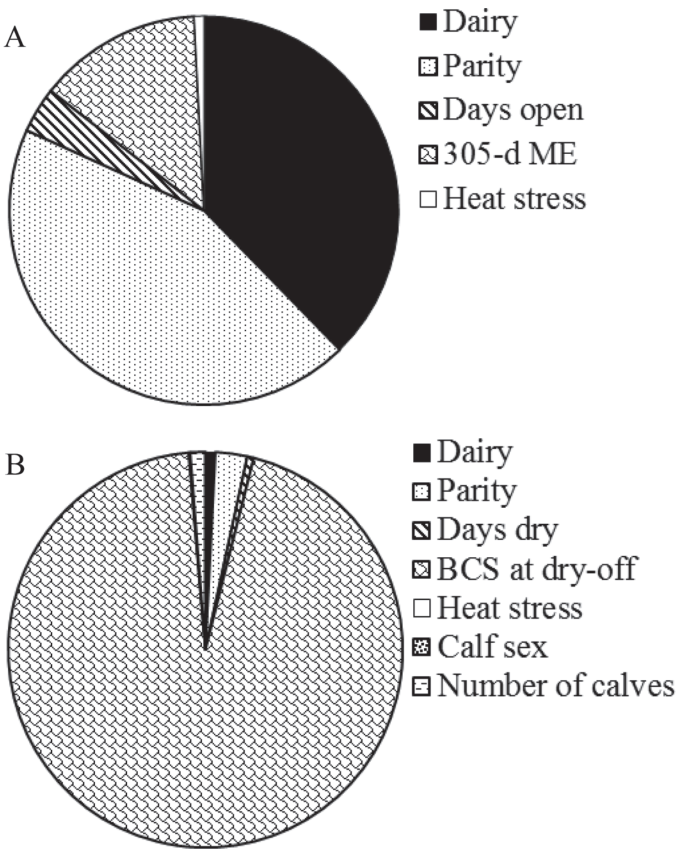

Figure 2. Proportion of variation (%) in BCS at dry off (A) and BCS change during the dry period (B) explained by independent variables retained in the multivariate model. Coefficient of determination of multivariate model for BCS at dry off = 6.9% (dairy = 38%, parity = 44%, days open = 4%, 305-d ME = 14%, heat stress = 1%); R^2 of multivariate model for BCS change during the dry period = 57.4% (dairy = 0.8%, parity = 2.6%, length of the dry period = 0.5%, BCS at dry off = 94.7%, percentage of days with temperature-humidity index ≥72 = 0.04%, calf sex = 0.09%, number of calves born = 1.2%). Heat stress: Cows were classified as exposed to no heat stress when <35% of days had temperature-humidity index ≥72, whereas cows were classified as being exposed to heat stress when ≥35% of days had temperature-humidity index ≥72. 305-d ME = 305-d milk yield mature equivalent.

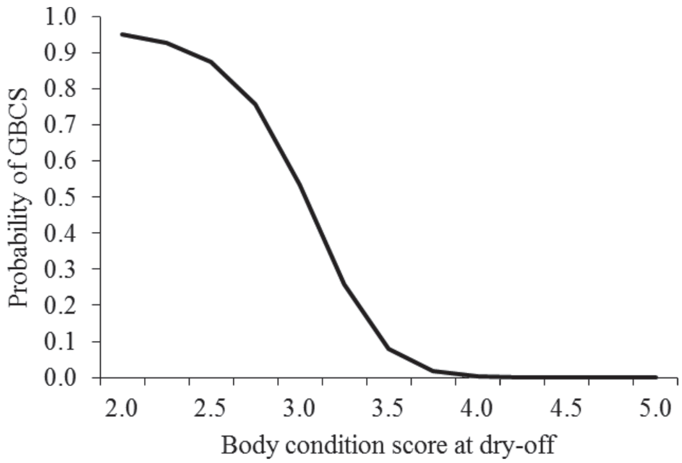

Figure 3. Probability of cows gaining BCS during the dry period (GBCS) according to BCS at dry off based on the results of the multivariate logistic regression. Effect of BCS at dry off (linear, P = 0.02; quadratic, P < 0.001), dairy (P < 0.001), parity (P < 0.001), length of the dry period (P < 0.001), and number of calves born (P < 0.001).

We observed (P < 0.001) an association between ΔBCS and the likelihood of uterine disease (Table 1). Cows with ELBCS were (P < 0.001) more likely to be diagnosed with uterine disease than MLBCS, NCBCS, and GBCS cows. Although the likelihood of uterine disease did not differ between MLBCS and NCBCS cows (P = 0.77) and between NCBCS and GBCS cows (P = 0.12), MLBCS cows were (P = 0.01) more likely to be diagnosed with uterine disease than GBCS cows. Cows from dairy A were (P < 0.001) more likely to be diagnosed with uterine diseases than cows from dairy B (Table 1). Additionally, gestation length was (P < 0.001) associated with the likelihood of uterine disease because cows with SGL were more likely to be diagnosed with uterine disease than NGL and LGL cows (Table 1). Dry period length was (P < 0.001) associated with the likelihood of uterine disease because cows with

Table 1. Final logistic regression model of factors associated with uterine diseases postpartum

Independent variable	Incidence, % (n)	Odds ratio	95% CI	*P*-value
ΔBCS[1]				<0.001
ELBCS	15.8 (1,604)	1.68[a]	1.39, 2.03	
MLBCS	13.6 (6,430)	1.24[b,x]	1.08, 1.42	
NCBCS	13.3 (4,819)	1.17[b]	1.02, 1.35	
GBCS	12.2 (3,251)	Referent[b,y]		
Dairy				<0.001
A	20.9 (5,263)	3.00	2.68, 3.34	
B	9.8 (10,841)	Referent		
Calf sex				<0.001
Female	11.9 (7,530)	0.79	0.71, 0.87	
Male	15.2 (8,154)	Referent		
Number of calves born				<0.001
Singleton	12.3 (14,665)	0.39	0.34, 0.46	
Twins	31.6 (1,019)	Referent		
Gestation length				<0.001
≤273 d	23.2 (2,335)	1.64[a]	1.44, 1.87	
274–283 d	11.8 (11,123)	Referent[b]		
≥284 d	11.8 (2,646)	1.01[b]	0.87, 1.17	
Length of the dry period				<0.001
≤47 d	17.9 (2,515)	1.86[a]	1.61, 2.15	
48–69 d	12.0 (11,477)	Referent[b,A]		
≥70 d	16.1 (2,112)	1.22[b,B]	1.05, 1.41	

[a,b]Within parameter, rows with different superscripts differ ($P \leq 0.01$).

[x,y]Within parameter, rows with different superscripts differ ($P \leq 0.01$).

[A,B]Within parameter, rows with different superscripts tend to differ ($0.01 < P \leq 0.05$).

[1]ΔBCS = body condition score change during the dry period; ELBCS = cows with ΔBCS ≤−0.75; MLBCS = cows with ΔBCS of −0.5 to −0.25; NCBCS = cows with ΔBCS of 0; GBCS = cows with ΔBCS ≥0.25.

SDP were ($P < 0.001$) and cows with LDP tended to be ($P = 0.03$) more likely to be diagnosed with uterine disease than cows with NDP (Table 1).

Change in BCS during the dry period was not ($P = 0.36$) associated with the likelihood of metabolic diseases. Cows from dairy A were (AOR = 12.4, 95% CI = 9.28–16.57; $P < 0.001$) more likely to have metabolic diseases than cows from dairy B. Primiparous cows were (AOR = 0.24, 95% CI = 0.18–0.30; $P < 0.001$) less likely to have metabolic diseases than multiparous cows. Additionally, cows that delivered female calves tended to be (AOR = 0.80, 95% CI = 0.65–0.98; $P = 0.03$) and cows that delivered singletons were (AOR = 0.38, 95% CI = 0.29–0.50; $P < 0.001$) less likely to have metabolic diseases than cows that delivered male and twin calves, respectively. Length of the dry period was ($P < 0.001$) associated with the likelihood of metabolic diseases because LDP cows were (AOR = 1.70, 95% CI = 1.36–2.13; $P < 0.001$) more likely to have metabolic diseases compared with NDP cows (referent), but SDP cows (AOR = 1.50, 95% CI = 0.96–2.35) did not differ from LDP ($P = 0.87$) and NDP ($P = 0.18$) cows.

The interaction between ΔBCS and parity tended ($P = 0.03$) to be associated with the likelihood of indigestion (Table 2). Primiparous cows with ELBCS and GBCS had reduced incidence of indigestion compared with MLBCS and NCBCS primiparous cows (ELBCS = 1.11, MLBCS = 2.48, NCBCS = 2.03, GBCS = 1.17%), but the likelihood of indigestion was greatest among multiparous cows with ELBCS and lowest among multiparous cows with GBCS (ELBCS = 5.35, MLBCS = 4.39, NCBCS = 3.55, GBCS = 2.94%). Cows that delivered singletons were ($P < 0.001$) less likely to have indigestion than cows that delivered twins (Table 2). Length of the dry period was ($P < 0.001$) associated with the likelihood of indigestion because cows with SDP and LDP were more likely to have indigestion than cows with NDP (Table 2). Cows that were not exposed to heat stress during the dry period were ($P = 0.01$) less likely to have indigestion than cows exposed to heat stress (Table 2).

The interaction between ΔBCS and parity tended ($P = 0.05$) to be associated with the likelihood of lameness within 60 d postpartum. Although the likelihood of lameness was slightly lower among NCBCS primiparous cows (ELBCS = 2.8%, MLBCS = 2.5%, NCBCS = 1.8%, GBCS = 2.6%), the likelihood of lameness was lowest in ELBCS multiparous cows (ELBCS = 2.6%, MLBCS = 4.3%, NCBCS = 4.4%, GBCS = 4.2%). We noted a tendency ($P = 0.02$) for cows that delivered singletons to be more likely (AOR = 1.68, 95% CI = 1.09–2.60) to be lame within 60 d postpartum than cows that delivered twins. Cows that were not exposed to heat stress tended ($P = 0.05$) to be less likely (AOR = 0.81, 95% CI = 0.65–1.00) to be lame than cows exposed to heat stress.

Change in BCS during the dry period was not (P = 0.07) associated with the likelihood of mastitis within 60 d postpartum. Cows from dairy A were (AOR = 2.11, 95% CI = 1.87–2.38; $P < 0.001$) more likely to be diagnosed with mastitis within 60 d postpartum than cows from dairy B. Primiparous cows were (AOR = 0.53, 95% CI = 0.47–0.60; $P < 0.001$) less likely to be diagnosed with mastitis within the first 60 d postpartum than multiparous cows.

We observed no (P = 0.29) association between ΔBCS and the likelihood of other diseases within 60 d postpartum. Cows from dairy A were (AOR = 8.08, 95% CI = 6.49–10.06; $P < 0.001$) more likely to have other diseases than cows from dairy B. Primiparous cows (AOR = 0.62, 95% CI = 0.52–0.74; $P < 0.001$) and cows that delivered singletons (AOR = 0.41, 95% CI = 0.32–0.53; $P < 0.001$) were less likely to have other diseases within 60 d postpartum than multiparous cows and cows that delivered twins, respectively. We noted a tendency (P = 0.04) for the length of the dry period to be associated with the likelihood of other diseases because LDP cows tended to be (AOR = 1.31, 95% CI = 1.06–1.61; P = 0.04) more likely to be have other diseases than NDP cows (referent), but SDP cows (AOR = 0.93, 95% CI = 0.63–1.38) did not differ from LDP (P = 0.26) and NDP (P = 0.93) cows.

The interaction between ΔBCS and the dry period length tended (P = 0.04) to be associated with the likelihood of treatment with antimicrobials. Among cows with short (ELBCS = 17.4%, MLBCS = 19.3%, NCBCS = 18.1%, GBCS = 14.3%) and normal (ELBCS = 11.9%, MLBCS = 9.9%, NCBCS = 10.6%, GBCS = 8.9%) dry periods, GBCS cows were less likely to be treated with antimicrobials; however, among cows with long dry periods, cows with NCBCS and GBCS were less likely to be treated with antimicrobials (ELBCS = 18.5%, MLBCS = 17.1%, NCBCS = 12.2%, GBCS = 13.7%). Cows from dairy A were ($P < 0.001$) more likely to be treated with antimicrobials than cows from dairy B (Table 3). Primiparous cows were ($P < 0.001$) less likely to be treated with antimicrobials than multiparous cows (Table 3). Cows that delivered female ($P < 0.001$) and singleton ($P < 0.001$) calves were less likely to be treated with antimicrobials than cows that delivered male and twin calves, respectively (Table 3). Gestation length was ($P < 0.001$) associated with the likelihood of treatment with antimicrobials because cows with SGL were ($P < 0.001$) more likely to be treated with antimicrobials than cows with NGL and LGL, whereas we observed no difference between cows with NGL and LGL (Table 3). Cows that were not exposed to heat stress during the dry period were ($P < 0.001$) less likely to be treated with antimicrobials than cows exposed to heat stress (Table 3).

The interaction between ΔBCS and parity tended (P = 0.04) to be associated with the likelihood of treatment with anti-inflammatories. Primiparous cows that gained BCS during the dry period were less likely to

Table 2. Final logistic regression model of factors associated with indigestion within 60 d postpartum

Independent variables	Incidence, % (n)	Odds ratio	95% CI	P-value
ΔBCS[1]*				0.01
ELBCS	2.7 (1,604)	1.03	0.65, 1.63	
MLBCS	3.4 (6,430)	1.58[A]	1.16, 2.17	
NCBCS	2.8 (4,819)	1.40	1.01, 1.95	
GBCS	2.2 (3,251)	Referent[B]		
Parity				<0.001
Primiparous	2.0 (8,161)	0.39	0.30, 0.50	
Multiparous	3.9 (7,943)	Referent		
Number of calves born				<0.001
Singleton	2.7 (14,665)	0.56	0.42, 0.75	
Twins	5.7 (1,019)	Referent		
Length of the dry period				<0.001
≤47 d	4.7 (2,515)	2.44[a]	1.94, 3.08	
48–69 d	2.1 (11,477)	Referent[b]		
≥70 d	4.8 (2,112)	2.06[a]	1.61, 2.63	
Percentage of days in the dry period with THI[2] ≥72				0.01
<35%	2.7 (12,896)	0.76	0.61, 0.94	
≥35%	3.6 (3,208)	Referent		

[a,b]Within parameter, rows with different superscripts differ ($P \leq 0.01$).

[A,B]Within parameter, rows with different superscripts tend to differ ($0.01 < P \leq 0.05$).

[1]ΔBCS = body condition score change during the dry period; ELBCS = cows with ΔBCS ≤−0.75; MLBCS = cows with ΔBCS of −0.5 to −0.25; NCBCS = cows with ΔBCS of 0; GBCS = cows with ΔBCS ≥0.25.

[2]THI = temperature-humidity index.

*Interaction: ΔBCS × Parity (P = 0.03).

Table 3. Final logistic regression model of factors associated with treatment with parenteral antimicrobial within 60 d postpartum

Independent variable	Incidence, % (n)	Odds ratio	95% CI	P-value
ΔBCS[1]*				<0.001
ELBCS	14.1 (1,604)	1.57[a,A]	1.24, 2.00	
MLBCS	12.4 (6,430)	1.32[a]	1.10, 1.57	
NCBCS	11.8 (4,819)	1.15[B]	0.95, 1.39	
GBCS	10.1 (3,251)	Referent[b]		
Dairy				<0.001
A	15.9 (5,263)	2.06	1.83, 2.31	
B	10.0 (10,841)	Referent		
Parity				<0.001
Primiparous	9.7 (8,161)	0.65	0.58, 0.72	
Multiparous	14.2 (7,943)	Referent		
Calf sex				<0.001
Female	10.4 (7,530)	0.78	0.71, 0.87	
Male	13.4 (8,154)	Referent		
Number of calves born				<0.001
Singleton	10.9 (14,665)	0.44	0.37, 0.51	
Twins	27.2 (1,019)	Referent		
Gestation length				<0.001
≤273 d	20.0 (2,335)	1.38[a]	1.19, 1.58	
274–283 d	10.6 (11,123)	Referent[b]		
≥284 d	10.3 (2,646)	0.98[b]	0.83, 1.14	
Length of the dry period				<0.001
≤47 d	18.0 (2,515)	2.17[a]	1.84, 2.56	
48–69 d	10.0 (11,477)	Referent[b]		
≥70 d	14.9 (2,112)	1.31[c]	1.10, 1.57	
Percentage of days in the dry period with THI[2] ≥72				<0.001
<35%	11.3 (12,896)	0.81	0.72, 0.92	
≥35%	14.4 (3,208)	Referent		

[a–c]Within parameter, rows with different superscripts differ ($P \leq 0.01$).

[A,B]Within parameter, rows with different superscripts tend to differ ($0.01 < P \leq 0.05$).

[1]ΔBCS = body condition score change during the dry period; ELBCS = cows with ΔBCS ≤−0.75; MLBCS = cows with ΔBCS of −0.5 to −0.25; NCBCS = cows with ΔBCS of 0; GBCS = cows with ΔBCS ≥0.25.

[2]THI = temperature-humidity index.

*Interaction: ΔBCS × number of days in the dry period ($P = 0.04$).

be treated with anti-inflammatories (ELBCS = 10.6%, MLBCS = 8.3%, NCBCS = 7.9%, GBCS = 5.6%). Multiparous cows with NCBCS and GBCS were less likely to be treated with anti-inflammatories (ELBCS = 18.5%, MLBCS = 11.9%, NCBCS = 7.8%, GBCS = 7.9%). The interaction between ΔBCS and dry period length tended ($P = 0.03$) to be associated with the likelihood of treatment with anti-inflammatories. Among cows with SDP, GBCS cows were less likely to be treated with anti-inflammatories (ELBCS = 17.2%, MLBCS = 18.9%, NCBCS = 17.8%, GBCS = 13.7%); whereas among cows with LDP, NCBCS cows were less likely to be treated with anti-inflammatories (ELBCS = 17.8%, MLBCS = 12.2%, NCBCS = 6.9%, GBCS = 9.1%). Among cows with NDP, NCBCS and GBCS cows were less likely to be treated with anti-inflammatories (ELBCS = 11.4%, MLBCS = 7.4%, NCBCS = 6.3%, GBCS = 5.6%). Cows from dairy A were ($P < 0.001$) less likely to be treated with anti-inflammatories than cows from dairy B (Table 4). Primiparous cows were ($P < 0.001$) less likely to be treated with anti-inflammatories than multiparous cows (Table 4). Cows that delivered female calves ($P < 0.001$) and singletons ($P < 0.001$) were less likely to be treated with anti-inflammatories than cows that delivered male and twin calves, respectively (Table 4). Gestation length was ($P < 0.001$) associated with the likelihood of treatment with anti-inflammatories because SGL cows were more likely to be treated with anti-inflammatories than LGL and NGL cows (Table 4). Cows not exposed to heat stress during the dry period were ($P < 0.001$) less likely to be treated with anti-inflammatories than cows exposed to heat stress (Table 4).

We observed ($P < 0.001$) an association between ΔBCS and the likelihood of treatment with supportive therapy because ELBCS, MLBCS, and NCBCS cows were more likely to receive supportive therapy than GBCS cows (Table 5). Cows from dairy A were ($P < 0.001$) more likely to receive supportive therapy than cows from dairy B (Table 5). Primiparous cows were ($P < 0.001$) less likely to receive supportive therapy than multiparous cows (Table 5). Similarly, cows that delivered female ($P < 0.001$) and singleton ($P < 0.001$) calves were less likely to receive supportive therapy than cows that delivered male and twin calves, respectively (Table 5). Cows with SGL were ($P < 0.001$) more likely to receive supportive therapy than NGL and LGL cows, but we observed no difference between NGL and LGL cows (Table 5). Length of the dry period was ($P < 0.001$) associated with the likelihood of treatment with supportive therapy because SDP and LDP cows were ($P < 0.001$) more likely to receive supportive therapy than NDP cows (Table 5).

The interaction between ΔBCS and dry period length was ($P = 0.001$) associated with the likelihood of culling within 60 d postpartum. Cows with ELBCS and GBCS and SDP were less likely to be culled than MLBCS and NCBCS cows with SDP (ELBCS = 1.5%, MLBCS = 4.9%, NCBCS = 5.5%, GBCS = 2.2%). Among cows with LDP, GBCS cows were less likely to be culled than ELBCS, MLBCS, and NCBCS cows (ELBCS = 10.8%, MLBCS = 11.1%, NCBCS = 8.7%, GBCS = 5.7%). Among cows with NDP, those with ELBCS were less likely to be culled within 60 d postpartum than MLBCS, NCBCS, and GBCS cows (ELBCS = 2.0%, MLBCS = 4.6%, NCBCS = 5.5%, GBCS = 4.4%). Cows from dairy A were ($P < 0.001$) more likely to be culled within 60 d postpartum than cows from dairy B (AOR = 1.32, 95% CI = 1.13–1.54). Primiparous cows were ($P < 0.001$) less likely to be culled within 60 d postpartum than multiparous cows (AOR = 0.43, 95% CI = 0.36–0.50). Cows that delivered singletons were (AOR = 0.54, 95% CI = 0.43–0.68; $P < 0.001$) less likely to be culled within 60 d postpartum than cows delivering twins. Gestation length was ($P = 0.001$) associated with the likelihood of culling within 60 d postpartum because cows with SGL (AOR = 1.47, 95% CI = 1.20–1.81) were more likely to be culled within 60 d postpartum than cows with NGL (referent) and LGL (AOR = 1.01, 95% CI = 0.82–1.24).

The interactions between ΔBCS and parity ($P = 0.008$; Figure 4) and between ΔBCS and length of the dry period ($P < 0.001$; Figure 5) were associated with the hazard of removal from the herd up to 305 DIM. Cows that had ELBCS had (AHR = 0.30, 95% CI = 0.21–0.42; $P < 0.001$) reduced hazard of removal than GBCS cows. Cows that had NCBCS, however, had (AHR = 1.44, 95% CI = 1.26–1.66; $P < 0.001$) greater hazard of removal than GBCS cows. No difference in hazard of removal was observed between MLBCS (AHR

Table 4. Final logistic regression model of factors associated with treatment with parenteral anti-inflammatory within 60 d postpartum

Independent variable	Incidence, % (n)	Odds ratio	95% CI	*P*-value
ΔBCS[1]				<0.001
ELBCS	13.7 (1,604)	1.57[a]	1.22, 2.03	
MLBCS	10.0 (6,430)	1.25	1.02, 1.52	
NCBCS	7.9 (4,819)	1.04[b]	0.83, 1.29	
GBCS	6.7 (3,251)	Referent[b]		
Dairy				<0.001
A	6.8 (5,263)	0.77	0.67, 0.89	
B	10.2 (10,841)	Referent		
Parity				<0.001
Primiparous	8.0 (8,161)	0.67	0.59, 0.76	
Multiparous	10.3 (7,943)	Referent		
Calf sex				<0.001
Female	8.1 (7,530)	0.80	0.72, 0.90	
Male	10.2 (8,154)	Referent		
Number of calves born				<0.001
Singleton	8.4 (14,665)	0.45	0.38, 0.54	
Twins	20.9 (1,019)	Referent		
Gestation length				<0.001
≤273 d	17.0 (2,335)	1.47[a]	1.26, 1.72	
274–283 d	7.9 (11,123)	Referent[b]		
≥284 d	7.3 (2,646)	0.98[b]	0.82, 1.17	
Length of the dry period				<0.001
≤47 d	17.7 (2,515)	2.10[a]	1.77, 2.48	
48–69 d	7.0 (11,477)	Referent[b]		
≥70 d	10.3 (2,112)	1.40[c]	1.16, 1.70	
Percentage of days in the dry period with THI[2] ≥72				<0.001
<35%	8.5 (12,896)	0.74	0.65, 0.85	
≥35%	11.7 (3,208)	Referent		

[a–c]Within parameter, rows with different superscripts differ ($P \leq 0.01$).

[1]ΔBCS = body condition score change during the dry period; ELBCS = cows with ΔBCS ≤−0.75; MLBCS = cows with ΔBCS of −0.5 to −0.25; NCBCS = cows with ΔBCS of 0; GBCS = cows with ΔBCS ≥0.25.

[2]THI = temperature-humidity index.

Table 5. Final logistic regression model of factors associated with supportive therapy within 60 d postpartum

Independent variable	Incidence, % (n)	Odds ratio	95% CI	P-value
ΔBCS[1]				<0.001
ELBCS	8.1 (1,604)	1.63[a]	1.26, 2.09	
MLBCS	8.4 (6,430)	1.51[a]	1.26, 1.81	
NCBCS	7.6 (4,819)	1.38[a]	1.14, 1.66	
GBCS	5.9 (3,251)	Referent[b]		
Dairy				<0.001
A	10.7 (5,263)	1.95	1.70, 2.23	
B	6.1 (10,841)	Referent		
Parity				<0.001
Primiparous	4.6 (8,161)	0.41	0.36, 0.47	
Multiparous	10.8 (7,943)	Referent		
Calf sex				<0.001
Female	6.4 (7,530)	0.78	0.69, 0.89	
Male	8.8 (8,154)	Referent		
Number of calves born				<0.001
Singleton	6.7 (14,665)	0.36	0.30, 0.43	
Twins	21.5 (1,019)	Referent		
Gestation length				<0.001
≤273 d	13.1 (2,335)	1.41[a]	1.19, 1.67	
274–283 d	6.7 (11,123)	Referent[b]		
≥284 d	6.9 (2,646)	0.89[b]	0.74, 1.08	
Length of the dry period				<0.001
≤47 d	10.1 (2,515)	1.97[a]	1.64, 2.38	
48–69 d	6.2 (11,477)	Referent[b]		
≥70 d	12.8 (2,112)	1.87[a]	1.58, 2.21	

[a,b]Within parameter, rows with different superscripts differ ($P \leq 0.01$).

[1]ΔBCS = body condition score change during the dry period; ELBCS = cows with ΔBCS ≤−0.75; MLBCS = cows with ΔBCS of −0.5 to −0.25; NCBCS = cows with ΔBCS of 0; GBCS = cows with ΔBCS ≥0.25.

= 1.05, 95% CI = 0.91–1.20; P = 0.51) and GBCS cows. The mean intervals from calving to removal from the herd were 292.5 ± 1.3, 273.6 ± 1.0, 264.5 ± 1.2, and 277.1 ± 1.3 d for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. The percentages of cows censored by 305 DIM were 92.8, 79.5, 72.4, and 80.9% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. Cows that delivered singletons had (AHR = 0.80, 95% CI = 0.70–0.90; P < 0.001) reduced hazard of removal from the herd up to 305 DIM than cows that delivered twins. We noted (P < 0.001) an association between length of gestation and hazard of removal from the herd up to 305 DIM because cows with SGL had (AHR = 1.24, 95% CI = 1.12–1.38) greater hazard of removal than NGL (referent) and LGL (AHR = 0.932, 95% CI = 0.84–1.03) cows, which did not differ.

Association Between ΔBCS and Reproductive Parameters

The likelihood of cows receiving the first postpartum AI upon detected estrus (P = 0.22) and the DIM at first postpartum AI (P = 0.48) were not associated with ΔBCS. Body condition score change during the dry period was (P < 0.001) associated with the likelihood of pregnancy 35 ± 7 d after the first postpartum AI. Cows with ELBCS (AOR = 0.41, 95% CI = 0.36–0.47), MLBCS (AOR = 0.59, 95% CI = 0.54–0.65), and NCBCS (AOR = 0.71, 95% CI = 0.64–0.78) were less likely to be pregnant 35 ± 7 d after the first postpartum AI than GBCS cows. Primiparous cows were (AOR = 1.14, 95% CI = 1.07–1.23; P < 0.001) more likely to be pregnant 35 ± 7 d after the first postpartum AI than multiparous cows. Cows that delivered singletons calves were (AOR = 1.23, 95% CI = 1.05–1.43; P = 0.009) more likely to be pregnant 35 ± 7 d after the first postpartum AI than cows that delivered twin calves. Cows not exposed to heat stress during the dry period were (AOR = 1.25, 95% CI = 1.14–1.37; P < 0.001) more likely to be pregnant 35 ± 7 d after the first postpartum AI than cows exposed to heat stress.

Change in BCS during the dry period was (P < 0.001) associated with the likelihood of pregnancy 67 ± 3 d after the first postpartum AI (Table 6). Primiparous cows were (P < 0.001) more likely to be pregnant 67 ± 3 d after the first postpartum AI than multiparous cows (Table 6). Cows that delivered singletons were (P = 0.005) more likely to be pregnant 67 ± 3 d after the first postpartum AI than cows that delivered twin calves (Table 6). Cows not exposed to heat stress dur-

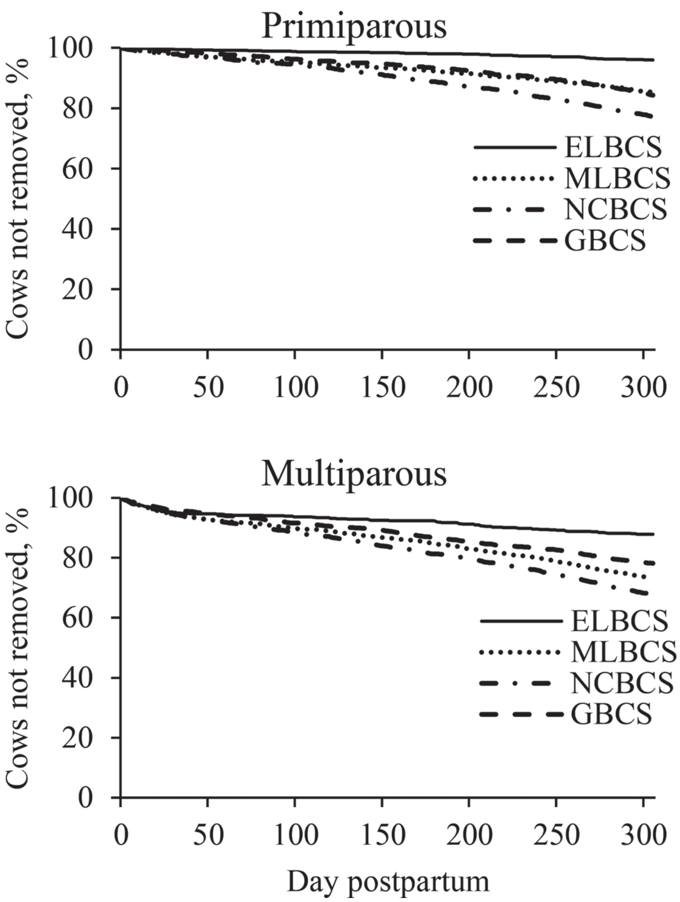

Figure 4. Survival analysis of the interval from parturition to removal from the herd according to BCS change during the dry period (ΔBCS) and parity. Test of equality Wilcoxon: mean (±SEM) days to removal for primiparous cows ($P < 0.001$): ELBCS (ΔBCS ≤−0.75) = 299.5 ± 1.1, MLBCS (ΔBCS = −0.5 to −0.25) = 283.7 ± 1.1, NCBCS (ΔBCS = 0) = 274.5 ± 1.5, and GBCS (ΔBCS ≥0.25) = 286.1 ± 1.5 d; mean (±SEM) days to removal for multiparous cows ($P < 0.001$): ELBCS = 273.5 ± 2.8, MLBCS = 262.6 ± 1.6, NCBCS = 254.9 ± 1.8, and GBCS = 269.9 ± 1.9 d.

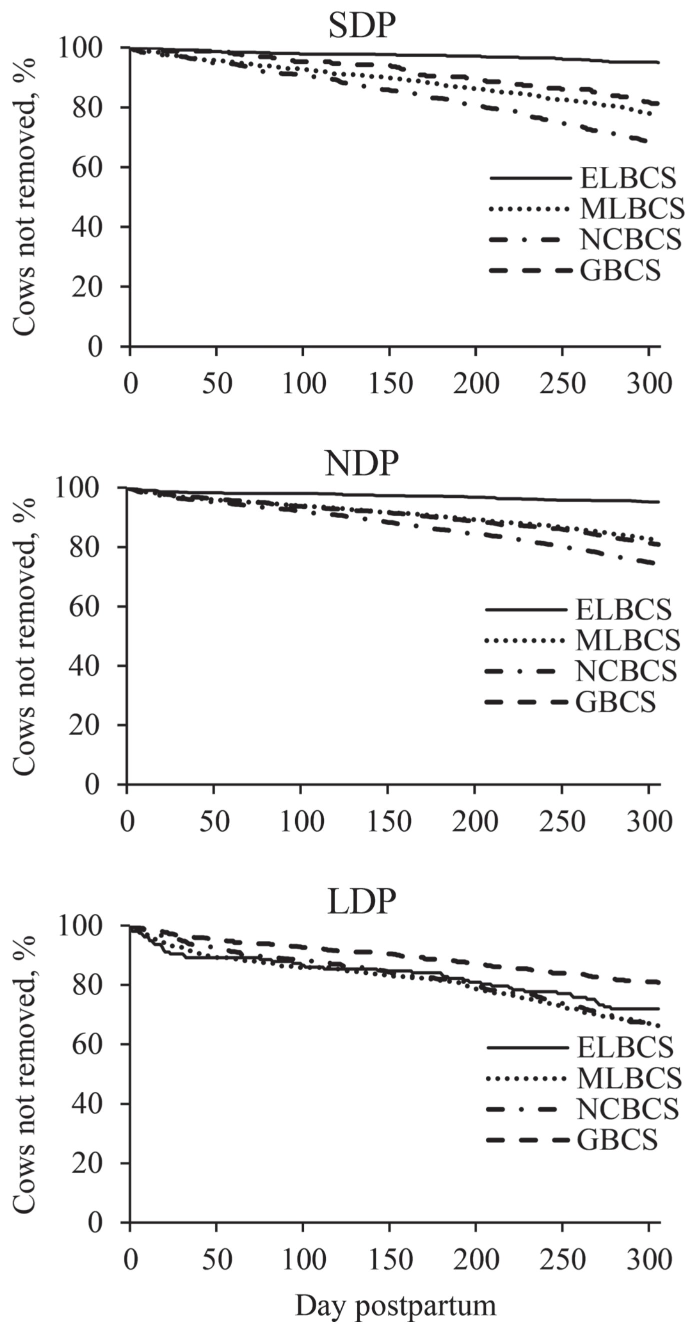

Figure 5. Survival analysis of the interval from parturition to removal from the herd according to BCS change during the dry period (ΔBCS) and length of the dry period. Test of equality Wilcoxon: mean (±SEM) days to removal for cows with short dry period (SDP; $P < 0.001$): ELBCS (ΔBCS ≤−0.75) = 297.1 ± 2.0, MLBCS (ΔBCS = −0.5 to −0.25) = 268.7 ± 2.3, NCBCS (ΔBCS = 0) = 258.8 ± 3.4, and GBCS (ΔBCS ≥0.25) = 277.8 ± 3.5 d; mean (±SEM) days to removal for cows with normal dry period (NDP; $P < 0.001$): ELBCS = 291.7 ± 1.4, MLBCS = 278.4 ± 1.1, NCBCS = 266.7 ± 1.3, and GBCS = 277.2 ± 1.4 d; mean (±SEM) days to removal for cows with long dry period (LDP; $P < 0.001$): ELBCS = 235.1 ± 7.1, MLBCS = 250.1 ± 3.4, NCBCS = 254.3 ± 3.6, and GBCS = 273.8 ± 3.5.

ing the dry period were ($P < 0.001$) more likely to be pregnant 67 ± 3 d after the first postpartum AI than cows exposed to heat stress (Table 6).

The interaction between ΔBCS and parity tended ($P = 0.02$) to be associated with pregnancy loss from 35 ± 7 to 67 ± 3 d after the first postpartum AI. Among primiparous cows, pregnancy loss was 18.6, 11.0, 6.2, and 4.7% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively, whereas among multiparous cows pregnancy loss was 10.2, 9.9, 8.6, and 4.3% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. Additionally, we noted a tendency ($P = 0.05$) for the interaction between ΔBCS and length of the dry period to be associated with pregnancy loss from 35 ± 7 to 67 ± 3 d after the first postpartum AI. Among cows with

Table 6. Final logistic regression model of factors associated with pregnancy at 67 d after first postpartum AI

Independent variable	P/AI,[1] % (n)	Odds ratio	95% CI	*P*-value
ΔBCS[2]				<0.001
ELBCS	20.8 (1,540)	0.36[a]	0.31, 0.41	
MLBCS	28.3 (5,812)	0.55[b]	0.50, 0.60	
NCBCS	33.1 (4,258)	0.68[c]	0.62, 0.75	
GBCS	41.9 (2,955)	Referent[d]		
Parity				<0.001
Primiparous	32.4 (7,711)	1.13	1.05, 1.22	
Multiparous	30.9 (6,854)	Referent		
Number of calves born				0.005
Singleton	32.3 (13,298)	1.26	1.07, 1.48	
Twins	25.2 (882)	Referent		
Percentage of days in the dry period with THI[3] ≥72				<0.001
<35%	32.7 (11,676)	1.26	1.15, 1.39	
≥35%	27.5 (2,889)	Referent		

[a–d]Within parameter, rows with different superscripts differ ($P \leq 0.01$).

[1]P/AI = pregnancy per AI.

[2]ΔBCS = body condition score change during the dry period; ELBCS = cows with ΔBCS ≤−0.75; MLBCS = cows with ΔBCS of −0.5 to −0.25; NCBCS = cows with ΔBCS of 0; GBCS = cows with ΔBCS ≥0.25.

[3]THI = temperature-humidity index.

SDP, pregnancy loss was 16.4, 6.7, 8.3, and 6.5% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. Pregnancy loss was 10.3, 13.9, 4.6, and 3.6% for ELBCS, MLBCS, NCBCS, and GBCS cows with LDP, respectively. Finally, among cows with NDP pregnancy loss was 15.8, 11.0, 7.7, and 4.4% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively.

The interaction between ΔBCS and parity tended ($P = 0.04$) to be associated with the likelihood of pregnancy 35 ± 7 d after the second postpartum. Among primiparous cows, P/AI was 23.4, 31.3, 33.3, and 40.7% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. The P/AI among multiparous cows was 27.3, 27.2, 28.4, and 35.9% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. The likelihood of pregnancy at 35 ± 7 d after the second postpartum AI was ($P = 0.01$) associated with the interaction between ΔBCS and exposure to heat stress during the dry period. Among cows not exposed to heat stress, the P/AI was 24.9, 30.2, 31.0, and 36.4% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. Among cows exposed to heat stress, the P/AI was 24.5, 26.7, 30.3, and 44.7% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. We observed a tendency ($P = 0.02$) for gestation length to be associated with the likelihood of pregnancy 35 ± 7 d after the second postpartum AI because LGL cows were (AOR = 0.84, 95% CI = 0.74–0.96) less likely to be pregnant than cows with normal (referent) and short (AOR = 0.89, 95% CI = 0.77–1.02) gestation length. Length of the dry period was ($P < 0.001$) associated with the likelihood of pregnancy 35 ± 7 d after the second postpartum AI because SDP cows tended to be (AOR = 1.17, 95% CI = 1.03–1.34; $P = 0.02$) more likely to be pregnant 35 ± 7 d after the second postpartum AI than NDP cows (referent), whereas LDP cows were (AOR = 0.80, 95% CI = 0.69–0.93; $P = 0.004$) less likely to be pregnant 35 ± 7 d after the second postpartum AI than NDP cows.

The interaction between ΔBCS and parity tended ($P = 0.02$) to be associated with the likelihood of pregnancy 67 ± 3 d after the second postpartum. Among primiparous cows, the P/AI was 20.4, 28.4, 31.2, and 38.8% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. The P/AI among multiparous cows was 25.0, 24.9, 26.6, and 34.4% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. We observed a tendency ($P = 0.02$) for the interaction between ΔBCS and exposure to heat stress during the dry period to be associated with the likelihood of pregnancy at 67 ± 3 after the second postpartum AI. Among cows not exposed to heat stress the P/AI was 21.9, 27.5, 29.2, and 34.9% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. Among cows exposed to heat stress, the P/AI was 22.8, 24.3, 28.0, and 42.3% for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively. We observed a tendency ($P = 0.02$) for gestation length to be associated with the likelihood of pregnancy 67 ± 3 d after the second postpartum AI. Cows with LGL were (AOR = 0.84, 95% CI = 0.74–0.96) less likely to be pregnant than NGL (referent) and SGL (AOR = 0.89, 95% CI = 0.77–1.03) cows. Length of the dry period was ($P < 0.001$) associated with the likelihood of pregnancy at 67 ± 3 d after the second postpartum AI. Cows with SDP were (AOR = 1.20, 95% CI = 1.05–1.38; $P = 0.008$) more likely to be pregnant than NDP cows (referent), whereas LDP cows were (AOR = 0.81, 95% CI = 0.70–0.95; $P = 0.009$) less likely to be pregnant than NDP cows.

Change in BCS during the period was ($P < 0.001$) associated with the likelihood of pregnancy loss between 35 ± 7 and 67 ± 3 d after the second postpartum AI. Cows with ELBCS (AOR = 2.53, 95% CI = 1.49–4.29) were more likely to have pregnancy loss than NCBCS (AOR = 1.41, 95% CI = 0.88–2.28) and GBCS (referent) cows, whereas cows with MLBCS (AOR = 2.02, 95% CI = 1.31–3.11) were more likely to have pregnancy loss than GBCS cows. We noted a tendency ($P = 0.05$) for cows that delivered singletons to be less (AOR = 0.61, 95% CI = 0.37–1.00) likely to have pregnancy loss between 35 ± 7 and 67 ± 3 d after the second postpartum AI than cows that delivered twins.

The interactions between ΔBCS and dairy ($P < 0.001$; Figure 6) and between ΔBCS and parity ($P = 0.01$; Figure 7) were associated with the hazard of pregnancy up to 305 DIM. Cows with ELBCS tended to ($P = 0.03$) and cows with MLBCS and NCBCS had ($P < 0.001$) reduced hazard of pregnancy than GBCS cows (Table 7). Cows that delivered singletons had ($P < 0.001$) greater hazard of pregnancy than cows that delivered twins (Table 7). Gestation length was ($P = 0.002$) associated with the hazard of pregnancy because SGL and LGL cows had reduced hazard of pregnancy compared with NGL cows (Table 7). Length of the dry period was ($P < 0.001$) associated with the hazard of pregnancy because SDP cows had greater hazard of pregnancy than NDP cows, whereas LDP cows had reduced hazard of pregnancy than NDP cows (Table 7). Finally, cows not exposed to heat stress during the dry period tended ($P = 0.03$) to have greater hazard of pregnancy than cows exposed to heat stress during the dry period (Table 7).

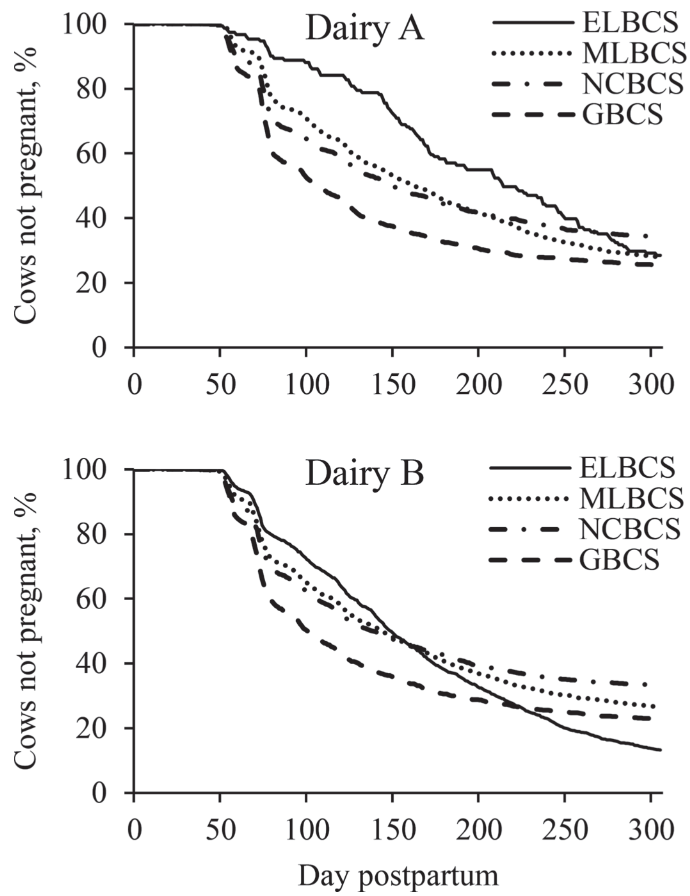

Figure 6. Survival analysis of the interval from parturition to pregnancy according to BCS change during the dry period (ΔBCS) and dairy. Association between ΔBCS and the interval from parturition to pregnancy according to the test of equality Wilcoxon: mean (±SEM) days to pregnancy for cows from dairy A ($P < 0.001$): ELBCS (ΔBCS ≤−0.75) = 199.9 ± 6.9 d, MLBCS (ΔBCS = −0.5 to −0.25) = 161.2 ± 2.2 d, NCBCS (ΔBCS = 0) = 153.5 ± 2.3 d, and GBCS (ΔBCS ≥0.25) = 133.2 ± 2.3 d; mean (±SEM) days to pregnancy for cows from dairy B ($P < 0.001$): ELBCS = 160.4 ± 2.1 d, MLBCS = 157.2 ± 1.4 d, NCBCS = 159.2 ± 1.9 d, and GBCS = 136.3 ± 2.3 d.

Association Between ΔBCS and Productive Parameters

The interaction between ΔBCS and month of lactation was ($P < 0.001$) associated with milk yield (Figure 8A). Mean daily milk yield over 305 d was highest for GBCS cows (40.60 ± 0.11 kg/d), followed by NCBCS cows (39.58 ± 0.10 kg/d) and MLBCS (39.20 ± 0.09 kg/d) and ELBCS (39.28 ± 0.15 kg/d) cows, which did not differ. Cows from dairy A had ($P < 0.001$) greater milk yield than cows from dairy B (39.91 ± 0.12 vs. 39.42 ± 0.10 kg/d). Multiparous cows had ($P < 0.001$) greater milk yield than primiparous cows (40.19 ± 0.09 vs. 39.14 ± 0.09 kg/d). Cows that delivered twins had ($P < 0.001$) lower milk yield than cows that delivered singletons (38.56 ± 0.16 vs. 39.10 ± 0.09 kg/d). Cows with SGL (38.37 ± 0.12 kg/d) had ($P < 0.001$) the lowest milk yield followed by NGL (40.11 ± 0.08 kg/d) and LGL (40.52 ± 0.12 kg/d) cows. Cows with SDP (36.85 ± 0.15 kg/d) had ($P < 0.001$) lower milk yield than cows with NDP (39.84 ± 0.11 kg/d) and LDP (39.79 ± 0.14 kg/d). Cows exposed to heat stress during the dry period had ($P < 0.001$) reduced milk yield than cows not exposed to heat stress (38.41 ± 0.13 vs. 39.24 ± 0.11 kg/d).

We noted ($P < 0.001$) an association between ΔBCS and fat yield because GBCS cows (1.50 ± 0.01 kg/d) had the highest fat yield, followed by NCBCS (1.45 ± 0.01 kg/d), MLBCS (1.42 ± 0.01 kg/d), and ELBCS (1.40 ± 0.01 kg/d) cows. Cows from dairy A had ($P < 0.01$) lower fat yield than cows from dairy B (1.41 ± 0.01 vs. 1.48 ± 0.01 kg/d). Primiparous cows had ($P = 0.01$) lower fat yield than multiparous cows (1.44 ± 0.01 vs. 1.45 ± 0.01). Cows that delivered singletons had ($P < 0.001$) greater fat yield than cows that delivered twins (1.43 ± 0.01 vs. 1.39 ± 0.01 kg/d). We observed (P

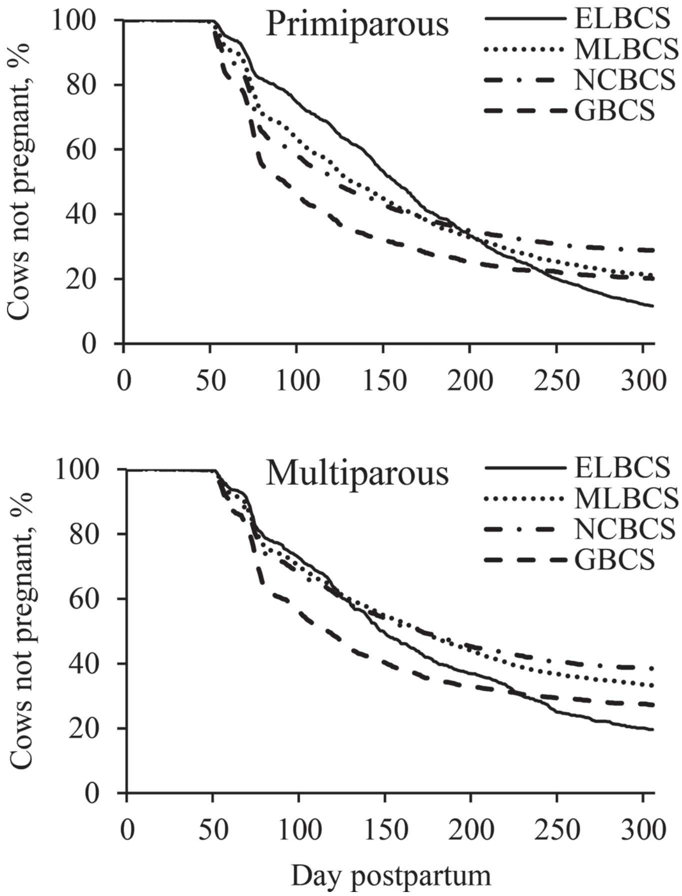

Figure 7. Survival analysis of the interval from parturition to pregnancy according to BCS change during the dry period (ΔBCS) and parity. Association between ΔBCS and the interval from parturition to pregnancy according to the test of equality Wilcoxon: mean (±SEM) days to pregnancy for primiparous ($P < 0.001$): ELBCS (ΔBCS ≤−0.75) = 166.3 ± 2.5 d, MLBCS (ΔBCS = −0.5 to −0.25) = 153.2 ± 1.5 d, NCBCS (ΔBCS = 0) = 151.2 ± 2.0 d, and GBCS (ΔBCS ≥0.25) = 130.5 ± 2.4 d; mean (±SEM) days to pregnancy for multiparous ($P < 0.001$): ELBCS = 159.6 ± 3.4 d, MLBCS = 164.4 ± 1.8 d, NCBCS = 163.8 ± 2.1 d, and GBCS = 138.8 ± 2.2 d.

< 0.001) an association between gestation length and fat yield because cows with SGL (1.40 ± 0.01 kg/d) had the lowest fat yield, followed by NGL (1.45 ± 0.01 kg/d) and LGL (1.47 ± 0.01 kg/d) cows, respectively. Similarly, cows with SDP (1.35 ± 0.01 kg/d) had ($P <$ 0.001) lower fat yield than NDP (1.43 ± 0.01 kg/d) and LDP (1.44 ± 0.01 kg/d) cows. Cows exposed to heat stress during the dry period had ($P = 0.003$) reduced fat yield compared with cows not exposed to heat stress (1.40 ± 0.01 vs. 1.41 ± 0.01 kg/d).

Cows that gained BCS during the dry period had the greatest yield of 3.5% FCM (41.87 ± 0.16 kg/d), followed by NCBCS cows (40.61 ± 0.15 kg/d), MLBCS cows (39.94 ± 0.14 kg/d), and ELBCS cows (39.30 ± 0.29 kg/d). Cows from dairy A had ($P < 0.001$) lower 3.5% FCM yield than cows from dairy B (39.83 ± 0.15 vs. 41.03 ± 0.17 kg/d). Primiparous cows had ($P <$ 0.001) lower 3.5% FCM yield than multiparous cows (40.25 ± 0.14 vs. 40.60 ± 0.14 kg/d). Additionally, cows that delivered singletons had ($P < 0.001$) greater 3.5% FCM yield than cows that delivered twins (40.78 ± 0.11 vs. 40.08 ± 0.21 kg/d). Gestation length was ($P < 0.001$) associated with 3.5% FCM yield because cows with SGL had the smallest 3.5% FCM yield (39.34 ± 0.18 kg/d), followed by cows with NGL (40.75 ± 0.14 kg/d) and cows with LGL (41.20 ± 0.18 kg/d). Additionally, cows with SDP (38.12 ± 0.31 kg/d) had ($P < 0.001$) the lowest 3.5% FCM yield followed by cows with NDP (40.48 ± 0.14 kg/d) and LDP (40.47 ± 0.19 kg/d). Cows exposed to heat stress during the dry period had ($P < 0.001$) reduced 3.5% FCM yield than cows not exposed to heat stress (39.41 ± 0.18 vs. 39.96 ± 0.16 kg/d).

The interaction between ΔBCS and month of lactation tended ($P = 0.02$) to be associated with protein yield (Figure 8B). Cows that gained BCS during the dry period (1.22 ± 0.01 kg/d) had ($P < 0.001$) greater protein yield than NCBCS (1.19 ± 0.01 kg/d), MLBCS (1.18 ± 0.01 kg/d), and ELBCS (1.18 ± 0.01 kg/d) cows. Cows from dairy A tended ($P = 0.03$) to have lower protein yield than cows from dairy B (1.19 ± 0.01 vs. 1.20 ± 0.01 kg/d). Gestation length was ($P <$ 0.001) associated with protein yield because SGL cows (1.17 ± 0.01 kg/d) had ($P < 0.001$) lower protein yield than NGL (1.20 ± 0.01 kg/d) and LGL (1.21 ± 0.01 kg/d) cows, which did not ($P = 0.18$) differ. Length of the dry period was ($P < 0.001$) associated with protein yield because SDP cows had ($P < 0.001$) lower protein yield (1.16 ± 0.01 kg/d) than NDP (1.20 ± 0.01 kg/d) and LDP (1.19 ± 0.01) cows, whereas LDP cows tended ($P = 0.02$) to have lower protein yield than NDP cows. Cows exposed to heat stress during the dry period had ($P = 0.005$) reduced protein yield compared with cows not exposed to heat stress during the dry period (1.18 ± 0.01 vs. 1.19 ± 0.01 kg/d).

Change in BCS during the dry period was ($P <$ 0.001) associated with somatic cell linear score in the subsequent lactation (ELBCS = 3.55 ± 0.06, MLBCS = 3.52 ± 0.03, NCBCS = 3.43 ± 0.03, and GBCS = 3.35 ± 0.03). Cows with ELBCS tended to have ($P =$ 0.04) and had ($P < 0.001$) greater somatic cell linear score than NCBCS and GBCS cows, respectively, but did not ($P = 0.77$) differ from MLBCS cows. Somatic cell linear score of cows with MLBCS ($P < 0.001$) and NCBCS ($P = 0.007$) were greater than the somatic cell linear score of GBCS cows. When milk yield was added to the multivariate model, ΔBCS was ($P = 0.004$) still associated with somatic cell linear score (ELBCS = 3.42 ± 0.05, MLBCS = 3.42 ± 0.02, NCBCS = 3.36 ± 0.02, GBCS = 3.33 ± 0.03). Somatic cell linear score

Table 7. Final logistic regression model of factors associated with hazard of pregnancy up to 305 DIM

Independent variable	Censored, % (no.)	Hazard ratio	95% CI	P-value
ΔBCS[1]*				<0.001
ELBCS	14.7 (1,604)	0.88[A]	0.79, 0.99	
MLBCS	26.9 (6,430)	0.76[a]	0.70, 0.83	
NCBCS	33.7 (4,819)	0.70[a]	0.64, 0.77	
GBCS	24.1 (3,251)	Referent[b,B]		
Number of calves born				<0.001
Singleton	26.3 (14,665)	1.24	1.14, 1.35	
Twins	37.4 (1,019)	Referent		
Gestation length				0.002
≤273 d	31.7 (2,335)	0.93[a]	0.87, 0.98	
274–283 d	25.6 (10,314)	Referent[b]		
≥284 d	28.6 (3,455)	0.93[a]	0.88, 0.98	
Length of the dry period				<0.001
≤47 d	24.7 (2,515)	1.08[a]	1.02, 1.15	
48–69 d	26.0 (11,477)	Referent[b]		
≥70 d	36.6 (2,112)	0.91[c]	0.85, 0.97	
Percentage of days in the dry period with THI[2] ≥72				0.03
<35%	26.9 (12,896)	1.05	1.01, 1.10	
≥35%	28.0 (3,208)	Referent		

[a–c]Within parameter, rows with different superscripts differ ($P \leq 0.01$).

[A,B]Within parameter, rows with different superscripts tend to differ ($0.01 < P \leq 0.05$).

[1]ΔBCS = body condition score change during the dry period; ELBCS = cows with ΔBCS ≤−0.75; MLBCS = cows with ΔBCS of −0.5 to −0.25; NCBCS cows with ΔBCS of 0; GBCS = cows with ΔBCS ≥0.25.

*Interactions: ΔBCS × Dairy ($P < 0.001$); ΔBCS × Parity ($P = 0.01$).

[2]THI = temperature-humidity index.

within 60 d before dry off was ($P < 0.001$) associated with ΔBCS (ELBCS = 3.06 ± 0.06, MLBCS = 3.45 ± 0.03, NCBCS = 3.60 ± 0.03, GBCS = 3.47 ± 0.03) because ELBCS cows had ($P < 0.001$) lower somatic cell linear score than MLBCS, NCBCS, and GBCS cows, MLBCS cows had ($P < 0.001$) lower somatic cell linear score than NCBCS cows, and NCBCS cows had ($P < 0.001$) higher somatic cell count than GBCS cows. Cows from dairy A had ($P < 0.001$) reduced somatic cell linear score compared with cows from dairy B (3.31 ± 0.03 vs. 3.61 ± 0.03); additionally, primiparous cows ($P < 0.001$) had lower somatic cell linear score than multiparous cows (3.18 ± 0.03 vs. 3.74 ± 0.03).

DISCUSSION

The current study was a retrospective observational study. As such, we may only determine the associations between independent variables and dependent variables. Body condition score change during the dry period was highly dependent on the BCSD. Hayirli et al. (2002) demonstrated that BCS 21 d before the expected calving date explained 9.7% of the variability in DMI during the prepartum period. The only factors with greater contribution to the variability in DMI in the prepartum period were proximity to calving, NDF of the diet, and parity (Hayirli et al., 2002). In the current study, BCSD explained 95% of the variability in ΔBCS, granted the model only explained 57.4% of the variability in ΔBCS and several dietary and environmental (e.g., stocking density) factors were not accounted for. Hayirli et al. (2002) demonstrated that cows classified as obese 21 d before the expected calving date had lower DMI (as a percent of BW) from 21 d before the expected calving date to calving compared with thinner cows. Additionally, the reductions in DMI from 21 d before the expected calving date to calving were 40, 29, and 28% for obese, moderate, and thin cows, respectively (Hayirli et al., 2002). Hoedemaker et al. (2009) demonstrated that the BCS of cows that lost more than 0.25 units of BCS during the last 30 d of gestation was approximately 3.5 at 6 wk prepartum, the BCS of cows that lost 0.25 unit of BCS during the last 30 d of gestation was approximately 3.3 at 6 weeks prepartum, and BCS of cows that maintained or gained BCS during the last 30 d of gestation was approximately 3.1 at 6 wk prepartum. In the current study, BCSD ≤3.25 was a good predictor of GBCS during the dry period. Additionally, whereas the differences in BCSD among ELBCS, MLBCS, NCBCS, and GBCS cows averaged 0.26 units, the differences in BCS at calving among ELBCS, MLBCS, NCBCS, and GBCS cows averaged 0.13 units. These data suggest that the cows used in our study were genetically programmed to converge to BCS at calving between 3.25 and 3.5. In a review, Garnsworthy and Wiseman (2006) suggested that Holstein cows are genetically programmed to converge to BCS between 2.5 and 3 around 12 wk postpartum. Heritability of BCS at 0 to

60, 130 to 170, and 280 to 320 DIM is approximately 0.26 ± 0.08 (Vallimont et al., 2010), supporting the hypothesis that Holstein cows are programmed to be within ranges of BCS at different stages of gestation and lactation.

Cows that lost BCS during the dry period were more likely to be diagnosed with uterine diseases and indigestion and were more likely to receive antimicrobial, anti-inflammatory, and supportive therapies. The interaction between ΔBCS and parity tended to be associated with the likelihood of indigestion, the interaction between ΔBCS and dry period length tended to be associated with the likelihood of treatment with antimicrobials, and the interactions between ΔBCS and parity and between ΔBCS and dry period length tended to be associated with the likelihood of treatment with anti-inflammatories. In general, GBCS cows had better health than NCBCS, MLBCS, and ELBCS cows. Huzzey et al. (2007) demonstrated that cows diagnosed with metritis postpartum had reduced DMI as early as 13 d prepartum. Hammon et al. (2006) demonstrated that cows in the lowest quartile for DMI in the last 3 wk of gestation had reduced myeloperoxidase activity compared with cows in the highest quartile for DMI. Furthermore, a moderate negative correlation exists between nonesterified fatty acid plasma concentration and neutrophil activity (Hammon et al., 2006). Ospina et al. (2010) demonstrated that increased prepartum and postpartum nonesterified fatty acid plasma concentrations were associated with increased risk of retained fetal membranes, metritis, clinical ketosis, and displacement of abomasum. Furthermore, an increase in prepartum fat mobilization and serum lipoprotein metabolism was associated with increased risk of metritis and retained fetal membranes (Kaneene et al., 1997; Contreras, et al., 2004). Our study was retrospective; thus, it was not possible to determine whether differences in concentrations of metabolites and hormones existed during the prepartum and postpartum according to ΔBCS. Nonetheless, the amounts of ΔBCS from dry off to calving were −0.85 ± 0.16, −0.34 ± 0.12, 0 ± 0, and 0.34 ± 0.17 for ELBCS, MLBCS, NCBCS, and GBCS, respectively. Therefore, if the BW of the cows in the current study was approximately 700 kg, such ΔBCS would represent approximately −383, −153, 0, and 181 Mcal of NE_L during the dry period for ELBCS, MLBCS, NCBCS, and GBCS cows, respectively (NRC, 2001). It can be speculated that cows that had ELBCS and MLBCS had negative energy balance and, consequently, impaired immune response during the periparturient period, which may have predisposed them to uterine diseases. Smith et al. (2017) demonstrated that cows diagnosed with uterine diseases and metabolic disorders lost −0.27 and −0.24 unit of BCS from dry off to calving, respectively, whereas healthy cows lost −0.11 unit of BCS during the same period. The lack of association between ΔBCS and metabolic diseases postpartum in the current study was somewhat unexpected. Only clinical metabolic diseases were recorded in the current study; thus, an association between ΔBCS and the likelihood of subclinical metabolic diseases may not be disregarded.

In the current study, ΔBCS was associated with the likelihood of pregnancy after the first and second postpartum AI. Interestingly, cows that gained BCS during the dry period were less likely to lose pregnancy between 35 ± 7 and 67 ± 3 d after the first and second postpartum AI. The associations between ΔBCS and reproductive outcomes could have been confounded by

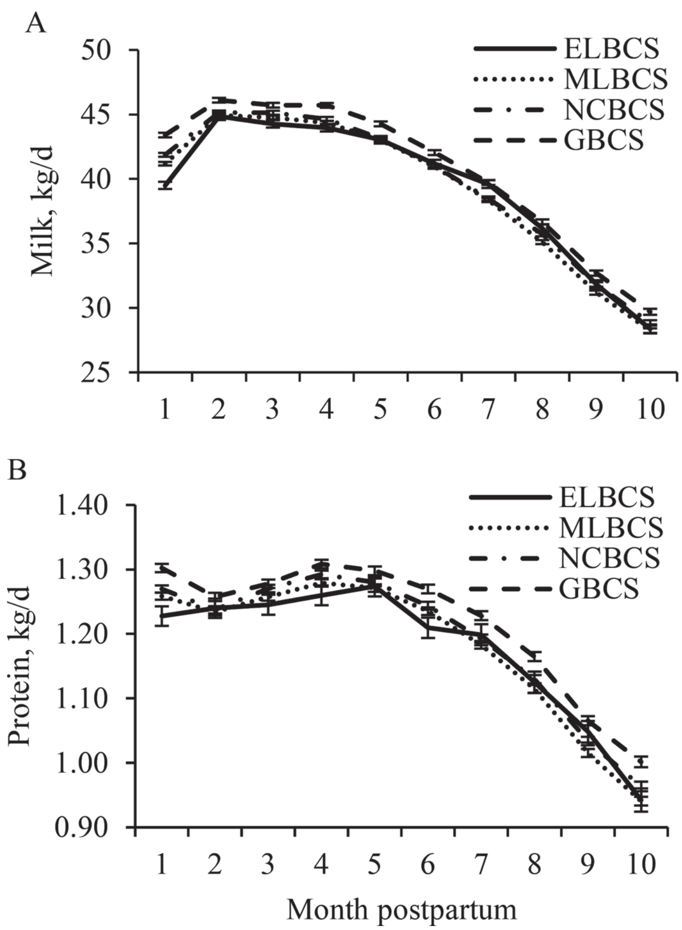

Figure 8. Associations between change in BCS during the dry period (ΔBCS) and yield of milk (A) and protein (B). Milk yield (±SEM; ΔBCS: $P < 0.001$, ΔBCS × month postpartum: $P < 0.001$): ELBCS (ΔBCS ≤−0.75) = 39.28 ± 0.15, MLBCS (ΔBCS = −0.5 to −0.25) = 39.20 ± 0.09, NCBCS (ΔBCS = 0) = 39.58 ± 0.10, and GBCS (ΔBCS ≥0.25) = 40.60 ± 0.11 kg/d. Protein yield (±SEM; ΔBCS: $P < 0.001$, ΔBCS × month postpartum: $P = 0.02$): ELBCS = 1.177 ± 0.008, MLBCS = 1.179 ± 0.004, NCBCS = 1.191 ± 0.004, and GBCS = 1.217 ± 0.004 kg/d.

the increased likelihood of health disorders affecting ELBCS, MLBCS, and NCBCS cows. The occurrence of postpartum diseases, such as dystocia and uterine diseases, are associated with postponed resumption of ovarian cycles postpartum, reduced pregnancy per AI, and increased pregnancy loss (LeBlanc et al., 2002; Santos et al., 2009; Ribeiro et al., 2013, 2016). When cows diagnosed with any of the postpartum diseases evaluated in the current study were removed from the analysis, however, differences in pregnancy per AI and pregnancy loss after the first and second postpartum AI according to ΔBCS were still observed (data not shown). Holstein cows in Germany that lost ≥0.25 units BCS during the last 6 wk of gestation were less likely to conceive after the first postpartum AI, were less likely to be pregnant by 200 DIM, and had longer interval from calving to conception compared with cows that had no change or gained BCS during the last 6 wk of gestation (Hoedemaker et al., 2009). In a study conducted in New York, researchers demonstrated that loss of BCS during the dry period was associated with greater risk of dystocia, culling, and reproductive failure (Gearhart et al., 1990). Although Domecq et al. (1997a) did not observe an association between ΔBCS during the dry period and conception to the first postpartum AI, they did not report the long-term effects of ΔBCS on reproductive performance. Sheehy et al. (2017) demonstrated that, during the prepartum, cows that lost BCS during the last 15 d of gestation tended to have greater nonesterified fatty acid concentrations and had reduced insulin concentrations compared with cows that maintained BCS, whereas, during the postpartum, cows that lost BCS during the last 15 d of gestation had greater nonesterified fatty acid and BHB concentrations and reduced insulin concentration compared with cows that maintained BCS. Chen et al. (2015) demonstrated that cows that resumed ovarian cycles before 21 DIM had greater BCS from 1 to 8 wk postpartum. Additionally, cows with normal ovarian cycles (18–24 d) had greater concentrations of insulin and IGF-1 from 1 to 8 wk postpartum (Chen et al., 2015). As explained previously, our study is a retrospective analysis of the factors associated with ΔBCS and the consequences of ΔBCS to performance. Nonetheless, it is reasonable to speculate that cows with ELBCS and MLBCS had altered metabolite and hormone concentrations as described by Chen et al. (2015) and Sheehy et al. (2017), which may have led to impaired reproductive performance.

Cows that gained BCS during the dry period had greater yield of milk, fat, protein, and 3.5% FCM than cows that maintained BCS and cows that lost BCS during the dry period. Compared with GBCS cows, ELBCS, MLBCS, and NCBCS cows produced an average of 4.17, 2.34, and 1.59 kg/d fewer of milk, respectively, and 4.0, 2.15, and 1.66 kg/d fewer of 3.5% FCM, respectively, in the first month postpartum. Differences in yield of milk and 3.5% FCM over the entire lactation, however, were smaller. This suggests that cows that gained BCS during the dry period were actually better able to cope with the demands of onset of lactation. Domecq et al. (1997b) demonstrated that a 1-unit increment in BCS during the dry period resulted in increased milk yield of 0.32 kg/d among multiparous cows. Nutrient requirements of pregnant cows increase significantly in the last weeks of gestation (Moe and Tyrrell, 1972) and DMI decreases in the last days of gestation, resulting in slight negative energy balance during the last days before parturition (Bertics et al., 1992). Cows that gained BCS during the dry period would have more positive energy balance in the last 60 d of gestation than cows with NCBCS, MLBCS, and ELBCS, which may have resulted in more energy reserves at the onset of lactation for higher yields of milk, fat, and protein. Although the reduced incidence of health disorders and treatments among GBCS cows may suggest a confounding effect of health disorders on the association between ΔBCS and productive parameters, when cows that had any of the health disorders evaluated in the current study were removed from the analysis similar differences in productive parameters were still observed among GBCS, NCBCS, MLBCS, and ELBCS cows (data not shown). It is surprising that GBCS cows had significantly better P/AI following the first and second postpartum inseminations compared with NCBCS, MLBCS, and ELBCS cows while still producing significantly more milk, fat, and protein early postpartum. This leads to the conclusion that prevention of BCS loss in the dry period is critical for the success of the subsequent lactation, whereas the importance of BCS at calving must be evaluated in light of the ΔBCS.

The association between ΔBCS and somatic cell score linear is interesting and reinforces the speculation that cows that lost BCS during the dry period may have had impaired innate immunity reducing the cow's ability to resolve preexisting IMI and prevent new IMI during the dry period. It is particularly striking that ELBCS cows had reduced somatic cell linear score before dry off than all other cows but, postpartum, ELBCS cows tended to have and had greater somatic cell linear score than NCBCS and GBCS cows, respectively. Valde et al. (2007) reported that, in herds with greater incidence of mastitis, cows had greater BCS during the dry period than herds with lower incidence of mastitis, but by the second month of lactation BCS did not differ. Leelahapongsathon et al. (2016) demonstrated that greater BCS during the dry period and reduced BCS at calving were predisposing factors to IMI. As discussed previously, reduced DMI prepartum was associated with reduced myeloperoxidase activity (Hammon et al., 2006) and increased plasma concentrations of nonesterified fatty acid were associated with reduced neutrophil activity (Hammon et al., 2006) and increased risk of retained fetal membranes, metritis, clinical ketosis, and displacement of abomasum (Ospina et al., 2010). Prevention of BCS loss during the dry period may have a positive effect on udder health and incidence of mastitis postpartum.

CONCLUSIONS

The current study is retrospective and, consequently, no cause and effect may be established. Loss of BCS during the dry period was associated with negative health, reproductive, and productive performances. This is an important finding because it reinforces the perception that a successful lactation starts during the dry period. Subpar management and environmental conditions that prevent BCS gain in the dry period must be avoided at all costs. Of particular importance to prevent BCS loss during the dry period is to ensure that cows are dried off at BCS $\leq$3.25, which is attainable by proper genetic selection, high milk yield, and efficient reproductive management.

ACKNOWLEDGMENTS

The authors thank Jack DeJong and the staff of River Ranch and John DeJong dairies.

REFERENCES

Bertics, S. J., R. R. Grummer, C. Cadorniga-Valino, and E. E. Stoddard. 1992. Effect of prepartum dry matter intake on liver triglyceride concentration and early lactation. J. Dairy Sci. 75:1914–1922.

Cardoso, F. C., S. J. LeBlanc, M. R. Murphy, and J. K. Drackley. 2013. Prepartum nutritional strategy affects reproductive performance in dairy cows. J. Dairy Sci. 96:5859–5871.

Chen, J., N. M. Soede, H. A. van Dorland, G. J. Remmelink, R. M. Bruckmaier, B. Kemp, and A. T. van Knegsel. 2015. Relationship between metabolism and ovarian activity in dairy cows with different dry-period lengths. Theriogenology 84:1387–1396.

Contreras, L. L., C. M. Ryan, and T. R. Overton. 2004. Effects of dry cow grouping strategy and prepartum body condition score on performance and health of transition dairy cows. J. Dairy Sci. 87:517–523.

Correa, M. T., H. Erb, and J. Scarlett. 1993. Path analysis for seven postpartum disorders of Holstein cows. J. Dairy Sci. 76:1305–1312.

Crookenden, M. A., C. G. Walker, A. Heiser, A. Murray, V. S. R. Dukkipati, J. K. Kay, S. Meier, K. M. Moyes, M. D. Mitchell, J. J. Loor, and J. R. Roche. 2017. Effects of precalving body condition and prepartum feeding level on gene expression in circulating neutrophils. J. Dairy Sci. 100:2310–2322.

Domecq, J. J., A. L. Skidmore, J. W. Lloyd, and J. B. Kaneene. 1997a. Relationship between body condition scores and conception at first artificial insemination in a large dairy herd of high yielding Holstein cows. J. Dairy Sci. 80:113–120.

Domecq, J. J., A. L. Skidmore, J. W. Lloyd, and J. B. Kaneene. 1997b. Relationship between body condition scores and milk yield in a large dairy herd of high yielding Holstein cows. J. Dairy Sci. 80:101–112.

Erb, H. N., and Y. T. Grohn. 1988. Symposium: Health problems in the periparturient cow. Epidemiology of metabolic disorders in the periparturient dairy cow. J. Dairy Sci. 71:2557–2571.

Ferguson, J. D., D. T. Galligan, and N. Thomsen. 1994. Principal descriptors of body condition score in Holstein cows. J. Dairy Sci. 77:2695–2703.

Garnsworthy, P. C., and J. Wiseman. 2006. Body condition score in dairy cows: Targets for production and fertility. Pages 61–86 in Recent Advances in Animal Nutrition. Nottingham University Press, Nottingham, UK.

Gearhart, M. A., C. R. Curtis, H. N. Erb, R. D. Smith, C. J. Sniffen, L. E. Chase, and M. D. Cooper. 1990. Relationship of changes in condition score to cow health in Holsteins. J. Dairy Sci. 73:3132–3140.

Gröhn, Y. T., H. N. Erb, C. E. McCulloch, and H. S. Saloniem. 1989. Epidemiology of metabolic disorders in dairy cattle: Association among host characteristics, disease, and production. J. Dairy Sci. 72:1876–1885.

Grummer, R. R., D. G. Mashek, and A. Hayirli. 2004. Dry matter intake and energy balance in the transition period. Vet. Clin. North Am. Food Anim. Pract. 20:447–470.

Hammon, D. S., I. M. Evjen, T. R. Dhiman, J. P. Goff, and J. L. Walters. 2006. Neutrophil function and energy status in Holstein cows with uterine health disorders. Vet. Immunol. Immunopathol. 113:21–29.

Hayirli, A., R. R. Grummer, E. V. Nordheim, and P. M. Crump. 2002. Animal and dietary factors affecting feed intake during the prefresh transition period in Holsteins. J. Dairy Sci. 85:3430–3443.

Hoedemaker, M., D. Prange, and Y. Gundelach. 2009. Body condition change ante- and postpartum, health and reproductive performance in German Holstein cows. Reprod. Domest. Anim. 44:167–173.

Huzzey, J. M., D. M. Veira, D. M. Weary, and M. A. von Keyserlingk. 2007. Prepartum behavior and dry matter intake identify dairy cows at risk for metritis. J. Dairy Sci. 90:3220–3233.

Inoue, T., H. Saito, T. Matsuda, K. Fukatsu, I. Han, S. Furukawa, S. Ikeda, and T. Muto. 1998. Growth hormone and insulin-like growth factor I augment bactericidal capacity of human polymorphonuclear neutrophils. Shock 10:278–284.

Kadivar, A., M. R. Ahmadi, and M. Vatankhah. 2014. Associations of prepartum body condition score with occurrence of clinical endometritis and resumption of postpartum ovarian activity in dairy cattle. Trop. Anim. Health Prod. 46:121–126.

Kaneene, J. B., R. Miller, T. H. Herdt, and J. C. Gardiner. 1997. The association of serum nonesterified fatty acids and cholesterol, management and feeding practices with peripartum disease in dairy cows. Prev. Vet. Med. 31:59–72.

Klucinski, W., A. Degorski, E. Miernik-Degorska, S. Targowski, and A. Winnicka. 1988. Effect of ketone bodies on the phagocytic activity of bovine milk macrophages and polymorphonuclear leukocytes. Zentralbl. Veterinarmed. A 35:632–639.

LeBlanc, S. J., T. F. Duffield, K. E. Leslie, K. G. Bateman, G. P. Keefe, J. S. Walton, and W. H. Johnson. 2002. Defining and diagnosing postpartum clinical endometritis and its impact on reproductive performance in dairy cows. J. Dairy Sci. 85:2223–2236.

Leelahapongsathon, K., T. Piroon, W. Chaisri, and W. Suriyasathaporn. 2016. Factors in dry period associated with intramammary infection and subsequent clinical mastitis in early postpartum cows. Asian-Australas. J. Anim. Sci. 29:580–585. https://doi.org/10.5713/ajas.15.0383.

Moe, P. W., and H. F. Tyrrell. 1972. Metabolizable energy requirements of pregnant dairy cows. J. Dairy Sci. 55:480–483.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th ed. Natl. Acad. Press, Washington, DC.

Ospina, P. A., D. V. Nydam, T. Stokol, and T. R. Overton. 2010. Evaluation of nonesterified fatty acids and β-hydroxybutyrate in transition dairy cattle in the northeastern United States: Critical

thresholds for prediction of clinical diseases. J. Dairy Sci. 93:546–554.
Ribeiro, E. S., G. Gomes, L. F. Greco, R. L. Cerri, A. Vieira-Neto, P. L. Monteiro Jr., F. S. Lima, R. S. Bisinotto, W. W. Thatcher, and J. E. Santos. 2016. Carryover effect of postpartum inflammatory diseases on developmental biology and fertility in lactating dairy cows. J. Dairy Sci. 99:2201–2220.
Ribeiro, E. S., F. S. Lima, L. F. Greco, R. S. Bisinotto, A. P. Monteiro, M. Favoreto, H. Ayres, R. S. Marsola, N. Martinez, W. W. Thatcher, and J. E. Santos. 2013. Prevalence of periparturient diseases and effects on fertility of seasonally calving grazing dairy cows supplemented with concentrates. J. Dairy Sci. 96:5682–5697.
Roche, J. R., N. C. Friggens, J. K. Kay, M. W. Fisher, K. J. Stafford, and D. P. Berry. 2009. Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. J. Dairy Sci. 92:5769–5801.
Rukkwamsuk, T., T. A. Kruip, and T. Wensing. 1999. Relationship between overfeeding and over conditioning in the dry-period and the problems of high producing dairy cows during the postparturient period. Vet. Q. 21:71–77.
Sander, A. K., M. Piechotta, G. Schlamberger, H. Bollwein, M. Kaske, A. Sipka, and H. J. Schuberth. 2011. Ex vivo phagocytic overall performance of neutrophilic granulocytes and the relation to plasma insulin-like growth factor-I concentrations in dairy cows during the transition period. J. Dairy Sci. 94:1762–1771.
Santos, J. E., H. M. Rutigliano, and M. F. Sá Filho. 2009. Risk factors for resumption of postpartum estrous cycles and embryonic survival in lactating dairy cows. Anim. Reprod. Sci. 110:207–221.
Sheehy, M. R., A. G. Fahey, S. P. Aungier, F. Carter, M. A. Crowe, and F. J. Mulligan. 2017. A comparison of serum metabolic and production profiles of dairy cows that maintained or lost body condition 15 days before calving. J. Dairy Sci. 100:536–547.
Smith, G. L., N. C. Friggens, C. J. Ashworth, and M. G. G. Chagunda. 2017. Association between body energy content in the dry period and post-calving production disease status in dairy cattle. Animal 11:1590–1598. https://doi.org/10.1017/S1751731117000040.
Valde, J. P., M. L. Lystad, E. Simensen, and O. Østerås. 2007. Comparison of feeding management and body condition of dairy cows in herds with low and high mastitis rates. J. Dairy Sci. 90:4317–4324. https://doi.org/10.3168/jds.2007-0129.
Vallimont, J. E., C. D. Dechow, J. M. Daubert, M. W. Dekleva, J. W. Blum, C. M. Barlieb, W. Liu, G. A. Varga, A. J. Heinrichs, and C. R. Baumrucker. 2010. Genetic parameters of feed intake, production, body weight, body condition score, and selected type traits of Holstein cows in commercial tie-stall barns. J. Dairy Sci. 93:4892–4901.
Vieira-Neto, A., K. N. Galvão, W. W. Thatcher, and J. E. Santos. 2017. Association among gestation length and health, production, and reproduction in Holstein cows and implications for their offspring. J. Dairy Sci. 100:3166–3181.
Wathes, D. C., Z. Cheng, W. Chowdhury, M. A. Fenwick, R. Fitzpatrick, D. G. Morris, J. Patton, and J. J. Murphy. 2009. Negative energy balance alters global gene expression and immune responses in the uterus of postpartum dairy cows. Physiol. Genomics 39:1–13.