Original scientific paper

UDK: 637.112.2

The effect of body condition score in the transition period on milk, fertility, and health traits of Holstein cows

DOI: 10.15567/mljekarstvo.2024.0106

*Ariadna V. Alvarado[1], Alan S. Alvarado[1], Fernando Arellano[1], Francisco G. Véliz[1], Ángeles de Santiago[1], Viridiana Contreras[1], Miguel Mellado[2]**

[1]Autonomous Agrarian University Antonio Narro, Dept. Veterinary Science, Torreon, 27054 Mexico
[2]Autonomous Agrarian University Antonio Narro, Dept. Animal Nutrition, Saltillo, 25315 Mexico

Received: 27.02.2023. **Accepted:** 01.12.2023.

*Corresponding author: melladomiguel07@gmail.com

Abstract

This study aimed to investigate the relationship between measures of body condition score (BCS) during the transition period and milk yield, reproductive performance, and occurrence of metritis and ketosis in cows. A total of 5026 lactations of 2424 Holstein cows from a single dairy farm were assessed for BCS (5-point scale; 0.25-point increments) 15 days precalving, at calving, and first service. ΔBCS were classed as <0.25, 0.25-0.5, 0.5-0.75, and >0.75 from 15 days precalving to parturition and from calving to first artificial insemination. BCS classes at parturition were <3.5, 3.5-3.75, and >3.75. 305-d milk yield was the highest in cows with BCS change (ΔBCS) <0.25 between 15-d precalving and parturition (11526±1088 kg), and the lowest (10878±1114) in cows with precalving ΔBCS <0.75. The total milk yield was the highest in cows with ΔBCS <0.25 between 15-d precalving and parturition (13861±2541 kg), and lowest (13214±3174) in cows with precalving ΔBCS >0.75. The overall pregnancy rate was least [281/836 (33.6%); p<0.01] for cows that lost >0.75 units of BCS, and greatest for cows that lost <0.25 BCS [477/615 (77.6 %)]. Puerperal metritis occurred more often in cows that lost >0.75 BCS between calving and the first artificial insemination (AI) [175/836 (20.9 %); p<0.01). Cows with reduced BCS loss between calving and first AI were less likely to present metritis [67/615 (10.9 %); p<0.01], whereas cows with ≥ 0.75 BCS loss between calving and first AI were 2.3 times more likely [175/836 (20.9 %)] to suffer metritis. In conclusion, greater changes in BCS between calving and first AI increased 305-d and the total milk yield, and occurrence of puerperal metritis and clinical ketosis, although fertility was reduced.

Keywords: pregnancy rate; milk yield; body condition score; metritis; ketosis

Introduction

Body condition scoring (BCS) provides a subjective assessment of the amount of body energy reserves in dairy cows. Therefore, BCS has been used as a tool in the reproductive (Bedere et al., 2018; Çolakoğlu et al., 2019), nutritional (Roche et al., 2009), and health (Roche et al., 2015) management of dairy herds. Extensive evidence links excessive BCS loss during the transition period to postpartum reproductive performance and puerperal diseases in dairy cows (Roche et al., 2009).

The peripartum period in high-yielding dairy cows is a critical physiological stage because cows suffer from a negative energy balance, leading to the mobilization of fat, muscle, and mineral stores (McCabe and Boerman; 2020; Mann, 2022; Grala et al., 2022). The increased energy demands for fetus development and colostrum production (van Hoeij et al., 2017), and insufficient feed intake (Pascottini et al., 2020), predispose cows to infectious and metabolic diseases (Fiore et al., 2017) and alter fertility and milk yield (Meikle et al., 2018; Mezzetti et al., 2021). Also, a complex interplay of multiple pathways, including metabolic and hormonal adaptations, entails metabolic and infectious diseases post-partum (Sundrum, 2015), and these health problems during the transition period constitute a major risk factor for subsequent milk yield and reproductive performance (Barletta et al., 2017).

Given that the changes in BCS have a substantial influence on dairy cows' fertility, milk yield, and health, monitoring BCS in dairy cows is very important (Thorup et al., 2012). This assessment has been extensively recommended to evaluate the nutritional management of dairy cows (Adrien et al., 2012) because BCS reflects dairy cows' fat and protein reserves and can predict metabolic diseases (Wang et al., 2019).

Eluding over-conditioning and avoiding cows from over-consuming energy relative to their nutrient requirements in late pregnancy causes a higher dry matter intake and less negative energy balance after parturition (Drackley and Cardoso, 2014) which leads to improved fertility (Gobikrushanth et al., 2019) and milk yield (Jamali Emam Gheise et al., 2017). On the other hand, thin cows do not necessarily have reduced fertility, but the loss of BCS in early lactation leads to low reproductive performance (Bastin and Gengler, 2013; Carvalho et al., 2014) and reduced milk yield.

Previous studies have observed the effect of different levels of BCS change postpartum and fertility, milk yield, and health of dairy cows. However, there is a lack of studies at commercial farms in hot environments looking at associations between BCS change from 15 days precalving to parturition and calving to first service in high-yielding cows subjected to heat stress. Additionally, many studies on this topic have been carried out on pasture and cow numbers at the upper and lower end of the BCS scale have been scarce. Thus, it was hypothesized that BCS loss prepartum and at calving, as well as ΔBCS from calving to first service is associated with higher occurrence of postpartum health disorders, increased milk yield, and reduced reproductive performance. This study aimed to evaluate the associations between precalving BCS change, BCS at calving, and BCS change (ΔBCS) from calving to first service on milk production, reproductive performance, and puerperal health of high-yielding Holstein cows.

Material and methods

Animals, housing, and feeding of cows

This study was approved by the Ethics Committee of the Research Department of the Autonomous Agrarian University Antonio Narro (protocol 3001-2423). The dairy farm was located in northern Mexico (25° N, 103° W, mean annual rainfall 230 mm, mean annual temperature 23.7 ºC). Milk yield, fertility, and health records for a three years period from 2019 to 2022 (5026 lactations of 2424 high-yielding Holstein cows; 34.9 kg/day herd's average annual daily milk yield) were obtained from a single large commercial dairy farm. The percentage of cows according to the number of lactations was 32.0, 29.6, 17.6, 11.3, 7.1, and 2.4 for 1 to ≥6 lactations, respectively. Days in milk (mean ± SD) for cows in this herd was 386±113.

Cows were kept in open-dirt pens equipped with metal framework shades in the center of the pens. Additional shades covered the feed alleys, which had fans and sprinklers. Both lactating and dry cows were fed a total mixed ration twice daily. Diet for lactating was formulated to meet the nutrient requirements for Holstein cows weighing 660 kg and producing 38 kg of 3.5 % FCM (at least 1.62 Mcal/kg NEl and 18 % crude protein; NRC, 2001).

Body condition score and disease recording

BCS was recorded for all cows based on the visual and palpation of the lumbar spine technique using the 5-point scale with a 0.25 increment, with 1 being too thin and 5 being too obese (Ferguson et al., 1994). Cows were body condition scored at the time of enrollment (15 days prepartum, in the preparturient pen), at parturition, and at the first artificial insemination (AI; approximately 60 d postpartum). BCS was recorded by two well-trained personnel with plenty of practical experience assessing BCS in commercial dairy farms, before the morning feeding with cows kept in a normal standing posture. Other variables of interest were ΔBCS from 15 days precalving to calving, and from calving to first artificial insemination.

The farm veterinarians diagnosed and treated all postparturient disorders. Puerperal metritis was diagnosed by rectal palpation and was defined as the presence of watery red-brown and extremely smelly vaginal discharge within 21 days of calving (Sheldon et al., 2006). Ketosis was defined as depressed appetite with evidence of elevated urine ketones using ketone strips (Ketostix, Bayern Corporation, Elkhart, IN), which were soaked with urine obtained by manual stimulation of the escutcheon (area below the vulva). The amount of acetoacetate in mg/dL was estimated according to the color intensity of the Ketostix diagnostic test.

Reproductive management

The vaccination program against diseases affecting reproductive performance was typical for dairy farms in the zone. All cows included in this investigation were vaccinated against brucellosis at 6 months of age and every year thereafter. Cows were vaccinated annually against bovine respiratory syncytial virus, bovine viral diarrhea types 1 and 2, para-influenza 3, infectious bovine rhinotracheitis, and leptospirosis caused by five *Leptospira* serovars (CattleMaster Gold FP5®, Zoetis, Mexico DF, Mexico). Cows were also annually vaccinated against leptospirosis (5-serovars; LEPTAVOID-H®; Merck Sharp & Dohme Corp., Mexico DF) 30 days postpartum.

Estrus was detected by direct visual observation for about 25 min before the morning and afternoon milkings. After a voluntary waiting period of 50 days postpartum, cows in estrus were artificially inseminated following the a.m./p.m. guide. Fixed-time AI using the Ovsynch program was used in all repeat-breeding cows. A commercially available frozen-thawed semen from multiple high genetic merit bulls from the USA was used. The herd veterinarians performed a pregnancy diagnosis at 45±3 days from their last recorded AI. The fertility measures included: first-service pregnancy rate, second-service pregnancy rate, pregnancy at three to five services, and pregnancy rate at all services, and services per pregnancy (only pregnant cows).

Milk yield recording

Cows were milked three times per day at 0:00 a.m., 08:30, and 16:00. Milk recording was made at every milking with electronic milk meters and electronic cow identification interfaced with Dairy Comp 305 (Valley Agricultural Software, Tulare, CA) in the milking facility. 305-d milk yield, total milk yield (lactations >305 days), days in milk, peak milk yield, and days at peak were recorded. Also, the entire lactation persistency [total milk yield/(peak milk yield x 305) x 100], and 305-d lactation milk yield persistency [305-d milk yield/(peak milk yield x 305) x 100] were estimated.

Statistical analyses

This study was a retrospective observational study. The data were checked for biological plausibility (e.g., lactations starting with abortion or induced hormonally were deleted; 305-d lactations <8500 kg or lactations from cows with dry periods <30 days were removed). Some cows had more than one lactation, and given that various lactations from the same cow cannot be considered independent events, for these cows, the sampling unit (lactation) was nested within cows to account for the cluster effect (lactations nested within cows; included in the model as a random effect).

Milk yield traits (305-d milk yield, total milk yield, peak milk, days to peak milk yield, and persistency yield were analyzed using a mixed linear model (PROC GLIMMIX of SAS; SAS Institute Inc., Cary, NC, USA, version 9.4M5, 2017) with groups (ΔBCS <0.25, 0.25-0.5, 0.5-0.75 and >0.75 from 15 days precalving to parturition and from calving to first artificial insemination. BCS classes at parturition were <3.5, 3.5-3.75, and >3.75. BCS were considered as fixed effects, cows as a random effect, and season of calving, year of parturition, and parity (primiparous or pluriparous) were incorporated in the model as covariates. The model used to compare ΔBCS and BCD groups for milk traits was $Y_{ijk} = \mu + G_i + C_{j(i)}, + L_{k(j)} + B_1X_{ij}, + e_{ijk}$, where Y represents the dependent variable, μ, overall mean; G, groups; C, cow within groups; X, covariate; L, lactation within cow; and e, residual. The PDIFF adjust=tukey option of SAS was used to compare the group's means.

A generalized linear model using the GENMOD procedure of SAS was used to assess the effect of BCS in the periparturient period and the change in BCS between calving and AI on reproductive metrics. Season of calving, year of parturition, and the number of lactations (primiparous or pluriparous) were included in the model as covariates. The model used was similar to that described for milk traits. After limiting the number of services per pregnancy to pregnant cows, the outcome of group of cows according to BCS on the number of services per pregnancy was analyzed by the Wilcoxon rank-sum test (PROC NPAR1WAY of SAS).

Multivariate mixed logistic regression models produced odds ratios (OR) as estimates of the strength of association between the periparturient BCS and the occurrence of metritis and ketosis. The response variable for the cow-level risk factors was binomial, with cows classified as presenting or not puerperal metritis and ketosis. The multivariate model contained, in addition to the BCS class, season of calving, parity, degree of calving assistance, and year of parity, regardless of its significance, for controlling for these confounders. The following model was used:

$$\text{Logit}\,(Y_{ijk}\ldots.n) = \alpha + \beta_i(x_i) + \beta_j(x_j) + \ldots + \beta_n(x_n) + e_{ijk}\ldots.n$$

Where: Y_{ijk} = Probability of occurrence of metritis or ketosis, α =intercept, X1… Xn = independent variables (risk factors), $\beta_1 \ldots \beta_n$ = slope, and $e_{ijk} \ldots n$ = random variation. For all statistical analyses, values with $p<0.05$ were regarded as statistically significant.

Results and discussion

Milk yield

Table 1 shows the lactation traits of cows showing different BCS changes from 15 days prepartum to calving. Lactation length did not differ among cows with BCS changes from <0.25 to >0.75. 305-d milk yield decreased ($p<0.01$) linearly with increasing changes in BCS from 15 days precalving to calving.

Causes of prepartum loss of BCS were unknown, but these changes in BCS in this phase may occur because of inadequate nutrition, poor management, or controlled feeding in over-conditioned cows (Roche, 2006; Cardoso et al., 2013), and more importantly, the spontaneous reduction in feed intake before parturition (Pascottini et al., 2020). Thus, these results suggest that the degree of BCS reduction before calving is a dependable predictor of 305-d milk yield. A greater effect of prepartum BCS loss has been observed on metabolic activity in the postpartum period than in the postpartum period. Also, serum concentrations of IGF-I one week postcalving decrease in thinner cows prepartum (Sheehy et al., 2017). These responses explain in part the detrimental consequence of prepartum BCS loss on 305-d milk yield. The present findings concur with Roche et al. (2015), who found that thinner cows one-month precalving produced less milk than cows in moderate BCS. Also, Chebel et al. (2018) in a retrospective observational study found that loss of BCS during the dry period was associated with reduced milk yield. These findings disagree with Sheehy et al. (2017) who found no differences in milk production among cows that maintained BCS between d -15 and d 0 and those that lost BCS, although milk yield in this study was recorded only for 75 days.

The total milk yield did not differ between cows with changes in BCS from <0.25 to 0.75, but cows with a change >0.75 units had a lower (p<0.01) total milk yield than cows with a less severe change in BCS before calving. Peak milk yield was higher (p<0.01) in cows with the lowest change in BCS precalving than in cows with more pronounced changes in BCS. Total and 305-d lactation persistency was greater in cows with a lower decrease in precalving BCS than cows in the higher BCS loss groups.

The average BCS at calving was 3.2 ± 0.3, a value within the boundary for optimum BCS (3.0-3.5) reported by Roche et al. (2004) and Samarütel et al. (2006). Cows in high BCS at calving (i.e., >3.75) produced more milk than cows in good and moderate BCS (Table 2). This favourable response of high BCS at calving on milk production was in line with previous findings on pasture (Roche et al., 2009, 2013) and confinement (Domecq et al., 1997) studies. Results of this study are opposite to previously reported findings indicating that the optimum calving BCS for milk production is between 3.0 and 3.5 in Holstein cows and that further increases in BCS at calving result in reduced milk yield (Roche et al., 2009). BCS at calving <3.5 resulted in fewer (p<0.01) days in milk than cows with BCS >3.5 (Table 2). The group with the highest BCS at calving produced more milk in 305-d or total lactation than the group with the lowest BCS at calving. Peak milk yield increased by 1.6 kg in cows with >3.75 BCS than in cows with a BCS <3.5 at calving. 305-d and total lactation persistency was higher in cows with BCS <3.5 at calving than in cows with BCS >3.5 at calving.

Lactation length was 65 days shorter (p<0.01) in cows with <0.25 change in BCS between calving and first service, compared to cows with a BCS change >0.75 units (Table 3). For both 305-d and total lactation, milk yield increased (p<0.01) with increasing BCS loss between calving and first artificial insemination. Lactation persistency (305-d and total) was higher in cows with the lowest BCS change than in cows with the greatest BCS loss between calving and first service. These results were consistent with findings of

Table 1. Change of body condition score (ΔBCS) from 15 days precalving to calving in relation to milk yield (means ± standard deviations) of high-yielding Holstein cows in a hot environment

Variables	<0.25	0.25-0.5	0.5-0.75	>0.75
Lactation length, days	393±98	399±113	403±125	395±121
305-d milk yield, kg	11526±1088^{a}	11320±1147^{b}	11082±1127^{c}	10878±1114^{d}
Total milk yield, kg	13861±2541^{a}	13727±2829^{a}	13571±3067^{a}	13214±3174^{b}
Peak milk yield, kg	48.8±7.5^{a}	47.8±7.9^{b}	47.4±7.8^{b}	47.3±7.9^{b}
Days to peak milk yield	76±29	74±30	75±30	74±29
Persistency 305-d milk yield	63.0±9.7^{a}	62.7±10.2^{ab}	61.8±10.7^{b}	61.7±9.9^{b}
Persistency total milk yield	74.6±9.5^{a}	74.6±9.8^{a}	73.8±9.6^{ab}	73.2±10.3^{b}

Values within a row with different superscript letters differ at p<0.01.
Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 2. Body condition score (BCS) at calving in relation to milk yield (means ± standard deviations) of high-yielding Holstein cows in a hot environment

Variables	<3.5	3.5-3.75	>3.75
Lactation length, days	393±115^{b}	405±122^{a}	403±110^{a}
305-d milk yield, kg	11154±1558^{b}	11205±1115^{b}	11363±1084^{a}
Total milk yield, kg	13376±2876^{c}	13758±3019^{b}	13970±2827^{a}
Peak milk yield, kg	47.2±7.9^{b}	47.7±8.3^{b}	48.8±7.1^{a}
Days to peak milk yield	74.2±30.0^{b}	73.2±29.5^{b}	77.3±30.3^{a}
Persistency 305-d milk yield	63.6±10.4^{a}	61.5±9.4^{b}	61.2±10.9^{b}
Persistency total milk yield	74.7±9.8^{a}	74.1±10.3^{ab}	73.4±9.1^{b}

Values within a row with different superscript letters differ at p<0.01.
Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Roche et al. (2015) who showed a greater BCS loss in fatter cows, combined with higher serum ß-hydroxybutyrate (BHB) concentrations and higher milk yield. Also, Gobikrushanth et al. (2019) reported a higher 305-d mature equivalent milk yield for extreme BCS loss compared with cows that gained BCS postpartum. Berry et al. (2007) confirmed the previous studies and found that cows that lose more BCS in early lactation produced more milk. A positive association is, therefore, expected between the degree of BCS loss postpartum and milk production. This association between BCS loss postpartum and milk production is consistent with fitted functions reported by Berry et al. (2006) and Roche et al. (2007) which depicted BCS profiles as mirror images of lactation curves.

Reproductive performance

The percentage of cows pregnant with one or two services was extremely low and was not affected by BCS change between 15 days prepartum and calving (Table 4). Pregnancy rate with three to five services was highest ($p<0.01$) for cows with moderate BCS change compared with other groups with low and high changes in BCS. Likewise, moderate change in BCS before calving resulted in the highest ($p<0.01$) pregnancy rate for all services; cows with the highest BCS change precalving presented the lowest pregnancy rate. These results are consistent with a previous study where prepartum BCS loss of 0.25 or ≥ 0.5 points reduced the overall pregnancy rate in dairy cows (Çolakoğlu et al., 2019). This response could be due to the more drastic energy shortage reflected by unfavourable BCS change early in lactation. Also, results in the current study agree with Pryce et al. (2000) who observed that thinner cows had longer calving intervals. Likewise, Kadarmideen (2004) reported that cows with a good BCS had shorter intervals to first service after calving and were more likely to be pregnant within 56 days after the first service. Another study by Kim and Suh (2003) showed that losing BCS (1.0–1.5 points) from the dry to near calving periods increases the number of days to first breeding after calving in comparison with the moderate BCS loss (0–0.75 points). Services per pregnancy were lowest in cows with the lowest BCS change prepartum and highest for cows with the highest BCS change before calving.

Table 5 shows the reproductive performance of cows as a function of BCS at calving. Surprisingly, cows with the highest BCS at calving had the lowest ($p<0.01$) pregnancy rate at first service than cows with lower BCS at calving. However, pregnancy rate at second and third to fifth services was consistently lower in cows with the greatest BCS at calving. The lowest services per pregnancy were for cows with BCS 3.25-3.5 and cows with BCS <3.25 required the highest number of services to get pregnant.

Cows with a BCS change <0.25 between calving and first AI had higher pregnancy rates at first AI than all other groups with higher BCS change postpartum (Table 6). Pregnancy rate at second, 3 to 5, and total services decreased with increasing BCS change between calving and first AI. Services

Table 3. Change of body condition score (ΔBCS) from calving to first artificial insemination with reference to milk yield (means ± standard deviations) of high-yielding Holstein cows in a hot environment

Variables	<0.25	0.25-0.5	0.5-0.75	>0.75
Lactation length, days	345±58[b]	406±118[a]	406±125[a]	410±118[a]
305-d milk yield, kg	11061±1066[c]	11130±1147[c]	11296±1127[b]	11422±1071[a]
Total milk yield, kg	12145±1756[c]	13664±2956[b]	13935±3033[a]	14134±2992[a]
Peak milk yield, kg	47.4±4.8[c]	47.0±8.7[c]	48.1±8.1[b]	49.2±6.6[a]
Days to peak milk yield	67.9±28.6[a]	75.0±29.7[b]	74.9±30.4[b]	77.5±29.8[b]
Persistency 305-d milk yield	69.2±10.0[a]	61.8±8.8[b]	61.5±10.2[b]	60.4±12.0[c]
Persistency total milk yield	75.2±8.1[a]	74.6±10.4[ab]	74.2±9.8[b]	72.4±9.0[c]

Values within a row with different superscript letters differ at p<0.01.
Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 4. Change of body condition score (ΔBCS) from 15 days precalving to calving with reference to reproductive performance of high-yielding Holstein cows in a hot environment. Values are means ± standard deviations

Variables	<0.25	0.25 - 0.5	0.5-0.75	> 0.75
First-service pregnancy rate, %	18/420 (4.3)	120/2574 (4.9)	69/1452 (4.8)	21/580 (3.6)
Second-service pregnancy rate, %	40/420 (9.5)	305/2574 (11.9)	159/1452 (11.0)	57/580 (9.8)
3 to 5 service pregnancy rate, %	95/420 (22.6)[b]	760/2574 (29.5)[a]	387/1452 (26.7)[b]	134/580 (23.1)[b]
Overall pregnancy rate, %	233/420 (55.5)[b]	1585 /2574 (61.6)[a]	757/1452 (52.1)[b]	237/580 (40.9)[c]
Services per pregnancy	5.1 ± 3.6[d]	5.6 ± 3.7[c]	6.2 ± 3.9[b]	6.6 ± 4.0[a]

Values within a row with different superscript letters differ at p<0.01.
Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

per pregnancy increased with increasing BCS change between calving and first AI. Although inconsistent reports from various studies, there has been a tendency for a deleterious effect of BCS loss postcalving on measures of reproductive success in dairy cows (Santos et al., 2009; Torres et al., 2020; Manríquez et al., 2021). Moreover, cows present higher pregnancy rate when they gain or maintain BCS during the first three weeks postpartum (Carvalho et al., 2014). Few technicians in intensive dairy farms register BCS at calving and the first service. However, recording BCS at parturition and first AI presents a valuable practice to evaluate whether BCS change will limit the fertility of dairy cows.

Association between ΔBCS and health outcomes

The ΔBCS-group-specific odds ratios for metritis and ketosis are presented in Table 7. The risks of puerperal metritis increased with BCS change between calving and AI. Also, compared to all other cows, the cows with >0.75 BCS change between calving and AI were 2.1 times more likely to have clinical ketosis. The occurrence of periparturient diseases is associated with changes in BCS in early lactation (Barletta et al., 2017), but this confounder was introduced in the model as covariate, thus, cow health effects were

Table 5. Body condition score (BCS) at calving in relation to the reproductive performance of high-yielding Holstein cows in a hot environment

Variables	<3.25	3.25 - 3.5	>3.5
First-service pregnancy rate, %	115/2247 (5.1)^{a}	76/1675 (4.5)^{a}	37/1104 (3.4)^{b}
Second-service pregnancy rate, %	287/2247 (12.8)^{a}	175/1675 (10.5)^{b}	99/1104 (9.0)^{b}
3 to 5 service pregnancy rate, %	636/2247 (28.3)^{a}	280/1675 (28.2)^{a}	165/1104 (24.3)^{b}
Overall pregnancy rate, %	1206/2247 (53.7)^{A}	987 /1675 (58.9)^{B}	619/1104 (56.1)^{B}
Services per pregnancy	6.4 ± 4.0^{A}	5.4 ± 3.6^{B}	6.2 ± 4.0^{A}

Values within a row with different superscript lowercase letters differ at p<0.05.
Values within a row with different superscript capital letters differ at p<0.01.
Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 6. Change of body condition score (ΔBCS) from calving to first artificial insemination at calving in relation to the reproductive performance of high-yielding Holstein cows in a hot environment

Variables	<0.25	0.25-0.5	0.5–0.75	>0.75
First-service pregnancy rate, %	42/615 (6.8)^{a}	105/2158 (4.9)^{b}	56/1417 (4.0)^{b}	25/836 (3.0)^{b}
Second-service pregnancy rate, %	111/615 (18.1)^{A}	281/2158 (13.0)^{B}	121/1417 (8.5)^{C}	48/836 (5.7)^{D}
3 to 5 service pregnancy rate, %	636/615 (28.3)^{A}	280/2158 (28.2)^{B}	337/1417 (23.8)^{C}	102/836 (12.2)^{D}
Overall pregnancy rate, %	477/615 (77.6)^{A}	1334 /2158 (61.8)^{B}	720/1417 (50.8)^{C}	281/836 (33.6)^{D}
Services per pregnancy	5.4 ± 3.4^{C}	5.8 ± 3.8^{BC}	5.9 ± 3.9^{B}	6.6 ± 4.3^{A}

Values within a row with different superscript lowercase letters differ at p<0.05.
Values within a row with different superscript capital letters differ at p<0.01.
Cows had their BCS evaluated using a 5-point scale with 0.25 increments.

Table 7. Multivariate logistic regression model for factors associated with the incidence of metritis and ketosis in high-yielding Holstein cows in a hot environment

Variables		Odds ratio (OR)	95% CI OR	p
	Metritis			
BCS change calving-AI				
>0.75	175/836 (20.9)	2.3	1.5-3.6	0.0002
0.5-0.75	265/1417 (18.7)	1.9	1.4-2.5	<.0001
0.25 - 0.5	348/2158 (16.1)	1.6	1.2-2.1	0.0013
<0.25	67/615 (10.9)	Reference		
	Ketosis			
>0.75	70/836 (8.4)	2.1	1.3-3.3	0.0025
0.5-0.75	71/1417 (5.0)	1.2	0.8-1.9	0.4524
0.25-0.5	115/2158 (5.3)	1.3	0.8-2.0	0.2777
<0.25	26/615 (4.2)	Reference		

BCS=Body condition score (1 to 5 scale scoring system, 0.25 points increment).
AI= first artificial insemination postcalving.

isolated; therefore, the detrimental effect of BCS loss postpartum seems to be due only to the reduced feed intake coupled with higher nutrient demands for milk synthesis, resulting in insufficient energy intake for lactation (Gross et al., 2011). Thus, managing cattle to predetermined levels of BCS loss postpartum is important in high-yielding cows. Additionally, BCS loss between calving and the first AI may be more significant as an indicator of reproductive outcome than BCS recorded on a single occasion (i,e., at calving).

The present study was carried out in a large commercial dairy herd; therefore, cows were exposed to similar herd-level factors such as feeding, management, quantity and quality of feedstuff, and environmental effects, which enhanced the validity of the association between postpartum BCS change and periparturient diseases. In the case of clinical ketosis, its higher incidence in cows with the greatest BCS loss arises from the fact that high-mobilizing cows are less able to overcome metabolic challenges in the early postpartum period which increases their serum BHB concentrations early postpartum (Gärtner et al., 2019), and the greater the lipid mobilization in early lactation the higher the odds of metritis (Torres et al., 2020). In line with the current results, Stevenson et al. (2020) reported an increased risk of ketosis in cows with greater loss of BCS postcalving, which corroborates that high-mobilizing cows are less able to overcome metabolic challenges during the puerperium, reflected by higher postpartum blood fatty acids and BHB concentrations (Gärtner et al., 2019).

In the case of metritis, a positive association has been found between the BCS loss and the incidence of infectious diseases (Sheehy et al., 2014; Chebel et al., 2018), particularly metritis (Kim and Suh, 2003), apparently derived from the fact that thinner cows before calving are prone to an accentuated reduction in peripartum immune competence, which increases the risk of infectious diseases (Sheehy et al., 2017; Beltman et al., 2020). Thus, as it has been previously shown (Kadivar et al., 2014; Stevenson et al., 2020), low BCS is a risk factor for postpartum metritis in dairy cows. Additionally, the increased demand for nutrients for the onset of lactation results in insufficient energy intake to meet the energetic requirements for lactation (Gross et al., 2011) and decreased feed intake (Hayirli et al., 2002; Hayirli and Grummer, 2004) in the weeks immediately before calving have been associated with the occurrence of two common transition diseases: metritis (Huzzey et al., 2007; Dubuc et al., 2010) and subclinical ketosis (Goldhawk et al., 2009; Ospina et al., 2010).

There are limitations and potential biases in this observational research due to the lack of randomization and the existence of factors that could have influenced the result. However, because of the numerous database data, it is deemed that the results can distinguish the potential causal association.

Conclusions

This study showed that pre-calving BCS loss was a major factor influencing 305-d milk yield and reproductive outcome, with lower milk production and reduced pregnancy rate as precalving BCS loss increased. Thus, in high-yielding Holstein cows in a hot environment, the optimum precalving BCS loss should not exceed 0.25 units to maximize milk yield and fertility. Also, postpartum BCS loss of >0.75 points positively affected the 305-d and the total milk yield but decreased reproductive performance. These findings reinforce the view that a high milk yield starts during the dry period and higher ΔBCS within 60 days in milk positively influences subsequent milk yield but hampered cows´ fertility. Finally, there was an association between the degree of BCS loss postpartum and the occurrence of puerperal metritis and ketosis which suggests that ensuring a moderate loss of BCS in early lactation can reduce the incidence of these periparturient diseases. Overall, these results indicate that cows with higher losses of BCS postpartum have increased milk production potential but poorer health status and reproductive performance. Thus, monitoring BCS loss during the calving and the first AI could be useful to identify cows susceptible to metabolic and infectious diseases and lower reproductive success.

Ethics statement

The Autonomous Agrarian University Antonio Narro Institutional Animal Care and Use Committee approved all actions connected with cows used for this study (protocol number 3001-2423).

Funding information

This work was supported by a grant from Autonomous Agrarian University Antonio Narro (research project 3001-2423).

Utjecaj ocjene tjelesne kondicije u prijelaznom razdoblju na mlijeko, plodnost i zdravstvena svojstva holstein krava

Sažetak

Cilj ovog istraživanja bio je utvrditi odnos između mjera procjene tjelesne kondicije (BCS) tijekom prijelaznog razdoblja i mliječnosti, reproduktivne sposobnosti i pojave metritisa i ketoze u krava. Ukupno 5026 laktacija u 2424 holstein krava s jedne mliječne farme procijenjeno je na BCS (ljestvica od 5 točaka; prirast od 0,25 točaka) 15 dana prije teljenja, pri teljenju i prvom osjemenjivanju. ΔBCS su klasificirani kao <0,25, 0,25-0,5, 0,5-0,75 i >0,75 od 15 dana prije teljenja do teljenja i od teljenja do prvog osjemenjivanja. BCS klase pri teljenju bile su <3,5, 3,5-3,75 i >3,75. 305-d mliječnost bila je najveća u krava s BCS promjenom (ΔBCS) <0,25 između 15-d predteljenja i partusa (11526±1088 kg), a najmanja (10878±1114) u krava s predteljenjem ΔBCS <0,75. Ukupna mliječnost bila je najveća u krava s ΔBCS <0,25 između 15 dana pred teljenje i teljenje (13861±2541 kg), a najmanja (13214±3174) u krava s ΔBCS >0,75 prije teljenja. Ukupna stopa bređosti bila je najmanja [281/836 (33,6 %); p<0,01] za krave koje su izgubile >0,75 jedinica BCS, a najveće za krave koje su izgubile <0,25 BCS [477/615 (77,6 %)]. Puerperalni metritis javljao se češće kod krava koje su izgubile >0,75 BCS između teljenja i prvog umjetnog osjemenjivanja (AI) [175/836 (20,9 %); p<0,01). Krave sa smanjenim gubitkom BCS-a između teljenja i prve AI imale su manju vjerojatnost da će imati metritis [67/615 (10,9 %); p<0,01], dok su krave s gubitkom BCS-a ≥0,75 između teljenja i prve AI imale 2,3 puta veću vjerojatnost [175/836 (20,9 %)] da obole od metritisa. Zaključno, veće promjene BCS-a između teljenja i prve AI povećale su 305-d i ukupni prinos mlijeka, te pojavu puerperalnog metritisa i kliničke ketoze, iako je plodnost bila smanjena.

Ključne riječi: stopa bređosti; mliječnost; procjena tjelesne kondicije; metritis; ketoza

References

1. Adrien, M.L., Mattiauda, D.A., Artegoitia, V., Carriquiry, M., Motta, G., Bentancur, O., Meikle, A. (2012): Nutritional regulation of body condition score at the initiation of the transition period in primiparous and multiparous dairy cows under grazing conditions: Milk production, resumption of post-partum ovarian cyclicity and metabolic parameters. *Animal* 6 (2), 292-299. https://doi.org/10.1017/S175173111100142X.
2. Barletta, R.V., Maturana Filho, M., Carvalho, P.D., Del Valle, T.A., Netto, AS., Rennó, F.P., Mingoti, R.D., Gandra, J.R., Mourão, G.B., Fricke, P.M., Sartori, R., Madureira, E.H., Wiltbank, M.C. (2017): Association of changes among body condition score during the transition period with NEFA and BHBA concentrations, milk production, fertility, and health of Holstein cows. *Theriogenology* 104, 30-36. https://doi.org/10.1016/j.theriogenology.2017.07.030
3. Bastin, C., Gengler, N. (2013): Genetics of body condition score as an indicator of dairy cattle fertility. A review. *Biotechnologie, Agronomie, Société et Environnement* 17, 64-75. https://doi.org/10.3168/jds.2014-9148
4. Bedere, N., Cutullic, E., Delaby, L., Garcia-Launay, F., Disenhaus, C. (2018): Meta-analysis of the relationships between reproduction, milk yield and body condition score in dairy cows. *Livestock Science* 210, 73-84. https://doi.org/10.1016/j.livsci.2018.01.017
5. Beltman, M.E., McNally, J.C., Kelly, E., Crowe, M.A. (2020): Relationship between plasma concentrations of IGF-I and clinical endometritis, and response to progesterone synchrony in dairy cows during early lactation. *Journal of Dairy Science* 103, 9493-9501. https://doi.org/10.3168/jds.2019-17974
6. Berry, D.P., Buckley, F., Dillon, P. (2007): Body condition score and live-weight effects on milk production in Irish Holstein-Friesian dairy cows. *Animal* 1 (9), 1351-1359**.** https://doi.org/10.1017/S1751731107000419

7. Berry, D.P., Veerkamp, R.F., Dillon, P. (2006): Phenotypic profiles for body weight, body condition score, energy intake, and energy balance across different parities and concentrate feeding levels. *Livestock Science* 104, 1-12. https://doi.org/10.1016/j.livsci.2006.02.012
8. Cardoso, F.C., LeBlanc, S.J., Murphy, M.R., Drackley, J.K. (2013): Prepartum nutritional strategy effects reproductive performance in dairy cows. *Journal of Dairy Science* 96, 5859-5871. http://dx.doi.org/10.3168/jds.2013-6759
9. Carvalho, P.D., Souza, A.H., Amundson, M.C., Hackbart, K.S., Fuenzalida, M.J., Herlihy, M.M., Ayres, H., Dresch, A.R., Vieira, L.M., Guenther, J.N., Grummer, R.R., Fricke, P.M., Shaver, R.D., Wiltbank, M.C. (2014): Relationships between fertility and postpartum changes in body condition and body weight in lactating dairy cows. *Journal of Dairy Science* 97(6), 3666-3683. http://dx.doi.org/10.3168/jds.2013-7809
10. Chebel, R.C., Mendonça, L.G.D., Baruselli, P.S. (2018): Association between body condition score change during the dry period and postpartum health and performance. *Journal of Dairy Science* 101 (5), 4595-4614. https://doi.org/10.3168/jds.2017-13732
11. Çolakoğlu, H.E., Yazlık, M.O., Pekcan, M., Kaya, U., Kaçar, C., Vural, M.R., Kurt, S., Yildirim, M.M., Bas, A., Küplülü, Ş. (2019): Impact of prepartum body condition score loss on metabolic status during the transition period and subsequent fertility in Brown Swiss dairy cows. *Journal of Veterinary Research* 63 (3), 375-382. https://doi.org/10.2478/jvetres-2019-0039
12. Domecq, J.J., Skidmore, A.L., Lloyd, J.W., Kaneene, J.B. (1997): Relationship between body condition scores and milk yield in a large dairy herd of high-yielding Holstein cows. *Journal of Dairy Science* 80, 101-112. https://doi.org/10.3168/jds.S0022-0302(97)75918-6
13. Drackley, J.K., Cardoso, F.C. (2014): Prepartum and postpartum nutritional management to optimize fertility in high-yielding dairy cows in confined TMR systems. *Animal* 8, 5-14. https://doi.org/10.1017/S1751731114000731
14. Drackley, J.K., Dann, H.M., Douglas, N., Guretzky, N.A.J., Litherland, N.B., Underwood, J.P., Loor, J.J. (2005): Physiological and pathological adaptations in dairy cows that may increase susceptibility to periparturient diseases and disorders. *Italian Journal of Animal Science* 4 (4), 323-344. https://doi.org/10.4081/ijas.2005.323
15. Dubuc, J., Duffield, T.F., Leslie, K.E., Walton, J.S., Leblanc, S.J. (2010): Risk factors for postpartum uterine diseases in dairy cows. *Journal of Dairy Science* 93, 5764-5771. https://doi.org/10.3168/jds.2010-3429
16. Ferguson, J.D., Galligan, D.T., Thomsen, N. (1994): Principal descriptors of body condition score in Holstein cows. *Journal of Dairy Science* 77, 2695-2703. https://doi.org/10.3168/jds.S0022-0302(94)77212-X
17. Fiore, E., Piccione, G., Rizzo, M., Morgante, M., Barberio, A., Giudice, E., Gianesella, M. (2018): Adaptation of some energetic parameters during transition period in dairy cows. *Journal of Applied Animal Research* 46 (1), 402-405. http://dx.doi.org/10.1080/09712119.2017.1313742
18. Gärtner, T., Gernand, E., Gottschalk, J., Donat, K. (2019): Relationships between body condition, body condition loss, and serum metabolites during the transition period in primiparous and multiparous cows. *Journal of Dairy Science* 102 (10), 9187-9199. https://doi.org/10.3168/jds.2018-15762
19. Gobikrushanth, M., Macmillan, K., Behrouzi, A., Hoff, B., Colazo, M.G. (2019): The factors associated with postpartum body condition score change and its relationship with serum analytes, milk production and reproductive performance in dairy cows. *Livestock Science* 228, 151-160. https://doi.org/10.1016/j.livsci.2019.05.016
20. Goldhawk, C., Chapinal, N., Veira, D.M., Weary, D.M., Von Keyserlingk, M.A.G. (2009): Prepartum feeding behavior is an early indicator of subclinical ketosis. *Journal of Dairy Science* 92(10), 4971-4977. https://doi.org/10.3168/jds.2009-2242.

21. Grala, T.M., Kuhn-Sherlock, B., Roche, J.R., Jordan, O.M., Phyn, C.V.C., Burke, C.R., Meier, S. (2022): Changes in plasma electrolytes, minerals, and hepatic markers of health across the transition period in dairy cows divergent in genetic merit for fertility traits and postpartum anovulatory intervals. *Journal of Dairy Science* 105(2), 1754-1767. https://doi.org/10.3168/jds.2021-20783
22. Gross, J., Van Dorland, H.A., Bruckmaier, R.M., Schwarz, F.J. (2011): Performance and metabolic profile of dairy cows during a lactational and deliberately induced negative energy balance with subsequent realimentation. *Journal of Dairy Science* 94(4), 1820-1830.
https://doi.org/10.3168/jds.2010-3707
23. Hayirli, A., Grummer, R.R. (2004): Factors affecting dry matter intake prepartum in relationship to etiology of peripartum lipid-related metabolic disorders: A review. *Canadian Journal of Animal Science* 84, 337-347.
https://doi.org/10.4141/A03-122
24. Hayirli, A., Grummer, R.R., Nordheim, E.V., Crump, P.M. (2002): Animal and dietary factors affecting feed intake during the pre-fresh transition period in Holsteins. *Journal of Dairy Science* 85, 3430-3443.
https://doi.org/10.3168/jds.S0022-0302(02)74431-7
25. Huzzey, J.M., Veira, D.M., Weary, D.M., von Keyser-lingk, M.A.G. (2007): Prepartum behavior and dry matter intake identify dairy cows at risk for metritis. *Journal of Dairy Science* 90, 3220-3233.
https://doi.org/10.3168/jds.2006-807
26. Jamali Emam Gheise, N., Riasi, A., Zare Shahneh, A., Celi, P., Ghoreishi, S.M. (2017): Effect of pre-calving body condition score and previous lactation on BCS change blood metabolites, oxidative stress and milk production in Holstein dairy cows. *Italian Journal of Animal Science* 16 (3), 474-483.
https://doi.org/10.1080/1828051X.2017.1290507
27. Kadarmideen, H.N. (2004): Genetic correlations among body condition score, somatic cell score, milk production, fertility and conformation traits in dairy cows. *Animal Science* 79 (2), 191-201.
https://doi.org/10.1017/S1357729800090056
28. Kadivar, A., Ahmadi, M.R., Vatankhah, M. (2014): Associations of prepartum body condition score with occurrence of clinical endometritis and resumption of postpartum ovarian activity in dairy cattle. *Tropical Animal Health and Production* 46 (1), 121-126. https://doi.org/10.1007/s11250-013-0461-9
29. Kim, I.H. Suh, G.H. (2003): Effect of the amount of body condition loss from the dry to near calving periods on the subsequent body condition change, occurrence of postpartum diseases, metabolic parameters and reproductive performance in Holstein dairy cows, *Theriogenology* 60, 1445-1456.
https://doi.org/10.1016/S0093-691X(03)00135-3
30. Mann, S. (2022): Symposium review: The role of adipose tissue in transition dairy cows: Current knowledge and future opportunities. *Journal of Dairy Science* 105 (4), 3687-3701. https://doi.org/10.3168/jds.2021-21215
31. Manríquez, D., Thatcher, W.W., Santos, J.E.P., Chebel, R.C., Galvão, K.N., Schuenemann, G.M., Bicalho, R.C., Gilbert, R.O., Rodriguez-Zas, S., Seabury, C.M., Rosa, G.J.M., Pinedo, P. (2021): Effect of body condition change and health status during early lactation on performance and survival of Holstein cows. *Journal of Dairy Science* 104 (12), 12785-12799.
https://doi.org/10.3168/jds.2020-20091
32. McCabe, C.J., Boerman, J.P. (2020): Invited Review: Quantifying protein mobilization in dairy cows during the transition period. *Applied Animal Science* 36 (3), 389-396. https://doi.org/10.15232/aas.2019-01929
33. Meikle, A., Brun, V.D., Carriquiry, M., Soca, P., Sosa, C., Adrien, M.D.L., Chilibroste, P., Abecia, J.A. (2018): Influences of nutrition and metabolism on reproduction of the female ruminant. *Animal Reproduction* 15 (1), 899-911.
http://dx.doi.org/10.21451/1984-3143-AR2018-0017

34. Mezzetti, M., Cattaneo, L., Passamonti, M.M., Lopreiato, V., Minuti, A., Trevisi, E. (2021): The transition period updated: A review of the new insights into the adaptation of dairy cows to the new lactation. *Dairy* 2 (4), 617-636. https://doi.org/10.3390/dairy2040048
35. NRC. (2001): Nutrient Requirements of Dairy Cattle 7th rev. ed., National Academies Press, Washington, D.C.
36. Ospina, P.A., Nydam, D.V., Stokol, T., Overton, T.R. (2010): Associations of elevated nonesterified fatty acids and β-hydroxybutyrate concentrations with early lactation reproductive performance and milk production in transition dairy cattle in the northeastern United States. *Journal of Dairy Science* 93 (4), 1596-1603. https://doi.org/10.3168/jds.2009-2277.
37. Pascottini, O.B., Leroy, J.L.M.R., Opsomer, G. (2020): Metabolic stress in the transition period of dairy cows: Focusing on the prepartum period. *Animals* 10 (8), 1419. https://doi.org/10.3390/ani10081419
38. Pryce, J.E., Coffey, M.P., Brotherstone, S. (2000): The genetic relationship between calving interval, body condition score and linear type and management traits in registered Holsteins. *Journal of Dairy Science* 83 (11), 2664-2671. https://doi.org/10.3168/jds.S0022-0302(00)75160-5
39. Roche, J.R., Macdonald, K.A., Burke, C.R., Lee, J.M., Berry, D.P. (2007): Associations among body condition score, body weight, and reproductive performance in seasonal-calving dairy cattle. *Journal of Dairy Science* 90 (1), 376-391. https://doi.org/10.3168/jds.S0022-0302(07)72639-5
40. Roche, J.F. (2006): The effect of nutritional management of the dairy cow on reproductive efficiency. *Animal Reproduction Science* 96, 282-296. https://doi.org/10.1016/j.anireprosci.2006.08.007
41. Roche, J.R., Macdonald, K.A., Schütz, K.E., Matthews, L.R., Verkerk, G.A., Meier, S., Loor, J.J., Rogers, A.R., McGowan, J., Morgan, S.R., Taukiri, S., Webster, J.R. (2013): Calving body condition score affects indicators of health in grazing dairy cows. *Journal of Dairy Science* 96 (9), 5811-5825. https://doi.org/10.3168/jds.2013-6600
42. Roche, J.R., Meier, S., Heiser, A., Mitchell, M.D., Walker, C.G., Crookenden, M.A., Riboni, M.V., Loor, J.J., Kay, J.K. (2015): Effects of precalving body condition score and prepartum feeding level on production, reproduction, and health parameters in pasture-based transition dairy cows. *Journal of Dairy Science* 98 (10), 7164-7182. https://doi.org/10.3168/jds.2014-9269
43. Roche, J.R., Dillon, P.G., Stockdale, C.R., Baumgard, L.H., Van Baale, M.J. (2004): Relationships among international body condition scoring systems. *Journal of Dairy Science* 87, 3076-3079. https://doi.org/10.3168/jds.S0022-0302(04)73441-4
44. Roche, J.R., Friggens, N.C., Kay, J.K., Fisher, M.W., Stafford. KJ, Berry, D.P. (2009): Invited review. Body condition score and its association with dairy cow productivity, health, and welfare. *Journal of Dairy Science* 92, 5769-801. https://doi.org/10.3168/jds.2009-2431
45. Samarütel, J., Ling, K., Jaakson, H., Kaart, T., Kart, O. (2006): Effect of body condition score at parturation on the production performance, fertility and culling in primiparous Estonian Holstein cows. *Veterinarija ir Zootechnika* 36(58), 69-74.
46. Santos, J.E.P., Rutigliano, H.M., Sá Filho, M.F. (2009): Risk factors for resumption of postpartum estrous cycles and embryonic survival in lactating dairy cows. *Animal Reproduction Science* 110, 207-221. https://doi.org/10.1016/j.anireprosci.2008.01.014
47. Sheehy, M.R., Fahey, A.G., Aungier, S.P.M., Carter, F., Crowe, M.A., Mulligan, F.J. (2017): A comparison of serum metabolic and production profiles of dairy cows that maintained or lost body condition 15 days before calving. *Journal of Dairy Science* 100 (1), 536-547. https://doi.org/10.3168/jds.2016-11206
48. Sheldon, I.M., Lewis, G.S., LeBlanc, S., Gilbert, R.O. (2006): Defining postpartum uterine disease in cattle. *Theriogenology* 65, 1516-1530. https://doi.org/10.1016/j.theriogenology.2005.08.021

49. Stevenson, J.S., Banuelos, S., Mendonça, L.G.D. (2020): Transition dairy cow health is associated with first postpartum ovulation risk, metabolic status, milk production, rumination, and physical activity. *Journal of Dairy Science* 103 (10), 9573-9586. https://doi.org/10.3168/jds.2020-18636
50. Sundrum, A. (2015): Metabolic disorders in the transition period indicate that the dairy cows' ability to adapt is overstressed. *Animals* 5 (4), 978-1020. https://doi.org/10.3390/ani5040395
51. Thorup, V.M., Edwards, D., Friggens, N.C. (2012): On-farm estimation of energy balance in dairy cows using only frequent body weight measurements and body condition score. *Journal of Dairy Science* 95 (4), 1784-1793. https://doi.org/10.3168/jds.2011-4631
52. Torres, E., García, J.E., Véliz, F.G., Leyva, C., Macías-Cruz, U., Hernández-Bustamante, J.D., Mellado, M. (2020): Influence of blood metabolites and body condition score at parturition on fertility and milk yield in Holstein cows. *Revista Colombiana de Ciencias Pecuarias* 34 (4), 291-304. https://doi.org/10.17533/udea.rccp.v34n4a06
53. Torres, E., Mellado, M., Leyva, C., García, J.E., Véliz, F.G., Hernández-Bustamante, J. (2020): Serum metabolites and body condition score associated with metritis, endometritis, ketosis, and mastitis in Holstein cows. *Pesquisa Agropecuária Brasileira* 55, e01308. https://doi.org/10.1590/S1678-3921.pab2020.v55.01308
54. van Hoeij, R.J., Dijkstra, J., Bruckmaier, R.M., Gross, J.J., Lam, T.J.G.M., Remmelink, G.J., Kemp, B., van Knegsel, A.T.M. (2017): The effect of dry period length and postpartum level of concentrate on milk production, energy balance, and plasma metabolites of dairy cows across the dry period and in early lactation. *Journal of Dairy Science* 100 (7), 5863-5879. https://doi.org/10.3168/jds.2016-11703
56. Wang, Y., Huo, P., Sun, Y., Zhang, Y. (2019): Effects of body condition score changes during peripartum on the postpartum health and production performance of primiparous dairy cows. *Animals* 9 (12), 1159. https://doi.org/10.3390/ani9121159