Interactions Between Body Condition at Calving and Cooling of Dairy Cows During Lactation in Summer[1]

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ABSTRACT

This study examined the interactions between dietary manipulation for increased body condition during the last trimester of pregnancy (spring) and postpartum cooling (summer lactation). Effects of diet on milk production of Holstein cows were examined to determine whether body stores could compensate for reduced DMI during heat stress. Cows calving between May and July with high (3.8 on a six-point scale) or low (2.7) body condition scores were assigned postpartum to be cooled by sprinkling and ventilation or to serve as uncooled controls. Cooled cows ate 1.6 kg more DM/d and consumed 9 L less of water/d than uncooled cows. Cooled cows maintained body temperatures below 38.9°C during day hours; peak body temperature for uncooled cows was 39.7°C. For 8 wk postpartum, glucose and insulin concentrations in plasma were unaltered by cooling or body condition. The NEFA were lower, and urea was slightly higher, for cows with low body condition. Milk production increased 1.9 kg/d with cooling, fat production increased with both body condition and cooling, and protein production increased with cooling but not with body condition. Performance was lowest for the uncooled subgroup with low body condition. Among cooled cows, no advantage was attributable to high body condition. An additive effect of high body condition and cooling on milk production in summer was not evident.

(**Key words**: body condition, cooling, heat stress, milk production)

Abbreviation key: **BC** = body condition, **C** = cooled, **HBC** = high BC, **HS** = heat stress, **LBC** = low BC, **THI** = temperature-humidity index, **UC** = uncooled.

INTRODUCTION

Over the last decade, efficient cooling systems for dairy cows have been developed based on the latent heat of water evaporation from the cow itself or from the air surrounding the cow. The sequential sprinkling and ventilation cooling system increases milk production during the summer by 1 to 5 kg/d per cow (1, 3, 24). Cooling may directly influence milk secretion from the mammary gland, but its primary effect is to restore feed intake that had been depressed about 10% by heat stress (**HS**) (7, 13).

Mean herd production records of >10,000 kg of milk/yr are common in the dairy industry (16). Milk production increases metabolic heat production and utilization of body energy reserves (2). During early lactation, energy in-

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TABLE 1. Composition of wheat hay and TMR fed during the experiment.

	Wheat hay	TMR
DM, %	86	65
CP, %	8.7	16.8
Crude fiber, %	28.0	15.3
Metabolizable energy, Mcal/kg	2.13	2.90
Ca, %	.42	.72
P, %	.40	.40

take lags behind milk energy output, a situation that is aggravated during summer when high feed intake is also depressed by HS. This study examined whether increasing body stores prepartum during spring would compensate for the reduced postpartum feed intake during summer and improve summer milk production.

MATERIALS AND METHODS

Cows

A 2 × 2 factorial design experiment was carried out over two consecutive summers on the experimental herd of the Agricultural Research Organization in Beit-Dagan, Israel. A total of 79 multiparous Holstein cows in their second to sixth lactation were included in the experiment. During the last trimester of lactation, cows were sorted by lactation number, milk production, and expected date of calving and then randomly allotted to two experimental body condition (**BC**) groups. During late lactation and the dry period, cows were fed to attain a high (**HBC**; 3.75) or low (**LBC**; 2.50) BC [six-point scale; 0 = thin to 5 = fat (27)] by 1 mo prior to calving. Cows were expected to calve between May 15 and July 30, so that the first 5 mo of lactation coincided with summer (June to October). After parturition, half of each group was randomly assigned to be cooled (**C**), and the other half was held in a conventional shed to serve as uncooled (**UC**) controls. Cows with clinical signs of mastitis postpartum were excluded from the experiment. The number of cows in C plus HBC, C plus LBC, UC plus HBC, and UC plus LBC groups was 20, 16, 21, and 22, respectively.

Diets

The cows in the HBC group were fed 16 kg of DM/d of a TMR (Table 1) during the last trimester of lactation prior to the experimental lactation and fed 10.5 kg of DM/d during the dry period until 1 wk before expected calving. Lactating cows in the LBC group were fed 9.6 kg of DM/d of the same TMR supplemented with wheat hay until dry-off (Table 1) to equal the DMI of 16 kg/d of the HBC group. During the dry period, cows in the LBC group were fed wheat hay for ad libitum intake. When cows in the HBC and LBC groups reached the target BC, they were housed together and fed a ration consisting of 20% TMR and 80% wheat hay to maintain BC (Table 2). All cows received the latter ration from 1 wk before expected calving until parturition. After calving, cows were fed the TMR provided during lactation for ad libitum intake (Table 1).

Housing and Cooling System

After calving, cows were kept in an open shed with slatted floor adjoining an unshaded

TABLE 2. Mean daily feed intake during the prepartum late lactation and dry periods of cows with high (HBC) or low body condition (LBC).

	Late lactation		Dry period	
	LBC (TMR plus hay)	HBC (TMR)	LBC (Hay)	HBC (TMR)
DM, kg	16.0	16.0	8.5	10.5
CP, g	2168	2687	736	1756
Crude fiber, g	3260	2447	2380	1606
Metabolizable energy, Mcal/kg	41.2	46.4	18.1	30.4
Ca, g	94.6	115.2	35.7	75.6
P, g	64.0	64.0	34.0	42.0

yard. The cooling system has been described previously (3, 8, 28). Briefly, an array of fans produced air velocities of 2 m/s or more from 0600 to 2400 h in the shed. Fans and sprinklers were sequentially activated to repeat cycles of wetting (.5 min) and ventilation (4.5 min) for seven periods of .5 h each at 1.5 to 2.0-h intervals between 0730 and 1830 h during the 150-d lactation phase of the experiment.

Measurements

Air temperature and relative humidity were recorded at a meteorological station located 1.5 km from the experimental farm. The means and ranges of maximal and minimal air temperatures during the 150 d were, respectively, 30°C (26 to 36°C) and 18°C (12 to 25°C); relative humidities were 90% (81 to 91%) and 50% (47 to 52%), respectively. Means and ranges for maximal and minimal temperature-humidity index (THI) (14) were 78 (75 to 80) and 64 (59 to 67), respectively. Body temperatures were recorded seven times per day on a representative 8 d during the two summers. The BC was determined weekly from 60 d before expected calving to 150 d of lactation (n = 2036). The BW was determined weekly during 150 d of lactation (n = 1547). Water and feed intake (on a group basis) of C and UC groups were recorded daily and twice weekly, respectively. Cows were milked three times a day, and production of individual cows was recorded at every milking. Milk composition was determined at biweekly intervals for fat and protein content at the official Israeli Dairy Cattle Association Laboratory.

Jugular blood samples were taken weekly, from 6 wk before calving until 8 wk after calving, for a total of 232 and 426 samples pre- and postpartum, respectively; missing values for parameters determined on blood samples ranged from 2 to 3%. Blood sampling was carried out at 1200 h from 12 randomly selected cows from each of the four experimental groups. Samples were centrifuged, and plasma was stored at –20°C. Plasma concentrations of glucose, urea, insulin, and NEFA were determined as described earlier (4, 5). Glucose and urea were measured enzymatically (glucose-oxidase-peroxidase-test and Azur™-test; Galenopharm, Geneva, Switzerland). Immunoreactive insulin was determined by radioimmunoassay (Insik 3; Sorin Biomedia, Saluggia, Italy). Nonesterified fatty acids were measured using colorimetric micromethod.

Data Analysis

Statistical analyses of BC, BW, milk production, milk composition, body temperature, feed and water intake, and blood metabolites were carried out by least squares analysis of variance, using the general linear models procedures of SAS (23). The effect of year and its interactions were initially included in the analyses. These terms were not statistically significant, probably because of the similarity and stability of weather during the two summers, which was typical for this climatic region. The emphasis on stability of animal management during the two summers was probably another factor contributing to the small differences in cow responses between summers. The year term and its interactions were hence excluded from the models. The results thus present a general pattern of dairy cow responses to an interaction between heat stress relief and BC score in moderately humid summer conditions. For data analysis of the prepartum period, the independent terms of the model included BC (low vs. high), cows within BC group, weeks prepartum (5 wk, as class variable), and week by BC interaction. For data analysis of the postpartum period, the independent terms of the model included BC, cooling (C vs. UC), BC by cooling interaction, cows within BC and cooling subgroups (which served as an error term for BC and cooling main effects and for their interaction), week in lactation, the two-way interaction of lactation week by BC or cooling, and the three-way interaction of lactation week by BC by cooling (tested against the residual error term). The cooling effect on feed and water intake (on a group basis) was tested by a general linear model in which feed or water intakes were dependent variables and cooling was the independent term.

Milk production and composition were analyzed separately by two approaches. In the first approach, data for the 150 d of lactation were analyzed. These data included milk data from cows that calved during the 2.5 mo from late

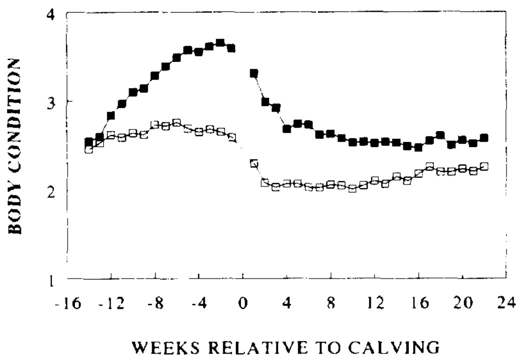

Figure 1. Body condition score during the dry period and postpartum of high (■) and low body condition (□) groups.

May to end of July (n = 6382 for milk, n = 679 for 4% FCM, and n = 704 for fat and protein production). Because cows that calved later did not complete 150 d of lactation until October, milk production data were based on 55% of the potential 150 d of lactation records. As an outcome of calving distribution, cows that calved earlier experienced mild postpartum HS in June, and the cows calving later were exposed postpartum to severe HS conditions in August. Therefore, to assess the effect of postpartum cooling on milk production using a more uniform data file, we defined a hot period of 85 d, starting from mid-July. Milk data were from this period (n = 5809 for milk and a mean of n = 410 4% FCM, fat, and protein production; missing values ranged from 11 to 14% for the different variables). During this period, cows were exposed to relatively severe HS conditions; THI were ≥72 from 1000 to 1600 h during the 85-d hot period, which was stressful for dairy cows (14). Mean days postpartum at the beginning of the hot period were similar for C (53 ± 3) and UC (54 ± 4) cows.

RESULTS

BC and BW

As parturition neared, BC of the HBC cows stabilized at a significantly higher BC than that of the LBC cows ($P < .01$; Figure 1). At parturition, BC of HBC and LBC groups were 3.80 ± .08 and 2.65 ± .07, respectively ($P < .01$). During the dry period, plasma concentrations of immunoreactive insulin and urea of HBC cows were higher than those of LBC cows ($P < .05$; Table 3); glucose and NEFA concentrations were similar in the two groups. For the HBC cows, BC score declined by one unit during the first 4 wk postpartum, which was followed by a gradual decrease, reaching a BC score of 2.5 at wk 22 (150 d) postpartum (Figure 1). For the LBC cows, BC declined moderately (.5-unit reduction) during the first 4 wk postpartum. Then, BC leveled off and later gradually rose to reach by wk 22 a BC that was lower by about .3 unit than that of HBC cows ($P < .01$ for BC by week interaction). The patterns of changes of BC in the C and UC groups were very similar (data not shown).

TABLE 3. Mean concentrations of metabolites in plasma of cows with high (HBC) or low body condition (LBC) during the last 40 d of the dry period prior to the experimental period.

	HBC	LBC	SE
Glucose, mmol/L	3.54	3.43	1.0
Insulin, mU/L	17.5	10.7*	1.5
NEFA, mmol/L	.49	.58	.1
Urea, mmol/L	5.84	4.29*	.3

*$P < .01$.

At parturition, BW was higher for HBC cows ($P < .01$; Figure 2) than for LBC cows. During the first 4 wk postpartum, HBC and LBC cows lost about 50 and 15 kg of BW, respectively. The UC plus LBC group had the lowest BW throughout the experiment (544 ± 2 kg; $P < .01$ for BC by C interaction). The BW differences from other groups ranged from 33 to 52 kg; mean BW for C plus LBC, C plus HBC, and UN plus HBC cows were 577 ± 2, 586 ± 3, and 596 ± 4 kg, respectively. This BW difference was sustained during the experimental period; at 150 d postpartum, UC plus LBC cows were 20 kg lighter than those in the other three groups (Figure 2). Cooling enhanced BW gain of the LBC group, which reached the mean BW of the two HBC groups by about 12 wk postpartum.

During the first 8 wk postpartum, insulin was lower for C cows ($P < .01$ for thermal treatment by weeks interaction; Table 4). Generally, NEFA concentration was lower for the LBC cows ($P < .05$ for main BC effect).

TABLE 4. Effects of high (HBC) or low body condition (LBC) at parturition and cooling on concentration of metabolites in plasma during the first 8 wk postpartum.

	HBC		LBC			
	C[1]	UC	C	UC	SE	Contrast[2]
						P
Glucose, mmol/L	3.17	3.29	3.43	3.45	.1	W[3]
Insulin, mU/L	10.0	13.2	10.9	12.1	1.4	
NEFA, mmol/L	.41	.40	.31	.25	.1	BC, T × BC × W
Urea, mmol/L	6.48	7.00	6.92	7.96	.3	T, BC

[1] C = Cooled, UC = uncooled.

[2] $P < .05$.

[3] T = Thermal treatment, BC = body condition, and W = weeks in lactation.

This prepartum treatment effect did not persist uniformly during the postpartum period; the significant BC by week interaction ($P < .01$) was caused by the presence of a large difference in plasma NEFA concentration between HBC and LBC cows during the first 3 wk postpartum, which later decreased so that similar NEFA values prevailed in all four groups from wk 4 to 8 postpartum (Table 4; figure not shown). Cooling and HBC slightly reduced plasma urea concentrations ($P < .05$).

Body Temperature and Feed and Water Intake

Cooling proved effective in maintaining body temperature within normothermic range; mean body temperatures of C cows remained below 38.9°C during the entire experimental period (Table 5). The relief of ambient heat load, however, was effective only as long as the cooling system was active; body temperature of C cows peaked (38.9°C) at 1900 h, soon after cessation of cooling. Mean body temperature of UC cows was higher ($P < .01$) than that of the C group and peaked in the evening at 39.7°C ($P < .01$). Cooling was also effective in increasing feed intake; daily DMI was 1.6 kg higher for C cows than for UC cows ($P < .01$). The opposite effect was observed for water intake, which was 10% higher ($P < .01$) for the UC group (Table 5).

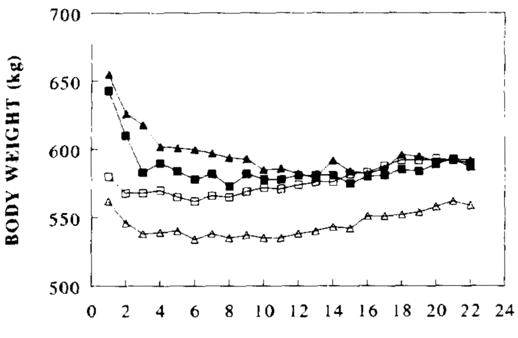

Figure 2. Body weights of the four experimental subgroups postpartum. Cooled plus high (■) or low (□) body condition cows and uncooled plus high (▲) or low (△) body condition cows.

Milk Production and Composition

Milk production curves for the four subgroups during the 150 d postpartum are presented in Figure 3 and Table 6. Cooling and BC did not significantly affect milk produc-

TABLE 5. Mean daily feed and water intake and body temperatures of cooled (C) and uncooled (UC) cows during the 5-mo experimental lactation period.

	C	UC	SE
DMI, kg/d	19.4	17.8*	.2
Water intake, L/d	93.6	102.7*	1.4
Body temperature, °C			
Daily mean	38.7	39.2*	.1
Peak[1]	38.9	39.7*	.1

[1] At 1900 h.

*$P < .01$.

TABLE 6. The effect of high (HBC) or low body condition (LBC) at parturition and cooling during 150 d of lactation on milk production and composition.

	HBC		LBC			
	C[1]	UC	C	UC	SE	Contrast[2]
						P
Milk, kg/d	34.4	33.5	35.3	33.0	1.3	T × BC × W[3]
4% FCM, kg/d	28.8	28.3	27.5	26.4	.8	BC[a]
Fat, %	2.97	2.90	2.72	2.59	.09	BC, BC × W
Fat, kg/d	1.00	.98	.92	.86	.04	BC
Protein, %	2.96	2.90	3.01	2.88	.04	T, W
Protein, kg/d	1.00	.98	1.03	.96	.02	T, W

[a] $P < .07$.

[1] C = Cooled; UC = uncooled.

[2] $P < .5$.

[3] T = Thermal treatment, BC = body condition, and W = weeks in lactation.

tion. However, an interaction was detected for HS relief treatment by BC score by weeks of lactation (Table 6; $P < .01$), which reflected the higher peak production reached by the two C groups than by the two UC groups (wk 4 to 8) and the earlier occurrence of peak milk production of the C plus LBC cows relative to the other three subgroups (Figure 3). The higher BC at parturition enhanced milk production; mean 4% FCM for 150 d tended to be higher ($P < .07$), and daily fat production was 10% higher, for HBC cows than for LBC cows ($P < .01$). Mean daily production of milk protein was about 5% higher for C cows than for UC cows ($P < .05$).

During the 85-d hot period (Table 7; Figure 4), cooling increased milk production by almost 2 kg/d ($P < .05$). A three-way interaction was detected for cooling by BC by week, reflecting the higher milk production of C groups during the second half of the hot period; in the first half, the production of C plus LBC cows was lower than that of the cows in the C plus HBC group and similar to that of cows in the UC plus HBC group (Figure 4). At peak HS conditions, from wk 5 to 10 of the hot period, milk production of C cows was 3 to 4 kg/d higher than that of UC cows. Fat production tended to be higher for C cows and for HBC cows ($P < .10$). Protein

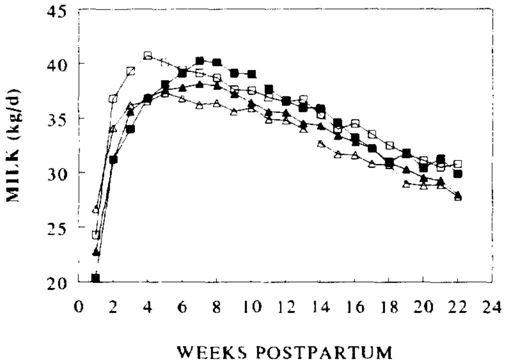

Figure 3. Milk production by the four experimental subgroups during the 150-d experimental period. Cooled plus high (■) or low (□) body condition cows and uncooled plus high (▲) or low (△) body condition cows.

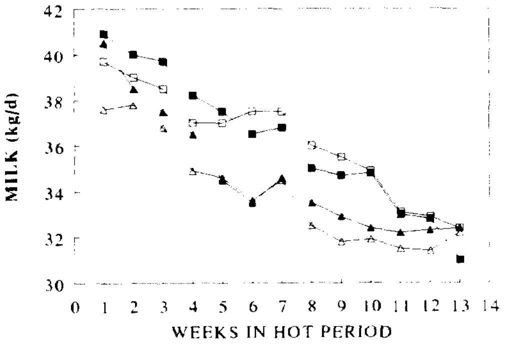

Figure 4. Milk production by the four experimental subgroups during the 85-d hot period, starting on d 53 after calving. Cooled plus high (■) or low (□) body condition cows and uncooled plus high (▲) or low (△) body condition cows.

production increased with cooling (+8%; $P < .01$); BC had no effect.

DISCUSSION

This study shows the benefit of direct evaporative body cooling by sequential sprinkling and forced ventilation of high producing dairy cows exposed to a moderately hot and humid environment. Results confirm a previous study (12) in which a short-term cooling period (10 d) increased milk production of high producing cows by 1.9 kg/d. Similar increases were also recorded for low producing cows under humid conditions (13, 23). The improvement in milk production was greater in studies using spray and fan cooling in a hot, arid climate (1). Regardless of BC at parturition, cooling prevented body temperature from rising above 39°C during the day and significantly increased feed intake. The higher concentrations of plasma urea observed in the UC cows probably reflect enhanced tissue catabolism to supply the nutritional demands for milk production during suppression of feed intake during HS. This presumption is supported by the rise in plasma urea that has been reported (18) for cows in early lactation and restricted feed consumption. The overall improved performance of C cows reflects the efficacy of the cooling system in maintaining a normal thermal state and improving the nutritional status of cows subjected to a high metabolic heat load in a hot environment.

During this study, BC of the HBC group was elevated more efficiently during late lactation than during the dry period, as previously documented (6). The higher plasma insulin concentration in prepartum cows with HBC (Table 3) probably points to a surplus of glucose entering circulation. The higher plasma urea concentration in the HBC group may similarly reflect a surplus of protein intake (Table 2). The major effects of higher BC at calving were mostly evident during early lactation only. Larger differences in BC score, BW, and blood metabolite concentrations between HBC and LBC groups prevailed mostly during the first 4 wk postpartum; however, consistent but small differences in BC score and BW were maintained during the entire 150-d experimental period. Increasing BC status thus induced larger BW and BC score losses postpartum, which were similar to results of other studies (19, 25) on the effects of modifying the body stores available at calving. These differences in body mass and in subjective BC estimates are also evident in the sharp postpartum decline of plasma NEFA concentration in the HBC cows; LBC cows experienced only a moderate decline. This result probably reflects differences induced by fat depot size in the rate of fat mobilization (22).

A larger nutritional reserve at calving did not improve milk production of C cows. Neither milk production nor fat and protein production differed between C plus HBC and

TABLE 7. The effect of high (HBC) or low body condition (LBC) at parturition and cooling during the 85-d hot period, starting on d 53 after calving, on milk production and milk composition.

	HBC		LBC			
	C[1]	UC	C	UC	SE	Contrast[2]
						P
Milk, kg/d	36.2	34.7	36.2	33.9	.9	T,[3] T × BC × W
4% FCM, kg/d	29.3	28.5	28.6	26.2	.7	T, BC[a], W
Fat, %	2.77	2.82	2.59	2.48	.1	BC, T × W[b]
Fat, kg/d	.99	.97	.93	.83	.03	T[b], BC[b], T × BC[b]
Protein, %	2.90	2.82	2.93	2.82	.04	T, T × W
Protein, kg/d	1.03	.97	1.05	.94	.02	T

[a] $P < .06$.

[b] $P < .10$.

[1] C = Cooled; UC = uncooled.

[2] $P < .05$.

[3] T = Thermal treatment, BC = body condition, and W = weeks in lactation.

C plus LBC cows. Studies carried out on the effects of BC at calving on subsequent milk production in temperate climates, where HS does not prevail to limit dairy cows performance, produced conflicting results (11, 26). The conflicting results may reflect the antagonistic effects of body reserves in not only providing a store but also concomitantly reducing the postpartum rise in feed intake (17). Also possible, however, is that the C plus LBC cows did not have sufficient body stores for milk production under the improved environmental conditions. This conjecture may find support in a study (9) that suggested that calving at a BC score ≤2.5 units suppresses subsequent milk production.

The effect of a low BC at calving probably is worsened by HS, and the UC plus LBC cows had the lowest milk and fat production (Figures 3 and 4; Tables 6 and 7). Those cows were in the worst condition; their body reserves were limited, and their feed consumption was suppressed by HS. A similar situation was reported in a study (10) in which restricted energy before and after calving lowered milk production. The UC plus LBC cows in our study were unable to increase their BW to the degree of the other three subgroups (Figure 2). The similarity between the two UC subgroups in protein production (Tables 6 and 7) indicates that a high body energy store at calving cannot substitute for cooling.

An important finding was that cooling significantly increased protein production, regardless of BC at calving, as was also found for low production cows (24). This increase may result from an induced increase in feed intake and hence in protein supply from HS relief, or from the prevention of a hyperthermia-induced impairment of protein synthesis in the mammary gland. In support of the former, the higher concentration of milk protein in early lactation was related to diet energy density more than to BC at calving (15). Another factor that may be directly involved in milk synthesis is mammary blood flow; for example, a reduction of amino acid transport to the udder may limit synthesis of milk protein. A limited number of studies indicate a 35% decrease in mammary blood flow in early lactation rabbits (21) and a slight decline in blood flow in midlactation cows (20).

CONCLUSIONS

The combined effect of a shortage of body reserves and decreased feed consumption because of HS suppresses milk, fat, and protein production; this suppression was evident in the UC plus LBC group. An additive effect on milk production of high BC at calving and cooling during the first 5 mo of lactation was not detected. Protein production was affected by cooling, but not by BC. Increased body reserves at calving may compensate for decreased DMI by increasing fat production. This study did not support the presumption that the creation of a larger body store during the cooler, spring period preceding summer calvings might be a tentative strategy for improving summer dairy cow performance in hot climates.

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