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Environmental Heat Effects on Growth, Plasma T_3, and Postheat Compensatory Effects on Holstein Calves[1] (41648)

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Abstract. Five Holstein heifers, 5 months of age, were housed in the Missouri Climatic Laboratory and subjected to an experiment to measure the effects of heat stress on rates of growth, plasma triiodothyronine (T_3) levels, and ability to compensate in rate of gain and thyroid function following the stress period. The experiment consisted of 3 weeks at thermoneutral (TN_1), followed by 5 weeks of individually controlled heat stress conditions (32.5 to 34°C) dependent on heat tolerance of individual animals. This was followed by a 4-week thermoneutral, postheat compensatory period (TN_2). Average daily gains were significantly depressed during the heat stress period (HS). Following heat stress the average body weights attained the projected or expected levels within a 21- to 28-day period following return of animals to thermoneutral conditions. Ratios of feed intake/body weight ($W^{0.75}$) were reduced during heat stress treatment indicating the thermal inhibition. Ratios or amount of feed intake per unit of gain were greater during HS treatment indicating less weight gain per unit of daily feed intake. Plasma T_3 was reduced during heat treatment similarly to daily weight gain. Following the postheat treatment period (TN_2) plasma T_3 increased markedly as did daily weight gains to demonstrate strong compensatory responses in both measures. In summary, these results demonstrated parallel and positive changes of plasma T_3 with daily weight gain during thermoneutral, heat, and postheat compensatory periods, and an inverse relationship of rectal temperature to weight gain and plasma T_3.

There have been many attempts to determine the role of thyroid function in growth of meat-producing species, however, the relationship of the thyroid gland activity to growth rates still is questionable. Many years ago Kunkel *et al.*(1, 2) and Gawienowski *et al.* (3) demonstrated in cattle and swine, respectively, a relationship between plasma protein-bound iodine (PBI) and growth, though Robertson and Falconer (4) showed little relationship in growing sheep.

With the improved techniques for measuring release of radioactive iodine from the thyroid gland, Draper *et al.* (5, 6) demonstrated a significant relationship between growth rate and rate constant (K_4) in growing lambs. Data on the augmentation of thyroid activity to promote increases in growth rate was earlier demonstrated to be contradictory with increases in growth shown by Peo (7), Perry *et al.* (8), and Reineke and McMillen (9) and no effect or even decreases in growth were shown by Perry *et al.* (8), Van Der Noot *et al.* (10), and Whiteker *et al.* (11).

Newer techniques of thyroid function estimations by plasma thyroxine (T_4) and triiodothyronine (T_3) with radioimmunoassay procedures continued to produce some contradictions. For example Kahl *et al.* (12) have shown that male dairy calves grew faster than female calves and had higher plasma T_4 levels. Plasma T_3 in this study was unrelated with rate of growth.

This relationship of growth rates and thyroid function still remains to be fully documented. A related question, however, is the possible role that thyroid function (known to be depressed by environmental heat (13)) plays in reduced growth rates associated with heat stress and the postheat stress effects on growth rates and thyroid function.

The relationship between environmental heat stress and growth rate in dairy calves has been described by Johnson and Ragsdale (14), Colditz and Kellaway (15), Kellaway and Colditz (16), and Neuwirth *et al.* (17). It is known

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that individual animals within a breed vary in their ability to grow under environmental heat stress conditions (5). Environmental limitations of growth and subsequent increased growth rates of beef cattle following environmental amelioration have been demonstrated by Hahn (18), Wilson and Osbourn (19), and Langewisch (20) on poultry, beef cattle, and swine, but not on dairy cattle. The physiological mechanisms, such as thyroid function, have not been studied in relation to the varied growth rates due to the environment or postheat stress compensatory gains. We will refer to compensatory gain generally as the ability of an animal to regain the weight lost due to a prior period of time in which growth was reduced due to heat stress as previously described by Hahn *et al.* (18). Kahl *et al.* (12) demonstrated that the plasma levels of T_4 and T_3 were positively correlated with the relatively greater growth rates of the male than female Holstein calves, though the latter was nonsignificant.

The purpose of this investigation was to measure the effects of environmental heat on growth rates, plasma triiodothyronine (T_3) as an indicator of thyroid function, rectal temperature, and feed intake as indicators of thermal inhibition, and to also measure these functions during the postenvironmental heat period. The ultimate objective was to relate the growth rates to these measured functions under environmental heat stress and during the compensatory growth phase following the stress period.

Materials and Methods. Six Holstein heifers, 5 months of age, were placed in the Missouri Climatic Laboratory for this study. Animals were adjusted to the laboratory for a period of 3 weeks. Each animal was maintained in individual temperature- and relative humidity-controlled chambers with feed and water available *ad libitum*. During the experiment one animal became sick and was removed from the study. The experiment was designed to provide a 3-week period at thermoneutral conditions 20°C, and 50% relative humidity (RH); (TN_1) followed by a 5-week period of environmental heat (HS) in which environmental temperatures were within a range of 32.5 to 34°C depending on the individual animal's tolerance to heat. A rectal temperature of 40.5°C was sought for each individual which permitted all animals regardless of heat tolerance to be compared under a similar heat stress level.

Following this HS period, temperatures were lowered to 18°C for period of 4 weeks (TN_2) to measure the recovery or postheat compensatory changes. A calf ration concentrate (Table I) of 3.6 kg/day/calf was provided with alfalfa hay cubes *ad libitum*. Animals were fed twice daily, at 8 A.M. and 4 P.M. All concentrate was consumed during all treatments and alfalfa-cube intake was measured by use of weighbacks of remaining cubes at each feeding time. Feed intake and water intake were recorded daily. Rectal temperatures were measured at 10 A.M., 2 P.M., and 10 P.M. and averaged as daily values. Body weights were recorded weekly.

Estimation of body weight deviation from projected "normal" values (TN_1) during heat (HS) and postheat (TN_2) were based on differences from a linear regression equation. Linear, quadratic, and cubic functions were tested and only the linear relation was significant ($P < 0.05$). The statistical model for the analysis of the temperature-treatment effects on the variables contained the effects of cow, week, and days within week.

Plasma triiodothyronine (T_3) was measured on plasma samples taken on alternate days for each calf. Plasma T_3 concentrations were determined by radioimmunoassay kit, Micromedic Solid Phase, Horsham, Pennsylvania. The intraassay coefficient of variation was 5.4%, and 6.3% for interassay variation.

All of the experimental data were analyzed by analysis of variance which contained the effect of cow, week, and the nested effect of day within week. Week mean differences were

TABLE I. RATION CONCENTRATE COMPOSITION[a]

Ingredient	International Ref. No.	Percentage
Corn	4-10-422	30
Oats	4-08-471	30
Soybean meal 44% protein	5-04-604	15
Alfalfa pellets		15
Molasses	4-04-696	10
Vitamin A		Trace

[a] Approximately 20% crude protein.

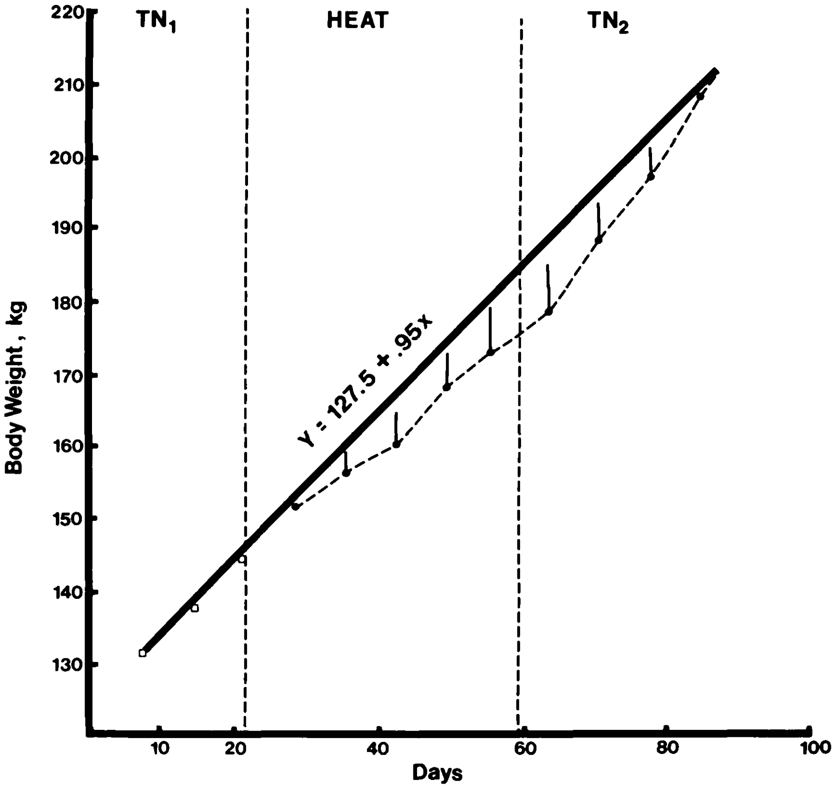

FIG. 1. Effects of environmental heat on body weight of growing dairy calves. Dotted line represents actual body weight of five calves and also represents a deviation from the body weight as predicted from the equation ($Y = 127.5 + 0.95X$). Significant difference from predicted line based on TN_1 data for Days 31, 38, 45, 52, 59, 66, 73, 80, and 87 are, ns, 0.01, 0.05, 0.01, 0.05, 0.05, 0.01, and ns, respectively.

ascertained using the least significant difference (LSD) mean separation technique. Also differences between TN, H, and TN_2 were accomplished by pooled-mean contrasts.

Results and Discussion. Figure 1 expresses the average increase in body weight of the five calves during the 21-day TN_1 period. This growth curve was projected throughout the HS and TN_2 period as a basis for estimation of any deviation during HS and compensation during TN_2. The linear regression equation was $Y = 127.5 + 0.95X$. Days of experiment (X) were used to predict Y and determine significance of differences by LS means from actual body weights. All values were significantly different except at 31 and 87 days. After return from environmental heat conditions to TN_2 on Day 56, approximately 24–28 days were required to reach the projected levels. A longer period of heat stress may have logically lengthened the compensation period, and recovery from the stressor may not have been attained (21).

Table II shows the individual daily weight

TABLE II. DAILY WEIGHT GAIN (kg/DAY) OF GROWING DAIRY HEIFERS DURING THERMONEUTRAL (TN_1), HEAT STRESS (HS) AND THERMONEUTRAL (TN_2) POSTHEAT COMPENSATORY TREATMENTS

Calf No.	TN_1	HS	TN_2	Percentage decrease (HS—TN_1)
914	0.85	0.86	1.43	0
912	1.14	0.86	1.38	25
915	1.9	0.61	1.67	29
916	0.8	0.61	1.29	28
918	1.11	0.58	1.48	46
$\bar{x}$	0.97^a	0.70^b	1.45^c	
$S_{\bar{x}}$	±0.06	±0.09	±0.09	
C.V.	12.52	16.75	9.24	

^{a,b,c} Means in the same row bearing different superscripts differ significantly ($P < 0.05$) and b is different from c ($P < 0.01$).

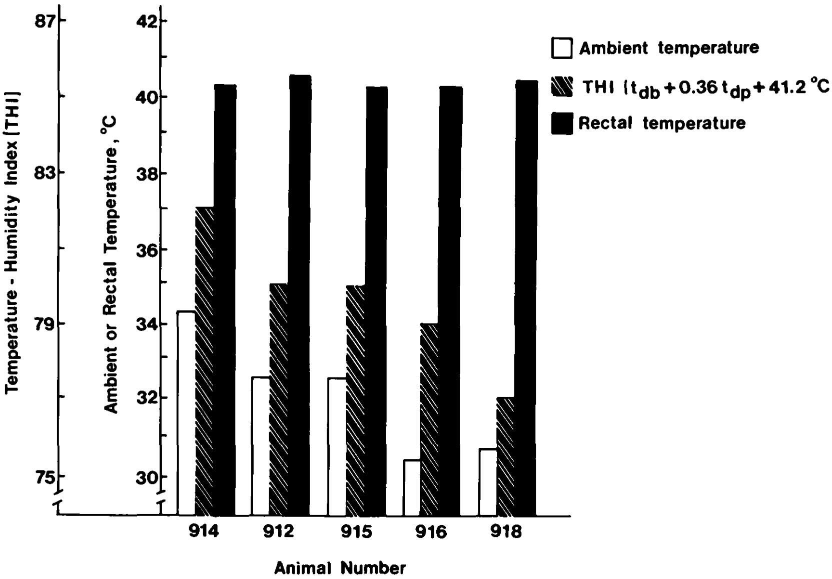

FIG. 2. Comparative mean ambient temperature, temperature-humidity index (THI), and rectal temperature for each individual growing dairy heifer during heat-stress (HS) treatment period. Various ambient temperatures and THI were necessary to provide the same elevation in rectal temperature.

gains during TN_1, HS, and TN_2. Weight gains were significantly depressed by the environmental heat and significantly elevated during the TN_2 period. The daily gain was much greater during the TN_2 postheat period than either TN_1 or HS. The animals that generally decreased daily gains most during HS also tended to demonstrate a greater postheat rate of gain.

Figure 2 illustrates the ambient temperature and temperature humidity index (THI) necessary to maintain the same body temperature in all animals during HS. The different ambient temperature and THI levels indicated the relative differences in individual animal heat tolerance. For example, animal 914 was relatively more tolerant to higher environmental temperatures and THI than 918, and 914 could tolerate approximately a 4°C higher ambient temperature of 34.2°C and still maintain the same level of rectal temperature.

In contrast, animal 918 was least tolerant in that only a lower air temperature of about 30°C caused a 40.5°C body temperature. It is of interest that 918 and 916 were still most depressed in growth rate during HS though at a 4°C lower air temperature (Table II). In contrast the average daily gain of 914 was not affected during HS (0.85 vs 0.86 kg/day, Table II).

Field studies by daSilva (22) have generally shown that cattle which had the highest increase in rectal temperature during hot days had relatively lower rates of growth. He recommended the high negative correlation between daily gain and daily body temperature increase be used as a heat tolerance index for beef cattle selection in the tropics.

Table III describes the feed intake/$W^{0.75}$ for each animal and overall average for each

TABLE III. DAILY FEED INTAKE (kg/kg $W^{0.75}$) OF GROWING DAIRY HEIFERS DURING THERMONEUTRAL (TN_1, TN_2) AND HEAT STRESS (HS) TREATMENTS

Calf No.	TN_1	HS	TN_2	Percentage decrease (HS—TN_1)
914	0.139	0.140	0.154	0
912	0.152	0.138	0.153	15
915	0.144	0.122	0.142	26
916	0.110	0.101	0.110	9
918	0.142	0.118	0.142	18
$\bar{x}$	0.137^a	0.124^b	0.140^a	
$S_{\bar{x}}$	±0.007	±0.007	±0.008	
C.V.	11.67	12.90	12.86	

^{a,b} Means in the same row bearing different superscripts differ significantly ($P < 0.05$).

TABLE IV. Feed Conversion (Average Daily Feed (Kilograms) per Kilogram Body Weight Gain) of Growing Dairy Heifers during Thermoneutral (TN_1, TN_2) and Heat Stress (HS) Treatments

Calf No.	TN_1	HS	TN_2	Percentage increase (HS—TN_1)
914	7.07	8.75	6.01	20
912	6.04	8.21	6.21	27
915	6.52	9.94	4.52	35
916	5.31	8.25	4.39	36
918	5.42	9.05	4.86	41
$\bar{x}$	6.07^{a}	8.75^{b}	5.19^{a}	31
$S_{\bar{x}}$	±0.2	±1.2	±0.3	
C.V.	14.24	6.52	16.86	

^{a,b} Means in the same row bearing different superscripts differ significantly ($P < 0.05$).

treatment. The average feed intake/$w^{0.75}$ declined significantly during HS and increased considerably during TN_2, but did not significantly show the great compensatory increase that was observed in body weight gain. Table IV demonstrates clearly that more feed was consumed relative to gain in body weight during HS. This was consistently true for all animals. And again, the most heat tolerant animal (914) showed less increase in this ratio during HS than the other animals, although all animals were at the same level of rectal temperature. Why less daily gain per unit of feed intake occurred during HS in this study is not immediately clear. The lower levels of T_3 during the HS period may be a contributing factor. The feed conversion ratio was similar for TN_1 and TN_2 though the compensatory daily gain was much greater during TN_2.

The period and treatment effects on rectal temperature, T_3, daily gain, and feed intake are shown in Table V. Rectal temperatures were similar for all of the weekly periods within each treatment. The HS effect was highly significant.

The weekly T_3 values were similar within each of the TN periods. After the first weeks of HS the plasma T_3 rapidly declined to as low as 0.97 ng/ml by the third week of HS. The values during the last four periods of HS were significantly different from TN_1. During post-HS (TN_2), plasma T_3 values for all periods were much higher than even the prior TN_1 periods. Even during week 12, T_3 was still higher than TN_1. This overall period and treatment response for T_3 is very similar to data for daily gain. That is, a significant decline in daily gain during HS was followed by an impressive increase in growth rate during TN_2 that was also higher than TN_1. Feed intake per animal was not lower during HS (Table V) because the animals showed a slow increase

TABLE V. Environmental Treatment and Period Effects within Treatment on Recal Temperature, T_3, Daily Weight Gain, and Feed Intake

Weeks	Days	Temp	RT (°C)	T_3 (ng/ml)	Daily wt gain (kg/day)	Feed intake (kg/day)
1	3–10	TN_1	39.3 ± 0.03^{a}	1.46 ± 0.07^{a}	0.896 ± 0.19^{a}	5.2 ± 0.1^{a}
2	11–17	TN_1	39.2 ± 0.03^{a}	1.82 ± 0.05^{a}	0.996 ± 0.21^{a}	5.8 ± 0.1^{a}
3	18–24	TN_1	39.2 ± $0.03^{a,d}$	1.62 ± $0.08^{a,d}$	1.01 ± 0.19^{a}	5.8 ± 0.1^{a}
	Mean		39.24 ± 0.1^{A}	1.65 ± 0.2^{A}	0.97 ± 0.06^{A}	5.6 ± 0.3^{A}
4	25–31	HS	40.2 ± 0.03^{b}	1.53 ± $0.05^{b,d}$	0.71 ± 0.38^{b}	5.5 ± 0.1^{a}
5	32–38	HS	40.3 ± 0.03^{b}	1.13 ± 0.05^{b}	0.57 ± 0.13^{b}	5.5 ± 0.1^{a}
6	38–44	HS	40.3 ± 0.03^{b}	0.97 ± 0.05^{b}	0.74 ± 0.18^{b}	5.8 ± 0.1^{a}
7	45–51	HS	40.3 ± 0.03^{b}	0.97 ± 0.05^{b}	0.74 ± 0.18^{b}	5.8 ± 0.1^{a}
8	52–59	HS	40.3 ± 0.03^{b}	1.18 ± 0.05^{b}	0.79 ± 0.10^{b}	6.0 ± 0.1^{a}
	Mean		40.32 ± 0.07^{B}	1.16 ± 0.02^{B}	0.70 ± 0.09^{B}	5.8 ± 0.3^{A}
9	60–67	TN_2	39.1 ± $0.03^{c,d}$	2.20 ± 0.06^{c}	1.42 ± 0.49^{c}	6.6 ± 0.1^{b}
10	68–74	TN_2	38.8 ± 0.03^{c}	2.38 ± 0.06^{c}	1.33 ± 0.29^{c}	7.0 ± 0.1^{b}
11	75–81	TN_2	39.0 ± 0.03^{c}	2.25 ± 0.05^{c}	1.52 ± 0.30^{c}	7.4 ± 0.1^{b}
12	82–89	TN_2	39.0 ± 0.13^{c}	1.91 ± 0.06^{c}		8.1 ± 0.1^{b}
	Mean		39.0 ± 0.04^{C}	2.20 ± 0.02^{C}	1.42 ± 0.09^{C}	7.2 ± 0.6^{B}

^{a,b,c,d} Different superscripts in columns of period values indicate significant difference ($P < 0.01$).

^{A,B,C,D} Different superscripts in columns of mean values for each environmental treatment indicate significant differences ($P < 0.01$).

in size during the HS period. However, the postheat effect or compensatory response was greater than HS or TN_1, similar to T_3 and daily gain.

The relationship of rectal temperature and plasma T_3 to daily weight gains are graphically summarized in Fig. 3. The significant positive correlation ($r = 0.91$) between plasma T_3 and daily weight gains demonstrates that higher levels of plasma T_3 are likely to be related to higher growth rates. Conceivably the lowest T_3 values under heat stress may contribute to the lower growth rates and the greater quantity of feed required per unit gain in weight, however, this requires further inquiry. Previous data have shown (23) that energy metabolism, feed intake, and body weight decline under heat stress, though total body water increases slightly. These changes suggest the reduced weight gains under HS represents less synthesis. The relationship of RT to rate of gain is negative ($r = -0.89$) which reflects, in part, the thermal inhibitory effect on feed intake/$w^{0.75}$ and plasma T_3. Data of Magdub (24) previously demonstrated in lactating dairy cows the negative relationship of rectal temperature to plasma T_3 and T_4 and to milk T_3 and T_4. These data are generally in agreement with results of Mueller *et al.* (25) who showed a depression of plasma TSH in rats by heat stress. This study has demonstrated the negative thermal effects on plasma T_3, a positive relationship of plasma T_3 to growth rate, and a strong postheat stress or compensatory effect of increased growth rates and higher levels of plasma T_3. The role that higher T_3 plasma levels may play in increased gain in body weight during TN_2 remains to be determined.

This investigation, of course, did not explore further the relationship of growth rate and thyroid function in animals which are not subjected to environmental limitations, but experimentally used environmental heat to lower the growth rates and thyroid function. An inverse relationship was measured for rectal temperature, rate of growth, and thyroid function, and a positive relationship for growth rate and thyroid function (T_3). These data support the earlier data of Draper *et al.* (5) on thyroid (K_4) function and growth rate, and further suggest that if environmental conditions exist in which thyroid function is directly

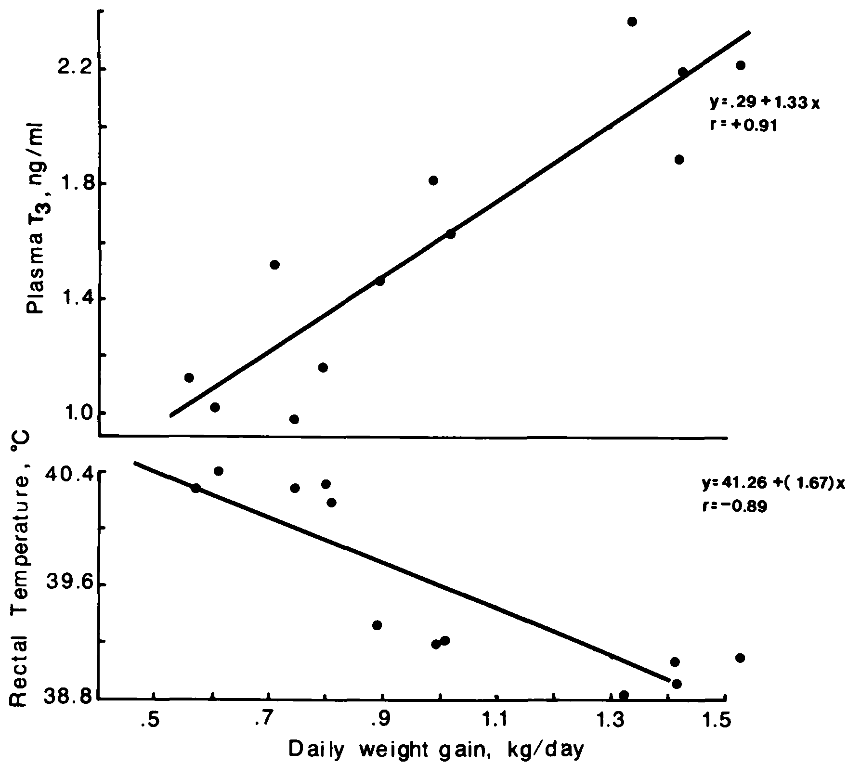

FIG. 3. Relationship of plasma T_3 and rectal temperature to daily weight gains.

or indirectly depressed, and growth rates, feed intake, and body temperature altered, then positive relationships exist in growth and thyroid function. This may partially explain some of the contradictory results (21, 26) observed in growth rates and thyroid hormone supplementation studies. That is, the appropriate level of thyroid hormone supplementation may improve growth if growth rate is being reduced due to lower thyroid function or feed level alteration caused by some environmental or genotypic factor. This laboratory is currently exploring the possibility of improving the lowered growth rate of dairy calves during environmental heat stress by daily subcutaneous injections of T_3.

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