The effect of calf jackets on the health, performance, and skin temperature of dairy origin beef calves

Naomi H. Rutherford,[†,‡,1] **Alan W. Gordon,**[§] **Gareth Arnott,**[‡] **and Francis O. Lively**[†]

[†]Agri-Food and Biosciences Institute, Hillsborough BT26 6DR, United Kingdom; [‡]Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, Belfast, BT7 1NN, United Kingdom; and [§]Agri-Food and Biosciences Institute, Newforge Lane, Belfast BT9 5PX, United Kingdom;

ABSTRACT: Variations and extremities in climatic conditions can result in cold stress for dairy calves during the preweaning period. The objective of this study was to investigate the effect of calf jackets on the health, performance, and skin temperature of dairy-origin beef calves. This study took place in a designated calf rearing unit, spanned for a duration of 1 yr, and consisted of five batches of calves. Calves (30.9 ± 1.68 d of age; 55.9 ± 0.20 kg live weight) were assigned to one of four treatment groups on arrival at the rearing unit. Treatments consisted of control (no jacket), arrival (jacket for 2 wk postarrival), weight (jacket for a minimum of 2 wk and until 65 kg live weight), and wean (jacket until 5 d postweaning). Ambient conditions differed significantly ($P < 0.001$) during each of the five batches; batch 4 was the coldest with a mean ambient temperature of 6.16 °C. Significant differences were observed between the five batches for day 50 weight ($P < 0.01$) and disease incidence ($P < 0.05$). However, treatment had no significant effect on calf health or performance ($P > 0.05$) during any of the five batches. Skin temperature was significantly greater ($P < 0.001$) for calves wearing a jacket. Furthermore, there was a significant ($P < 0.001$) relationship between ambient temperature-humidity index and skin temperature for calves with and without a calf jacket. Therefore, although calf jackets had no benefit in terms of health or performance, they did act as a barrier to environmental conditions.

Key words: ambient conditions, calf jacket, cold stress, disease, seasonality, skin temperature

Transl. Anim. Sci. 2020.4:316–323
doi: 10.1093/tas/txz172

INTRODUCTION

At birth, a calf's thermoregulatory system is metabolically immature (Hill et al., 2016) due to its inability to generate heat through rumen fermentation (Collier et al., 1982; Tao and Dahl, 2013; Roland et al., 2016). Further to this, they have a large surface area to body weight ratio, resulting in a large area for heat loss (Collier et al., 1982; Roland et al., 2016). This is of particular concern during variations and extremities in climatic conditions (Bateman et al., 2012; Bhat et al., 2015; Roland et al., 2016). The thermoneutral zone (TNZ) is classed at the optimum range of ambient temperatures at which a calf can maintain its own body temperature. Scanes (2011) stated that the TNZ ranged from 15 to 25 °C, with a lower critical temperature range of 9–15 °C for newborn calves.

Calf jackets present an opportunity to provide calves with a barrier to environmental conditions

[1]Corresponding author: naomi.rutherford@afbini.gov.uk
Received July 8, 2019.
Accepted November 5, 2019.

without restricting airflow through the house. Research has primarily focused on their use within the first weeks of life with mixed results in terms of performance being obtained (Loy et al., 2000; Earley et al., 2004; Scoley et al., 2019). In the case of dairy-origin beef calves, they are often moved from the farm of origin to a beef farm at a young age; this is done either through a livestock market or farm to farm movement. The change in environment, nutrition, and social grouping results in additional stressors for calves, the effects of which should be minimized to ensure health and performance are not compromised.

Thus, the aim of this study was to investigate the effects of calf jackets on the health, performance, and skin temperature of dairy-origin beef calves from arrival at a rearing unit until weaning. Furthermore, this study was repeated with five batches of calves over the course of a 1-yr period in order to take seasonality into account.

MATERIALS AND METHODS

This trial was undertaken on a commercial calf rearing farm located in Hillsborough, United Kingdom with latitudes and longitudes of 54.45° and −6.03°, respectively. All experimental procedures used in this study were conducted in compliance with the United Kingdom Animals (Scientific Procedures) Act 1986.

The trial that lasted for 1 yr commenced on April 24, 2017 and finished on May 3, 2018. Over the course of the year, five batches of dairy-origin beef were brought onto the farm in an all-in-all out system. Calves were purchased from a number of reputable suppliers; only calves that were healthy and of a minimum age of 10 d were purchased. Details on each of the five batches are shown in Table 1.

On arrival, calves were vaccinated for viral pneumonia *(Ringvac and Rispoval Intranasal),* weighed, and assigned to one of four treatment groups, which were balanced for weight, age, breed, sex, and source farm:

1) Control—no calf jacket
2) Arrival—calf jacket for 2 wk postarrival
3) Weight—calf jacket for a minimum of 2 wk and until 65 kg live weight
4) Weaning—calf jacket until 5 d postweaning

The calf jackets were breathable and water repellent with a filling of 200 g (Cosy Calf, Dorset, United Kingdom). Calves were group housed with each batch being split equally between four pens. Each of the pens consisted of an equal number of calves from each treatment group. The shed was naturally ventilated and straw bedding was used throughout the study. Calves were fed milk via an automatic feeder (VARIO smart, Förster-Technik, Germany). Milk replacer (MR) was 20% crude protein (CP) and was fed at an inclusion rate of 12.3%. Milk replacer intakes were recorded daily by the automatic feeder. Pelleted concentrate feed (16% CP) was offered ad libitum in a trough and, thus, individual intakes were not available. Calves also had access to ad libitum fresh water and straw.

Calves were weighed daily using an electronic half-body scale (Förster-Technik, Germany) connected to the automatic milk feeder. Final weight was obtained using a manual weighbridge on day 50. Disease incidence and antibiotic treatments were recorded daily throughout the preweaning and the postweaning period until the calf left the farm. Calves receiving antibiotic treatment were also health scored on the day of treatment (Table 2).

Skin surface temperature (°C) was monitored during weeks 2 and 3 at 10-min intervals using a

Table 1. Details of each of the five batches

		B1	B2	B3	B4	B5
Arrival date		April 1, 2017	June 22, 2017	September 15, 2017	November 30, 2017	February 28, 2018
End date		June 16, 2017	August 29, 2017	November 24, 2017	February 13, 2017	May 3, 2018
Number of calves		88	75	78	100	81
Number of source farms		8	13	13	10	7
Sex	Male	45	34	42	51	44
	Female	43	41	36	49	37
Breed	AA	37	25	26	38	45
	BB	15	30	28	48	16
	HER	35	19	7	8	12
	LIM	1	0	4	3	4
	SIM	0	1	13	3	4

AA, Aberdeen Angus; BB, Belgian Blue; HER, Hereford; LIM, Limousin; SIM, Simmental.

DS1922L iButton (Maxim Integrated, USA) on calves with and without a calf jacket. The iButton was attached to the calf as described by Sutherland et al. (2013). Any data loggers that became lost during the 2-wk period, or had lost direct contact with the skin, were excluded from the data set.

Ambient temperature (°C) and relative humidity (RH; %) were monitored every 10 min throughout the study using three DS1923 iButtons (Maxim Integrated, USA) placed diagonally across the shed just above calf height. The data was then used to calculate the temperature-humidity index (THI) using the formula outlined below where T is ambient temperature (°C) and RH is relative humidity (%) (NRC, 1971):

$$THI = (1.8T + 32) - (0.55 - 0.0055\,RH)(1.8T - 26)$$

Statistical Analysis

All statistical analysis was conducted using Genstat (19th ed.). Ambient conditions were analyzed using a one-way analysis of variance followed by a Fisher's Least Significant Test to assess the pairwise differences between batches. Performance and intakes were analyzed were modeled using linear mixed-model (LMM) methodology using the restricted maximum likelihood (REML) estimation method. A factorial arrangement of the batch, treatment, age at arrival, and start weight were fitted as fixed effects, while source farm was fitted as the random effect in the modeling process. A Fisher's Least Significant Test was used to further assess pairwise differences between the individual levels of the effects. With regard to calf health, the continuous variable (days after arrival) was analyzed using LMM methodology using the REML estimation method, with the factorial arrangement of batch and treatment, and random effect of source farm. Again a Fisher's Least Significant Test was used to further assess pairwise differences. The remaining health variables were modeled using generalized LMM methodology with the same fixed and random effects as for the continuous variable. The binary variables used a binomial distribution with a logit link function while the count variables used a Poisson distribution with a logarithmic link function. Skin temperature was modeled using an LMM methodology using the REML estimation method. In this case, the fixed effects were batch and treatment (jacket or no jacket), while calf ID was fitted as the random effect. Pairwise differences were assessed using Fisher's Least Significant Test. The relationship between THI and skin temperature was modeled using simple linear regression with each batch being analyzed independently.

Table 2. Health scores used when calves received antibiotic treatment

Respiratory score		Fecal score	
0	Normal	0	Formed
1	Runny nose or eyes	1	Semiformed or soft
2	Coughing	2	Runny
3	Increased respiratory rate	3	Watery
4	Heavy/labored breathing	4	Runny or watery with blood

RESULTS

Mean ambient conditions within the calf house differed significantly according to batch (Table 3). There was over a 10 °C difference in mean ambient temperature throughout the year-long trial. Batch 4 had the lowest mean ambient temperature of 6.16 °C. RH was greatest in batch 4, thus creating cold damp conditions, which is confirmed by the low THI 43.13. Batch 2 had the greatest THI of 61.74. Batch 1 saw the greatest ambient temperature range of 26.04 °C, while conditions during batch 4 reached a minimum of −2.78 °C.

Calves in batches 2 and 3 were the youngest (24.46 and 23.20 d, respectively) at the commencement of this trial, while batch-1 calves were the oldest at 39.44 d of age (Table 4). Start weight was significantly different between batches, which, however, ranged only from 55.06 to 56.49 kg. Calves in batch 2 had the greatest final weight of 103.8 kg. Daily live weight gain (DLWG) also varied according to batch, again

Table 3. Ambient conditions within the calf house during each batch

	B1	B2	B3	B4	B5	Min SEM	Max SEM	*P*-value
Mean ambient temperature, °C	15.25[d]	16.93[e]	11.84[c]	6.16[a]	8.47[b]	0.041	0.034	<0.001
Mean RH, %	76.05[a]	81.34[b]	92.26[d]	99.22[e]	91.31[c]	0.124	0.103	<0.001
Mean THI	58.94[d]	61.74[e]	53.41[c]	43.13[a]	47.51[b]	0.068	0.056	<0.001
Minimum ambient temperature, °C	2.56	8.25	2.39	−2.78	−0.60	–	–	–
Maximum ambient temperature, °C	28.60	27.94	24.26	15.45	22.95	–	–	–

[a-d]Represent significant differences between the means in each row.

Table 4. Milk replacer intakes and live weight of calves in each of the five batches

	B1	B2	B3	B4	B5	Average SED	*P*-value
Age at arrival, d	9.44[c]	24.46[a]	23.20[a]	32.47[b]	34.95[bc]	2.478	<0.001
Start weight, kg	55.87[ab]	55.06[a]	55.93[ab]	56.49[b]	56.05[ab]	0.614	<0.001
Final weight, kg	99.36[bc]	103.8[c]	101.23[bc]	96.86[ab]	93.96[a]	2.683	<0.01
DLWG, kg/d	0.86[bc]	0.95[c]	0.90[bc]	0.81[ab]	0.76[a]	0.054	<0.01
Days on milk	47.17[c]	48.56[c]	42.16[a]	44.30[b]	41.85[a]	1.018	<0.001
Total MR intake, kg/FW	28.14[b]	30.44[c]	25.75[a]	28.25[b]	26.29[a]	0.795	<0.001
Daily MR intake, kg/FW	0.60[a]	0.63[b]	0.62[ab]	0.64[b]	0.63[b]	0.013	<0.01

DLWG, daily live weight gain; FW, fresh weight; MR, milk replacer; SED, standard error of the difference.

[a-d]Represent significant differences between the means in each row.

Table 5. Milk replacer intakes and live weights of calves according to calf jacket treatment

						P-value	
	Control	Arrival	Weight	Wean	Average SED	Batch	Batch treatment
Age at arrival, d	31.87	30.67	30.41	30.66	1.927	NS	NS
Start weight, kg	56.08	55.96	55.97	55.52	0.549	NS	NS
Final weight, kg	99.94	99.08	98.13	98.03	1.884	NS	NS
DLWG, kg/d	0.88	0.86	0.86	0.84	0.038	NS	NS
Days on milk	45.32	45.09	44.41	44.41	0.679	NS	NS
Total MR intake, kg/FW	27.92	28.27	27.45	27.45	0.554	NS	NS
Daily MR intake, kg/FW	0.62	0.63	0.62	0.62	0.009	NS	NS

DLWG, daily live weight gain; FW, fresh weight; MR, milk replacer; NS, not significant; SED, standard error of the difference.

Table 6. Incidence rates of ill health for each batch

	B1	B2	B3	B4	B5	Average SED	*P*-value
Disease incidence	0.1766 (0.0933–0.3089)	0.3395 (0.1694–0.5644)	0.4491 (0.3087–0.5980)	0.1802 (0.0944–0.3167)	0.2627 (0.1519–0.4146)	–	<0.05
Relapses	0.1745 (0.0969–0.3143)	0.4240 (0.2324–0.7739)	0.5320 (0.3638–0.7780)	0.1856 (0.1043–0.3303)	0.2801 (0.1688–0.4647)	–	<0.001
Respiratory score	0.1766 (0.0933–0.3089)	0.3395 (0.1694–0.5644)	0.4491 (0.3087–0.5980)	0.1802 (0.0944–0.3167)	0.2627 (0.1519–0.4146)	–	<0.05
Days after arrival*	2.02	6.43	6.17	5.07	5.96	2.059	NS

PRED (LCI-UCI).

NS, not significant.

*Number of days after arrival that first disease incidence occurred.

ranging from 0.76 to 0.95 kg/d. Days on milk ranged from 41.85 d for batch 5 to 48.56 d for batch 2; subsequently, total milk replacer intake followed a similar trend, ranging from 25.75 to 30.44 kg FW. Daily milk replacer intakes were significantly different between batches. Table 5 shows that calf jacket treatment had no significant effect on any of the parameters shown. Furthermore, there was no significant interaction between batch and treatment, so the results are not presented.

Batch 3 had the greatest disease incidence, relapse rate, and respiratory score (Table 6). There was no significant difference between batches for the days after arrival that ill health occurred. Calf jacket treatment had no significant effect on calf health (Table 7). Furthermore, there was no significant interaction between batch and treatment, so the results are not shown. There were no incidences of calf diarrhea during this study; therefore, the results for fecal scores are not shown.

Mean skin temperature for calves with a jacket was 36.08 °C, while that for calves without a jacket was 31.77 °C ($P < 0.001$). Figure 1 shows the interaction between batch and jacket treatment; calves without a jacket had a consistently lower skin temperature but also had a much wider interquartile range than those with a jacket. Table 8 shows a significant relationship between THI and skin

Table 7. Incidence rates of ill health according to calf jacket treatment

	Arrival	Control	Weight	Weight	Average SED	*P*-value
Disease incidence	0.3467 (0.2403–0.4709)	0.4070 (0.2947–0.5300)	0.3803 (0.2613–0.5157)	0.3493 (0.2334–0.4862)	–	NS
Relapses	0.4120 (0.2892–0.5859)	0.5053 (0.3636–0.7021)	0.4641 (0.3279–0.6569)	0.3707 (0.2409–0.5703)	–	NS
Respiratory score	0.3467 (0.2403–0.4709)	0.4070 (0.2947–0.5300)	0.3803 (0.2613–0.5157)	0.3493 (0.2334–0.4862)	–	NS
Days after arrival*	4.46	5.18	6.32	4.57	1.618	NS

PRED (LCI-UCI).
NS, not significant.
*Number of days after arrival that first disease incidence occurred.

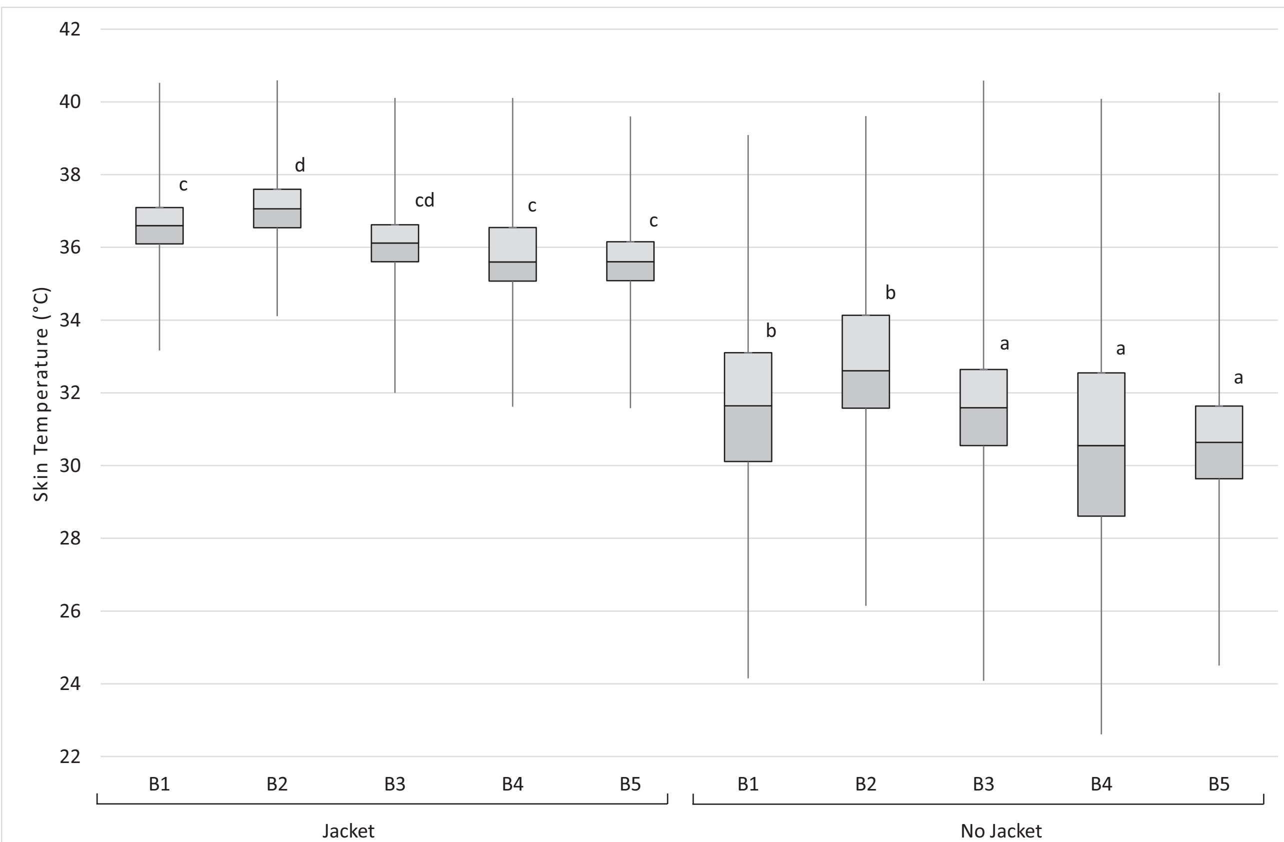

Figure 1. Box plots showing skin temperature of calves with and without a jacket during each of the five batches. a–d = significant differences between mean skin temperature ($P < 0.001$).

temperature for each of the five batches. Calves in batch 4 with a jacket had the greatest R^2 of 77, while that of batch 1 without a jacket had the lowest (48.5).

DISCUSSIONS

The lower critical temperature (LCT) for calves up to 8 wk of age has been reported at 8 °C (Gonzalez-Jimenez and Blaxter, 1962; Webster et al., 1978). Therefore, with a mean ambient temperature of 6.16 °C, batch 4 was the only group with a mean temperature below this threshold. Furthermore, during batch 4, ambient temperatures were below this threshold for 66% of the time. However, when taking into account minimum temperatures, all five batches reached this LCT for a period of time.

The significant differences in performance and health that were observed between batches would have been expected. As this was an on-farm trial, calves were sourced from a number of different dairy farms and transported to a commercial calf rearing facility. Thus, these calves would all have

Table 8. The relationship between THI and skin temperature for calves with and without a jacket during each of the five batches

Batch	Jacket	R^2	F pr.	No Jacket	R^2	F pr.
One	$y = 0.07498x + 32.30$	67.4	<0.001	$y = 0.22155x + 18.85$	48.5	<0.001
Two	$y = 0.09363x + 31.14$	59.1	<0.001	$y = 0.15273x + 23.56$	51.8	<0.001
Three	$y = 0.10063x + 30.49$	62.4	<0.001	$y = 0.22647x + 18.70$	60.0	<0.001
Four	$y = 0.09915x + 31.15$	77.0	<0.001	$y = 0.17018x + 22.98$	66.3	<0.001
Five	$y = 0.08021x + 32.04$	65.5	<0.001	$y = 0.16148x + 23.42$	61.8	<0.001

y = skin temperature (°C); x = THI.

had different neonatal care and levels of passive transfer. Furthermore, each farm would have had a different disease burden, giving the calves differing levels of exposure to disease (Windeyer et al., 2014). The genetic potential of these calves would have varied as some were AI bred, while others were from a stock bull.

Calf jacket treatment had no effect on calf performance during this study. Therefore, even the duration that a calf jacket was worn for was irrelevant. Furthermore, the fact that there was no significant interaction between batch and treatment shows that, even during the cold conditions of batch 4, calf jackets did not improve performance. These findings are in agreement with a number of studies. Scoley et al. (2019) investigated the use of calf jackets during the first 3 wk of life and found no difference in live weight at the end of the study period (d63). Similar results were found by Earley et al. (2004), where calves of 19 d of age were assigned to one of three treatments, again with no difference in performance observed.

The lack of any impact of calf jacket treatment on health during the prewean period is consistent with the findings of previous calf jacket research (Earley et al., 2004; Scoley et al., 2019). However, cold stress is considered within the literature to negatively impact calf health (Nonnecke et al., 2009; Roland et al., 2016). Bovine respiratory disease (BRD) is well known to be a multifactorial disease (Earley et al., 2017) and, thus, is influenced by a vast number of environmental stressors, together with infectious agents and host factors (Caswell, 2014; Guzman and Taylor, 2015). Thus, the results observed in this study are not atypical, particularly, as these calves were moved to the rearing unit immediately prior to the commencement of this trial and, thus, would have been exposed to a number of stressors.

As the calves in this study originated from different farms, they would have been exposed to different ambient conditions prior to arrival. This would have largely depended on the type of housing and the provision and quality of bedding. Thus, some of the calves may have been acclimatized to a cool environment. Roy and Collier (2012) outlined that this adaption my take days or weeks and is characterized by an increase in coat thickness, subcutaneous fat depth, or an increase in feed intake. Thus, as this study was conducted under commercial conditions, these calves were a number of weeks old at arrival. Hence, this adaption may already have taken place and the calves would have had little need for a jacket.

Milk replacer intakes were consistent across the four treatment groups, while concentrates were offered ad libitum in a group feeding system. Therefore, we are unable to determine if concentrate intakes varied according to calf jacket treatment. Nonnecke et al. (2009) found that, in cold environments, calves would consume more concentrates in order to meet their additional metabolic requirements. Yet, the literature has also shown apposing results (Hepola et al., 2006). Hill et al. (2007) found that bedding material was as important as feed intake in supporting the daily live weight gain in cold conditions. Furthermore, calves have the ability to tolerate cold environments provided the lying area is dry and draught free (Rawson et al., 1989). In this study, calves were housed in a purpose-built, draught-free shed and bedded in deep straw. Therefore, these calves would have been nesting allowing them to conserve heat during periods of fluctuating temperature (Hänninen et al., 2003; Hepola et al., 2006). In addition, this study was conducted on a farm that was operated to a very high standard, following best practice guidelines, hence, further explaining why calf jackets had no significant effect on health or performance.

One further consideration is that ambient conditions were possibly not extreme enough to highlight any benefit of calf jackets. This study, which ran for a full year in order to take into account seasonality, unfortunately did not have any batches experience ambient temperatures consistently below the LCT. Although variations in temperature are considered to be as problematic (Carroll et al., 2012), these reductions in temperature, which occurred primarily at night, could be compensated for by nesting and huddling behaviors (Ingram and Mount, 1975; Hepola et al., 2006; Lago et al., 2006).

Skin temperature was 4.31 °C greater for calves with a jacket. Scoley et al. (2019) reported differences of 6.37 °C between calves with and without a calf jacket. The difference between the two studies may be due to the fact that the calves in this study were older and, thus, were able to withstand cooler temperatures (Gonzalez-Jimenez and Blaxter, 1962; Webster et al., 1978). However, a number of studies have documented that skin temperature is not directly related to either rectal or vaginal temperature (Sutherland et al., 2017; Scoley et al., 2019). Therefore, although calf jackets appear to create a warmer microenvironment for the calf, they may not be having any impact on core body temperature. The significant relationship between THI and skin temperature is consistent with previous research. Ambient temperature has been shown to influence tail temperature with increases of 0.0325 °C observed for every 1 °C increase in ambient temperature (Hill et al., 2016).

CONCLUSIONS

Over the duration of 1 yr, only one batch of calves experienced mean ambient conditions below the recommended LCT. Significant differences in calf health and performance were observed between batches. These results were as expected and were likely due to the fact that calves were sourced from a number of different farms. Calf jackets had no significant effect on calf health or performance during any of the five batches. During this study, calves were housed in a well-designed calf rearing shed, with excellent calf management practices. Therefore, although the shed was well ventilated, it was draught free and calves always had a deep and dry straw bed, thus encouraging nesting behavior in times of low ambient temperatures. The differences in skin temperature indicate that calf jackets do create a microenvironment for the calf and, therefore, act as a barrier to adverse ambient conditions.

ACKNOWLEDGMENTS

The authors gratefully acknowledge ABP Food Group and the Hooke family for their assistance in this study. This study was funded by the Department of Agriculture, Environment and Rural Affairs and co-funded by AgriSearch.

Conflict of interest statement. The authors declare that there is no conflict of interest.

LITERATURE CITED

Bateman, H. G., T. M. Hill, J. M. Aldrich, R. L. Schlotterbeck, and J. L. Firkins. 2012. Meta analysis of the impact of initial serum protein concentration and empirical prediction model for growth of neonatal Holstein calves through eight weeks of age. J. Dairy Sci. 95:363–369. doi:10.3168/jds.2011-4594

Bhat, S. A., B. Bhushan, S. A. Sheikh, T. Chandrasekar, A. S. Godara, P. Bharti, and K. P.K. P. Japheth. 2015. Effect of infrared lamps to ameliorate cold stress in Vrindavani calves. Vet. World. 8:777–82. doi:10.14202/vetworld.2015.777-782

Carroll, J. A., N. C. Burdick, C. C. Chase, Jr., S. W. Coleman, and D. E. Spiers. 2012. Influence of environmental temperature on the physiological, endocrine, and immune responses in livestock exposed to a provocative immune challenge. Domest. Anim. Endocrinol. 43:146–53. doi:10.1016/j.domaniend.2011.12.008

Caswell, J. L. 2014. Failure of respiratory defenses in the pathogenesis of bacterial pneumonia of cattle. Vet. Pathol. 51:393–409. doi:10.1177/0300985813502821

Collier, R. J., D. K. Beede, W. W. Thatcher, L. A. Israel, and C. J. Wilcox. 1982. Influences of environment and its modification on dairy animal health and production. J. Dairy Sci. 65:2213–2227. doi:10.3168/jds.S0022-0302(82)82484-3

Earley, B., K. Buckham Sporer, and S. Gupta. 2017. Invited review: relationship between cattle transport, immunity and respiratory disease. Animal. 11:486–492. doi:10.1017/S1751731116001622

Earley, B., M. Murray, J. A. Farrell, and M. Nolan. 2004. Rearing calves outdoors with and without calf jackets compared with indoor housing on calf health and live-weight performance. Irish J. Agr. Food Res. 43:59–67.

Gonzalez-Jimenez, E., and K. L. Blaxter. 1962. The metabolism and thermal regulation of calves in the first month of life. Br. J. Nutr. 16:199–212. doi:10.1079/BJN19620021

Guzman, E., and G. Taylor. 2015. Immunology of bovine respiratory syncytial virus in calves. Mol. Immunol. 66:48–56. doi:10.1016/j.molimm.2014.12.004

Hänninen, L., H. Hepola, J. Rushen, A. M. De Passill, P. Pursiainen, V. M. Tuure, L. Syrjälä-qvist, M. Pyykkönen, and H. Saloniemi. 2003. Resting behaviour, growth, and diarrhoea incidence rate of young dairy calves housed individually or in groups in cold or warm buildings. Acta Agric. Scand. Sect. A: Anim. Sci. 53:21–28. doi:10.1080/09064700310002008

Hepola, H., L. Hanninen, P. Pursiainen, V. M. Tuure, L. Syrjala-Qvist, M. Pyykkonen, and H. Saloniemi. 2006. Feed intake and oral behaviour of dairy calves housed individually or in groups in warm or cold buildings. Livest. Sci. 105:94–104. doi:10.1016/j.livsci.2006.04.033

Hill, T. M., I. H. G. Bateman, J. M. Aldrich, and R. L. Schlotterbeck. 2007. Effects of feeding rate of milk replacers and bedding material for calves in a cold, naturally ventilated nursery. Professional Anim. Scientist. 23:656–664. doi:10.15232/S1080-7446(15)31037-8

Hill, T. M., H. G. Bateman, II, F. X. Suarez-Mena, T. S. Dennis, and R. L. Schlotterbeck. 2016. Short communication: changes in body temperature of calves up to 2 months of age as affected by time of day, age, and ambient temperature. J. Dairy Sci. 99:8867–8870. doi:10.3168/jds.2016-10994

Ingram, D. L., and L. E. Mount. 1975. Man and animals in hot environments. New York (NY): Springer-Verlag.

Lago, A., S. M. Mcguirk, T. B. Bennett, N. B. Cook, and K. V. Nordlund. 2006. Calf respiratory disease and pen microenvironments in naturally ventilated calf barns in winter. J. Dairy Sci. 89:4014–4025. doi:10.3168/jds.S0022-0302(06)72445-6

Loy, T. W., J. W. Schroederl, G. P. Lardy, G. T. Wallacel, M. Zimmerman, M. Rose, J. Dhuyvetter, and W. D. Siangerl. 2000. Efficacy of wool polyester blankets in improving weight gain and health of newborn beef calves in dry lot conditions. J. Anim. Sci. 78:34.

Nonnecke, B. J., M. R. Foote, B. L. Miller, M. Fowler, T. E. Johnson, and R. L. Horst. 2009. Effects of chronic environmental cold on growth, health, and select metabolic and immunologic responses of preruminant calves. J. Dairy Sci. 92:6134–6143. doi:10.3168/jds.2009-2517

NRC. 1971. A guide to environmental research on animals. Washington (DC): National Academy of Sciences.

Rawson, R. E., H. E. Dziuk, A. L. Good, J. F. Anderson, D. W. Bates, G. R. Ruth, and R. C. Serfass. 1989. Health and metabolic responses of young calves housed at -30 degrees C to -8 degrees C. Can. J. Vet. Res. 53:268–274.

Roland, L., M. Drillich, D. Klein-Jöbstl, and M. Iwersen. 2016. Invited review: influence of climatic conditions on the development, performance, and health of calves. J. Dairy Sci. 99:2438–2452. doi:10.3168/jds.2015-9901

Roy, K. S. and R. J. Collier. 2012. Regulation of acclimation to environmental stress. In: Collier, R. J., editor, Environmental physiology of livestock. Chichester (UK): John Wiley & Sons.

Scanes, C. 2011. Fundamentals of animal science. Clifton Park (NY): Delmar.

Scoley, G., A. Gordon, and S. J. Morrison. 2019. The effect of calf jacket usage on performance, behaviour and physiological responses of group-housed dairy calves. Animal. 1–9. doi:10.1017/S1751731119001071

Sutherland, M. A., M. Stewart, and K. E. Schütz. 2013. Effects of two substrate types on the behaviour, cleanliness and thermoregulation of dairy calves. Appl. Anim. Behav. Sci. 147:19–27. doi:10.1016/j.applanim.2013.04.018

Sutherland, M. A., G. M. Worth, C. Cameron, C. M. Ross, and D. Rapp. 2017. Health, physiology, and behavior of dairy calves reared on 4 different substrates. J. Dairy Sci. 100:2148–2156. doi:10.3168/jds.2016-12074

Tao, S., and G. E. Dahl. 2013. Invited review: heat stress effects during late gestation on dry cows and their calves. J. Dairy Sci. 96:4079–4093. doi:10.3168/jds.2012-6278

Webster, A. J. F., J. G. Gordon, and R. Mcgregor. 1978. The cold tolerance of beef and dairy type calves in the first weeks of life. Anim. Prod. 26:85–92. doi:10.1017/S0003356100012046

Windeyer, M. C., K. E. Leslie, S. M. Godden, D. C. Hodgins, K. D. Lissemore, and S. J. Leblanc. 2014. Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. Prev. Vet. Med. 113:231–40. doi:10.1016/j.prevetmed.2013.10.019