



Relationships of body surface thermography with core temperature, birth weight and climatic variables in neonatal lambs born during early spring in an arid region



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ABSTRACT

The main cause of death in newborn lambs is hypothermia, so is necessary to identify the factors affecting variations in body surface temperatures of sheep neonates because approximately 60% of their body heat losses occur through the skin. This study aimed to establish relationships among body surface thermography from different regions with rectal temperature (RT), birth weight (BW) and climatic variables in hair breed newborn lambs during early spring in an arid region. Data of body surface temperatures measured by infrared thermography (entire head, eye, muzzle, ear, entire body, shoulder, rump, loin, right flank, belly and leg), RT and BW were collected at 0, 12 and 24 h post-lambing in 85 lambs born in early spring. Relative humidity [RH], temperature [Te] and temperature-humidity index [THI] were also recorded. RT was not correlated with surface temperatures at 0 and 24 h, but it was at 12 h with all of them ($0.36 \leq r \leq 0.44$). BW and some surface temperatures were negatively correlated at 0 and 24 h ($-0.24 \leq r \leq -0.30$), but positively at 12 h ($0.25 \leq r \leq 0.27$). All surface temperatures were positively correlated ($0.51 \leq r \leq 0.85$) with Te and THI in the three sampling times. Principal component (PC) analysis showed that PC1 explained the majority of the variance (71–72%), followed by PC2 (8–9%) at 0, 12 and 24 h. Body surface temperatures increased as Te and THI also increased, but decreased with the increase in HR. In conclusion, under early spring environment (predominantly cold), the variations in body surface temperatures of hair sheep neonates were more closely related to climatic variables than to RT and BW. Thermography proved to be an effective tool to determine body heat loss by radiation in skin of neonate lambs.

1. Introduction

Thermoregulation of the fetus in the last third of pregnancy depends largely on maternal thermal protection, which consists of vascular changes that are beneficial to maintain or dissipate heat from the uteroplacental unit (Laburn et al., 2002). Simultaneously, the fetus activates a mechanism known as fetal thermal inertia to maintain its core temperature relatively stable and above the maternal core temperature (± 0.5 °C; Sahni, 2017). This maternal protection is lost at lambing, and consequently, the newborn lamb must make changes to quickly adapt to the extrauterine environment (Vannucchi et al., 2012). Among the adaptation changes to environmental conditions out of the

maternal thermal protection, the capacity that newborn lambs must acquire to regulate their own body temperature during the first hours of life has been highlighted (Plush, 2014). So, to avoid hypothermia after birth, lambs require a properly combination of internal heat generation using energy from brown fat (non-shivering thermogenesis), and heat loss by radiation from skin (McCoard et al., 2014) under thermoneutral conditions or slight cold stress. Moreover, shivering thermogenesis is a thermoregulation mechanism activated by the neonate when hypothermia or a severe cold stress is present (Plush et al., 2016a).

The non-evaporative mechanism heat radiation through the skin surface is an important source of heat body loss (60%) by newborn lambs after lambing (McCoard et al., 2014), and is responsible for

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causing hypothermia and early neonatal death. In consequence, recent studies about thermogenesis in newborn lambs have been focalized in determining variations of their body surface temperature (skin and hair coat) using infrared thermography, as well as taking rectal temperature (RT) measures as it is traditionally done (McCoard et al., 2014; El Hadi et al., 2016; Labeur et al., 2017). Those studies using wool sheep concluded that infrared thermography is a practical and non-invasive tool for studying thermoregulation mechanisms of neonates by helping to measure heat losses through the skin under cold stress conditions. Notably, no study in the literature was found about using this technology in hair breed sheep neonates. Likewise, there was no information on factors that control variations of body surface thermography in newborn lambs of any genotype during their early postnatal life. The generation of this information is essential to develop management strategies that help to reduce the body heat losses through the skin and then neonatal lamb mortality. Likewise, to understand more precisely how heat losses through the skin in hair breed newborn lambs are regulated.

Newborn lambs from hair sheep breeds are devoid of wool, have lower birth weights (BW) and trivial deposition of subcutaneous fat compared with those from wool breeds; so they may be more susceptible to develop more intense heat losses through the skin under cold environments, and consequently, hypothermic death (Vicente-Pérez et al., in press). It has been documented that genetic (e.g. BW, lamb size and birth rank) and environmental (temperature, humidity and feeding) factors can alter the ability to transfer body heat through the skin in neonates (Faurie et al., 2004). In this sense, we hypothesized that variations in body surface thermography of hair breed newborn lambs are associated with RT, BW and weather variables under environmental conditions of early spring in an arid region. Therefore, the objective of this study was to establish relationships of body surface thermography from different regions with rectal temperature, birth weight and climatic variables during the first twenty-four hours after birth in hair breed lambs subjected to environmental conditions of early spring in an arid region.

2. Materials and methods

2.1. Site of study

The study was carried out during the spring season in the Sheep Experimental Unit of the Instituto de Agricultural Sciences, Autonomous University of Baja California (UABC). This institution is located in the Mexicali Valley, Baja California, within the Sonora desert region, in northwestern Mexico (32° 24'N and 115° 22'W). The climate is arid and dry, with thermoneutral environmental conditions predominant in late autumn and early spring (INEGI, 2017).

2.2. Animals and management

All lambs were managed according to approved Official Mexican Technique (NOM-051-ZOO-1995, humanitarian care of animals during mobilization; and NOM-062-ZOO-1999, technique specifications to production, care, and use of laboratory animals). Additionally, accepted guidelines by the Federation Animal Science Society (FASS Federation Animal Science Society, 2010) were also followed. The Animal Care Committee of the UABC supervised the compliance of the techniques and procedures applied.

The study was performed with 85 newborn lambs from Dorper x Katahdin genotype born during early spring season. All lambs born from 52 multiparous ewes, which had single or twin lambing. From breeding until lambing, ewes received similar housing, reproductive and feeding management. So, they were confined during the mating season and pregnancy in 25-m² pens (5 × 5 m; 12 to 13 ewes by pen), which were equipped with waterers, feeding troughs and shade (1.04 m²/ewe). To ensure births during early spring, ewes were treated

for estrous synchronization with intravaginal sponges containing synthetic progestagens (Chronogest, Intervet, D.F., Mexico) during 10 d and an i.m. injection of 250 IU of eCG (Folligon, Intervet, D.F., Mexico) 24 h before sponge's removal. Then ewes in estrous were mated twice naturally (one at estrus detection, and the other 12 h later) using white Dorper rams (8–10 ewes/ram). Pregnancy diagnosis was carried out 40 d after post-mating using real-time ultrasound equipment (Draminski, Animal Profi model, Poland). Non-pregnant ewes were removed from the group (< 10%). Ewes were fed a complete diet formulated to meet daily nutrient requirements for twin pregnancy according to two periods (NRC, 2007): 1) 2.0 Mcal of metabolizable energy (ME)/kg of dry matter (DM), and 2) 90 g of crude protein (CP)/kg of DM during the first 100 d of pregnancy, as well as 2.4 Mcal of ME/kg of DM and 120 g of CP/kg of DM during the last third of pregnancy. Feed and water were offered *ad libitum*, and health status was monitored daily by direct observation. Additionally, ewes were observed continuously from day 144 of pregnancy until lambing and study variables in the offspring at 0, 12 and 24 h post-lambing were recorded.

2.3. Data collection

Data of environmental temperature (Te) and relative humidity (RH) were obtained from a portable weather station (Davis Instruments, model Vantage PRO2™, CA, USA) programmed to record climatic variables every 15 min. Only climatic data that corresponded to the measurement times of physiological variables of each lamb were considered. The temperature-humidity index (THI) was also calculated for the sampling times using the formula: $THI = 0.80 \times Te + RH (Te - 14.4) + 46.4$ (Hahn, 1999).

At lambing, lambs were identified with numbered collars, and BW as well as thermoregulation variables were measured before the first colostrum intake. Thermoregulation variables (RT and average surface temperature from the following body sites: entire head, eye, muzzle, ear, entire body, shoulder, rump, loin, right flank, belly and leg) were measured again at 12 and 24 post-lambing. While RT was measured introducing a digital thermometer (Delta Trak®, Pleasanton, CA, USA) in the rectum for one minute, body surface temperatures were obtained by taking infrared thermal imaging with a thermographic camera (Fluke Ti10, Everett, WA, USA) at a 1.0-m distance. All images were downloaded in a computer to be processed with the Fluke Smart View® 3.9 software, and the different average temperatures of each body region were obtained. One picture per lamb and per sampling was taken, and surface areas of each body region were defined as is indicated in Fig. 1. This methodology was repeated for each picture, although the size of the circumscribed area of each body region varied according to the body size of the lamb; this was done to maintain a proper ratio between the size of the circumscribed area and the size of each animal.

2.4. Statistical analysis

Data were analyzed using the SAS statistical program (SAS institute, 2004). Initially, normality was tested for all study variables with the PROC UNIVARIATE statement. Then, descriptive statistics were obtained for all study variables using the PROC MEANS statement. Relationships of body surface thermography with BW, RT and climatic variables on each sampling time (0, 12 and 24 h) were analyzed through Pearson correlations using the PROC CORR statement. Correlation coefficients (r) between variables were declared significant at $P \leq 0.05$ and were classified as high ($r > 0.68$), moderate ($0.36 < r < 0.67$) and low ($r < 0.35$) according to the estimated values (Taylor, 1990). Given that Te and THI showed the highest correlation ($P < 0.01$; $0.51 \leq r \leq 0.85$) with several surface body temperatures in all sampling times, a simple linear regression (SLR) analysis for each body surface temperature (dependent variables) were performed using the PROC REG statement, where THI was considered the predictor variable. Since the correlation values between THI and

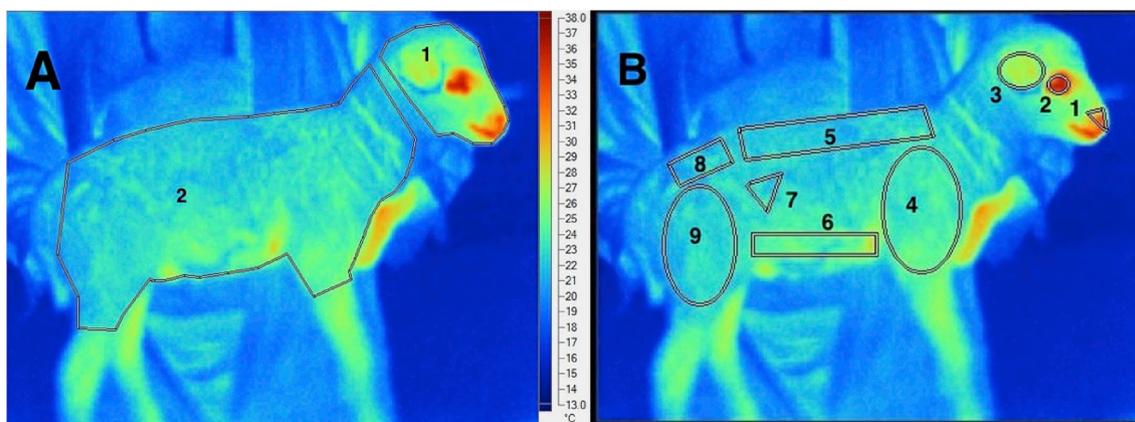


Fig. 1. Infrared thermography from neonatal lambs sectioned in different body sites: A [entire head (1) and entire body (2)] and B [muzzle (1), eye (2), ear (3), shoulder (4), loin (5), belly (6), right flank (7), rump (8) and leg (9)].

each surface temperature were consistent at every sampling time, data at 0, 12 and 24 h post-lambing were included together for the SLR analysis of each dependent variable. Finally, a principal component (PC) analysis was conducted for each sampling time (i.e. 0, 12 and 24 h post-lambing) as well as overall using the PROC PRINTCOMP statement. Plots of PC1 vs. PC2 were developed, as those PC had eigenvalues ≥ 1.0 (Jolliffe, 1973).

3. Results

Results of descriptive statistic for each study variable are shown in Table 1 and Fig. 2. Overall climatic conditions (mean \pm standard deviation) registered during the first 24 h post-lambing were $19.7 \pm 5.7^\circ\text{C}$, $52.7 \pm 30.9\%$ and 63.9 ± 6.4 units for Te, RH and THI, respectively. Lamb BW varied from 1.4 to 4.8 kg, with an average value of 3.2 kg. The RT averaged 39.8°C , with range of 3.0°C . Averages of surface temperatures in the different body regions showed a high variability, since there was a range from 24.4 to 32.7°C , being lower for ear and higher for eye.

Results of Pearson's correlation coefficients are shown in Table 2. Body surface temperatures were not correlated with RT at 0 and 24 h,

Table 1

Descriptive statistics for climatic variables, birth weight, rectal temperature and body thermography recorded in the first 24 h post-lambing in lambs born during early spring in an arid region.

Items	Mean	SD	Min	Max
Climatic variables				
Temperature ($^\circ\text{C}$)	19.7	5.7	10.4	34.0
Relative humidity (%)	52.7	30.9	7.9	100
THI (units)	63.9	6.4	51.0	78.9
Birth weight (kg)	3.2	0.8	1.4	4.8
Rectal temperature ($^\circ\text{C}$)	39.8	0.4	38.1	41.1
Body surface temperatures ($^\circ\text{C}$)				
Entire head	27.0	5.4	14.9	39.5
Eye	32.7	3.9	14.2	39.8
Ear	23.8	7.0	9.7	42.7
Muzzle	27.3	5.1	16.1	38.8
Entire body	25.5	5.3	14.6	38.1
Shoulder	25.8	5.3	12.5	40.1
Rump	24.4	5.8	14.3	38.3
Belly	25.8	5.0	15.2	37.3
Right flank	25.3	5.3	12.8	37.6
Leg	24.5	5.6	14.0	37.2
Loin	24.7	5.5	13.0	39.4

SD= Standard deviation, Min = Minimum, Max = Maximum, THI = Temperature-humidity index.

Descriptive statistics were obtained considering variable values recorded at 0, 12 and 24 h post-lambing for newborn lamb.

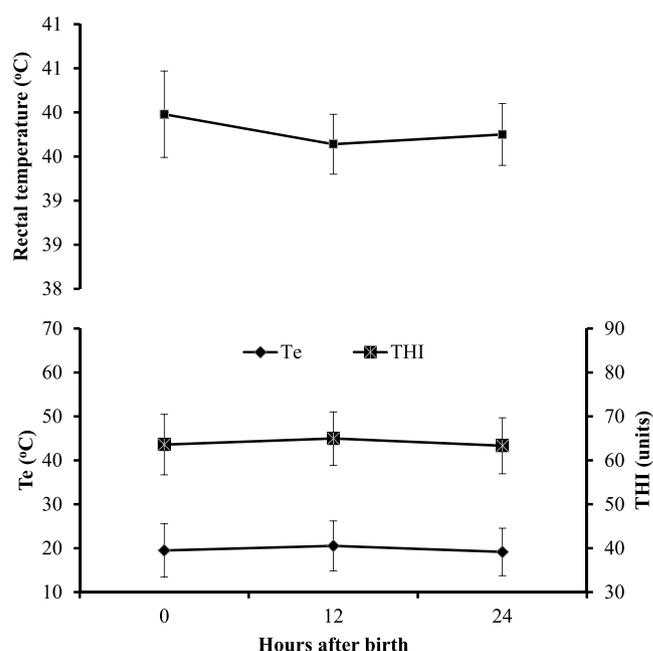


Fig. 2. Variations in temperature (Te), temperature-humidity index (THI) and lamb rectal temperatures recorded at the time of taking thermography measurements. Bars in each mean represent standard deviations.

but they were at 12 h in a positive and moderate way ($P < 0.05$; $0.36 \leq r \leq 0.44$). Some surface temperatures also showed negative and positive low correlations ($-0.30 \leq r \leq 0.27$) but significant ($P < 0.05$) with BW during all sampling times; however, these correlations were negative at 0 h (e.g. entire body, right flank, shoulder, rump, leg, loin) and at 24 h (e.g. right flank, belly), and positive at 12 h (e.g. entire head, eye, ear). All surface temperatures were positively correlated ($P < 0.01$), and in most cases highly correlated ($0.69 \leq r \leq 0.82$), with Te and THI in all sampling times. For its part, RH was negatively correlated ($P < 0.05$) with all surface temperatures at 0 ($-0.42 \leq r \leq -0.73$) and 24 h ($-0.24 \leq r \leq -0.62$), as well as with temperatures of the entire head and body, shoulder, rump and belly at 12 h ($-0.27 \leq r \leq -0.58$). Most of the correlation coefficients observed between surface temperature and RH were classified as moderate at 0 and 24 h, and as low at 12 h.

Results of SLR analysis among THI and each body surface temperature are shown in Figs. 3 and 4. The THI explained ($P < 0.01$) between 50 and 60% of the variation of all body surface temperatures, except for eye temperature in which only 33% was explained. All

Table 2

Correlation analysis of body surface temperatures with rectal temperature, birth weight and climatic variables at 0, 12 and 24 h post-lambing for lambs born during early spring in an arid region.

Body surface temperatures											
	Entire head	Eye	Ear	Muzzle	Entire body	Right flank	Shoulder	Rump	Belly	Leg	Loin
0 h post-lambing (at birth)											
RT	0.04	0.06	0.06	0.05	0.03	-0.01	0.00	0.02	-0.01	0.00	0.05
BW	-0.14	-0.09	0.021	-0.13	-0.24*	-0.28*	-0.27*	-0.28*	-0.18	-0.30*	-0.27*
Te	0.75**	0.61*	0.74**	0.70**	0.78**	0.73**	0.76**	0.76**	0.76**	0.78**	0.72**
RH	-0.73**	-0.57**	-0.66**	-0.53**	-0.63**	-0.48**	-0.52**	-0.51**	-0.59**	-0.56**	-0.42*
THI	0.72**	0.59**	0.71**	0.67**	0.75**	0.69**	0.74**	0.73**	0.72**	0.75**	0.69**
12 h post-lambing											
RT	0.36*	0.41*	0.36*	0.39*	0.41*	0.40*	0.44**	0.40*	0.44*	0.40*	0.40*
BW	0.27*	0.25*	0.27*	0.21	0.16	0.08	0.10	0.11	0.08	0.12	0.09
Te	0.78**	0.52**	0.75**	0.75**	0.79**	0.72**	0.75**	0.74**	0.71**	0.79**	0.72**
RH	-0.58**	-0.34	-0.52	-0.38	-0.42**	-0.24	-0.29*	-0.27*	-0.31*	-0.33	-0.26
THI	0.76**	0.51**	0.74**	0.76**	0.80**	0.74**	0.76**	0.76**	0.70**	0.81**	0.74**
24 h post-lambing											
RT	-0.02	0.03	-0.03	0.03	0.01	0.04	0.06	0.02	0.06	0.00	0.05
BW	-0.05	-0.12	-0.07	-0.06	-0.16	-0.24*	-0.20	-0.21	-0.24*	-0.19	-0.20
Te	0.82**	0.58**	0.79**	0.76**	0.85**	0.79**	0.82**	0.79**	0.81**	0.82**	0.80**
RH	-0.62**	-0.24*	-0.59**	-0.45**	-0.48**	-0.32*	-0.36*	-0.37*	-0.36*	-0.40*	-0.35*
THI	0.79**	0.56**	0.78**	0.74**	0.82**	0.77**	0.80**	0.77**	0.79**	0.80**	0.77**

RT = Rectal temperature, BW = Birth weight, Te = Environmental temperature, RH = Relative humidity, THI = Temperature-humidity index.

* $P < 0.05$, ** $P < 0.01$ and no asterisk indicates non-significant ($P > 0.05$) correlation between variables.

surface temperatures linearly increased as the THI increased from 51 to 79 units.

Results of PC analysis are shown in Fig. 5. Sixteen PC explained 100% of the total variance at each sampling time (i.e. at 0, 12 and 24 h), and only PC1 and PC2 were selected at each time because they had eigenvalues ≥ 1.0 . PC1 and PC2 explained most of the total variance (i.e. 81, 80 and 81% at 0, 12 and 24 h, respectively). However, it should be noted that PC1 alone explained around 72%, while PC2 only explained about 9% of the total variance through the post-lambing sampling times (Fig. 5). In the three post-lambing sampling times, the

analysis of eigenvectors showed that PC1 were loaded greatly with Te, THI and all body surface temperatures, while PC2 was more loaded with RH and BW. The RT showed to be more associated with PC1 at 12 h, and also with PC2 at 0 and 24 h. Thus, the PC1 showed that body surface temperatures, Te and THI increased together during the first 24 h post-lambing. Only at 12 h the RT showed a weak and positive association with all trunk surface temperatures. For its part, the PC2 showed a rise in lamb BW as RH decreased at 0, 12 and 24 h; similar negative relationship was observed between RT and RH at 0 and 24 h.

On the other hand, the 67% of the total variance was explained by

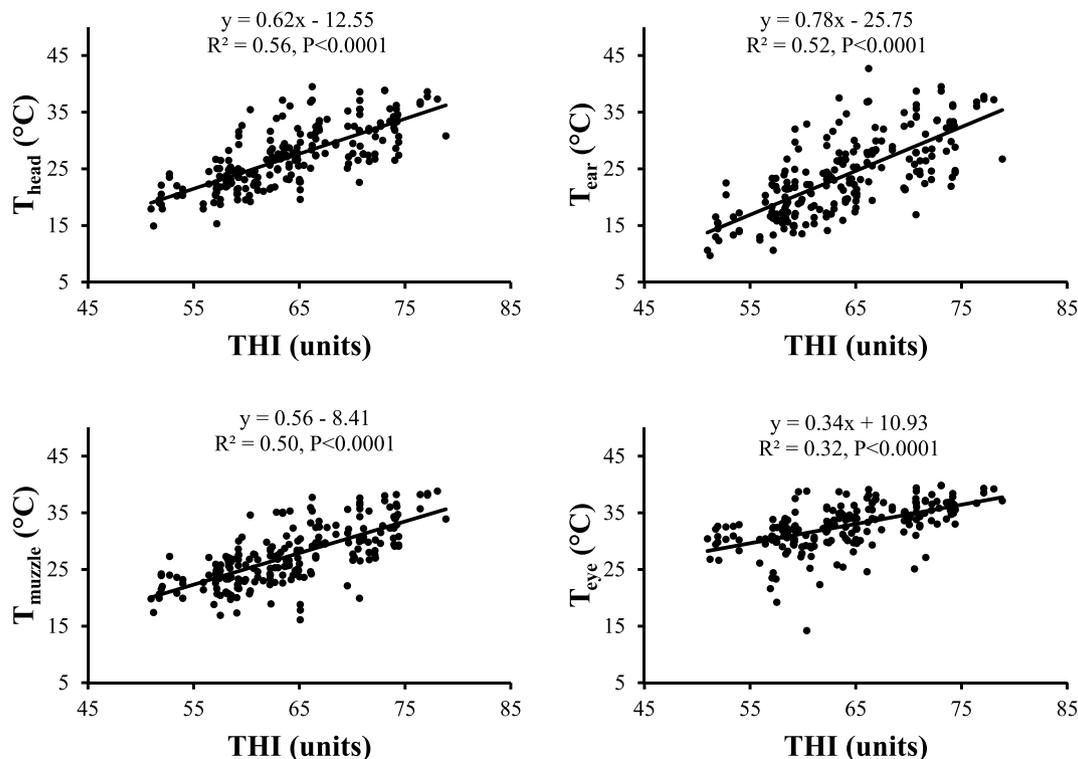


Fig. 3. Relationships among temperature-humidity (THI) index and surface temperatures from entire head (T_{head}), eye (T_{eye}), ear (T_{ear}) and muzzle (T_{muzzle}) recorded in lambs born during early spring in an arid region.

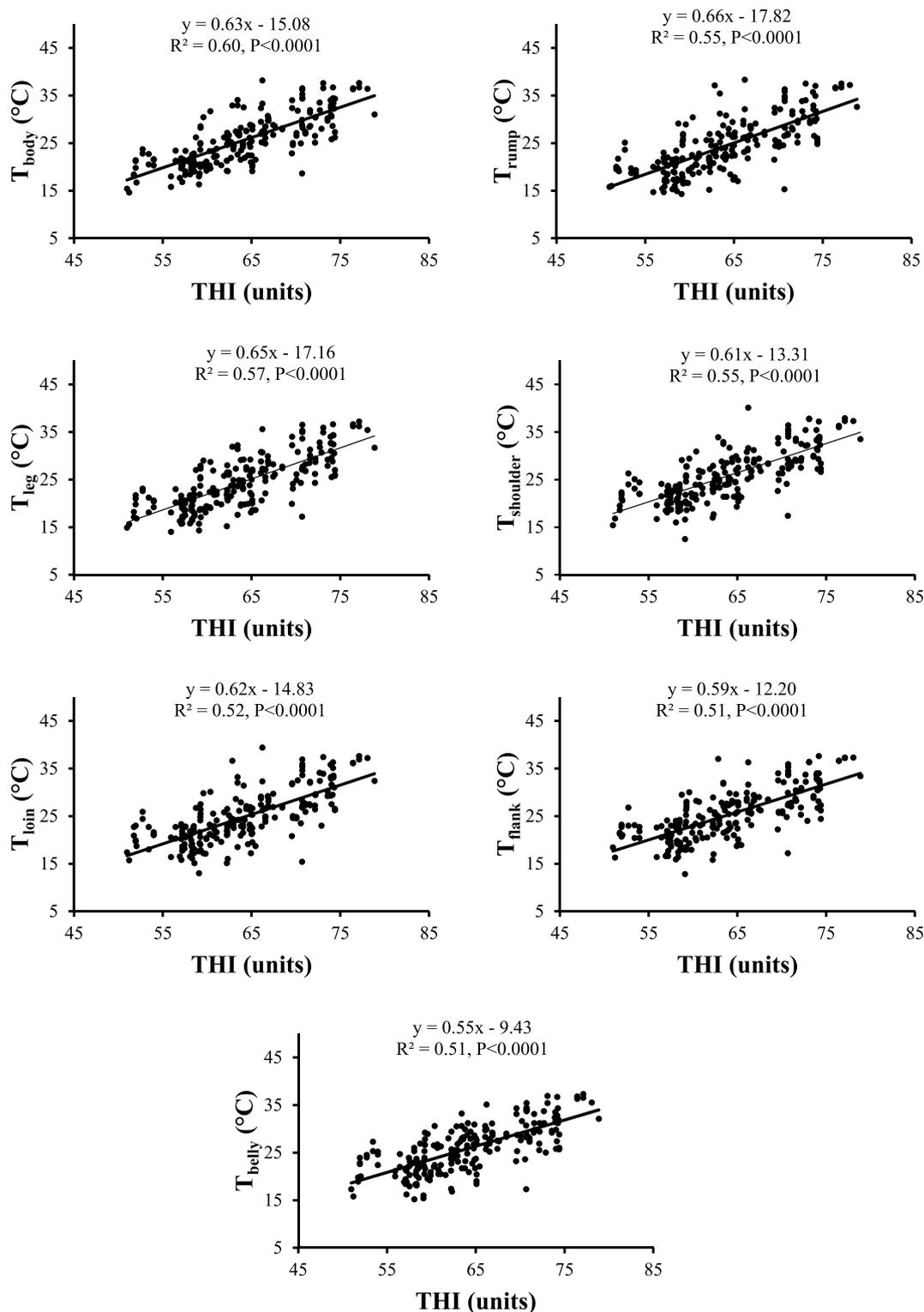


Fig. 4. Relationships among temperature-humidity (THI) index and surface temperatures from entire body (T_{body}), right flank (T_{flank}), shoulder ($T_{shoulder}$), rump (T_{rump}), belly (T_{belly}), leg (T_{leg}) and loin (T_{loin}) recorded in lambs born during early spring in an arid region.

the PC1 (49%) and PC2 (18%) in the overall PC analysis. Climatic and physiological variables were associated with PC1 at 0 and 24 h, and also with PC2 at 12 h post-lambing. Both PCs showed to have a very low BW load. The PC1 exhibited the presence of a positive association among body surface temperatures, T_e and THI recorded at 0 and 24 h after birth; the PC2 also showed these positive associations, but only at 12 h post-lambing. All body surface temperatures seemed to increase with the decrease in RH during the first 24 h post-lambing. Variables as BW

and RT at 0 and 24 h did not show to be related with body surface temperatures.

4. Discussion

Unlike growing lambs or adult sheep, newborn lambs are more susceptible to circadian fluctuations of outdoor T_e and THI because they are unable to thermoregulate themselves properly (Dwyer, 2008;

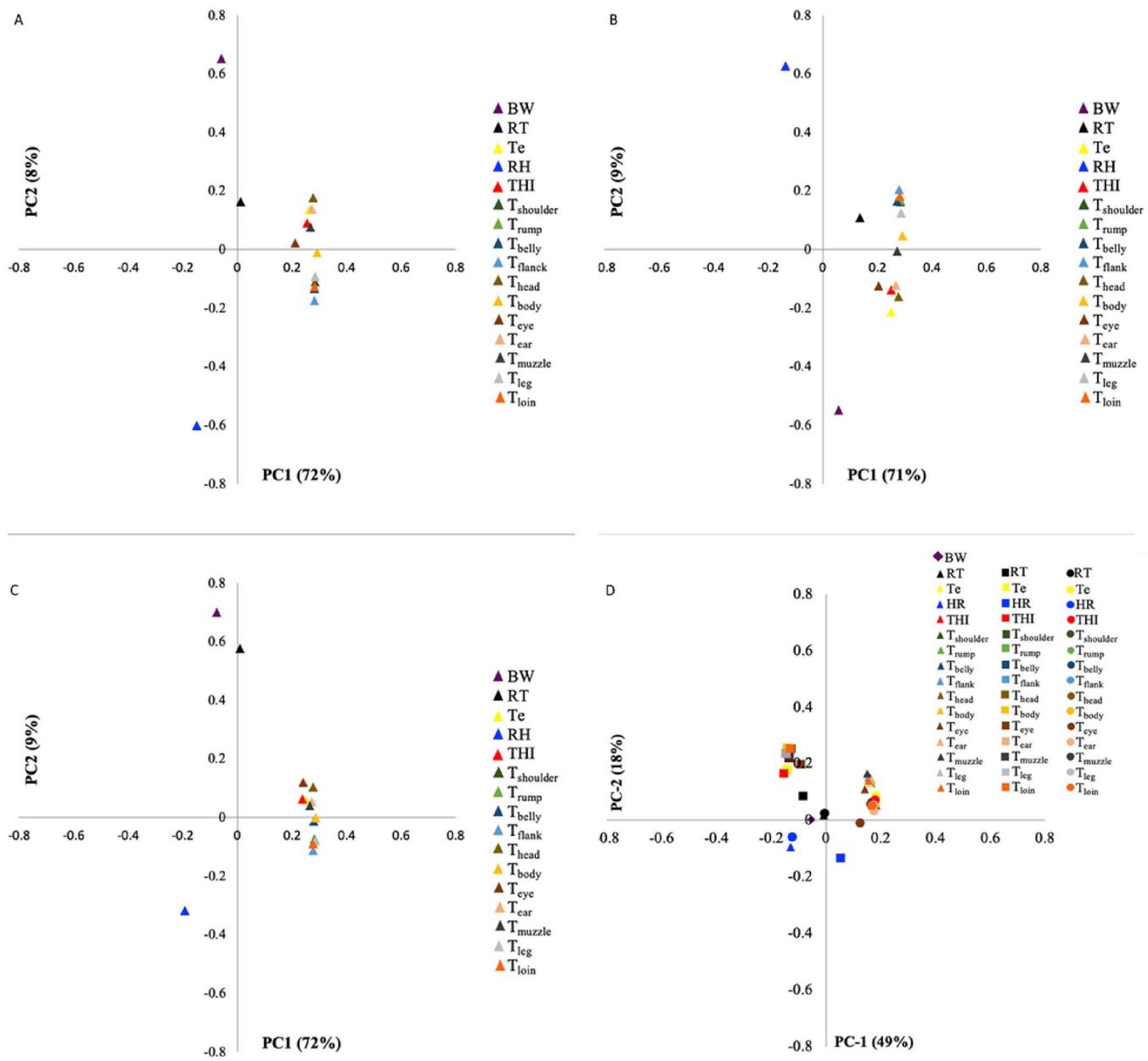


Fig. 5. Principal component analysis for temperature (Te), relative humidity (RH), temperature-humidity (THI) index, rectal temperature (RT), birth weight (BW) and body surface temperatures (T) at 0 (A), 12 (B) and 24 h (C) post-lambing, as well as in overall (D). The values between parentheses represent the variation explained by each component.

Plush et al., 2016a). As a result, the thermoneutral zone of neonate lambs is very narrow (28–32 °C; Bianca, 1974). In the current study, Te ranged from 10 to 34 °C, with an average of 19.7 °C, which means that lambs were predominantly exposed to a steady level of cold stress during the first 24 h after birth. A thermoneutral environment for newborns prevailed only during the afternoon (13:00 to 17:00 h). Environmental temperatures above 32 °C were recorded only few times.

Lamb BW averaged 3.2 ± 0.8 kg and were similar to others previously published for hair breed lambs born during the spring season (3.1–3.5 kg; Macías-Cruz et al., 2009, 2017) in arid regions. On the other hand, lambs showed adequate capacity to thermoregulate their body during the first 24 h post-lambing under experimental environmental conditions, given that average RT (39.8 ± 0.8 °C) fell within the normal range for sheep (38.3–39.9 °C; Marai et al., 2007). In addition, this RT average agreed with those average values reported for

hair (Macías-Cruz et al., 2017) and wool (Dwyer and Morgan, 2006) newborn lambs under thermoneutral environment.

Thermography evidenced a high variability in body surface temperatures (24.4–32.7 °C) across body regions. Both circadian fluctuations of Te and a heterogeneous distribution in the blood flow directed toward peripheral tissues (Sahni, 2017) could explain these thermography results. It should be mentioned that surface temperature values observed for each body region were not in agreement with other values reported in the literature for newborn lambs (McCoard et al., 2014; Labeur et al., 2017; Macías-Cruz et al., 2017), which can be attributed to variations in breed and environmental conditions that prevailed on each study.

The present study hypothesized that variations in body surface thermography are associated with RT, BW and climatic variables in hair sheep neonates subjected to environmental conditions of early spring in

an arid region. Our results partially supported this hypothesis, since body surface temperatures were always closely associated with climatic variables during the first 24 h post-lambing, but not RT and BW. In fact, the PC analysis confirms this finding, since BW did not show an association with surface temperatures during the first 24 h post-lambing, whereas RT only seemed to be weakly associated with trunk surface temperatures at 12 h. In agreement with these findings, several studies conducted in sheep mention also this direct relationship between environmental conditions and skin/hair temperature in newborns (Nowak and Poindron, 2006; Dwyer, 2008; Paim et al., 2012). Thus, cold, wet and/or windy environments are associated with large decreases in body surface temperature of the neonate and hypothermia problems (Nowak and Poindron, 2006).

It is known that newborn lambs lose a high amount of body heat by radiation through the skin in the first post-lambing hours; so they can easily reach hypothermia and death in the first 24 h of life if there is no quick adaptation to the new environment (McCoard et al., 2014; Plush et al., 2016a). The combination of internal heat production from brown fat and the radiated heat loss reduction from the skin surface is important to maintain core body temperature (Dwyer, 2008). In sheep, different factors have been associated with the capacity of the newborn to maintain normothermia such as BW, available amount of brown fat, colostrum intake, environmental conditions, among others (Dwyer and Morgan, 2006; Plush et al., 2016b). Overall results of this study suggest that, at least in hair sheep breed neonates born during early spring in an arid region, factors involved in regulation of body heat losses by radiation in the first 24 h post-lambing are mainly climatic variables (Te, THI, and RH).

The RT was a factor with little contribution to explain the variations in body thermography and, consequently, the losses of radiated heat through the skin of our newborn lambs. We observed that at 12 h after birth, RT was positively correlated with body thermographic measures of all body regions. This was attributed to a decrease in the colostrum production as a previous study using Katahdin x Pelibuey lactating ewes reported a decline in the colostrum secretion at 12 h post-partum (Macías-Cruz et al., 2017). Considering that thermogenesis from brown fat is efficient within 1–5 h post-lambing, and then body heat production depends on colostrum intake (Symonds et al., 1995), a decrease in the availability of this neonatal food could lead to a lower RT, and consequently to a vasoconstriction in the peripheral blood system (lower surface temperature) to preserve body core temperature (Plush et al., 2016b). In agreement with our findings, there is also a report suggesting little relationship between radiated heat loss from skin and RT for lambs at 3–12 h after birth when were exposed to temperatures between 11 and 18 °C (outdoor) or 0 °C (cold room by 30 min) (McCoard et al., 2014). However, other study found that wool newborn lambs (4 h old) exposed to brief immersion in cold water (8–10 °C) and then to cold room conditions (4 °C for 1 h), showed a decrease in body surface temperature as the RT tended to increase (Labeur et al., 2017). The authors hypothesized that this result may have been due to a vasoconstriction in the skin as a response to the cold exposure. Both cooling strategies and the lamb breed used in this last study could explain the discrepancies between results.

According to results of the Pearson correlation analysis but not from the PC analysis, lamb BW was a factor that relatively controlled the heat radiation emitted from the skin during the first 24 h post-lambing. Notably, Pearson correlation coefficients between those variables were low ($-0.24 \leq r \leq 0.27$) at all sampling times, so implications of those results should be taken with caution. In addition, PC analysis indicated that BW was not associated with body surface temperatures during the 24-h post-lambing period. At birth, lightweight lambs tended to lose more heat across the skin from different body regions, except from head. A greater surface to body mass ratio, as well as lower amount of fat and muscle tissue under the skin may explain the higher susceptibility of low BW lambs to radiate its body heat toward the exterior (Dwyer, 2008; McCoard et al., 2017). Additionally, lightweight lambs

take more time to stand after birth, which is favorable to increase convective heat loss (Dwyer and Morgan, 2006). This could have been another fact that contributed to the presence of a negative relationship between body weight and thermography at birth, since we measured hair coat thermography at birth when the lamb was standing for first time (5–10 min after birth). Interestingly, BW was positively correlated with head temperatures at 12 h post-lambing, but not with body surface temperatures of trunk and limbs. We do not have an explanation for this finding.

On the other hand, lamb BW had a negative relationship at 24 h post-lambing with surface temperature around the stomach complex (i.e. right flank and belly). This was attributed to the fact that lightweight lambs tend to have a greater proportion of gastrointestinal tract with respect to the empty live weight in the early neonatal period (Greenwood et al., 2004). Also, to a lower skin thickness and fat coverage (McCoard et al., 2017). It has been demonstrated that the gastrointestinal tract tissue has higher growth and development than any other body tissue during the first day of birth in several domestic species including sheep, since both stomach complex and intestines must mature faster to receive and take advantage of ingested food (Xu, 1996; Blum and Hammon, 2000).

As expected, variations in body surface temperatures of neonatal lambs were highly associated with changes in climatic variables (i.e. Te, RH and THI) during the first 24 h post-lambing. It is known that environmental conditions directly influence body surface temperatures because affect the heat exchange capacity between the organism and the external environment (Macías-Cruz et al., 2016). Thus, under environmental condition of this study, Te and THI were closely associated with all recorded surface temperatures, which increased as THI changed from 51 to 79 units. This findings agree with results from other studies conducted with hair breed lambs (Paim et al., 2012; McManus et al., 2015). Therefore, this suggests that skin and hair coat temperatures in neonatal lambs depends, beside the internal body heat radiated as thermoregulation mechanism, on the heat load acquired from the environment. Remarkably, despite the positive relationship between Te and surface temperatures, the temperature gradient between Te and any surface temperature was always favorable for surface temperatures, indicating that hair sheep neonates have continued body heat loss by radiation through the skin within the first 24 h of life.

On the other hand, RH was a climatic factor that negatively affected the amount of radiated heat across the skin in hair lambs during the early postnatal period, given that the relationships between RH and body surface temperatures within 24 h post-lambing was negative. In agreement with this finding, Paim et al. (2012) reported that an increase in the environmental RH caused a decrease in body surface temperatures of lambs aged between zero and six days of life.

Results of PC analysis confirmed findings of the Pearson correlation analysis, that is, climatic variables are mainly responsible for variations in body surface temperatures of newborns lambs. So, in neonate hair sheep, body surface temperatures increase as Te and THI also increase, but those surface temperatures decrease with the increase in RH. Performing PC analysis as in the current study, Paim et al. (2012) also found a strong relationship among climatic variables and body surface temperatures in newborn lambs. In that study, CP1 and CP2 explained 70.6 and 11.1%, respectively, of the total variance, which agrees with the variance explained by PCs constructed in this study within each sampling time. Finally, it seems that thermography from entire head, eye, ear and muzzle could be the best body regions to evaluate thermoregulation of hair breed sheep neonates, since temperatures from those regions showed to be more related with climatic variables (Fig. 5).

5. Conclusions

It is concluded that, under early spring environmental conditions of an arid region (i.e. between light cold stress and thermoneutral), hair

breed lambs were losing body heat by radiation across the skin during the first 24 h after birth. Climatic variables were the main cause of the variability of body surface temperatures, and consequently, of the amount of body heat radiated through the skin in neonates. Both BW and RT had little influence across the analyzed time points, although higher birth weight lambs lost less body heat immediately after birth. Finally, thermography is a practical tool to study neonatal thermoregulation as it allows measuring body heat losses through the skin in sheep. Some regions of the head or the entire head could be good body points to measure thermography and evaluate the body heat loss in this hair breed lambs.

Conflicts of interest

The authors declared that there is not conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jtherbio.2019.04.001>.

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