**Conditions to evaluate differences among individual
sheep and goats in resilience to high heat load index**

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Abstract

Thirty-three yearling Katahdin sheep (KAT, 38.9 kg) and Boer (BOE, 28.6 kg) and Spanish goat wethers (SPA, 22.7 kg) were used to determine conditions appropriate for evaluating resilience to high heat load index (HLI). Grass hay (69% NDF and 9.5% CP) was consumed ad libitum with concentrate supplemented at 0.5% BW. Period 1 was 2 wk and periods 2-5 were each 1 wk. Target HLI for the five periods during the day/night was 70/70, 80/70, 90/76.5, 95/80.75, and 100/85, and measured HLI was 66/66, 80/75, 92/84, 97/86, and 101/89, respectively. Respiration rate increased with advancing period except from period 4 to 5 when there was a smaller decline for KAT than for BOE or SPA. Rectal temperature also increased as the experiment progressed until period 4 and was similar among animal types in period 5 when values for BOE and SPA were lower than in period 4, in contrast to similar values for KAT. Respiration rate at 13:00 and 17:00 h increased with advancing period up to a plateau at 150-155 breaths/min converse to much lower rates (i.e., 32-83) at 06:00 in periods 2-5. Respiration rate at 06:00 h differed more among days of period 5 than at 13:00 or 17:00 h, with values increasing from day 1 to 3 and thereafter generally declining from 118 to 37 breaths/min on day 7. Rectal temperature for KAT was lower than for goats early in period 5 but similar among animal types on days 6 and 7. In conclusion, a HLI in the range of 95/80.75 and 100/85 seems appropriate, periods longer than 1 wk appear necessary for full adaptation, and measures should occur during both night and day.

Key words: Goats, Sheep, Heat Load, Heat Stress

1. Introduction

In developed regions of the world, livestock production systems with well-controlled environmental conditions are common, particularly for swine, poultry, and dairy cattle. In such cases animals selected for high levels and efficiencies of production are used to achieve adequate profit, without great concern given to characteristics sometimes referred to as ‘hardiness.’ Relatedly, in some instances negative relationships have been noted between genetic potential for productivity with well-controlled environments and properties such as heat tolerance (Menéndez-Buxadera et al., 2012). However, the majority of ruminant livestock in the world are raised in production systems for which there is limited control of climatic conditions. Concomitantly, the degree of adaptation to those specific conditions is very important, although certainly production level remains a key consideration. In this regard, climate change may affect the suitability of particular livestock for specific environments.

One of the most significant and widespread environmental stress factors faced by ruminant livestock and their producers is high temperature and(or) humidity. Even in temperate regions there are frequently periods of very high heat load index (HLI), used to address combined effects of temperature, humidity, and wind. Heat stress can have a myriad of effects on ruminant livestock, including reduced ADG, milk yield, reproductive performance, and immunity (Finch, 1984; Lu, 1989; Silanikove, 2000; Sevi et al., 2001, 2002; Chedid et al., 2014). More variable climatic conditions throughout the year are expected in the future with climate change, and it is thought that some regions will experience increases in HLI and others decreases (Devendra, 2012; Silanikove and Koluman, 2015). Therefore, in addition to natural adaptation processes, selection of animals for resilience to high HLI may take on an increasing importance.

Breeds of ruminant livestock vary in tolerance to high HLI (Brown et al., 1988; Silanikove, 2000; Gaughan et al., 2010), and the same is true for animals of breeds adapted to specific environmental conditions, resulting in ‘ecotypes’ (Lee et al., 1948; Silanikove, 2000). Moreover, considerable variability exists among individuals within ecotypes and breeds (Lee et al., 1948; Finch, 1984; Gaughan et al., 2010; Menéndez-Buxadera et al., 2012). For most rapid selection progress, relationships between genetic characteristics and resilience should be identified, which would be facilitated by development of simple and standardized methods of determining resilience phenotypes. Ideally, such models would be conducive to use at different institutions and locations, allowing potential pooling of data and coupling with genetic characteristics of phenotyped animals to develop breeding programs in regards to changing and more variable expected future climatic conditions. In this regard, related research has been previously conducted to determine means of assessing the ability of individual animals to minimize energy use with limited feed intake (Goetsch et al., 2017) and conserve water with reduced availability (Mengistu et al., 2016), characteristics also thought to increase in importance with projections of future climate change. Objectives of the present experiment were to determine conditions appropriate for a method of evaluating resilience to high HLI of individual animals of one hair sheep breed and two breeds of meat goats. Conditions receiving most attention were suitable HLI for expression of physiological responses indicative of resilience such as increased respiration rate to prevent or minimize rise in core body temperature as assessed by rectal temperature, length of time at set HLI, and appropriate time(s) of measurement.

2. Materials and methods

2.1. Animals, feedstuffs, and housing

The protocol for the experiment was approved by the Langston University Animal Care and Use Committee. Thirty-three wethers were used, 11 Boer goats (BOE), 11 Spanish goats (SPA), and 11 Katahdin sheep (KAT). Average BW during the baseline period was 28.6, 38.9, and 22.7 kg (SE = 1.12) for BOE, KAT, and SPA, respectively. BOE and SPA were derived from herds of the American Institute for Goat Research of Langston University, with initial age of 541 (SE = 3.4) and 564 days (SE = 3.5), respectively. The KAT were purchased from a local farm, with a similar age as the goats based on producer comments. Before the preliminary period wethers were vaccinated against clostridial organisms and treated for internal parasites.

The experiment consisted of 2 wk for adaptation to housing conditions followed by a 2-wk period to determine baseline or thermoneutral zone measures and then 4 wk with weekly stepwise increases in HLI. Wethers were housed individually in 1.05 × 0.55 m elevated pens with a plastic-coated expanded metal floor in one room. A moderate quality grass hay was fed free-choice at 120% of consumption on the preceding few days, along with 0.5% BW (DM) of concentrate that consisted of 80% ground corn and 20% soybean meal. Hay was given at 08:00 h after refusals had been collected and weighed. Concentrate was fed at 10:00 h in a bucket placed in the large plastic barrel containing hay and was completely consumed within a few minutes. Based on visual appearance before harvest, hay consisted primarily of equal quantities of Johnsongrass (*Sorghum halepense*) and bermudagrass (*Cynodon dactylon*) and was coarsely ground through a 3.8-cm screen. Feedstuffs were sampled daily following the preliminary period to form weekly composite samples, which were analyzed for DM, ash, (AOAC, 2006), CP (Leco TruMac CN, St. Joseph, MI), NDF with use of heat stable amylase and containing

residual ash, ADF, and ADL (hay only) (filter bag technique of ANKOM Technology Corp., Fairport, NY, USA). A small amount (8-10 g/day; as fed basis) of a mixture of 95% soybean meal and 5% of a trace mineral premix (275 mg/kg Co, 2,000 mg/kg I, 43,746 mg/kg Fe, 750 mg/kg Se, 18,748 mg/kg Cu, 68,744 mg/kg Zn, and 19,998 mg/kg Mn) was top-dressed on hay. Also, each wether had free access to a small trace mineralized salt block (NaCl: 96.5-99.5%; Zn: 4,000 ppm; Fe: 1,600 ppm; Mn: 1,200 ppm; Cu: 260-390 ppm; I: 100 ppm; and Co: 40 ppm) in the bottom of each feeder.

2.2. Experimental periods

HLI was estimated as proposed by Gaughan et al. (2010) for temperatures above 25° C: $HLI = 8.62 + (0.38 \times RH) + (1.55 \times BG) - (0.5 \times WS) + e^{(2.4 - WS)}$, with BG = black globe temperature (° C), RH = relative humidity (%), WS = wind speed (m/s; assumed zero), and e = base of the natural logarithm. In addition to the measurement of temperature inside the 15-cm diameter black globe, there were four temperature and humidity monitors (Hobo® Temperature/RH Data Logger, model number U12-011; Onset Computer Corp., Bourne, MA, USA) present at different locations in the room. The temperature-humidity index (THI) of Amundson et al. (2006; $(0.8 \times ^\circ C) + (RH / 100) \times (^\circ C - 14.4) + 46.4$) was calculated as well, which is nearly the same as that of Salama et al. (2014), with a correlation coefficient of 0.99996 ($P < 0.001$). The correlation coefficient between the THI and HLI was 0.970 ($P < 0.001$). The experiment occurred in the late fall before temperatures became very low, which allowed condition control by adjustments of heating and humidifying units.

Target HLI were 70, 80, 90, 95, and 100 during daytime (07:00 to 19:00 h) and 70, 70, 76.5, 80.75, and 85 during nighttime (19:00 to 07:00 h) in periods 1 (baseline), 2, 3, 4, and 5, which are also referred to as target HLI of 70/70, 80/70, 90/76.5, 95/80.75, and 100/85,

respectively. For periods 3 to 5, target HLI at night were 85% of that during the day. Actual values are in Table 1 and averaged 66, 80, 92, 97, and 101 during the day and 66, 75, 84, 86, and 89 at night in periods 1, 2, 3, 4, and 5, respectively. After period 5, thermoneutral zone conditions were maintained during days and nights for 1 wk.

2.3. Measures

At the beginning of the experiment, fiber in a 10 × 10 cm mid-side patch was clipped close to the skin using Oster clippers (McMinnville, TN, USA) fitted with a size 40 blade. The same area was clipped at the end of the study. Whole body fiber was calculated based on a surface area equation for Merino sheep, where surface area (m²) = 0.094 × kg BW^{0.67} (Bennett, 1973) and assuming 90% of the surface area to be fiber-producing. Clean and greasy fiber mass values were determined according to ASTM (1988) standards.

Intake of DM (DMI) was measured daily and BW was determined at the end of periods at 13:00 h, which includes both wk 1 and 2 of period 1 (i.e., baseline). BW was also determined on two other days each week, although these data are not presented. Respiration rate and rectal temperature were determined at the end of the weeks at 06:00, 13:00, and 17:00 h. In addition, in period 5 these measures occurred each day. Blood was collected via jugular venipuncture on the last day of the week once at 07:00 h into tubes with and without heparin and placed in ice. Packed cell volume (PCV) was determined with heparinized tubes (Clay Adams, Parsipany, NJ, USA).

2.5. Statistical analyses

Data were analyzed by mixed effects models with SAS (2004). Fiber mass at the beginning and end of the experiment was analyzed with a model consisting only of animal type. Other variables with one or more repeated measure were analyzed as split-plots. For BW, DMI,

and PCV, the model consisted of animal type, target HLI or period, and their interaction, with HLI as a repeated measure. Animal within animal type was random and the error term for testing the effect of animal type. When an interaction was significant ($P < 0.05$), interaction means are presented in a table or figure. Analyses for respiration rate and rectal temperature were the same except for including the sub-subplot term of hour of the day of measurement. Analyses for respiration rate and rectal temperature during the highest HLI conditions were similar to those described above, but with repeated measures of day and time of the day, along with 70/70 HLI values as covariates.

3. Results

3.1. *HLI conditions and feedstuff composition*

Daytime HLI was fairly close to targets in each period (Table 1). HLI during the evening was slightly above targets except in period 1 when it was a little less than 70. Concentrations of chemical constituents in weekly composite samples of hay and concentrate did not markedly differ (Table 2). The concentration of NDF in hay ranged from 67.6 to 70.2% and low and high CP concentrations were 8.5 and 10.7%, respectively.

3.2. *HLI treatments and periods*

3.2.1. *BW, fiber, DMI, and PCV*

BW ranked ($P < 0.001$) $KAT > BOE > SPA$ (Table 3). There were differences ($P < 0.05$) in BW among periods or HLI, although magnitudes were small. Fiber mass was greatest among animal types for KAT ($P < 0.005$). Greasy fiber mass was 259, 1118, and 273 g ($SE = 82.3$) at the beginning of the experiment and 337, 1,388, and 343 g at the end for BOE, KAT, and SPA, respectively ($SE = 85.2$). Clean fiber mass was 215, 713, and 213 g ($SE = 52.3$) at the beginning

of the experiment and 269, 863, and 259 g at the end for BOE, KAT, and SPA, respectively (SE = 54.1).

There were interactions between animal type and HLI in total ($P = 0.026$) and hay DMI ($P = 0.023$; Table 3). The interactions were due to a greater rate of decline for KAT from period 1 to 3 and a greater rate of increase from period 3 to 5 compared with BOE and SPA. Hay DMI was more similar between BOE and SPA in periods 1 and 2 than in other periods, especially period 3. Basing the amount of supplemental concentrate on BW resulted in very similar total DMI between BOE and SPA in periods 1, 2, 4, and 5. Total DMI relative to BW was affected ($P \leq 0.003$) by animal type (1.69, 2.03, and 2.22%BW for BOE, KAT, and SPA, respectively; SE = 0.101) and period (2.33, 2.10, 1.68, 1.81, and 1.98% BW in periods 1-5, respectively; SE = 0.066). There was an interaction ($P = 0.035$) between animal type and period in PCV. Values were greater for KAT vs. BOE and SPA. There were relatively small differences among periods that varied slightly among animal types. Means were less for SPA than for BOE in period 1 but greater for SPA in periods 3 and 5.

3.2.2. *Respiration rate and rectal temperature*

Each two-way interaction (animal type $\times$ HLI period, hour $\times$ period, and animal type $\times$ hour) was significant ($P < 0.001$) for respiration rate and rectal temperature (Table 3). Respiration rate increased for each animal type with advancing period and target HLI except for change from period 4 to 5. Values were very similar between KAT and SPA except in periods 4 and 5 when they were slightly greater for KAT. The increase from period 1 to 2 was much less for BOE than for KAT and SPA, so that values in period 2 were lowest for BOE. For each animal type respiration rate decreased from period 4 to 5, but change was slightly less for KAT than for BOE. The animal type $\times$ period interaction in rectal temperature was partially because

the value for KAT in period 1 was highest among animal types and increased less from period 1 to periods 2 and 3 compared with SPA and BOE. Values for each animal type peaked in period 4, decreasing for BOE and SPA from period 4 to 5 and remaining constant for KAT, resulting in similar values among animal types in period 5.

The interaction in respiration rate between measurement time and period was because of a very similar pattern of change with advancing period for times of 13:00 and 17:00 h as opposed to a very different pattern for 06:00 h (Table 3). Values for 13:00 and 17:00 h rose to a plateau in periods 4 and 5. Respiration rate measured at 06:00 h increased and decreased sequentially with each advancing period, being lower than at the other times except in period 1 with thermoneutral conditions. The interaction in rectal temperature between target HLI and measurement time displays how differences between values early in the morning are lower than in the afternoon even with thermoneutral conditions at night, but with differences generally increasing as period and target HLI increase. However, values at 13:00 h were slightly less than those at 17:00 h in periods 3, 4, and 5. The primary factor responsible for the animal type $\times$ time of measurement interaction in respiration rate was the KAT > SPA > BOE ranking at 06:00 h and more similar values at other times. The interaction in rectal temperature was because of a relatively low value for KAT at 17:00 h and more similar values among animal types with measures at 06:00 and 13:00 h. However, rectal temperature increased slightly from 13:00 to 17:00 h for BOE and SPA but was similar between times for KAT. Both respiration rate and rectal temperature at 13:00 and 17:00 h were much greater than at 06:00 h.

3.3. *Period 5 and target HLI of 100/85*

There were interactions ($P < 0.001$) in respiration rate between sampling time and animal type (52, 108, and 74 at 06:00 h, 153, 156, and 156 at 13:00 h, and 157, 157, and 158

breaths/min at 17:00 h for BOE, KAT, and SPA, respectively; SE = 3.9) and day of period 5 (Figure 1), but not between animal type and day ($P = 0.662$) as opposed to rectal temperature. For the former interaction, the value at 06:00 h ranked BOE < SPA < KAT but values were similar among animal types at 13:00 and 17:00 h. For the second interaction, the pattern of change with advancing day was much different when measured at 06:00 h than at 13:00 or 17:00 h; the latter values were fairly consistent among days. Conversely, 06:00-h means increased from day 1 to 3, declined to day 5 at a similar rate as the earlier increase, and were fairly steady thereafter.

Each two-way interaction in rectal temperature was significant ($P < 0.01$). The animal type $\times$ day interaction was largely because of lower values for KAT on day 1, 2, 3, and 4 and similar values among animal types thereafter (Figure 2). The interaction between animal type and measurement time primarily related to a lower value for KAT vs. BOE and SPA at 17:00 h and similar values among animal types at 06:00 and 13:00 h (39.17, 39.25, and 39.39 at 06:00 h, 40.15, 40.03, and 40.19 at 13:00 h, and 40.64, 40.23, and 40.65° C at 17:00 h for BOE, KAT, and SPA, respectively; SE = 0.099). The interaction between day and time involved greater differences among 06:00-h values on days 1, 2, 3, 4, and 5 compared with measurement at 13:00 and 17:00 h and more similar values between 06:00 h and the other times on days 2, 3, and 4 compared with days 1, 5, 6, and 7 (Figure 3).

4. Discussion

4.1. HLI treatments and periods

4.1.1. BW, DMI, and PCV

Periods longer than 1 wk would be necessary to derive value from BW as an indicator of resilience to high HLI, in accordance with findings of Mengistu et al. (2016) in regards to

restricted drinking water availability. However, even with periods 1 wk in length, DMI results were unexpected. Most often heat stress decreases voluntary feed intake by ruminants (Finch, 1984; Lu, 1989; Silanikove, 2000; Chedid et al., 2014; Salama et al., 2014; Sunagawa et al. 2015; Todaro et al., 2015), as occurred in the first few periods of the present experiment to extents varying among animal types. Change in DMI from periods 1 to 2 suggests greater susceptibility of KAT to increasing HLI than of BOE or SPA. However, all animal types appeared to undergo adaptation in physiological processes that allowed DMI to increase from period 3 to 5, most evident for KAT despite rising HLI. This may infer that the pattern of change in DMI as HLI increased would have differed with periods longer than 1 wk. Though the diurnal pattern in feed consumption was not characterized, it is possible and perhaps likely that a shift occurred from daytime to the night as HLI increased (Finch, 1984; Silanikove, 2000; Chedid et al., 2014). Reasons for lower DMI relative to BW for BOE than for SPA are unclear, although similar findings occurred with these and a few additional wethers in the previous experiment of Mengistu et al. (2016). This difference would not appear indicative of a response of BOE to minimize heat production, since DMI relative to BW was lower than for SPA in period 1 as well as later.

Much greater PCV for KAT than for BOE and SPA was also observed by Mengistu et al. (2016), and Burke et al. (2007) noted greater PCV in sheep than goats as well. Slight decreases in PCV with increasing HLI as period advanced for KAT and BOE presumably relates to unrestricted water intake, with heat stress increasing water consumption and degree of hydration (Finch, 1984; Silanikove, 2000; Marai et al., 2007; Chedid et al., 2014; Salama et al., 2014; Kaliber et al., 2016), although why there was relatively little change for SPA is unclear.

4.1.2. *Respiration rate and rectal temperature*

Comparisons of animal types in this experiment are of importance primarily in regards to the study of conditions most appropriate to evaluate differences among individual animals within animal type in resilience to the climate-related stress factor of high HLI. Nonetheless, one factor to consider that may have resulted in lower rectal temperature for KAT than for BOE and SPA in periods 3 and 5 is lower surface area relative to BW of KAT (McDowell et al., 1953; Finch, 1984), minimizing potential gain of heat through convection when temperature was near or above that of the body. Conversely, a high surface area to BW ratio with lower HLI should be advantageous for heat dissipation via cutaneous evaporation as well as possibly convection and conduction (Finch, 1984; Silanikove, 2000).

It may be somewhat surprising that even the increase in HLI from period 1 to 2 elicited substantial increases in respiration rate. However, Hamzaoui et al. (2013) reported an increase in respiration rate of 48 breaths/min by exposing dairy goats to climatic chambers with THI of 77 to 85 after THI of 60 to 65. The magnitude of increase in respiration rate from period 1 to 2 of the present experiment was considerably lower for BOE than for the other two animal types perhaps reflecting low DMI relative to BW of BOE, although less change for KAT and SPA from period 2 to 3 was compensatory.

Determining contributions of respiration and sweating to heat dissipation was beyond the scope of objectives of this study. Nonetheless, with water available free-choice, cutaneous evaporation would be greater than with limited water intake (Chedid et al., 2014). Respiration rate and rectal temperature in periods 4 and 5 may suggest that sweating was relatively more important in period 5 with highest HLI conditions. Although, other factors such as the possibility of more nighttime eating in period 5 than 4 could have been involved as well. In

regards to sweating, although comparisons between hair sheep and goats and BOE and SPA are not available, because of differences in fiber mass there may have been greater potential for heat dissipation through sweating by BOE and SPA vs. KAT. Relatedly, hair sheep breeds are more well suited for heat stress conditions than are wool sheep in part because of greater potential for heat loss from sweating (McManus et al., 2009). Moreover, fewer secondary hair follicles and cashmere fiber for BOE vs. SPA, as addressed by Patra et al. (2009), also imply greater potential for sweating by BOE. Regardless, it would appear that conditions in periods 4 and 5 that resulted in substantial need for heat dissipation without causing excessive stress would be appropriate for ranking resilience of individuals of these animal types to high HLI conditions.

Nighttime dissipation of body heat built up during daytime with relatively high HLI is crucial, and contributions to heat stress of periods with high nighttime HLI can be just as important as the level to which HLI rises during daytime (Lu, 1989; Silanikove, 2000; Al-Tamimi, 2007; Chedid et al., 2014; Sunagawa et al., 2015). Interactions between animal type and measurement time in respiration rate, rectal temperature, and their ratio infer that KAT expended relatively more energy for heat dissipation during the night compared with goats, which again could involve differences in sweating, and it appears that SPA also used more energy in respiration at night to dissipate heat than did BOE. However, for KAT this may be a bit surprising since rectal temperature was lower than for BOE and SPA at 17:00 h, although the lower surface area to BW ratio for KAT could have restricted heat gain by convection during daytime.

The similar respiration rate at 13:00 and 17:00 h in each period suggests that any time during the latter half of the daytime would be acceptable for assessing individual animal resilience to high HLI. No explanation is apparent for the pattern of change in respiration rate

measured at 06:00 h with advancing period and increasing HLI. Lower morning than afternoon rectal temperature is typically seen with moderate to high HLI, and smaller or no differences occur with milder conditions (Goetsch and Johnson, 1999). However, rectal temperature in the present experiment was less in the morning than afternoon in periods 1 and 2 in addition to the larger magnitudes of difference in periods 3, 4, and 5. In contrast to respiration rate, the specific time of measurement in the afternoon did have minor impact on rectal temperature. The similar decrease in rectal temperature from period 4 to 5 at each measurement time, respiration rate at 13:00 and 17:00 h that was similar between these periods, and respiration rate at 06:00 h lower than at other times in period 5 reflect the appreciable importance of heat dissipation at night regardless of changes in sources of heat being gained and modes of dissipation.

Reasons why respiration rate peaked in period 4 and then declined slightly in period 5 are unknown, apart from reflecting adaptation in various physiological conditions. Differences in respiration rate between periods 4 and 5 seemed to be because of lower values at 06:00 vs. 13:00 and 17:00 h in period 5 noted on days 5, 6, and 7; these differences corresponded closely to ones in rectal temperature. Thus, measurements during the night or early morning when HLI is lower than during daytime appear desirable and related to high HLI resilience.

4.2. Period 5 and target HLI of 100/85

The animal type $\times$ measurement time interaction in respiration rate agrees with the aforementioned importance of a measure at night when HLI is relatively low to fully characterize physiological conditions and, again, that one measurement time during the latter half of the 12-h daytime period would suffice for respiration rate. It is also notable that the difference in respiration rate at 06:00 h between BOE vs. KAT and SPA was much greater than noted earlier with period data.

The interaction in respiration rate between day of period 5 and measurement time also supports nighttime measurement, as there was much greater change at 06:00 h with advancing day compared with fairly constant values among days at 13:00 and 17:00 h. The values for 06:00 h show that changes in physiological conditions occurred until day 5, with relatively little change thereafter. Hence, it would appear that an adaptation period of at least 5 days is needed to reach steady state conditions. In contrast, two-way interactions in rectal temperature of day $\times$ animal type and day $\times$ time of measurement imply that a longer adaptation period such as 1 wk or more is desirable since values were fairly similar between days 5 and 6 but decreased from day 6 to 7. The animal type $\times$ day interaction suggests that greater capacity of or need for KAT vs. BOE and SPA to minimize rectal temperature by a high respiration rate waned in the latter days of period 5 when rectal temperature was similar among animal types. Thus, differences among animal types, and one would presume among ecotypes and individuals within ecotypes and breeds, may vary among the specific target HLI conditions selected. Hence, at least one high HLI regime, and perhaps one or more with lower and more moderate conditions, should be considered to fully address HLI resilience as would be encountered in normal production settings.

The interaction in rectal temperature between animal type and measurement time was fairly similar in nature to that for each period and target HLI. That is, lower rectal temperature for KAT than for BOE and SPA appeared due to the late-afternoon measurement time. It is interesting that rectal temperature for KAT was lower at 17:00 h compared with BOE and SPA and similar at other times, yet it was at 06:00 h when respiration rate was greatest among animal types for KAT. Such findings seem to encourage use of a nighttime HLI lower than during the day, typical in most practical production settings, rather than constant HLI conditions throughout

all 24 h of days. Use of a target nighttime HLI 85% of that during the day in latter periods was to simulate conditions in many areas of the world where small ruminants are produced and is similar to that used by Hamzaoui et al. (2013).

Differences among breeds of cattle in heat tolerance are due more to variation in potential for heat dissipation such as peripheral tissue vasodilation rather than basal metabolic rate (Finch, 1984). Nonetheless, this does not preclude some impact of the latter factor in the present experiment with hair sheep and meat goats. Decreased DMI with high HLI will contribute to decreased heat production, but increasing DMI from period 3 to 5 is not supportive of appreciable effect of feed intake primarily on splanchnic heat production. Though other factors including less sweating by KAT could have contributed to the greater magnitude of change in rectal temperature of BOE and SPA than KAT as day of period 5 advanced, greater change in basal metabolic rate of goats could be involved in light of the nonsignificant interaction in respiration rate between animal type and day. This is also in line with no change in rectal temperature for KAT from period 4 to 5 in contrast to decreases for BOE and SPA and decreased respiration rate for each animal type, resulting in a greater ratio of respiration rate to rectal temperature for KAT in both periods 4 and 5. It is doubtful that the contribution of splanchnic tissue metabolism could have been important to decreasing basal metabolic rate given the changes in DMI, but extra-splanchnic tissues usually account for a comparable proportion of whole body heat production (Goetsch, 1998a,b). In this regard, Asmare et al. (2011, 2012) found evidence that Rambouillet sheep were less able to decrease extra-splanchnic tissue heat energy with low energy and protein intake conditions than were Boer and Spanish goats. It is presumed that differences in the magnitude of decline in peripheral tissue protein turnover were primarily

responsible, but it is unclear if high HLI in the present experiment might elicit comparable change.

5. Conclusions

BW was not useful as an indicator of resilience to high HLI with the 1-wk periods, which was also true for DMI. A HLI in the range of targets of 95/80.75 and 100/85 seems appropriate as a relatively high level to evaluate differences among individuals of each of these animal types in resilience, although inclusion of one or more lower HLI regimes could be considered as well. An adaptation period to the highest HLI conditions of 5 days was adequate for respiration rate, although this could be influenced by the relatively small magnitudes of stepwise increases in HLI of this experiment. However, with this regime 1 wk or more was required for adaptation of physiological conditions to achieve stable rectal temperature. There were considerable differences in variables measured at 06:00 h compared with 13:00 or 17:00 h, and change with advancing day of the week at the highest HLI in some cases differed among times. There were some but relatively small differences between measures at 13:00 and 17:00 h. Overall, to adequately characterize resilience responses to elevated HLI there should be at least one measurement time during the nighttime when HLI is relatively low and a minimum of one time in the latter part of the daytime period with high HLI.

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Table 1

Average temperature, relative humidity, heat load index, and temperature-humidity index during the different heat load index periods

Time	Item	Period				
		1	2	3	4	5
Day	Temperature (° C)	19.9 ± 0.41	32.4 ± 1.18	38.9 ± 0.84	39.3 ± 0.69	42.0 ± 0.42
	Relative humidity (%)	41.7 ± 2.88	25.3 ± 1.13	32.7 ± 2.59	42.9 ± 2.20	41.9 ± 1.15
	Heat load index	66.3 ± 0.95	79.5 ± 1.66	92.4 ± 0.65	96.9 ± 1.11	100.7 ± 0.66
	Temperature-humidity index	64.5 ± 0.44	76.8 ± 1.19	85.5 ± 0.54	88.6 ± 0.81	91.6 ± 0.51
Night	Temperature (° C)	20.0 ± 0.50	29.2 ± 0.95	31.4 ± 1.13	29.6 ± 0.77	29.9 ± 0.85
	Relative humidity (%)	39.5 ± 3.07	25.8 ± 1.70	41.7 ± 2.70	53.7 ± 2.91	60.0 ± 3.96
	Heat load index	65.6 ± 1.13	74.7 ± 1.48	84.1 ± 0.93	85.9 ± 0.50	88.8 ± 1.65
	Temperature-humidity index	64.5 ± 0.56	73.5 ± 0.97	78.4 ± 0.90	78.1 ± 0.61	79.6 ± 1.16

¹Target heat load index values were 70/70, 80/70, 90/76.5, 95/80.75, and 100/85 during the day/night in periods 1, 2, 3, 4, and 5, respectively; mean ± SE.

Table 2

Chemical composition of feedstuffs

Sample	Period and week	Concentration (% DM)				
		Ash	NDF	CP	ADF	ADL
Hay	Period 1, week 1	8.3	67.6	8.7	41.3	7.5
	Period 1, week 2	9.1	69.7	10.7	38.3	7.3
	Period 2	9.2	70.2	9.5	38.5	6.4
	Period 3	8.5	69.4	8.5	42.5	7.5
	Period 4	9.4	68.0	9.8	38.8	6.9
	Period 5	8.0	69.5	9.9	39.3	7.1
Concentrate	Period 1, week 1	3.6	16.8	17.1	5.7	
	Period 1, week 2	3.6	17.2	16.6	5.6	
	Period 2	3.1	17.7	15.5	5.3	
	Period 3	2.9	17.6	15.3	5.0	
	Period 4	3.2	15.9	16.8	5.7	
	Period 5	2.8	16.2	15.8	5.0	

¹Target heat load index values were 70/70, 80/70, 90/76.5, 95/80.75, and 100/85 during the day/night in periods 1, 2, 3, 4, and 5, respectively.

Table 3

Effects of animal type, heat load index, and(or) measurement time on BW, DM intake, packed cell volume, respiration rate, and rectal temperature at the end of periods¹

Item ⁵	Interactions ^{2,3}		Animal type ³				Period ⁴					SE
	AT	Hour	BOE	KAT	SPA	SE	1	2	3	4	5	
BW (kg)			28.5 ^b	38.7 ^c	23.4 ^a	1.13	30.1 ^{ab}	30.0 ^{ab}	29.8 ^a	30.8 ^c	30.3 ^{bc}	0.67
DM intake (g/day)												
Hay	BOE						582	533	395	461	490	45.1
	KAT						940	796	666	726	799	
	SPA						590	563	455	499	516	
Concentrate			128 ^b	173 ^c	101 ^a	4.7	134	134	134	133	134	2.8
Total	BOE						453	403	266	337	363	42.6
	KAT						767	624	493	553	627	
	SPA						490	402	354	398	416	
PCV (%)	BOE						23.5	23.2	22.3	22.8	20.8	0.90
	KAT						29.5	28.9	28.2	28.7	28.5	
	SPA						22.4	23.5	23.6	23.3	23.1	
RR (breaths/min)	BOE						18	71	93	121	105	4.2
	KAT						25	104	101	139	126	
	SPA						22	105	104	129	109	
		06:00	31	105	109	3.6	20	71	32	83	38	3.5
		13:00	66	115	16		24	100	131	150	151	
		17:00	48	113	120		32	110	136	155	151	
RT (° C)	BOE						38.44	39.16	39.42	39.89	39.48	0.065
	KAT						38.86	39.14	39.18	39.62	39.55	
	SPA						38.55	39.37	39.57	40.00	39.62	
		06:00	38.52	39.50	39.82	0.056	38.15	38.88	38.55	39.04	38.65	0.056
		13:00	38.77	39.51	39.53		38.84	39.39	39.65	40.06	39.81	
		17:00	38.67	39.65	39.95		38.85	39.41	39.97	40.41	40.19	

¹Main effect means are presented when interactions was not significant (P > 0.05).

²AT = animal type.

³BOE = Boer goat wethers; KAT = Katahdin sheep wethers; SPA = Spanish goat wethers.

⁴Target heat load index values were 70/70, 80/70, 90/76.5, 95/80.75, and 100/85 during the day/night in periods 1, 2, 3, 4, and 5, respectively.

⁵PCV = packed cell volume; RR = respiration rate; RT = rectal temperature.

^{a,b,c}Main effect means without a common superscript letter differ (P < 0.05).

Figure 1. Respiration rate at 06:00, 13:00, and 17:00 h on the 7 days of period 5 with the target heat load index of 100 during daytime and 85 at night.

Figure 2. Rectal temperature of Boer goat, Katahdin sheep, and Spanish goat wethers on the 7 days of period 5 with the target heat load index of 100 during daytime and 85 at night.

Figure 3. Rectal temperature at 06:00, 13:00, and 17:00 h on the 7 days of period 5 with the target heat load index of 100 during daytime and 85 at night.

Figure
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