Comparison of different levels and lengths of restricted drinking water availability and measurement times with Katahdin sheep and Boer and Spanish goat wethers

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Abstract

Thirty-six yearling Boer goat (BOE), Katahdin sheep (KAT), and Spanish goat wethers (SPA) were used to study conditions for evaluating resilience to restricted drinking water availability. Moderate quality grass hay was consumed ad libitum with concentrate (80% corn, 20% soybean meal) supplemented at 0.5% BW. Baseline conditions were determined in the last 2 wk of a 3-wk period (i.e., 100% level). Thereafter, water availability was decreased by 10% every 1 (1X) or 2 wk (2X) to 40% of baseline intake (i.e., 90, 80, 70, 60, 50, and 40% levels), but also with 2 wk at 40% for the 1X restriction treatment. There was an interaction ($P < 0.001$) between animal type (AT) and restriction level in hay DM intake, with values of 346, 360, 358, 276, 286, 235, and 176 g/day for BOE, 656, 592, 592, 469, 522, 407, and 307 g/day for KAT, and 392, 390, 368, 273, 298, 298, and 219 g/day for SPA at levels of 100, 90, 80, 70, 60, 50, and 40%, respectively (SE = 29.1). Moreover, hay DM intake by 2X wethers was much lower in wk 2 vs. 1 at the 40% level (week $\times$ level interaction, $P = 0.008$; 409, 369, 345, 377, 336, and 276 g/day in wk 1 and 428, 398, 312, 352, 310, and 203 g/day in wk 2 at 90, 80, 70, 60, 50, and 40% levels, respectively; SE = 23.4). Restriction level affected ($P < 0.001$) plasma cortisol concentration in 2X wethers on the last day at each level (12.4, 14.0, 23.3, 26.4, and 32.6 nmol/L for 100, 70, 60, 50, and 40% levels, respectively; SE = 3.62). Plasma vasopressin concentration in 2X wethers at the end of each week at 60, 50, and 40% levels was affected by an interaction ($P = 0.006$) between week and level (3.98, 5.61, and 7.84 for wk 1 and 6.40, 7.22, and 7.06 pmol/L for wk 2, respectively; SE = 0.564). In conclusion, there was some indication that DM intake by KAT was more subject to adverse effects of very low water availability but not mild restriction compared with goats. Based on vasopressin concentration, a length of at least 2 wk rather than 1 with a set level(s) of restricted water availability seems desirable, which might also increase

meaningfulness of measures such as BW. Results for DM intake and cortisol concentration suggest appropriateness of a maximum restriction level of 50%.

Key words: Goats, Sheep, Water

1. Introduction

There is a general consensus that with the current rate of climate change, rainfall will decrease in some areas of the world (Devendra, 2012; Naqvi et al., 2015; Silanikove and Koluman, 2015). With limited drinking water availability, ruminant livestock production will become increasingly challenging. Moreover, even now each year there are some areas where water resources are low, which also affects availability of feed supplies. To cope with these shifting conditions, one of the first decisions that must be made is the species to be produced. In this regard, sheep and goats are more tolerant to adverse environmental conditions than cattle, including restricted drinking water availability and heat stress (Luow, 1984; Silanikove, 2000; Silanikove and Koluman, 2015). The next consideration would in most cases be breed or breeding program. Furthermore, the genetic makeup of animals also is impacted by environmental and ecological conditions causing adaptation into ecotypes, and differences among individuals of the same breed and ecotype exist as well. Therefore, in order to develop most efficient means of selecting small ruminants for high levels and(or) efficiencies of production for specific environments, relationships between genetic and most important and informative physiological characteristics should be determined considering different breeds, ecotypes, individuals, and hopefully populations from various relevant regions of the world.

Effects of water restriction have been studied in a number of ways, some of which are too expensive or laborious for use at a wide range of institutions (Luow, 1984). Thus, this study

focused on relatively simple methods not requiring a great deal of equipment and appropriate for large numbers of animals, with most important measures of DM intake, BW, and plasma osmolality. Some other variables were assessed as well to aid in determining most appropriate experimental conditions, such as plasma hormone concentrations. Even though infrequent watering regimes, most commonly every 2, 3, or 4 days, may continue to be important in production systems in some arid areas of the world, it was felt that restricted levels of water availability each day would be more widely applicable to limited drinking water supplies expected in the future and presumably also applicable to intermittent water access. One of the primary conditions addressed in the present experiment was level of restriction, with interest in identifying one(s) great enough to allow expression of differences in resilience but not imposing excessive stress in the experimental setting. Also, length of time on different levels of restriction was considered so that total study length could be minimized. Hence, the primary objective was to study appropriate conditions to evaluate differences among individual sheep and goats of two breeds in resilience to restricted drinking water availability, and a secondary objective was to compare sheep and two breeds of meat goats.

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. Thirteen Boer goat wethers (BOE), 11 Katahdin sheep wethers (KAT), and 12 Spanish goat wethers (SPA) were used. Average BW during the baseline period was 26.9, 33.6, and 20.5 kg (SE = 0.90) for BOE, KAT, and SPA, respectively. Initial age was 353 (SE = 3.3) and 372 days (SE = 3.4) for BOE and SPA, respectively, derived from herds of the

American Institute for Goat Research of Langston University. The KAT were purchased from a local farm, with a similar age as the goats based on producer comments.

The experiment consisted of a 4-wk preliminary period for adaptation to housing conditions followed by a 3-wk period to determine baseline or unrestricted water consumption by each wether. Thereafter, there were water restriction and realimentation periods. At most times wethers were housed individually in 1.05×0.55 m elevated pens with a plastic-coated expanded metal floor. 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 experimental area.

The Baseline period began on May 16, 2014. Restriction periods began on June 6 and ended on July 24 and August 28. The 2-wk Realimentation periods ended on August 7 and September 11. Thus, the experiment occurred in the late spring and summer. Mean, SE, minimum, and maximum hourly values in the experimental area were 79.9, 0.20, 61.3, and 93.3° C for temperature, 68.0, 0.22, 47.6, and 89.0% relative humidity, and 75.7, 0.15, 60.6, and 86.3 temperature-humidity index (THI; Amundson et al., 2006) [$(0.8 \times \text{temperature}) + (\text{relatively humidity} \times ((\text{temperature} - 14.3) / 100)) + 46.3$]. Moreover, Table 1 includes the mean, SE, minimum, and maximum daily averages during the three periods for temperature, humidity, THI, and daylength.

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 (Table 2). 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 larger tub containing hay and was completely consumed within a few minutes. Based on visual appearance

before harvest, the 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), nitrogen (Leco TruMac CN, St. Joseph, MI, USA), NDF with use of heat stable amylase and containing residual ash, ADF, and ADL (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. Preliminary period

A few months before the experiment, wethers were vaccinated against clostridial organisms with Covexin 8[®] (Schering-Plough Animal Health Corp., Omaha, NE, USA). At the beginning of the period wethers were orally treated for internal parasite with levamisole (Prohibit[®]; AgriLabs, St. Joseph, MO, USA) at 8 and 12 mg/kg for KAT and goats, moxidectin (Cydectin[®]; Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO, USA) at 0.5 mg/kg, and albendazole (Valbazen[®]; Pfizer Animal Health, New York, NY, USA) at 10 mg/kg. Albendazole treatment was repeated 24 h later. After 14 days fecal egg count for all KAT was 0, but means for BOE and SPA were 1,539 (SE = 258.2; minimum = 150; maximum = 5,550) and 2,067 (SE = 268.8; minimum=200; maximum=6,600). Therefore, treatments with levamisole and Cydectin[®] were repeated, along with six sequential doses of Valbazen[®] each 12 h apart. This

reduced fecal egg count 14 days later to 392 for BOE (SE = 258.2; minimum = 150; maximum = 1,150) and 796 for SPA (SE = 268.8; minimum=50; maximum=2,050). KAT wethers were sheared a few weeks before the experiment began. All wethers were weighed at the beginning and end of the preliminary period by an animal scale with 50-g increments. Fresh water was offered free-choice after hay was fed at 08:00 h in plastic buckets at approximately 120% of consumption on the previous few days. Electrical conductivity, measured weekly with a Traceable[®] Salinity Meter (Fisher Science Education, Pittsburgh, PA, USA), was 0.903 dS/m (SE = 0.0209).

2.3. Baseline period

Water was offered as in the preliminary period. The average of daily water intake for each wether in wk 2 and 3 was used as baseline or unrestricted intake (i.e., offering level of 100%) to determine later restricted amounts. Wethers were weighed at 13:00 h on each Monday, Wednesday, and Friday, with weeks starting on Friday. Thus, weighing intervals were 3, 2, and 2 days.

On the last day of wk 2 and 3 at 07:00 and 13:00 h, blood was collected by jugular venipuncture into tubes with and without heparin and placed in ice. Immediately after sampling, hemoglobin concentration and oxygen saturation were determined in heparinized blood with a OSM 3 Hemoximeter[™] (Radiometer, Westlake, OH, USA). Oxygen was calculated as described by Eisemann and Nienaber (1990). Packed cell volume (PCV) was determined with heparinized tubes (Clay Adams, Parsipany, NJ, USA). Plasma and serum were harvested by centrifugation at $3,000 \times g$ for 20 min. Plasma was used to determine osmolality with a Model 2020 Osmometer (Advanced Instruments, Inc., Norwood, MA, USA). Serum samples taken at

13:00 h were analyzed for cortisol, vasopressin, and aldosterone by ELISA[®] kits of Enzo Life Sciences (Farmingdale, NY, USA).

2.4. Restriction period

There were two restriction treatments that wethers had been previously randomly assigned within animal type. Water availability was decreased by 10% every 1 (1X) or 2 wk (2X) to 40%, but also with 2 wk at the 40% level for 1X. Hence, length of the period was 7 wk for 1X and 12 wk for 2X. There were seven and six BOE, six and five KAT, and six and six SPA on 2X and 1X treatments, respectively. Water was offered once daily at 07:00 h as before, and measures during the baseline period continued in each week. Blood samples collected at 13:00 h and at restriction levels of 70, 60, 50, and 40% were analyzed for hormones. One BOE on the 2X treatment was changed to the realimentation period in the 11th week because BW had declined by 26% of that during the baseline period, exceeding a predetermined threshold of 25%. With the relationship between BW and BCS (1-5) determined by Ngwa et al. (2007), a 25% decrease in BW would be equivalent to a change in BCS of 1.25 units assuming an average baseline period BCS of 3.0 (i.e., decrease in BCS from 3.0 to 1.75). Also, as noted later there were no animals were removed from the restriction period and rehydrated because of reaching thresholds in plasma osmolality or enophthalmos score.

2.5. Realimentation period

After the restriction period, the amount of water offered was increased sequentially by 10% increments every 2 days, with the final level being 120% of consumption during the baseline period. Therefore, the realimentation period was 14 days in length. Weekly samples were collected for blood constituent concentrations, other than hormones, at restriction levels of

80 and 120% on those particular days, with values in the last week of the restriction period used for the 40% level.

2.5. Statistical analyses

Data were analyzed by mixed effects models (SAS, 2004), with a main effect treatment arrangement of a 3×2 factorial (three animal types and two water restriction treatments). Variables with one or more repeated measures were analyzed as a split-plot. There were two ways that many variables were addressed. The first involved comparisons of values during the 1 or first week that 1X wethers received each restricted level of water with those in the second week that 2X wethers were subjected to the same water level. The average of values in wk 2 and 3 of the baseline period was also included as a 100% water allocation or no restriction. For feed and water intakes and BW, the model consisted of fixed effects of animal type (BOE, KAT, and SPA), restriction treatment (2X and 1X), animal type $\times$ restriction treatment, restriction or offering level (100, 90, 80, 70, 60, 50, and 40%), animal type $\times$ restriction level, restriction treatment $\times$ restriction level, and animal type $\times$ restriction treatment $\times$ restriction level. Animal within animal type $\times$ restriction treatment was random and the error term for testing main effects of animal type, restriction treatment, and their interaction, and residual variation was used to test subplot terms. The P values for these effects are in Table 3, and accompanying means are in Table 4 and Figures 1 and 2. When an interaction was significant ($P < 0.05$), interaction means are presented and, accordingly, encompassed main effect means are not. Because of the large number of interaction means in many instances, superscript letters to denote differences are omitted. When main effects and their interactions were not significant, means are presented regardless of the significance of differences. Table 5 lists DM intake (DMI) and BW for individual animals with the 50 and 40% restriction levels as percentages of baseline values, as

well as rankings from least to greatest. Analyses for blood characteristics, other than concentrations of hormones, were the same as for ones with one determination in a day, except for including sub-subplot terms of hour of the day of sampling. There were no significant four-way interactions involving animal type, restriction treatment, restriction level, and hour ($P > 0.05$) as shown in Table 6, but there were many three-way interactions. Means are presented in Table 7 and Figures 3, 4, 5, and 6 in the manner described earlier.

The second method of analyzing variables was to address effects of week within the 2 wk that 2X wethers were subjected to the same level of offered water. For this analysis, values in the baseline period were used as covariates, so that restriction levels addressed are 90, 80, 70, 60, 50, and 40%. Therefore, fixed sources of variation for feed and water intakes and BW were animal type, restriction level, week, animal type $\times$ restriction level, animal type $\times$ week, restriction level $\times$ week, and animal type $\times$ restriction level $\times$ week, with the appropriate baseline period measure as a covariate and animal within animal type used to test the effect of animal type, and the residual term used for other sources. The P values for these variables are in Table 8 and means are in Table 9 and Figures 7 and 8. The analysis was the same for blood characteristics, except for also addressing effects of time of sampling, with P values in Table 10 and means in Table 11 and Figures 9 and 10.

The analyses of blood hormone concentrations were similar to aforementioned ones except for some samples that were not analyzed because of cost considerations (e.g., wethers on the 1X restriction treatment, 2X wethers with 90 and 80% restriction levels, wk 2 of the 2-wk period on the 80% level). The model for levels in the second week of the 2 wk on each level included animal type, the repeated measure of restriction level, and their interaction, with P values and means in Table 12. The analysis to address week within the 2 wk on the different

levels of offered water was as noted before but did not encompass 90, 80, or 70% levels, with P values and means in Tables 13 and 14, respectively.

Though major interest resided in results during the restriction period, it was felt that changes during the realimentation period also could be meaningful. There were no covariates used in these analyses; however, values during the second week while on the 40% level were used for wk 0. The repeated measure for intakes of feed and water was realimentation level, whereas measurement day was used for BW. The P values are in Table 15 and means are in Table 16 and Figures 11, 12, and 13. The analysis of blood characteristics was the same, with week as a repeated measure, except for the additional repeated measure of sampling within day. Table 17 has P values and means are in Table 18 and Figures 14 and 15.

3. Results

3.1. Restriction period

3.1.1. Restriction treatments

Hay and total DMI were similar ($P = 0.100$ and 0.097 , respectively) for 1X and 2X and affected by an interaction between animal type and restriction level ($P < 0.001$; Table 4 and Figure 1). This appeared primarily a function of much greater DMI in the baseline period for KAT vs. BOE and SPA and greater decline for KAT as level of offered water decreased, with DMI by KAT decreased rather markedly by lowest water availabilities. There was an interaction ($P = 0.009$) between restriction treatment and level in BW, which was mainly because of a greater value at 60% for 1X than for 2X compared with more similar values at other times that ranged from 0 to 1.2 kg greater for 1X (Figure 2). However, the 1.2-kg difference was during the baseline period and, thus, may reflect a limited number of observations. The BW rankings in Table 4 were very similar between the two restriction levels compared except for one animal on

the 2X restriction treatment. Spearman's rank correlation coefficients were 0.92 and 0.96 ($P < 0.001$) for 2X and 1X, respectively. Values for BW were only slightly less with the 40 vs. 50% level. Conversely, many rankings of DMI, particularly for the 2X treatment, differed considerably between restriction levels. Overall, differences between restriction levels were notably greater for 2X than for 1X. In accordance, Spearman's rank correlation coefficients were 0.71 ($P = 0.001$) and 0.94 ($P < 0.001$) for 2X and 1X, respectively.

There were two three-way interactions ($P < 0.05$) in plasma osmolality, the first involving animal type and restriction treatment and level, and the second among restriction treatment and level and sampling time (Figures 3 and 4, respectively). Regarding the first interaction, for all six animal type $\times$ restriction treatment combinations, values generally increased slightly from the 100 to 70% level, with more marked change thereafter as water availability was decreased further with the 60, 50, and 40% levels. Means within level were not greatly different among the animal type $\times$ restriction treatment combinations, except for a relatively high value at 50% for SPA-2X wethers, for which factors responsible are unclear. For the second interaction, there were small differences among restriction treatment $\times$ sampling time combinations in the pattern of change as the level of offered water decreased. Values for samples collected at 08:00 h were very similar except at the 50% level, and the same was true for 13:00 h samples except for the two mildest levels of restriction of 90 and 80%. PCV was greater for KAT than for BOE and SPA, and concentrations of hemoglobin and blood oxygen ranked KAT $>$ SPA $>$ BOE ($P < 0.05$; Table 7). There were interactions ($P < 0.05$) in PCV and blood oxygen concentration among restriction treatment and level and sampling time (Figures 5 and 6, respectively). The interaction in PCV is particularly difficult to explain because of lower values for 1X vs. 2X at both sampling times during the baseline period, which again is presumably a function of the number of

observations. The interaction in blood oxygen concentration seems primarily due to relatively low values for 1X and the 13:00-h sampling time at restriction levels of 90, 80, and 70%.

3.1.2. *Week for 2X*

There were interactions ($P < 0.01$) between week and restriction level in hay and total DMI and BW, which were due to similar values between weeks at all restriction levels except 40%, for which values were lower in wk 2 than 1 (Table 9 and Figures 7 and 8). There was an interaction between week, restriction level, and sampling time in plasma osmolality ($P = 0.048$; Figure 9). One of the responsible factors was similar values at the 50 and 40% levels for all week $\times$ sampling time combinations except wk 1 at 08:00 h for which values were lower. There was an interaction in PCV between animal type and sampling time ($P = 0.035$) due to similar values for BOE and slightly lower ones at 13:00 vs. 08:00 h for KAT and SPA (Table 11). An interaction in blood oxygen concentration among week, time of sampling, and restriction level ($P = 0.013$) was partially due to more similar week $\times$ sampling time means at 50 and 40% restriction levels than with greater water availability (Figure 10).

3.1.3. *Hormones*

Based on samples of 2X wethers during the baseline period and at the end of wk 2 at each restriction level, plasma concentration of cortisol was much greater for BOE than for KAT and SPA (Table 12). Levels of vasopressin and aldosterone were similar among animal types. Levels of cortisol and vasopressin varied among restriction levels ($P < 0.001$), although the restriction level P value for aldosterone was 0.085. The cortisol concentration was lowest among restriction levels for 100 and 70% and greater for 40 vs. 60% ($P < 0.05$), with the value for 50% intermediate to those for 60 ($P = 0.432$) and 40% ($P = 0.118$). The concentration of vasopressin

was less for 100 and 70% than for 60, 50, and 40% levels ($P < 0.05$). Numerically, the level of aldosterone was lowest for the 100% level.

Plasma concentration of cortisol, based on samples at the end of wk 1 and 2 of 60, 50, and 40% levels, was not different among animal types ($P = 0.064$), although numerically values were again highest for BOE (Table 14). Plasma cortisol concentration was greater for the 40 vs. 60 and 50% restriction levels ($P < 0.05$). There was a week $\times$ restriction level interaction in the concentration of vasopressin, with values similar between weeks at the 40% level but much greater in wk 2 vs. 1 with 60 and 50% levels ($P < 0.03$). Unexpectedly, the level of aldosterone was lowest among restriction levels for 40% ($P < 0.05$).

3.2. Realimentation period

There were two-way interactions ($P < 0.001$) between level of water offered during the realimentation period and animal type in hay and total DMI (Table 16 and Figure 11). This was mainly due to a greater magnitude of change for KAT as also occurred during the restriction phase. Moreover, there were interactions ($P < 0.001$) in hay and total DMI between level of water offered and restriction treatment (Table 16 and Figure 12). This was because of similar values at the 50% level and slightly greater ones for 2X vs. 1X at 60%, but slightly greater values for 1X than for 2X at other levels.

In contrast to only a tendency ($P = 0.067$) for an interaction in BW between level of offered water in the restriction period and animal type, there was an interaction ($P < 0.001$) in the realimentation period (Figure 13). The main responsible factor appeared to be differences among animal types in the magnitude of change, which from day 0 to 14 was 4.3, 6.0, and 3.2 kg for BOE, KAT, and SPA, respectively.

There was an interaction ($P = 0.028$) in plasma osmolality among animal type, restriction treatment, and week of the realimentation period (Figure 14). There were some differences in the pattern of change during the weeks, such as a relatively large decrease from wk 0 to 1 for KAT-2X. Also, there were differences in the magnitude of change from wk 0 to 2, which were 15.3, 22.1, 17.2, 23.2, 21.5, and 23.3 mosm/L for BOE-2X, KAT-2X, SPA-2X, BOE-1X, KAT-1X, and SPA-1X, respectively. Moreover, an interaction ($P = 0.002$) in plasma osmolality between restriction treatment and sampling time was because of similar values between restriction treatments at 08:00 h but greater ones for 1X at 13:00 h (Table 18). There was an interaction ($P = 0.034$) in PCV among animal type, restriction treatment, and week of the realimentation period (Figure 15). This was largely because of generally increasing values for KAT but decreases for BOE and SPA as week advanced.

There was an interaction ($P = 0.003$) in PCV among restriction treatment, week of the realimentation period, and sampling time, with inconsistent differences between restriction treatments (Table 18). Blood oxygen concentration was greatest among animal types for KAT ($P = 0.001$), although in contrast to the restriction period means for BOE and SPA were not different.

4. Discussion

4.1. Restriction period

4.1.1. Restriction treatments

Based on literature reviewed by Silanikove and Koluman (2015), including no impact of THI less than 80 on milk yield by dairy goats, wethers in the present experiment were not affected by heat stress. Presumably this resulted in much lower intake of water than 7.4 L/day reported by Kaliber et al. (2016) with 75% German Fawn and 25% Hair goats (3 yr of age) when

given ad libitum water access and subjected to THI of 84, 89, and 86 at 08:00 to 09:00, 12:00 to 13:00, and 18:00 and 19:00 h, respectively. Relatedly, the greatest restriction level of 87% of ad libitum intake resulted in 2 L/day of offered water, which was slightly greater than twice the level of ad libitum intake by goats in the present experiment, exemplifying marked effect of high THI on water intake. Baseline water intake was fairly close to that predicted by the equation based on DMI of Forbes (1968). Conversely, control treatment water intake noted by Kaliber et al. (2016) was 2.2 L/day and 42% greater than predicted by this equation, which at least partially may have involved much greater intake of this 60% concentrate and 40% alfalfa hay diet (i.e., 4.8% BW) than of the lower quality diet used in the present experiment.

Decreasing DMI as level of water restriction increased agrees with relationships between food and water intake and water turnover rate addressed in the review of Silanikove (1994) and the study of Silanikove (1989) with Black Bedouin goats given ad libitum water access and consuming diets differing in quality and limited intake of a high quality forage. Depending on factors such as period length, decreased DMI with restricted water availability can lessen basal metabolic rate to minimize water loss.

In contrast to findings of the present experiment, Jaber et al. (2015) did not observe an effect of intermittent watering every 4 days on DMI by lactating Shami goats under non-heat stress conditions, although Alamer (2006) noted a marked effect on DMI by three local goat breeds with the same frequency of watering under hot summer conditions of Saudi Arabia. No effect on DMI by Boer goats or German black-headed mutton ewes occurred when water access was allowed 3 h/day or 6 h every 2 days with non-heat stress conditions (Al-Ramamneh et al., 2012). Somewhat comparable to results of the present experiment, Alamer (2009) caused a

similar and mild to moderate decrease in DMI by Aardi goats under hot summer conditions of Saudi Arabia in a 6-day period with water availability decreased by 25 or 50%.

The lack of differences in hay and total DMI between restriction treatments in the present experiment implies that most relevant processes of adaptation to water restriction affecting DMI had occurred in the 1 wk of the 1X treatment and first week of the 2X treatment. This is supported by the lack of interactions between restriction treatment and level. Animal type by restriction level interactions in DMI suggest that KAT were more subject to adverse effects of very low water availability but not mild restrictions compared with goats. Depending on particular breeds, sheep are generally viewed as less resilient to water restriction than goats (Louw, 1984). In the present study, it is notable that baseline period DMI values for KAT and SPA relative to BW were much greater than those for BOE. Similar to DMI results, differences in BW between restriction treatments were fairly consistent among restriction levels.

Although the P value for the interaction in BW between animal type and restriction level was slightly greater than 0.05, the difference between 100 and 40% levels was 3.8, 4.7, and 2.7 kg for BOE, KAT, and SPA, respectively, but, the decrease in BW was less and more similar among animal types between 40 and 50% levels (i.e., 2.6, 3.2, and 1.9 kg, respectively). In slight contrast to results of the present experiment, De et al. (2015) reported similar BW of adult Malpura ewes under hot summer conditions of India during 1 wk of ad libitum water intake and after 4 wk of water restriction levels of 20 and 40% and a 1-wk rehydration period with ad libitum intake. Based on these findings and differences in the present experiment between 1X and 2X treatments at the 60% restriction level, relatively short lengths of restricted water availability may limit value of change in BW as an indicator of individual animal resilience.

Based on findings with intermittent watering treatments, such as of Maltz et al. (1984) with Black Bedouin goats under apparent heat stress conditions of Israel, Alamer (2006), and Mengistu et al. (2007b) with non-heat stress conditions in eastern Ethiopia, the magnitude of change in plasma osmolality in the present experiment was less than anticipated, although smaller differences also were noted by Mengistu et al. (2007a) with intermittent water availability and non-heat stress conditions in eastern Ethiopia. Perhaps the relatively minor change in the present experiment was a function of decreasing DMI with the increasing degree of water restriction as well as changes in a number of other physiological processes. The interaction among restriction treatment and level and sampling time in plasma osmolality does not provide clear indication of a preferred time of sampling to detect differences in resilience to restricted water availability, with focus on the two or three greatest levels of restriction. Factors responsible for animal type differences in PCV, hemoglobin, and blood oxygen concentrations are unclear, although higher PCV for sheep vs. goats has been reported previously (Burke et al., 2007). Small and inconsistent effects of water restriction in the present experiment on PCV agrees with findings of Jaber et al. (2015) for watering lactating Shami goats every 4 days but not with the marked effect noted by Alamer (2006) also with 3 days of water deprivation for local Saudi Arabian goats.

4.1.2. Effects of week with 2X

Week $\times$ restriction level interactions in hay and total DMI and BW infer that 1 wk was adequate for adaptation in most physiological processes for the 10% sequential decreases in drinking water availability as postulated earlier. However, these results suggest that this might not be true with the most severe restriction level of 40%. Though it is probable that there would be variability among animals in stress experienced with the 40% level, the results suggest that at

least a slightly greater level of water availability, such as the 50% level, would be more appropriate to evaluate individual animal resilience to limited water availability. The interaction in plasma osmolality among week, restriction level, and sampling time implies special value in collection of a sample before the time when feed and water are offered. That values at the 50 and 40% levels were lower for wk 1-08:00 h than for wk 1-13:00 h, wk 2-08:00 h, and wk 2-13:00 h suggests that differences in the extent of change in physiological conditions affecting osmolality between the first and second week would be reflected by sampling at 07:00 h but not at 13:00 h.

4.1.3. Hormones

Cortisol concentrations in the second week of restriction levels for 2X wethers may depict stress elicited by water restriction (Chedid et al., 2014), which is in accordance with the elevated level of vasopressin to increase water resorption in the kidney at the 60, 50, and 40% levels. Jaber et al. (2015) stated that effects of water restriction on cortisol are quite variable and cited a number of studies with and without significant effects. Quite marked effects of intermittent watering on different days on vasopressin concentration in Ethiopian Somali goats have been noted as well (Mengistu et al., 2007a,b). Together, cortisol and vasopressin concentrations in the present study suggest that restriction levels of 60, 50, or 40% would be appropriate to evaluate individual animal differences in resilience to limited water availability. Although, the greater cortisol concentration for the 40 vs. 50% restriction level based on samples collected at the end of both wk 1 and 2 of restriction level steps suggests that a level of water restriction less severe than 40% is preferable. Moreover, lower levels of vasopressin in wk 1 vs. 2 with the 60 and 50% restriction levels indicate that conditions had not stabilized after only 1 wk. It is unclear if further change would have occurred with longer than 2 wk on each restriction

level, but it would seem that for greatest usefulness of other variables such as BW as an index of resilience, a longer period would be a consideration.

4.1.4. Restriction level

Similar to findings of the present experiment with the two greatest levels of water restriction, Maltz et al. (1984) noted BW loss of 23% for non-lactating Bedouin goats when deprived of water for 4 days, although loss by lactating goats was even greater (i.e., 32%). Therefore, the severity of the 40% and 50% water restriction levels could be considered comparable to water access given every 4 days. Furthermore, based on a reduction in BW threshold of 15% for non-desert ruminants, wethers in the present experiment on the greatest levels of water restriction levels were in phase 2 of dehydration (Silanikove, 1994).

A number of statements were given earlier regarding the most appropriate level of water restriction for evaluating individual animal resilience. An additional consideration is the length of time on that selected restricted level of offered water. The percentages of baseline BW for the 50 and 40% restriction levels do not clearly display an obvious advantage to either level. However, with one animal removed on the 2X treatment while on the 50% level and, therefore, not being exposed to the 40% level, and with two animals at 75% of baseline BW with the 40% level, if periods were any longer than 2 wk it is highly likely that a relatively large number of animals would need to be removed from the study and rehydrated if there was a maximal change in BW threshold as in this experiment. Removal or realimentation thresholds also existed for plasma osmolality (340 mosm/L) and a score of the degree of enophthalmos (2 on a scale of 0 to 3) as an index of dehydration (Naylor, 1987; Wenz et al., 2001), but no osmolality value came close to that value and all enophthalmos scores were 0. Another related consideration is DMI, as there was a fairly large number of animals on the 2X restriction treatment that experienced quite

substantial decreases when the level of offered water was decreased from the 50 to 40%. Thus, a 50% restriction level seems reasonable, with a longer length of time than 2 wk if possible to ensure complete adaptation of physiological processes and perhaps more usefulness of variables such as BW as indicators of resilience.

4.2. Realimentation period

The greater magnitudes of increase in hay and total DMI during the realimentation period by KAT than BOE and SPA were expected based on the corresponding decreases in the restriction period. However, it was anticipated that in the 2-wk realimentation period DMI would rise to the level in the baseline period. For example, hay DMI at the realimentation level of 120% was 77, 60, and 85 g/day less than baseline period intake for BOE, KAT, and SPA, respectively. It is unclear if this might have occurred with a more rapid increase in the amount of water offered, with the assumption that the regime of 10% increases every 2 days was somewhat conservative in regards to slow transfer of water from the gastrointestinal tract to the vascular system (Alamer, 2006). These interactions and greater DMI for 1X than for 2X throughout most of the realimentation period imply a relatively long length of time required for reestablishment of normal physiological conditions that influence feed intake given the specific restriction regime used in this experiment. Conversely, after a 6-day realimentation period with ad libitum water intake, DMI had recovered to control period levels for Aardi goats of Saudi Arabia that had been subjected to 6 days of a 25% restriction level (i.e., 75% of control period consumption) but not by ones exposed to a 50% restriction (Alamer, 2009).

The interaction between level of offered water and animal type in BW brings out a number of interesting points. The slightly greater increase in BW by BOE than SPA compensated for greater loss by BOE in the restriction period, as BW on day 14 for BOE was the

same as that in the baseline period (i.e., 26.9 kg) and BW of SPA differed only by 0.2 kg. Conversely, KAT BW on day 14 was 1.3 kg less than in the baseline period. Perhaps this simply relates to greater BW loss by KAT in the restriction period, because as noted above DMI at the 120% level in the realimentation period was slightly less than during the baseline period for all animal types. It is also notable that BW increased so rapidly and markedly in the 2-wk realimentation period despite feed intake recovering at a much slower pace. This may reflect the high proportion of body water lost during the restriction period and, concomitantly, the high level of water in BW gained during realimentation. Moreover, it is possible that even for BOE and SPA, levels of water in the whole body on day 14 of the realimentation period were not necessarily the same as during the baseline period, as may be implied by greater water consumption and perhaps over-hydration in the realimentation period at the 120 vs. 100% level of offered water. This finding is in contrast to less water intake by Aardi goats of Saudi Arabia in a 6-day realimentation period with free-choice access subsequent to 6 days of limited quantities of water of 25 and 50% of control consumption noted by Alamer (2009).

Plasma osmolality at the end of the realimentation period was appreciably lower than during the baseline period, with differences of 4.9, 10.2, 6.5, 6.0, 9.7, and 7.2 mosm/L for BOE-2X, KAT-2X, SPA-2X, BOE-1X, KAT-1X, and SPA-1X, respectively. This is supportive of the possibility mentioned above of different body water levels at the end of realimentation and baseline periods.

In addition to slightly greater change in plasma osmolality by KAT than BOE and SPA as week advanced, there is an interesting difference among animal types in PCV. Overall, values at the end of the realimentation period were fairly similar to those in the baseline period. Hence,

the small increase in values for KAT during the realimentation period compensated for a decline in the restriction period, and vice versa for BOE and SPA.

5. Conclusion

There was some indication that DMI by KAT was more subject to adverse effects of very low water availability but not mild restriction compared with goats, although this was not reflected in BW. Based on factors such as a lower plasma concentration of vasopressin in 2X wethers in the first than second week while on the 60 and 40% restriction levels, a length of at least 2 wk on a set water level(s) seems more appropriate than 1 wk. Periods longer than 2 wk could also increase meaningfulness and value of measures like BW for use to evaluate differences among relatively large numbers of sheep and goats in resilience to restricted drinking water availability. Furthermore, a lesser number of restriction level steps before the lowest target level(s) would seem feasible, supported by many previous studies of intermittent water access such as every 4 days. Higher plasma cortisol concentration for the restriction level of 40 than 50% and appreciable decreases in DMI by some 2X wethers in the second week on restricted levels indicates appropriateness of the 50% level. There were some indications of usefulness of collection of blood samples for determining plasma osmolality before feed and water were offered as well as at a later time. With the realimentation regime employed, a length of greater than 2 wk would be required for conditions to return to baseline.

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588

Table 1

Average daily conditions during the three phases

Item	Baseline	Restriction ¹		Realimentation	
		1X	2X	1X	2x
Temperature (°C)					
Mean	25.9	27.4	28.0	27.8	27.6
SE	0.63	0.34	0.25	0.61	0.73
Minimum	19.1	20.8	20.8	23.3	23.0
Maximum	29.8	31.2	31.3	31.0	30.7
Relative humidity (%)					
Mean	62.0	64.5	63.5	64.9	62.8
SE	1.42	1.00	0.76	1.90	1.37
Minimum	46.6	47.2	47.2	57.2	53.5
Maximum	74.0	76.2	80.2	80.2	72.5
Temperature-humidity index ²					
Mean	74.4	76.7	77.4	77.2	76.7
SE	0.93	0.48	0.33	0.73	0.95
Minimum	63.8	67.7	67.7	72.2	70.4
Maximum	79.9	81.3	81.3	81.0	80.8
Daylength (h)					
Mean	14.33	14.47	14.12	13.96	12.80
SE	0.026	0.019	0.053	0.031	0.041
Minimum	14.12	14.16	13.07	13.77	12.56
Maximum	14.51	14.60	14.60	14.13	13.03

¹2X = 2 wk at each water restriction level; 1X = 1 week at each water restriction level.²Amundson et al. (2006).

Table 2Composition of feedstuffs consumed by wethers (% DM)¹

Item	Feedstuff			
	Grass hay		Concentrate	
	Mean	SE	Mean	SE
Ash	8.1	0.14	3.2	0.11
Crude protein	7.6	0.21	15.6	0.55
Neutral detergent fiber	70.0	0.28	12.1	0.14
Acid detergent fiber	41.5	0.40	5.7	0.19
Acid detergent lignin	7.6	0.16	1.1	0.05

¹17 weekly composite samples formed from samples collected daily (3, 12, and 2 samples during baseline, restriction, and realimentation periods, respectively).

Table 3

P values for effects of animal type, water restriction treatment, and level of offered water on intake of DM and water and BW of wethers

Variable	P value ¹						
	A	R	A*R	L	A*L	R*L	A*R*L
Hay DM intake (g/day)	<0.001	0.100	0.422	<0.001	<0.001	0.281	0.718
Total DM intake (g/day)	<0.001	0.097	0.492	<0.001	<0.001	0.250	0.704
Water intake (g/day)	<0.001	0.930	0.760	<0.001	<0.001	0.295	0.953
BW (kg)	<0.001	0.403	0.871	<0.001	0.067	0.009	0.984

¹A = animal type; R = water restriction treatment; L = level of water offered or restriction.

Table 4

Effects of animal type, water restriction treatment, and level of offered water on intake of DM and water and BW of wethers

Item	Animal type	Animal type ¹				Restriction treatment ²			Level of water offered ³							
		BOE	KAT	SPA	SE	2X	1X	SE	100	90	80	70	60	50	40	SE
Hay DM intake (g/day)						349	395	19.2								
Total DM intake (g/day)						481	532	21.4								
	BOE								491	505	503	422	431	381	322	31.3
	KAT								815	750	751	628	681	566	458	
	SPA								491	489	467	372	397	397	318	
Water intake (g/day)						824	831	59.5								
	BOE								966	799	737	659	571	480	376	75.8
	KAT								1715	1492	1361	1192	1029	858	686	
	SPA								927	804	717	620	556	463	372	
BW (kg)		25.4 ^b	31.7 ^c	19.4 ^a	0.88											

¹BOE = Boer goats; KAT = Katahdin sheep; SPA = Spanish goats.²2X = 2 wk at each water restriction level; 1X = 1 week at each water restriction level.³Water offered as a percentage of ad libitum consumption during the baseline period.^{a,b,c}Main effect means without a common superscript letter differ ($P < 0.05$); main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

Table 5

DM intake and BW of individual wethers on the different restriction treatments and with water levels of 50 and 40% relative to the baseline period

Variable	2X ¹					1X ¹				
	No.	% Baseline ²		Ranking		No.	% Baseline		Ranking	
		50 L ³	40 L ³	50 L	40 L		50 L	40 L	50 L	40 L
DM intake	2017	52.8		1		2015	55.5	53.1	1	4
	136	55.8	36.6	2	1	140	57.9	52.7	2	2
	5026	62.7	40.5	3	2	134	58.1	52.8	3	3
	2016	62.8	48.1	4	6	2055	60.2	44.1	4	1
	135	65.4	45.2	5	4	5068	62.5	54.0	5	5
	137	67.6	47.0	6	5	139	65.5	60.5	6	8
	132	75.7	52.7	7	8	141	72.1	66.0	7	10
	2095	77.8	63.0	8	9	2081	72.4	55.9	8	6
	5056	79.3	65.6	9	13	5054	72.7	60.1	9	7
	5016	81.4	65.6	10	12	5031	76.1	63.4	10	9
	2088	81.4	64.1	11	11	503	77.3	75.1	11	12
	5085	84.7	71.4	12	15	2063	84.7	69.5	12	11
	131	85.6	50.5	13	7	133	89.1	84.7	13	15
	138	86.3	70.8	14	14	2085	90.6	81.9	14	13
	5066	90.4	76.0	15	16	5065	92.5	82.9	15	14
	5091	92.0	44.9	16	3	2070	99.8	93.5	16	17
	2077	93.8	63.9	17	10	5060	100.7	87.8	17	16
	201	98.2	90.2	18	17					
	2094	110.7	97.4	19	18					
BW	2017	74.2		1		5068	82.0	79.7	1	3
	136	77.6	75.0	2	1	140	84.3	80.6	2	4
	5016	82.1	75.3	3	2	2055	84.6	79.0	3	1
	2088	88.8	80.4	4	3	141	84.9	81.3	4	5
	5026	88.9	81.8	5	4	5031	85.8	79.7	5	2
	132	91.1	86.7	6	8	2081	87.3	83.9	6	6
	2016	91.3	86.1	7	7	2015	87.6	84.0	7	7
	2077	91.3	83.4	8	5	5054	88.4	85.1	8	8
	5056	92.3	89.2	9	12	134	89.9	87.7	9	11
	5085	93.2	88.4	10	9	2085	90.4	86.0	10	9
	2095	93.3	88.5	11	11	2070	92.0	87.2	11	10
	137	94.2	88.5	12	10	139	93.0	90.1	12	12
	131	94.7	86.0	13	6	503	93.3	91.4	13	14
	135	95.8	89.8	14	13	133	93.9	91.0	14	13
	5091	97.9	94.8	15	17	5060	96.0	95.1	15	16
	5066	98.4	90.0	16	14	5065	96.7	96.7	16	17
	138	100.4	92.4	17	16	2063	97.6	93.5	17	15
	2094	101.5	91.5	18	15					
	201	103.1	98.4	19	18					

¹2X = 2 wk at each water restriction level; 1X = 1 week at each water restriction level.

²Average during the one (i.e., 1X) or final week (i.e., 2X) as a percentage of baseline values.

³L = level of water offered as a percentage of ad libitum consumption during the baseline period.

Table 6

P values for effects of animal type, water restriction treatment, and level of offered water on blood characteristics of wethers

Source of variation	Variable				
	Plasma osmolality (mosm/L)	Packed cell volume (%)	Total hemoglobin (g/dL)	O ₂ saturation of hemoglobin (%)	O ₂ concentration (mmol/L)
A	0.962	<0.001	<0.001	0.064	<0.001
R	0.643	0.281	0.449	0.200	0.075
A*R	0.973	0.81	0.793	0.258	0.623
L	<0.001	<0.001	<0.001	<0.001	<0.001
A*L	0.177	0.664	0.392	0.402	0.370
R*L	0.010	<0.001	<0.001	0.016	<0.001
A*R*L	0.038	0.414	0.085	0.253	0.227
H	<0.001	<0.001	<0.001	0.003	<0.001
A*H	0.716	0.106	0.620	0.798	0.913
R*H	0.074	0.598	0.824	0.155	0.259
A*R*H	0.581	0.805	0.407	0.794	0.705
L*H	0.021	0.284	0.059	<0.001	0.034
A*L*H	0.684	0.995	0.819	0.818	0.544
R*L*H	<0.001	0.026	0.021	0.125	0.024
A*R*L*H	0.856	0.982	0.733	0.170	0.136

¹A = animal type; R = water restriction treatment; L = level of water offered or restriction; H = hour of sampling.

Table 7

Effects of animal type, water restriction treatment, and level of offered water on blood characteristics of wethers

Item	Interaction ¹		Animal type			SE	Level of water offered ²							SE
	R	H	BOE	KAT	SPA		100	90	80	70	60	50	40	
Packed cell volume (%)			21.9 ^a	28.3 ^b	23.3 ^a	0.59								
Total hemoglobin (g/dL)			8.23 ^a	11.07 ^c	9.24 ^b									
	2X	07:00					10.19	9.44	9.72	9.96	9.62	9.28	9.57	0.195
	2X	13:00					10.07	9.33	9.61	9.94	9.61	9.03	8.98	
	1X	07:00					9.52	9.36	9.30	9.35	9.56	9.64	9.80	
	1X	13:00					9.57	9.35	9.09	9.37	9.31	8.85	9.94	
O ₂ saturation of hemoglobin (%)			68.9	71.6	73.0	1.22								
	2X						64.3	70.7	72.7	73.6	73.7	74.5	75.2	1.37
	1X						65.6	65.7	70.3	70.9	74.8	72.6	72.0	
		07:00					67.6	71.2	71.4	73.6	74.6	72.3	73.2	1.19
		13:00					62.3	65.2	71.7	70.9	73.9	74.8	74.0	
O ₂ concentration (mmol/L)			3.39 ^a	4.73 ^c	4.02 ^b	0.084								

¹R = restriction treatment; H = hour of sampling or measurement; BOE = Boer goats; KAT = Katahdin sheep; SPA = Spanish goats; 2X = 2 wk at each water restriction level; 1X = 1 week at each water restriction level.

²Water offered as a percentage of ad libitum consumption during the baseline period.

^{a,b,c}Main effect means without a common superscript letter differ ($P < 0.05$); main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

Table 8

P values for effects of animal type, level of offered water, and week within the 2 wk on each level of water on intake of DM and water and BW of wethers on the 2X restriction treatment

Item	P value ¹							
	A	L	W	A*L	A*W	L*W	A*L*W	Covariate
Hay DM intake (g/day)	0.093	<0.001	0.032	0.418	0.282	0.008	0.751	0.036
Total DM intake (g/day)	0.167	<0.001	0.025	0.297	0.218	0.004	0.648	0.004
Water intake (g/day)	0.288	<0.001	0.312	<0.001	0.881	0.064	0.998	0.354
BW (kg)	0.998	<0.001	0.042	0.575	0.608	<0.001	0.902	<0.001

¹A = animal type; L = level of water offered or restriction; W = week of the 2-wk period on each level; Covariate = averages in wk 2 and 3 of the baseline period.

Table 9
Effects of animal type, level of offered water, and week within the 2 wk on each level of water on intake of DM and water and BW of wethers on the 2X restriction treatment

Item	Interaction ¹		Animal type				Week			Restriction level ²						
	A	W	BOE	KAT	SPA	SE	1	2	SE	90	80	70	60	50	40	SE
Intake (g/day)																
Hay DM			283	346	500	50.0										
Total DM			426	466	531	48.4										
		1								541	501	477	509	468	408	22.9
		2								560	530	444	484	442	330	
Water							752	763	62.3							
	BOE									854	763	688	592	498	391	165.9
	KAT									1306	1206	1035	867	705	534	
	SPA									899	806	733	667	587	502	
BW (kg)			24.9	25.0	24.8	0.99										

¹A = animal type; W = week within 2-wk period on each level of water; BOE = Boer goats; KAT = Katahdin sheep; SPA = Spanish goats; main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

²Water offered as a percentage of ad libitum consumption during the baseline period.

Table 10

P values for effects of animal type, level of offered water, and week within the 2 wk on each level of water on blood characteristics of wethers on the 2X restriction treatment

Source of variation	Variable				
	Plasma osmolality (mosm/L)	Packed cell volume (%)	Total hemoglobin (g/dL)	O ₂ saturation of hemoglobin (%)	O ₂ concentration (mmol/L)
A	0.863	0.001	<0.001	0.049	<0.001
L	<0.001	<0.001	<0.001	<0.001	0.002
W	0.483	0.091	0.197	0.020	0.005
A*L	0.146	0.120	0.041	0.513	0.709
A*W	0.911	0.787	0.806	0.037	0.090
L*W	<0.001	<0.001	<0.001	0.049	0.695
A*L*W	0.249	0.757	0.209	0.974	0.695
H	<0.001	<0.001	<0.001	0.398	0.006
A*H	0.873	0.035	0.248	0.500	0.267
L*H	<0.001	0.157	0.287	0.001	0.021
W*H	0.012	0.054	0.886	0.264	0.192
A*L*H	0.961	0.977	0.856	0.914	0.889
A*W*H	0.936	0.606	0.206	0.913	0.694
L*W*H	0.048	0.141	0.023	0.001	0.013
A*L*W*H	0.675	0.997	0.774	0.139	0.305
Covariate	0.002	0.004	0.350	0.493	0.374

¹A = animal type; L = level of water offered or restriction; W = week of the 2 wk on each level of water; H = hour of sampling; Covariate = averages in wk 2 and 3 of the baseline period.

Table 11

Effects of animal type, level of offered water, and week within the 2 wk on each level of water on blood characteristics of wethers on the 2X restriction treatment

Item	Interaction ¹			Animal type			SE	Restriction level ²						SE
	A	W	H	BOE	KAT	SPA		90	80	70	60	50	40	
Plasma osmolality (mosm/L)				312	313	313	0.7							
Packed cell volume (%) ³			07:00	22.7	27.5	24.2	0.64							
			13:00	22.7	26.7	23.3								
Total hemoglobin (g/dL)	BOE							8.74	8.48	8.55	8.24	7.99	8.13	0.242
	KAT							11.09	11.22	11.05	10.56	10.47	10.53	
	SPA							9.31	9.35	9.36	9.38	9.06	8.98	
		1	07:00					10.10	9.65	9.69	9.28	9.30	9.19	0.169
		1	13:00					10.00	9.76	9.03	9.07	9.10	9.13	
		2	07:00					9.43	9.71	9.96	9.61	9.27	9.56	
		2	13:00					9.33	9.61	9.94	9.61	9.03	8.98	
O ₂ saturation of hemoglobin (%)		1		66.7	75.3	73.6	2.07							
		2		70.6	76.2	73.5								
		1	07:00					69.6	73.5	73.1	73.0	75.1	71.0	1.94
		1	13:00					64.1	64.3	77.2	70.3	76.3	75.0	
		2	07:00					73.1	70.8	75.3	75.0	71.9	74.2	
		2	13:00					68.4	74.7	72.0	72.4	77.0	76.3	
O ₂ concentration (mmol/L)				3.42 ^a	4.90 ^c	4.04 ^b	0.097							

¹A = animal type; W = week within 2-wk period on each level of water; H = hour of sampling or measurement; BOE = Boer goats; KAT = Katahdin sheep; SPA = Spanish goats; main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

²Water offered as a percentage of ad libitum consumption during the baseline period.

³Main effect means were 24.4 and 24.6% for wk 1 and 2, respectively ($SE = 0.07$).

^{a,b,c}Main effect means without a common superscript letter differ ($P < 0.05$); main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

Table 12

Effects of animal type and level of offered water on plasma concentrations of cortisol, vasopressin, and aldosterone in wethers on the 2X restriction treatment at the end of the second week on each level

Item	P value ¹			Animal type ²				Restriction level ³					
	A	L	A*L	BOE	KAT	SPA	SE	100	70	60	50	40	SE
Cortisol (nmol)	0.004	<0.001	0.078	37.1 ^b	11.2 ^a	16.8 ^a	4.59	12.4 ^a	14.0 ^a	23.3 ^b	26.4 ^{bc}	32.6 ^c	3.62
Vasopressin (pmol)	0.814	<0.001	0.214	5.34	5.11	5.00	0.378	2.12 ^a	2.93 ^a	6.40 ^b	7.22 ^b	7.06 ^b	0.446
Aldosterone (pmol)	0.688	0.085	0.274	0.113	0.106	0.125	0.0166	0.075	0.124	0.126	0.118	0.131	0.0166

¹A = animal type; L = restriction level.

²BOE = Boer goats; KAT = Katahdin sheep; SPA = Spanish goats.

³Water offered as a percentage of ad libitum consumption during the baseline period.

^{a,b,c}Main effect means without a common superscript letter differ ($P < 0.05$); main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

Table 13

P values for effects of animal type, level of offered water, and week within the 2 wk on each level of water on plasma concentrations of cortisol, vasopressin, and aldosterone in wethers on the 2X restriction treatment

Item	Hormone		
	Cortisol	Vasopressin	Aldosterone
A	0.064	0.806	0.203
L	0.002	<0.001	0.008
A*L	0.633	0.167	0.814
W	0.296	0.010	0.541
A*W	0.930	0.790	0.788
L*W	0.926	0.006	0.834
A*L*W	0.991	0.506	0.618
Covariate	0.073	0.964	0.428

¹A = animal type; L = restriction level; W = week within the 2 wk on each level of water.

Table 14

Effects of animal type, level of offered water, and week within the 2 wk on each level of water on plasma concentrations of cortisol, vasopressin, and aldosterone in wethers on the 2X restriction treatment

Item	Week	Animal type ¹				Restriction level ²				Week ³		
		BOE	KAT	SPA	SE	60	50	40	SE	1	2	SE
Cortisol (nmol)		41.1	18.6	19.1	6.49	22.2 ^a	24.6 ^a	31.9 ^b	3.77	25.1	27.4	3.61
Vasopressin (pmol)		6.67	6.07	6.31	0.637							
	1					3.98	5.61	7.84	0.564			
	2					6.40	7.22	7.06				
Aldosterone (pmol)		0.100	0.103	0.133	0.0124	0.131 ^b	0.123 ^b	0.083 ^a	0.0114	0.116	0.108	0.0094

¹BOE = Boer goats; KAT = Katahdin sheep; SPA = Spanish goats.

²Water offered as a percentage of ad libitum consumption during the baseline period.

³Week within the 2 wk on each level of water.

^{a,b,c}Main effect means without a common superscript letter differ ($P < 0.05$); main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

Table 15

P values for effects of animal type, water restriction treatment, and level of offered water, and day during a 2-wk realimentation period on intake of feed and water and BW of wethers

Variable	P value ¹						
	A	R	A*R	L/D	A*L/D	R*L/D	A*R*L/D
Hay DM intake (g/day)	<0.001	0.205	0.806	<0.001	<0.001	<0.001	0.400
Total DM intake (g/day)	<0.001	0.178	0.826	<0.001	<0.001	<0.001	0.358
Water intake (g/day)	<0.001	0.546	0.769	<0.001	<0.001	<0.001	0.606
BW (kg)	<0.001	0.829	0.815	<0.001	<0.001	0.078	0.125

¹A = animal type; R = restriction treatment; L = level of water offered or restriction; D = day of the realimentation phase.

Table 16

Effects of animal type, water restriction treatment, and level of offered water and day during the 2-wk realimentation period on intake of feed and water and BW of wethers

Item	Interaction ¹		Restriction treatment			Realimentation level ^{2,3}								SE
	A	R	2X	1X	SE	40	50	60	70	80	90	100	120	
Intake (g/day)														
Total DM	BOE					323	305	319	326	373	384	414	415	30.1
	KAT					458	464	539	556	629	669	714	754	
	SPA					337	304	316	341	387	393	405	406	
		2X				327	344	414	386	428	455	488	494	24.6
		1X				418	371	369	429	498	509	534	556	
Water (g/day)	BOE					385	484	580	677	773	835	953	1169	79.4
	KAT					686	858	1029	1201	1372	1536	1710	2157	
	SPA					372	463	553	652	744	831	926	1040	
		2X				478	597	713	837	956	1043	1181	1314	64.2
		1X				484	606	729	850	970	1091	1212	1597	
BW (kg)			25.1	25.4	0.80									

¹A = animal type; R = restriction treatment; BOE = Boer goats; KAT = Katahdin sheep; SPA = Spanish goats; 2X = 2 wk at each water restriction level; 1X = 1 week at each water restriction level.

²Main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

³Water offered as a percentage of ad libitum consumption during the baseline period.

Table 17

P values for effects of animal type, water restriction treatment, level of offered water, day during the 2-wk realimentation period, and sampling time on blood characteristics of wethers

Source of variation	Variable				
	Plasma osmolality (mosm/L)	Packed cell volume (%)	Total hemoglobin (g/dL)	O ₂ saturation of hemoglobin (%)	O ₂ concentration (mmol/L)
A	0.222	<0.001	0.002	0.047	0.001
R	0.271	0.296	0.242	0.032	0.465
A*R	0.906	0.711	0.197	0.397	0.344
W	<0.001	0.001	0.266	<0.001	0.149
A*W	0.777	<0.001	0.142	0.202	0.163
R*W	0.001	<0.001	0.300	0.002	0.165
A*R*W	0.028	0.034	0.231	0.143	0.217
H	<0.001	0.002	0.356	0.150	0.446
A*H	0.425	0.057	0.275	0.805	0.311
R*H	0.002	0.141	0.224	0.200	0.299
W*H	0.508	0.002	0.227	0.960	0.266
A*R*H	0.908	0.276	0.248	0.594	0.315
A*W*H	0.966	0.086	0.243	0.364	0.314
R*W*H	0.146	0.003	0.181	0.045	0.116
A*R*W*H	0.476	0.226	0.205	0.090	0.254

¹A = animal type; R = restriction treatment; W = week of the realimentation period; H = hour of sampling.

Table 18

Effects of animal type, water restriction treatment, level of offered water, day during the 2-wk realimentation period, and sampling time on blood characteristics of wethers

Item	Interaction ¹			Mean	SE	Animal type ²			SE	Restriction treatment		
	R	W	H			BOE	KAT	SPA		2X	1X	SE
Plasma osmolality (mosm/L)			07:00							303	303	1.2
			13:00							310	313	
Packed cell volume (%)		0	07:00							25.4	23.3	0.55
		0	13:00							23.8	22.7	
		1	07:00							23.7	25.0	
		1	13:00							24.5	24.7	
		2	07:00							25.3	23.3	
		2	13:00							23.9	23.4	
Total hemoglobin (g/dL)						8.02 ^a	12.6 ^b	8.74 ^a	0.87	9.20	10.39	0.717
		0		9.13	0.871							
		1		9.31								
		2		10.95								
			07:00	9.33								
O ₂ saturation of hemoglobin (%)			13:00	10.26	0.712							
						72.7 ^a	77.7 ^b	76.5 ^b	1.40			
		0	07:00							74.4	71.7	1.87
		0	13:00							76.5	67.5	
		1	07:00							79.3	76.0	
		1	13:00							80.6	72.0	
		2	07:00							78.7	77.8	
		2	13:00							74.8	78.2	
O ₂ concentration (mmol/L)						3.48 ^a	5.85 ^b	4.00 ^a	0.425	4.27	4.62	0.338
		0		3.98	0.413							
		1		4.28								
		2		5.08								
			07:00	4.26	0.338							
			13:00	4.63								

¹R = restriction treatment; W = week during the realimentation period; H = hour of sampling or measurement; 2X = 2 wk at each water restriction level; 1X = 1 week at each water restriction level.

²BOE = Boer goats; KAT = Katahdin sheep; SPA = Spanish goats.

^{a,b}Main effect means without a common superscript letter differ ($P < 0.05$); main effect means are presented for each factor when not involved in an interaction; presence of interaction means denotes a significant interaction ($P < 0.05$), but superscripts were not included on interaction means.

Figure 1. Hay DM intake by Boer goat, Katahdin sheep, and Spanish goat wethers at different levels of drinking water restriction.

Figure 2. BW of wethers on drinking water restriction treatments at different levels of drinking water restriction. 2X and 1X = 10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 and 1 wk, respectively.

Figure 3. Plasma osmolality for Boer goat (BOE), Katahdin sheep (KAT), and Spanish goat wethers (SPA) on drinking water restriction treatments and different levels of drinking water restriction. 2X and 1X = 10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 and 1 wk, respectively.

Figure 4. Plasma osmolality for wethers on drinking water restriction treatments at 07:00 and 13:00 h and different levels of drinking water restriction. 2X and 1X = 10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 and 1 wk, respectively.

Figure 5. Packed cell volume (PCV) for wethers on drinking water restriction treatments at 07:00 and 13:00 h and different levels of drinking water restriction. 2X and 1X = 10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 and 1 wk, respectively.

Figure 6. Blood oxygen concentration on drinking water restriction treatments at 07:00 and 13:00 h and different levels of drinking water restriction. 2X and 1X = 10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 and 1 wk, respectively.

Figure 7. Hay DM intake by wethers on the 2X drinking water restriction treatment (10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 wk) in wk 1 and 2 at different levels of drinking water restriction.

Figure 8. BW of wethers on the 2X drinking water restriction treatment (10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 wk) in wk 1 and 2 at different levels of drinking water restriction.

Figure 9. Plasma osmolality for wethers on the 2X drinking water restriction treatment (10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 wk) in wk 1 and 2 at 07:00 and 13:00 h and different levels of drinking water restriction.

Figure 10. Blood oxygen concentration for wethers on the 2X drinking water restriction treatment (10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 wk) in wk 1 and 2 at 07:00 and 13:00 h and different levels of drinking water restriction.

Figure 11. Hay DM intake by Boer goat (BOE), Katahdin sheep (KAT), and Spanish goat wethers (SPA) during the realimentation period after different levels of drinking water restriction.

Figure 12. Hay DM intake by wethers during the realimentation period after treatments during the restriction period at different levels of drinking water restriction. 2X and 1X = 10% decreases in drinking water availability relative to ad libitum intake during the baseline period every 2 and 1 wk, respectively.

Figure 13. BW of Boer goat (BOE), Katahdin sheep (KAT), and Spanish goat wethers (SPA) during the realimentation period at different levels of drinking water restriction.

Figure 14. Plasma osmolality for Boer goat (BOE), Katahdin sheep (KAT), and Spanish goat wethers (SPA) in wk 1 and 2 of the realimentation period after treatments during the restriction period.

Figure 15. Packed cell volume (PCV) for Boer goat (BOE), Katahdin sheep (KAT), and Spanish goat wethers (SPA) in wk 1 and 2 of the realimentation period after treatments during the restriction period.

Figureg