animal

Thermoregulation and water balance in fat-tailed sheep and Kacang goat under sunlight exposure and water restriction in a hot and dry area

D. P. Rahardja[†], A. L. Toleng and V. S. Lestari

Animal Physiology Laboratory, Animal Agriculture Faculty, Hasanuddin University – Makassar, 90245 South Sulawesi, Indonesia

The objective of this study was to analyze differences in thermoregulation and water balance under conditions of heat load and water restriction between fat-tailed sheep (S) and Kacang goats (G). The daily intakes of food and water, daily outputs of urine and feces, rectal temperature, respiration rates, hematocrit values and plasma volumes of five shorn S and five G were determined over 10 days of four consecutive experimental conditions: (1) indoor – unrestricted water; (2) indoor – restricted water; (3) 10 h sunlight exposure – unrestricted water; and (4) 10 h sunlight exposure – restricted water. There was a 6- to 7-day adjustment period between two consecutive conditions. The study was conducted during the dry season. The animals were placed in individual cages, fed chopped native grass ad libitum and had free access to a urea–molasses multi-nutrient block. Under sunlight exposure with unrestricted water availability, S and G record an increase in the maximum rectal temperatures from 39.2°C to 40.2°C and from 39.9°C to 41.8°C, respectively. The thermoregulatory strategy used by S for maintaining a lower rectal temperature mostly depends on increasing the respiration rate as the main cooling mechanism. On the other hand, G apparently used sweating as the predominant mechanism for cooling. Moreover, G seemed to be more tolerable to higher heat storage and body temperature than S with a significant increase in plasma volume (P < 0.01), and this may be beneficial to the animals for the prevention of water loss. Under restricted water condition in either indoor or outdoor environment, both species decreased their plasma volume significantly, but rectal temperatures were relatively maintained. In all experimental conditions, the daily total water exchanges (ml/kg$^{0.82}$ per day) of S were significantly higher than G (P < 0.01). However, when the percentages of the total daily water exchange were considered, the water lost through urination (38% to 39%), defecation (11% to 14%) and evaporation (46% to 49%) by S and G was not significantly different. Therefore, the results from this study clearly showed that S and G have different homeostatic strategies for the regulation of body temperature and fluid to cope with heat load and water restriction. These differences may have an important impact on the production management of S and G.

Implication

Jeneponto, in South Sulawesi, Indonesia, is known to be the hottest and driest regency of the area. Under these conditions, fat-tailed sheep and Kacang goats are faced with high environmental temperatures and water scarcity. However, these animals are raised by small herders using same management strategies, as the farmers do not recognize the characteristic differences between these two species. Therefore, this study was designed to elucidate these differences, especially in their water balances and thermoregulation abilities. Understanding these characteristics is needed to boost the small herder incomes and to improve the rural farmer livelihood in this region.

Introduction

Environmental stress because of high temperature and/or water restriction has long been recognized as an important constraint for animal production in many parts of Indonesia. In South Sulawesi, Indonesia, Jeneponto is well known as one of the hottest and driest regions with an annual rainfall of less than 200 mm over 63 rainy days per year. Moreover, the daily temperature fluctuates between 17°C and 42°C. This climate may have both direct and indirect negative effects on animal production. However, the population of

[†] E-mail: djoniprawira@yahoo.com

sheep and goats is denser than other regions. It appears that these two species of small ruminants have been well adapted to thrive in the harsh environment of Jeneponto, including the climate conditions as well as nutrient and water availability. This observation seems to conflict with numerous comparative studies that have suggested that goats are superior to sheep in thermoregulation, digestion, water balance and adaptive abilities (El Nouty *et al.*, 1988; Silanikove, 1992; Silanikove, 2000a).

The determination of daily water exchange between animals and their environment is important for estimating water requirement as well as for evaluating their adaptability and productivity (Silanikove, 2000a and 2000b). The strategies used by these two species to adapt to the physical conditions of Jeneponto are intriguing. It is possible that the two species have the same level of water economy and less thermal discomfort. However, it is unknown whether sheep and goats use the same physiological strategies to counteract the climatic condition of Jeneponto. Therefore, this study was conducted to elucidate water balances and thermoregulation strategies used by sheep and goats under sunlight exposure and restricted water availability.

Material and methods

Five shorn fat-tailed sheep ewes (S) between 2 and 3 years and five Kacang goat does (G) between 1.5 and 2 years were used in this study. At the commencement of the study, the body weights of S and G were 26.98 ± 1.3 and 16.92 ± 1.14 kg, and at the end of the study their body weights were 26.65 ± 1.74 and 15.30 ± 1.25 kg, respectively. Both species originated from Jeneponto Regency, South Sulawesi, Indonesia.

The animals were individually placed in specifically constructed cages that had food and water containers in the cages, as well as feces–urine separators beneath the cages. The animals were fed chopped native grass and had access to a urea–molasses multi-nutrient block (UMMB; Food and Agriculture Organization, 2007) *ad libitum* throughout the experiment. All animals were orally dosed with an antihelminthic and intramuscularly injected with vitamin B-complex as well as a high dose of vitamin A shortly after being placed in the cages.

The experiment was conducted during the dry season. Table 1 shows that there were four treatment periods of 10 days each. Before collecting data for each period, the animals were allowed to acclimatize to the treatment conditions until the daily intakes of food and water were approximately constant, and a steady-state body temperature was obtained. It was assumed that a steady state was achieved when rectal temperature and respiratory rate remained constant for at least 1 h (within a range of 0.2°C and 10 respirations/min, respectively).

Total water intake was calculated daily as the sum of daily consumed water, water contained in ingested food (preformed water) and metabolic water. The preformed water from native grass and UMMB was determined separately by drying the samples at 80°C for 48 h, and then cooling them in desiccators for 8 h to achieve a constant weight as well as to determine the content of fecal water.

The metabolic water from digestible organic matter (protein, carbohydrates and fat) was estimated for each animal on the last 5 days for each period. The amount of metabolic water was calculated by multiplying the amount of each digestible organic matter (protein, carbohydrates and fat) by factors of 0.41, 0.60 and 1.07, respectively, and by calculating the sum of these values (Brody, 1945).

Evaporative water loss was estimated by subtracting the sum of fecal and urinary water loss from the total daily water intake. Evaporation from the drinking water in the vessel and ingested grass was corrected daily.

Urine and fecal outputs of each animal were monitored three times a day for each period, whereas a 10% pooled sample of urine and feces was collected each day. Dried food and fecal samples were finely ground to pass a 1 mm screen and were stored in sealed polyethylene containers for subsequent analysis. The organic matter content of the food or feces was calculated by subtraction of the ash content from the known weight of the food or feces sample; the ash content was determined by ignition of samples for 6 h at 550°C. Crude protein, fat and carbohydrate (fiber- and nitrogen-free extracts) contents of the food and feces were determined using the procedures of the proximate analysis (Association of Official Analytical Chemists, 1990).

Rectal temperatures and respiration rates were monitored four times each day at 0600, 1100, 1400 and 1600 h. Rectal temperatures were measured using a digital thermometer (accuracy ± 0.1°C) inserted at a ± 5 cm depth into the rectum. The respiration rates were determined by counting flank movements over a set period of time with the aid of a stopwatch.

Table 1 *Environmental condition and water availability during four consecutive periods of experiment of 10 days each*

Period	1	2	3	4
		Experimental condition		
Environment	Indoor (18°C to 30°C and 60% to 70% RH)		Outdoor (sunlight exposure for 10 h/day; 18°C to 39.3°C and 40% to 60% RH)	
Water	Unrestricted (control)	Restricted (50% of intake in the first period)	Unrestricted	Restricted (50% of intake in the third period)

RH = relative humidity.

Plasma volume was determined on the last day of each period at 1600 h using the dilution technique of Evan Blue, in accordance with the procedures previously described by Williams *et al.* (1991).

The research was arranged as a factorial experiment of 2×4 with five replications and one factor as repeated measures; the first factor was species (S and G) and the second factor was period (four measurement periods). The analysis of variance for data and Duncan's multiple range test for significant differences of mean values were performed by using the computer statistical package 'SYSTAT for Windows version 6' (SPSS Inc., Chicago, USA; Wilkinson, 1996).

Results

Physiological parameters
The effects of sunlight exposure and water restriction on several physiological parameters, including plasma volume, hematocrit value, rectal temperature and respiration rates, are shown in Table 2.

Direct exposure to sunlight did not significantly change body weights of S and G that had restricted or unrestricted water availability. The reduction of water intake significantly decreased the body weights of G in both environmental conditions ($P < 0.05$), but the decrease in body weight of S was not significant.

The plasma volume of S was not significantly altered by direct exposure to sunlight either when water availability was restricted or when unrestricted. Direct exposure to sunlight significantly increased the plasma volume in G that were given unrestricted access to water ($P < 0.05$), but the increase was not significant when water access was restricted.

S maintained a more constant plasma volume compared with G. The plasma volume in G increased significantly when the maximum air temperature was increased to 39°C. The plasma volume of both species decreased significantly when access to drinking water was reduced to 50% of the *ad libitum* level.

Although there were no significant differences in the minimum rectal temperature between S and G, the maximum rectal temperature of G was significantly higher than S ($P < 0.01$) in all experimental conditions. In contrast, increasing respiration rates to the maximum level in all experimental conditions were higher in S than in G ($P < 0.01$).

Organic matter intake and digestibility
Table 3 shows that under control conditions without a heat load or a reduction in the access to drinking water, S and G showed the same level of organic matter consumptions, with G exhibiting better digestibility than S. When the animals were exposed to heat, however, S had significantly lower organic matter consumption than G, whereas both species had significantly higher digestibility when exposed to heat than under the control conditions. When access to water was restricted, both species reduced their organic matter consumptions; however, the digestibility of G was significantly higher than S ($P < 0.01$). In all experimental conditions, G digested more organic matter, especially under conditions of heat stress ($P < 0.01$).

Water balance
Table 4 shows that in all experimental conditions, the total daily water intake of S was significantly higher than G.

Table 2 *The effects of sunlight exposure and water restriction on body weight, plasma volume, respiration rate and rectal temperature of S and G*

Parameters	Species and difference	Experimental condition			
		Indoor (18°C to 30°C and 60% to 70% RH)		Outdoor (18°C to 39°C and 40% to 60% RH)	
		Unrestricted water	Restricted water	Unrestricted water	Restricted water
Body weight (kg)	S	26.98 ± 1.31^a	26.10 ± 1.25^a	27.95 ± 1.19^a	26.65 ± 1.74^a
	G	16.92 ± 1.14^a	15.20 ± 1.45^b	17.85 ± 1.06^a	15.30 ± 1.25^b
	S *v.* G	**	**	**	**
Plasma volume (ml/kg$^{0.82}$)	S	59.35 ± 1.70^a	57.87 ± 1.48^b	59.93 ± 0.79^a	57.60 ± 1.17^b
	G	54.06 ± 1.19^a	51.67 ± 2.91^b	57.76 ± 1.82^c	52.79 ± 2.18^b
	S *v.* G	**	**	**	**
Hematocrit value (%)	S	30.85 ± 0.68^a	33.24 ± 0.97^b	27.82 ± 0.70^c	29.35 ± 0.97^a
	G	35.79 ± 0.92^a	37.43 ± 0.83^b	32.76 ± 0.38^c	34.90 ± 0.69^a
	S *v.* G	**	**	**	**
Min–max rectal temperature (°C)	S	38.7 to 39.2	38.7 to 39.2	38.9 to 40.2	38.7 to 40.4
	G	39.1 to 39.9	39.1 to 39.9	39.2 to 41.8	39.2 to 41.8
	S *v.* G	ns–*	ns–*	ns–*	ns–*
Min–max respiration rate/min	S	20 to 160	20 to 115	20 to 220	20 to 220
	G	32 to 136	32 to 98	36 to 190	36 to 190
	S *v.* G	**–**	**–**	**–**	**–**

S = fat-tailed sheep; G = Kacang goats; RH = relative humidity.
Means with different superscript letters at the same variable within the same row of S or G are significantly different at $P < 0.05$; S *v.* G differences at $^*P < 0.05$ and $^{**}P < 0.01$.

Table 3 *The effects of sunlight exposure and water restriction on the intakes and digestibility of organic matter of S and G*

Parameters	Species and difference	Indoor (18°C to 30°C and 60% to 70% RH)		Outdoor (18°C to 39°C and 40% to 60% RH)	
		Unrestricted water	Restricted water	Unrestricted water	Restricted water
Organic matter intake (g/kg$^{0.75}$ per day)	S	53.29 ± 5.97^a	43.44 ± 2.18^b	47.14 ± 3.01^c	38.32 ± 3.28^d
	G	55.47 ± 2.82^a	42.89 ± 4.28^b	55.62 ± 2.81^a	42.85 ± 2.83^b
	S v. G	ns	ns	**	*
Organic matter digestibility (%)	S	50.95 ± 0.84^a	53.95 ± 2.52^b	55.10 ± 2.02^b	62.00 ± 2.00^c
	G	52.46 ± 0.88^a	57.70 ± 1.47^b	55.24 ± 2.09^b	63.48 ± 0.87^c
	S v. G	*	**	ns	ns
Digestible organic matter (g/kg$^{0.75}$ per day)	S	27.20 ± 3.46^a	24.42 ± 1.07^b	25.94 ± 1.11^{ab}	23.78 ± 2.50^b
	G	29.14 ± 1.33^a	24.76 ± 2.70^b	30.73 ± 2.18^a	25.95 ± 2.10^b
	S v. G	ns	ns	**	ns

S = fat-tailed sheep; G = Kacang goats; RH = relative humidity.
Means with different superscript letters at the same variable within the same row of S or G are significantly different at $P < 0.05$; S v. G differences at $*P < 0.05$ and $**P < 0.01$.

Both species increased water consumption when the daily maximum air temperature increased to 39°C.

In all experimental conditions, the loss of water (g/kg$^{0.82}$ per day) through urination, defecation and evaporation by S was markedly higher compared with G ($P < 0.01$). However, the proportions of total water loss by urination, defecation and evaporation were comparable between both species. These proportions changed when the maximum air temperature was increased (from 30°C to 39°C), but did not change when drinking water was reduced to 50% of the *ad libitum* level.

Fecal water loss
The fecal water loss accounted for the smallest fraction of total water loss in S and G compared with the other mechanisms of water loss. The amount of fecal water loss was higher in S than in G when expressed as g/kg$^{0.82}$ per day. However, both species had comparable proportions of total water loss under all experimental conditions. At a maximum air temperature of 30°C, the proportion of the fecal water losses of both species ranged between 12% and 15% of the total water loss, whereas at a maximum air temperature of 39°C the proportion of fecal water loss decreased significantly to 5% to 7% ($P < 0.01$). Therefore, the proportion of fecal water loss was significantly affected by the increase in the maximum air temperature, but was not significantly affected when water consumption was restricted. In all experimental conditions, the feces produced by G were drier than those produced by S.

Urinary water loss
In all experimental conditions, the urinary water loss of S, expressed in g/kg$^{0.82}$ per day, was significantly higher than that of G. Both species showed a significant reduction in urinary water loss when the daily maximum air temperature increased from 30°C to 39°C or when water consumption was reduced. However, the proportion of urinary water loss of the total water loss was comparable between the two species.

Evaporative water loss
Evaporation was the major mechanism of water loss under all experimental conditions and was significantly higher in S than in G ($P < 0.01$). Both species showed a significant increase ($P < 0.01$) in water lost by evaporation, which increased up to 2.5 times when the daily maximum air temperature increased from 30°C to 39°C.

When the proportion of the total water loss was considered, the water lost through evaporation was not significantly affected by water availability ($P > 0.05$), and was not significantly different between S and G. Both species had a significant increase ($P < 0.01$) in the proportion of water lost through evaporation, which changed from 46% to 49% under indoor conditions to 75% to 78% under outdoor conditions. On the other hand, the proportion of water lost through urination and defecation was markedly reduced when the indoor and outdoor conditions were compared ($P < 0.01$), which changed from 38% to 39% to 17% to 19% for urination, and from 12% to 15% to 5% to 7% for defecation, respectively.

Discussion

The body weight and plasma volume of S were maintained more constantly at a higher level than G when the daily maximum air temperature was 39°C. The results from S are inconsistent with a study by Silanikove (1987), which showed that the blood plasma volume increased under heat stress in Merino sheep. The results from Silanikove (1987) are consistent with the general trend noted in ruminants, where an increase in plasma volume is in proportion to an increase in water turnover (Silanikove, 1992 and 2000b). Therefore, these inconsistencies may be explained by the higher water turnover observed in S, and suggest that the

Table 4 *Effects of sunlight exposure and water restriction on water balance of S and G*

| Parameters | Species and difference | Indoor (18°C to 30°C and 60% to 70% RH) | | Outdoor (18°C to 39°C and 40% to 60% RH) | |
		Unrestricted water	Restricted water	Unrestricted water	Restricted water
		Water intakes			
Ingested water (g/kg$^{0.82}$ per day)	S	242.71 ± 11.58^a	121.96 ± 2.34^b	397.65 ± 19.70^c	211.28 ± 14.94^d
	G	133.88 ± 10.13^a	64.13 ± 3.76^b	251.11 ± 9.63^c	132.96 ± 13.50^a
	S v. G	**	**	**	**
Preformed water (g/kg$^{0.82}$ per day)	S	32.79 ± 1.81^a	26.38 ± 0.37^b	28.17 ± 0.67^c	21.89 ± 1.66^d
	G	34.63 ± 1.31^a	26.58 ± 1.59^b	35.85 ± 1.32^a	25.28 ± 1.72^b
	S v. G	ns	ns	**	*
Estimated metabolic water (g/kg$^{0.82}$ per day)	S	6.91 ± 1.18^a	6.50 ± 1.73^a	7.44 ± 0.53^a	10.39 ± 1.10^b
	G	7.94 ± 0.22^a	7.49 ± 0.92^a	10.03 ± 0.63^b	12.77 ± 0.92^c
	S v. G	ns	ns	**	*
		Water loss			
In urine (g/kg$^{0.82}$ per day)	S	109.38 ± 6.91^a	60.36 ± 3.24^b	81.04 ± 8.26^c	41.44 ± 3.40^d
	G	71.10 ± 9.76^a	41.69 ± 4.68^b	53.32 ± 6.05^c	28.96 ± 2.21^d
	S v. G	**	**	**	**
In urine (% total water loss)	S	38.98 ± 1.09^a	39.33 ± 2.58^a	18.70 ± 3.13^b	16.99 ± 2.69^b
	G	38.31 ± 4.57^a	38.82 ± 3.90^a	18.42 ± 2.51^b	17.16 ± 2.55^b
	S v. G	ns	ns	ns	ns
In feces (g/kg$^{0.82}$ per day)	S	40.97 ± 2.74^a	21.15 ± 1.65^b	28.05 ± 1.90^c	23.83 ± 3.45^b
	G	27.04 ± 1.67^a	12.85 ± 0.82^b	20.22 ± 0.58^c	8.50 ± 0.40^d
	S v. G	**	**	**	**
In feces (% total water loss)	S	14.64 ± 1.49^a	13.12 ± 1.15^a	6.49 ± 0.36^b	5.68 ± 0.78^b
	G	14.60 ± 0.98^a	11.97 ± 1.86^a	6.97 ± 1.20^b	5.03 ± 0.65^b
	S v. G	ns	ns	ns	ns
Estimated evaporative water (g/kg$^{0.82}$ per day)	S	130.14 ± 8.14^a	74.33 ± 4.36^b	324.18 ± 12.43^c	178.30 ± 10.66^d
	G	87.14 ± 7.90^a	52.85 ± 5.39^b	216.66 ± 13.56^c	131.54 ± 12.09^d
	S v. G	**	**	**	**
Estimated evaporative water (% total water loss)	S	46.38 ± 4.23^a	47.55 ± 3.73^a	74.80 ± 7.28^b	77.34 ± 5.66^b
	G	47.09 ± 4.88^a	49.21 ± 4.24^a	74.61 ± 4.63^b	77.81 ± 6.53^b
	S v. G	ns	ns	ns	ns

S = fat-tailed sheep; G = Kacang goats; RH = relative humidity.
Means with different superscript letters at the same variable within the same row of S or G are significantly different at $P < 0.05$; S v. G differences at *$P < 0.05$ and **$P < 0.01$.

basal conditions (control) are heat stressful. These results may also reflect physiological differences between breeds adapted to semi-xeric condition (Merino) and breeds adapted to hot tropical environments (S of Jeneponto).

In G, alterations in plasma volume were apparently in proportion to the thermoregulatory requirement. This response seems to be similar to those found in desert-adapted goats (El Nouty *et al.*, 1988; Silanikove, 2000a). We hypothesize that this is a strategy of G having smaller body size compared with S as a mechanism for coping with the high environmental temperature.

A significant increase in plasma volume in G should occur concomitantly with an increase in the total amount of body water (TBW), as the plasma is a component of the extra-cellular fluid. Previously, Taymour *et al.* (1984) showed that heat stress increased TBW of the goats by about 8%, which is comparable with the increased plasma volume observed in our current study.

Accordingly, our present results indicate that heat load may also increase TBW in G, whereas it was relatively stable in S. Therefore, G seem to be more tolerable to higher heat storage and body temperature than S, and this may be beneficial to the animals for the prevention of water loss.

In this study, S and G showed different mechanisms for the dissipation of excessive heat because of an increase in air temperature. The basic mechanism for cooling is the eva-poration of water from the respiratory tract (panting) and body surface (sweating; Silanikove, 2000b; Robertshow, 2004). The present results showed that in addition to an increase in body temperature, an increase in air temperature resulted in a remarkable increase in the respiration rate of both species. S had an 11-fold increase in the respiration rate compared with the basal conditions. In G, however, a 5- to 6-fold increase was observed compared with basal condi-tions. An increase in the respiration rate leads to an increase in the ventilation rate, which causes an increase in heat loss

from the respiratory passage (Joshi *et al.*, 1977). Both species apparently used panting and sweating as a mechanism for cooling, and S used panting as the main evaporative cooling system, which is consistent with the general pattern for this species (Silanikove, 2000b). On the other hand, G used sweating as the main evaporative cooling system (Dmi'el, 1986; Baker and Nijland, 1993). Reduced sweating during dehydration and/or excessive heat storage resulted in increased body temperature and selective brain cooling (Dmi'el, 1986; Bakernd and Mijland, 1993), which most likely relates to the thermolability observed in G from the present experiment.

Moreover, the increase in the respiration rate observed in S may have more homeostatic relevance, in addition to the higher daily total water exchange, for the dissipation of excessive heat and the maintenance of a lower body temperature compared with G.

An increase in ambient temperature resulted in reduced feed intake, which was most likely due to the metabolic rate of S, as noted by Silanikove (1992). This may be attributable to a reduction in thyroid secretion as well as gut motility, which leads to an increase in gut fill (Abdullah and Falconer, 1977). Therefore, it is reasonable to hypothesize that the appetite reduction of S under heat load may be primarily due to an elevation in body temperature. In addition, it may also be related to an increase in gut fill and a slower passage rate of digested material in the gastrointestinal tract.

In addition, a reduction in feed intake by S occurred simultaneously with an increase in water consumption. However, under this condition, G appeared to maintain a constant consumption of both food and water.

There is a positive relationship between digestibility and ambient temperature, which would be expected from the slower rate of passage (Christopherson and Kennedy, 1983). Under heat stress, both species showed a similar increase in their digestibility. However, because S had a lower intake of organic matter than G, the digested organic matter was also lower. As a consequence, it may have resulted in a lower metabolic rate, heat production and body temperature in S than in G.

Previous studies have shown that the water content in the rumen tends to increase when water consumption increases, and the water turnover rate accelerates in goat (Silanikove, 1989), sheep (Degen and Shkolnik, 1978), cows (Silanikove and Tadmore, 1989) and swamp buffalo (Chaiyabutr *et al.*, 1987). The increased water content in the rumen was used to counterbalance water losses from the systemic fluid during dehydration.

The reductions in the plasma volume of S and G resulted from water restriction in either the indoor or outdoor conditions, and suggested that the release of vasopressin increased. An increase in vasopressin levels would suppress food intake (Purohit *et al.*, 1972; Meyer *et al.*, 1989) and increase water re-absorption from the kidneys (Molony *et al.*, 1987; Sand *et al.*, 1987) as well as from the last part of the gut (Robertson, 1984).

Under control conditions, S and G had a total water exchange of approximately 280 and 175 ml/kg$^{0.82}$ per day,

respectively. When S and G were exposed to heat load, their daily water exchange increased to 430 and 295 ml/kg$^{0.82}$, respectively, which showed that the water balance increased to a higher level than under the control conditions. These results could be attributed to the remarkable water economy exhibited by G as compared with S, which may have to do with the origin of the goats. Silanikove (2000a) suggested that goats originated from and adapted to hot and dry areas of the world, and that their water economy may be more efficient than other ruminants.

As expected, the daily total water consumption in both species increased at the daily maximum air temperature of 39°C. However, in relation to the organic matter intake and digestibility, the additional water (metabolic water and preformed water) in S was reduced, whereas in G these additional water amounts were relatively stable. Both species had a reduction in urinary and fecal water losses as well as in the amount of water per 100 g of fecal dry matter. In contrast, the water lost by evaporation remarkably increased.

The above discussion indicates that a simple physiological mechanism does not explain the remarkable tolerance of sheep and goats to heat stress and to low water availability. Sheep and goats that live in the harsh environment of Jeneponto may be able to withstand and adapt to the conditions because of their own mechanisms of heat and water balances.

The results clearly showed that under sunlight exposure with unrestricted water availability, S and G increased their maximum rectal temperatures from 39.2°C to 40.2°C and from 39.9°C to 41.8°C, respectively. Thermoregulatory strategies of S for maintenance of a lower rectal temperature mostly depend on increasing respiration rate as the main mechanism for dissipating excessive heat load. On the other hand, G apparently used sweating as the main cooling mechanism. Moreover, G seems to be more tolerable to a higher heat storage and body temperature than S, as there was a significant increase in plasma volume. This may be beneficial to the animals for the prevention of water loss. In all experimental conditions, the daily total water exchanges (ml/kg$^{0.82}$ per day) of S were higher than G. As a percentage of the daily total water exchange, however, the water losses through urination (38% to 39%), defecation (12% to 15%) and evaporation (46% to 49%) by S and G were not significantly different. Under conditions of sunlight exposure, the water lost through urination and defecation was decreased to 17% to 19% and 5% to 7%, respectively, whereas the loss through evaporation increased to 75% to 78%.

Conclusion

S and G have developed different homeostatic mechanisms of thermoregulation and water balance to cope heat stress with or without concomitant scarcity of water. Different mechanisms may have an important impact on production management for improving productivity in the harsh

environment of Jeneponto. The sheep with its own mechanism required more water compared with that of the goat. It may be beneficial for both species to lower their heat loads during the warmest hours of the day, thereby reducing the detrimental impact of thermal stress, such as by changing the time of feeding to the late afternoon.

Acknowledgements

References

Abdullah R and Falconer IR 1977. Response of thyroid activity to feed restriction in the goat. Australian Journal of Biological Sciences 30, 207–215.

Association of Official Analytical Chemists (AOAC) 1990. Official methods of analysis, 15th edition. AOAC, Washington, DC, USA.

Baker MA and Nijland MJM 1993. Selective brain cooling in goats – effects of exercise and dehydration. Journal of Physiology (London) 471, 679–692.

Brody S 1945. Bioenergetic and growth, with special reference to the efficiency complex in domestic animals. Reinhold Publishing Corporation, New York, NY, USA.

Chaiyabutr N, Buranakarl C, Muangcharoen V, Loypetjra P and Pichaichanarong A 1987. Effects of acute heat stress on changes in the rate of liquid flow from the rumen and turnover of body water of swamp buffalo. Journal of Agricultural Science (Cambridge) 108, 549–553.

Christopherson RJ and Kennedy PM 1983. Effect of thermal environment on digestion in ruminants. Canadian Journal of Animal Science 63, 447–496.

Dmi'el R 1986. Selective sweat secretion and panting modulation in dehydration goats. Journal of Thermal Biology 11, 157–692.

Degen AA and Shkolnik A 1978. Thermoregulation in fat-tailed Awassi, a desert sheep, in German mutton Merino, a mesic sheep. Physiological Zoology 51, 333–339.

El Nouty FD, Hassan GA, Taher TH, Samak MA, Abo-Ellezz Z and Salem MH 1988. Water requirement and metabolism in Egyptian Barki and Rahmani sheep and Baladi goats during spring, summer and winter seasons. Journal of Agricultural Science (Cambridge) 111, 27–34.

Food and Agriculture Organization (FAO) 2007. Feed supplementation block, urea–molasses multinutrient blocks: simple and effective feed supplement technology for ruminant agriculture, paper 164. FAO Animal Production and Health, Rome, Italy.

Joshi BC, Aravindam M, Singh K and Bhattacharyya NK 1977. Effect of high environmental stress on the physiological responses of bucks. Indian Journal of Animal Sciences 47, 200–202.

Meyer AH, Langhans W and Scharrer E 1989. Vasopressin reduces food intake in goats. Quarterly Journal of Experimental Physiology 74, 465–473.

Molony DA, Reeves WB, Hebert SC and Androli TE 1987. ADH increases apical Na^+, K^+, $2Cl^-$ entry into mouse medullary thick ascending limbs of Henle. American Journal of Physiology 252, F177–F180.

Purohit GR, Ghosh PK and Taneja GC 1972. Water metabolism in desert sheep, effects of various degrees of water restriction on the distribution of body water in Mawari sheep. Australian Journal of Agricultural Research 23, 685–691.

Robertshow D 2004. Temperature regulation and thermal environment. In Duke's physiology of domestic animals (ed. WO Reece), pp. 962–973. Comstock Publishing Associates, Cornell University Press, Ithaca and London.

Robertson GL 1984. Abnormalities of thirst regulation. Kidney International 25, 460–469.

Sand JM, Nonoguchi H and Knepper MA 1987. Vasopressin effects on urea and H_2O transport in inner medullary collecting duct sub-segments. American Journal of Physiology 253, F823–F827.

Silanikove N 1987. Impact of shelter in hot Mediterranean climate on feed intake, feed utilization and body fluid distribution in sheep. Appetite 9, 207–215.

Silanikove N 1989. Inter-relationship between water, food and digestible energy intake in desert and temperate goats. Appetite 12, 163–170.

Silanikove N 1992. Effects of water scarcity and hot environment on appetite and digestion in ruminants: a review. Livestock Production Science 30, 175–194.

Silanikove N 2000a. The physiological basis of adaptation in goats to harsh environments. Small Ruminant Research 35, 181–193.

Silanikove N 2000b. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livestock Production Science 67, 1–18.

Silanikove N and Tadmore A 1989. Rumen volume, saliva flow rate and systemic fluid homeostasis in dehydrated cattle. American Journal of Physiology 256, R809–R815.

Taymour KH, Kamar GAR, Gabr HA and El-Masry KM 1984. Water balance in goats maintained under mild and hot weather. Egyptian Journal of Animal Production 24, 237–246.

Wilkinson L 1996. Statistics: Systat 6.0 for Windows. SPSS Inc., Chicago, IL, USA.

Williams AJ, Thornberry KJ and Nicol H 1991. A comparative investigation of the volume of plasma and extracellular fluids and renal clearance of urea and creatinine in Merino sheep from flock with genetic capacities for wool. Australian Journal of Agricultural Research 42, 1311–1321.