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Assessment of the adaptation of Nguni goats to water stress

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ABSTRACT

The recurring drought and limited rainfall patterns occasioned primarily by climate change in sub-Saharan African countries threaten sustainable animal agriculture. The irreversibility of this natural phenomenon calls for an intensive and urgent selection of adaptable breeds that can cope but with minimal compromise on production indices. A water scarcity simulation study was conducted to assess the adaptation potential of Nguni goats to regulated watering by evaluating their growth performance, tolerance to heat and water stress and blood indices during the dry summer months. Eighteen growing Nguni goats (average age: 1 year; BW: 19.25 ± 1.6 kg) were assigned equally to three treatments: W0, without water restriction (**WR**); W70, WR of 70% ad libitum water intake (**WI**); and W50, WR of 50% ad libitum WI. The experimental trial lasted for 75 d following a 14-day acclimatisation to the housing condition. Data on growth performance, body thermal gradient, skin temperature (**ST**) and rectal temperatures, respiratory rate (**RR**), body condition scores (**BCs**), linear body indices and blood biochemical indices were taken. The results showed that the final BW was not affected ($P > 0.05$) by the water restriction levels. The daily gain, DM intake and total BW gain were similar ($P > 0.05$) in groups W70 and W50. Body thermal gradient and ST were not affected ($P > 0.05$). The RR and BCs decreased ($P < 0.05$) with increasing water restriction levels. The body and rump lengths and sternum height were similar ($P > 0.05$) for groups W70 and W50. There is an haemocentration (W0 < W70 < W50; $P < 0.05$) of sodium, Chloride, urea, creatinine, total protein, and cholesterol with water restriction levels. Generally, most physiological variables assayed were similar ($P > 0.05$) in the water-stressed groups (W70 and W50). Overall, Nguni goats showed an adaptive capacity to tolerate limited water intake.

Implications

The demand for quality water will continue to increase in the foreseeable future and will greatly impact animal agriculture if clamour falls short of supply. Therefore, sustainable livestock production will require the selection of adaptable breeds to water stress. This study aimed to determine the extent of adaptation to suboptimum water intake through three intermittent waterings. Under the watering regimens, the final BW of Nguni goats remains the same but with significant haemoconcentration in the water-limited groups. Nguni goat seems to have some measures of tolerance to water stress and thus holds promise for future selection.

Introduction

One of the primary issues confronting the world is water shortage, and the impact could worsen in the near future based on climate change projections (Dolan et al., 2021). The sub-Saharan African countries, especially South Africa, is not left out, as it is currently faced with severe water pressure occasioned by limited rainfall pattern, increasing water demand from rising population, inefficient water resources management and planning, and repeated droughts (Mahlalela et al., 2020). In most of South Africa, the summer rainfall time series showed that the drought prevalence was higher between the 1970s and 2017 than 1950 and 1970s (Blamey et al., 2018). The Eastern Cape Province, South Africa, is an arid to semiarid region with an average annual temperature of 17.6 °C (summer daily maximum temperature can reach 40 °C) and receives 350–550 mm rainfall per annum (Palmer, 2004; Mills et al., 2005). Due to the prolonged water shortages affecting most rural and urban areas, the province was declared a drought disaster region towards the end of 2019

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(Mahlalela et al., 2020). These harsh water scarcity conditions and elevated ambient temperature induce stress and significantly constrain animal agriculture (Rojas-Downing et al., 2017). Alongside feed shortages and other resources, water scarcity is a threat to sustainable agriculture, with a heightened severity in the water-scarce and dry zones of the world. Most affected in these areas are the resource-poor smallholder farmers who face multiple environmental stressors and lack the necessary adaptive capacity to manage water resources, primarily due to scarcity of funds (Gandure et al., 2013).

Animal husbandry requires a lot of water, both in quality and quantity, and the scarcity of this vital resource could burden farmers due to the economic losses incurred from stress-induced mortalities, especially on ruminants that are usually managed 'extensively' by smallholder and resource-limited farmers (Yitbarek and Berhane, 2014). Other less obvious consequences are reduced forage intake due to poor forage quality and reduced forage biomass, especially for livestock that depends on open-range grazing. Given its vital importance, suboptimum consumption of this nutrient or resource impairs homeostasis, productivity and immunity (Alamer, 2010). Under such an increasingly challenging environment, selecting breeds adapted to limited water intake will be instrumental in sustaining livestock production for the growing human population's food demand (Mpendulo et al., 2020).

Small ruminants have a more efficient coping mechanism to water stress than other livestock species, and thus their preference for the water-scarce, dry and drought-prone areas (Akinmoladun et al., 2019). Their water tolerance comparative advantages include small body size (hence reduced water intake) and the rumen water-conservative attributes, which are usually relied upon during shortfalls (Shkolnik et al., 1980; Silanikove, 2000). However, tolerance to water stress and the extent of water-use abilities are greatly influenced by animal species or breed, the kind and length of water stress and the degree of adaptability (Akinmoladun et al., 2020a). Despite enhanced adaptation due to continuous exposure, Habibu et al. (2017) affirmed different responses among breeds.

The Nguni goat is a commonly reared goat breed by smallholder farmers in the Eastern Cape Province, South Africa. Studies exploring their water-use abilities under a drought-prone environment, including the extent of adaptation to limited water intake, are scanty. This study is therefore focused on assessing the adaptability of Nguni goats to intermittent watering.

Material and methods

Study site

The experiment was conducted at the University of Fort Hare research farm (32°46′S; 26°51′E) in Alice, Eastern Cape Province of South Africa. The altitude of the farm location is 500–620 m above sea level and an 80 km inland distance from the Eastern Cape coastline in a bush-clump savanna popularly described as the False Thornveld of the Eastern Cape (Acocks, 1975).

Experimental design, animal management and diet

Eighteen (18) female Nguni goats (BW: 19.43 kg ± 0.26) were assigned to three different watering treatments (six goats/treatment group); without water restriction [**WR**] (W0, control), WR of 70% of *ad libitum* water intake [**WI**] (W70) and WR of 50% ad libitum WI (W50).

Before the commencement of the study, the goats were vaccinated against foot-and-mouth disease and dewormed using ivermectin. The goats were individually housed in pens (1.33 × 0.58 m) that contained a feeder and a water trough each. The animals were given 14 days to acclimate to the housing units before the 75 days of data collection. Throughout the trial, the animals' physical conditions were closely monitored and observed for symptoms of ill health.

The animals were offered feed (4% of their BWs; DM basis) and presented as a total mixed ration (70% Lucerne hay and 30% concentrate). The diet formulated was calculated to meet the nutrient requirements for growing goats (NRC, 2007). The ingredient and nutrient composition of the experimental diet is shown in Table 1. Samples of the dietary feed mixture were taken and analysed for DM (Number: 934.01), CP (Number: 954.01), ether extract (Number: 920.39), organic matter (Number: 925.05) and mineral matter (Number: 942.05) of AOAC (2004).

Meteorological data

The experimental station's relative humidity and ambient temperature were taken hourly using a portable data logger (Model: MT669, Major Tech, South Africa). The recorded meteorological data were used to calculate the Temperature-humidity index (**THI**) for 75 d of the experimental trial.

Measurements

Feed and growth measurements

WR percentages were calculated based on the daily *ad libitum* WI of the control group. The water supplied was measured daily, and the quantity ingested was calculated (after rebating water loss due to evaporation) by subtracting leftovers from the amount offered. Water loss due to evaporation was calculated by putting buckets containing known water volume at strategic points in the pen. The loss due to evaporation was factored into the WI calculation. The ratio of WI to FI was used as an index of water-use efficiency. Animals were fed in equal proportions twice per day (0900 and 1600 hrs). Daily feed intake was calculated by

Table 1
Ingredients and composition of experimental diet (g kg^{-1} as fed) for Nguni goats subjected to different watering regimens.

Ingredient	Quantity
Lucerne	700
Maize gluten	166.3
Sunflower husk	127.3
Limestone	2.1
MCDP	2.3
Salt	1.5
Premix[a]	0.6
Calculated composition	
Organic matter	889.5
CP	216.7
Ether extract	17.5
Crude fibre	215.3
Nitrogen-free extract	440
Phosphorous	3.8
Calcium	15.7
Magnesium	6.0
Potassium	8.3
Sodium mg/kg	2 263
Copper mg/kg	41
Iron mg/kg	116
Manganese mg/kg	38
Zinc mg/kg	18

Source: Akinmoladun et al. (2021).
MCDP = Monosodium diphosphate.
[a]Ca – 220 g/kg; P – 55 g/kg; Mg – 35 g/kg; S – 22 g/kg; Cl – 105 g/kg;Na – 70 g/kg; Mn – 1 500 mg/kg; Fe – 500 mg/kg; Zn – 1 550 mg/kg; Cu – 440 mg/kg; Co – 50 mg/kg; I – 40 mg/kg; Se – 20 mg/kg.

subtracting leftover feed from the feed offered. The animals were weighed each week to determine BW changes. At the end of the trial, total weight gain [final weight – initial weight] and average daily gain [total weight gain/days of trial] were calculated.

Heat tolerance

The THI equation (Marai et al., 2007); THI = db °C – [(0.31 – 0.31 RH %) (db °C – 14.4)] where db °C is the dry bulb thermometer, and RH, relative humidity was used to determine the extent of heat stress on the animal. According to the authors, THI value <22.2 indicates the absence of heat stress, while values of 22.2–<23.3, 23.3–<25.6 and >25.6 suggest moderate heat stress, severe heat stress and extreme severe heat stress, respectively.

Respiratory rate, rectal and skin temperatures

The respiratory rate (**RR**, breaths/min) and rectal temperature (**RcT**, °C) were recorded between 0900 and 1400 hr on days 15, 30, 45, 60 and 75. To determine RcT, a digital clinical thermometer was inserted into the animal's rectum (depth of about 5 cm) and allowed to contact the mucous membrane for 2 min. The number of flank movements in one complete respiration in one minute (each inward-outward flank movement makes one complete respiration) gives an index of RR. An infrared thermometer (Nubee NUB8380, California, USA) was positioned at a 15 cm distance from the animal to determine the skin temperature (ST). Averages of the temperature readings on the neck, belly and thurl regions give an index of ST for each goat (Zhang et al., 2019). Body thermal gradients, including internal gradient [RcT – ST], external gradient [RcT – ambient temperature] and total thermal gradient [ST – ambient temperature] (Richards, 1973), were also calculated.

Body condition scores and FAffa MAlan CHArt

The characteristic of the lumbar vertebrae following palpation of the spinous processes was arrived at by assigning a body condition score: 1 (very lean with little flesh, protruding backbone); 2 (lean); 3 (medium with slight round flesh over the spine); 4 (fat); and 5 (very fat, backbone undiscovered) (Mcgregor, 2012). The *FAffa MAlan CHArt* (**FAMACHA**) eye chart was used to assign a score after checking the colour of the ocular mucous membrane of each goat for evidence of anaemia. The colour pattern includes 1 (optimal; red colour non-anaemic); 2 (acceptable; red-pink colour non-anaemic); 3 (borderline; pink mildly anaemic); 4 (dangerous; pink-white anaemic) and 5 (fatal; porcelain-white; severely anaemic) (Kaplan et al. 2004).

Linear body morphometrics

Morphometric measurements were taken using a graduated measuring tape (values recorded to the nearest cm) from all the experimental goats in each group. After each animal was carefully restrained, measurements were taken following the procedure described by Salako (2006). The morphometric traits measured were body length (distance from the occipital protuberance to the base of the tail), rump height (distance from the ground to the rump), rump length (measured between the point and iscluim bone), rump width (measured as the distance between the two ends lumbar bone dorsum), tail length (distance between the tail base to the back of the coccygeal vertebrae), ear length (distance between the ear tip to the point of attachment), head width (distance between the edges of the head), head length (measured from the point above the horns to the snout or lips), canon bone circumference (measured around the cannon bone which is between the knee and the ergot), sternum height (vertical distance between the floor and the ventral surface of the sternum), withers height (measured from the highest part of the body to the ground perpendicularly), heart girth (body circumference just before the fore leg). Each dimension was measured thrice, and the mean value was recorded in centimetres. Body conformation indices such as body length index (BLI: body length/wither height) were also calculated.

Blood sampling

On days 30, 60 and 75, blood samples were collected from the jugular vein of each goat (three goats per group) into two vacutainers (heparinised and non-heparinised) tubes. Heparinised blood tubes were centrifuged (3 500 rpm for 10 min) and stored at −20 °C pending analysis. The Checks machine (9Next/Vetx Alfa Wasserman Analyser) and commercial kits were used to analyse plasma samples. The blood serum total protein, albumin, creatinine and alkaline phosphate concentrations were determined spectrophotometrically. Ultraviolet techniques were used to determine alanine transaminase and aspartate transaminase concentration, while the enzymatic method was employed to analyse glucose, urea and total cholesterol.

Statistical analysis

Data obtained were analysed using the SAS 'PROC MIXED' procedure (2001) to cater for the repeated and non-repeated measures. The two models used were as follows:

$$Y_{ijk}\ (\text{repeated}) = \mu + \beta C_i + \beta D_j + \beta (CD)_{ij} + \mathcal{E}_{ijk};$$
$$Y_{ij}\ (\text{non-repeated}) = \mu + \beta C_i + \mathcal{E}_{ij}.$$

where Y_{ijk} is the dependent variable, β is the known design that include covariable (IW) for the fixed effects, C_i and D_j are the fixed effects of the *ith* treatments and jth days of observation, respectively, $(CD)_{ij}$ is the interaction between treatments and days of observation, and $\mathcal{E}_{ijk}$ is the residual error. At $P < 0.05$, analysed data were viewed as significant.

Results

Temperature-humidity index and growth performance

Tables 2 and 3 show the results of the meteorological indices within the housing environment and the growth performance of Nguni goats subjected to different watering treatments, respectively. The average THI is 20.38 for the entire experimental period. Although the final weight was not affected ($P > 0.05$) by the water restriction levels, W0 had the highest ($P < 0.05$) BW gain, DM intake and the ratio of water to DM intake than the two water-restricted groups (W70 and W50). The average daily gain, DM intake/day, DM intake per metabolic BW, and the ratio of water to DM intake were similar ($P > 0.05$) in groups W70 and W50.

Table 2
Meteorological parameters of the housing environment of Nguni goats subjected to different watering regimens.

Days	Av. ambient T[1] (°C)	Av. RH (%)	Av. THI[2]
1–15	21.79	71.05	21.08
16–30	22.50	59.07	21.47
31–45	21.64	68.39	20.85
46–60	21.06	64.70	18.19
61–75	18.69	65.37	18.19
1–75	21.13	65.71	20.38

Abbreviations: THI = temperature-humidity index; RH: relative humidity; Av = average.
N.B: the average minimum and maximum temperatures recorded throughout the experiment were 18.03 °C and 27.04 °C, respectively.
[1]Average values of the sum total of minimum and maximum temperatures.
[2]Values computed using the average of the sum total of minimum and maximum temperatures.

Table 3
Growth performance of Nguni goats subjected to different watering regimens.

Variables	W0	W70	W50	SEM	P-value
Initial weight, kg	19.20	19.63	19.47	1.650	0.546
Final weight, kg	20.83	18.57	18.27	1.660	0.601
Gain, kg	1.63[a]	−1.07[b]	−1.20[b]	0.450	0.004
ADG, g/d	29.05[a]	−14.21[b]	−16.01[b]	0.590	0.026
$BW^{0.75}$	9.73	8.93	8.82	0.590	0.450
DMI, kg	53.58[a]	42.03[b]	39.32[b]	2.380	0.011
DMI/d	714.39[a]	560.45[b]	524.29[b]	31.750	0.027
DMI/d/$BW^{0.75}$	73.97[a]	63.48[b]	59.31[b]	4.670	0.008
WI/DMI	2.01[a]	1.67[b]	1.05[c]	0.070	0.040

Abbreviations: ADG = average daily gain; DMI = DM intake; W0 = *ad libitum* water intake; W70 = 70% of *ad libitum* water intake; W50 = 50% of *ad libitum* water intake; WI = water intake.
[a,b,c] Means with different superscripts within a row are significantly different ($P < 0.05$).

Skin temperature and body thermal gradient

The results of the skin temperature and body thermal gradient of Nguni goats under different watering regimens are shown in Table 4. The effect of the different watering regimens was not significant ($P > 0.05$) on the skin temperature (**ST**), internal gradient (**IG**) and total gradient (**TG**). However, on 60-d, the ST, IG, and TG values increased ($P < 0.05$) with water restriction levels.

Rectal temperature, respiratory rate, FAffa MAlan CHArt and body condition scores

Table 5 shows the results of the rectal temperature, respiratory rate, FAMACHA and body condition scores of Nguni goats subjected to the different watering regimens. The respiratory rate decreased significantly ($P < 0.05$) with water restriction levels on all the sampled days. Compared to W0 and W70, W50 had the highest ($P < 0.05$) FAMACHA scores on days 15 and 75. W0 had the highest ($P < 0.05$) body condition scores, and the values obtained decreased throughout the experimental period with water restriction levels.

Linear morphometrics

The result of the linear morphometrics of Nguni goats subjected to the different watering regimens is shown in Table 6. W0 had the highest ($P < 0.05$) body length. However, body length values obtained for W70 and W50 were similar ($P > 0.05$). Also, W0 had the highest ($P < 0.05$) values for rump length and sternum height. However, values obtained for rump length and sternum height in groups W70 and W50 were similar ($P > 0.05$). The different watering regimens did not affect other linear body morphometrics, including body conformation indices ($P > 0.05$).

Blood biochemical profile

Table 7 shows the result of the blood biochemical profile of Nguni goats subjected to the different watering regimens. Plasma concentrations of sodium, chloride, urea, creatinine, glucose, total protein, globulin, alanine aminotransferase and aspartate aminotransferase increased ($P < 0.05$) with water restriction levels. However, plasma concentrations of uric acid, albumin, triglyceride and

Table 4
Skin temperature and body thermal gradient of Nguni goats subjected to different watering regimens.

Parameters	Day	Treatment			SEM	T	D	T × D
		W0	W70	W50				
Skin Temperature (ST)					0.739	ns	**	ns
	15	31.23	31.13	32.10				
	30	31.67	30.80	31.40				
	45	30.77	30.40	30.80				
	60	23.33[b]	23.73[b]	25.40[a]				
	75	30.40	29.17	29.70				
Internal gradient (IG)					0.750	ns	**	ns
	15	7.43	7.87	7.00				
	30	6.77	7.83	7.50				
	45	7.87	8.13	7.56				
	60	12.46[b]	14.43[a]	14.14[a]				
	75	7.67	8.93	8.60				
External gradient (EG)					0.200	ns	**	ns
	15	16.82	17.15	17.25				
	30	16.58	16.78	17.05				
	45	16.78	16.68	16.52				
	60	15.92	16.02	16.02				
	75	17.15	16.25	16.45				
Total gradient (TG)					0.740	ns	**	ns
	15	9.38	9.28	10.25				
	30	9.82	8.95	9.55				
	45	8.92	8.55	8.95				
	60	1.48[b]	1.88[b]	3.55[a]				
	75	8.55	7.32	7.85				

ns, $P > 0.05$; *$P < 0.05$; **$P < 0.01$.
Abbreviations: T = treatment; D = day; W0 = *ad libitum* water intake; W70 = 70% of *ad libitum* water intake; W50 = 50% of *ad libitum* water intake.
[a,b] Means with different superscripts within a row are significantly different ($P < 0.05$).

Table 5
Rectal temperature, respiratory rate, FAMACHA and body condition scores of Nguni goats subjected to different watering regimens.

Parameters	Day	Treatment						
		W0	W70	W50	SEM	T	D	T × D
Rectal Temperature					0.202	ns	ns	ns
	15	38.67	39.00	39.10				
	30	38.43	38.63	38.90				
	45	38.63	38.53	38.37				
	60	37.77	37.87	37.87				
	75	38.06	38.10	38.30				
Respiratory Rate					2.520	**	ns	ns
	15	34.00[a]	30.67[a]	23.33[b]				
	30	34.00[a]	33.33[a]	24.67[b]				
	45	44.00[a]	35.33[b]	25.33[c]				
	60	42.67[a]	35.33[b]	24.67[c]				
	75	41.33[a]	30.00[b]	24.67[c]				
FAMACHA					0.270	*	**	ns
	15	2.00[b]	2.33[ab]	2.67[a]				
	30	2.33	2.33	2.33				
	45	3.00	3.00	3.33				
	60	3.00	3.00	3.33				
	75	2.00[b]	2.67[a]	2.67[a]				
Body Condition scores					0.333	**	ns	ns
	15	3.67[a]	2.67[b]	2.00[b]				
	30	3.33[a]	2.67[b]	2.33[b]				
	45	3.33[a]	2.00[b]	2.00[b]				
	60	2.67[a]	2.33[ab]	2.00[b]				
	75	2.67[a]	2.00[b]	2.00[b]				

ns, $P > 0.05$; *$P < 0.05$; **$P < 0.01$.
Abbreviations: T = treatment; D = day; W0 = *ad libitum* water intake; W70 = 70% of *ad libitum* water intake; W50 = 50% of *ad libitum* water intake.
[a,b,c] Means with different superscripts within a row are significantly different.

Table 6
Linear body morphometrics of Nguni goats subjected to different watering regimens.

Variables (cm)	W0	W70	W50	SEM	*P*-value
Body length	58.33[a]	55.33[b]	53.67[b]	1.560	0.037
Rump height	60.67	59.67	59.67	0.580	0.752
Rump length	14.33[a]	13.67[ab]	12.67[b]	0.750	0.007
Rump width	11.00	10.33	10.67	0.540	0.611
Tail length	13.67	13.33	13.25	0.470	0.480
Ear length	16.23	16.25	16.24	0.330	0.728
CBC	8.33	8.33	8.00	0.270	0.619
Head width	9.67	9.33	9.00	0.270	0.250
Head length	18.33	18.00	18.00	0.610	0.401
Sternum height	32.00[a]	30.33[b]	29.33[b]	0.790	0.008
Withers height	54.33	53.67	53.33	1.410	0.377
Heart girth	71.33	69.33	69.00	1.960	0.377
BLI	1.09	1.03	0.98	0.03	0.232

Abbreviations: W0 = *ad libitum* water intake; W70 = 70% of *ad libitum* water intake; W50 = 50% of *ad libitum* water intake; BLI = body length index; CBC = Canon bone circumference.
[a,b,c] Means with different superscripts within a row are significantly different ($P < 0.05$).

high-density lipoprotein were unaffected ($P > 0.05$) by the water restriction levels.

Discussion

Adaptation is the capacity and process of adjusting an animal to itself, to other living materials and the external environment. The adaptive mechanisms of goats to stress are usually evaluated based on behavioural, morphological, physiological, biochemical and hormonal changes. Under heat stress, the THI is the most preferred method in assessing the adaptive capacity of goats to heat stressors and other co-relations (Mili and Chutia, 2021). The THI value obtained in this study is less than <22.2 and thus indicates the absence of heat stress (Marai et al., 2007). Given that the upper critical temperature (25–30 °C) for goats in maintenance (Lu, 1989) during the experimental trial was not exceeded, this could probably explain the seemingly insignificant effect of heat stress on their body thermal gradients and skin temperature. Usually, goats adapt by constricting their thermal gradients between their bodies and the environments when faced with extreme heat stress. The mechanism is such that when the skin temperature increases, there is vasodilation of skin capillaries leading to an increased blood flow (Katiyatiya et al., 2017). Due to the absence of heat stress (THI < 22.2 °C), it was possible to attribute all the observed differences to water stress alone. Hence, we choose not to overstretch the discussion of heat stress and its impact on the goats.

An animal's BW and water are co-related; hence, resilience to water stress can be assessed based on the weight changes during stressful periods (Akinmoladun et al., 2019). Therefore, water-tolerant animals are adjudged based on their adaptive capacity to preserve more water (Ismail et al., 1996). The BW of Nguni goats in this study was not significantly affected by water restrictions and was confirmed statistically. This implies that the goats could efficiently manage their body nutrients and body water in the face of limited water intake for survival. However, the BW of Nguni goats decreased when subjected to 24 h and 48 h (followed by water supply for 24 h) of water deprivation for 40-d (Mpendulo

Table 7
Blood biochemical profile of Nguni goats subjected to intermittent watering.

Parameters	Day	Treatment			SEM	Probability		
		W0	W70	W50		T	D	T × D
Na					1.52	*	ns	ns
	30	137.25^{b}	137.00^{b}	143.75^{a}				
	60	138.00^{b}	140.50^{b}	145.00^{a}				
	75	137.00^{b}	139.00^{ab}	140.50^{a}				
Cl					1.70	*	ns	ns
	30	101.25^{c}	105.00^{b}	109.50^{a}				
	60	103.00^{b}	105.00^{ab}	106.00^{a}				
	75	106.00^{b}	105.00^{ab}	109.00^{a}				
Urea					0.47	*	*	ns
	30	5.90^{b}	7.75^{a}	8.65^{a}				
	60	7.80^{b}	8.73^{a}	8.80^{a}				
	75	8.05^{b}	10.30^{a}	10.20^{a}				
Creatinine					3.91	*	*	ns
	30	56.00^{b}	58.00^{b}	67.00^{a}				
	60	36.50^{b}	44.00^{a}	43.00^{a}				
	75	45.00^{b}	47.00^{b}	62.00^{a}				
Glucose					0.06	*	ns	ns
	30	2.80^{a}	2.60^{b}	2.50^{b}				
	60	2.80	2.70	2.70				
	75	3.20^{a}	2.68^{b}	2.60^{a}				
Uric acid					0.01	ns	ns	ns
	30	0.04	0.03	0.03				
	60	0.03	0.02	0.03				
	75	0.03	0.03	0.04				
Total Protein					1.85	*	*	*
	30	60.00^{ab}	59.00^{b}	62.25^{a}				
	60	59.00^{b}	60.75^{b}	65.00^{a}				
	75	57.00^{b}	60.00^{b}	66.75^{a}				
Albumin					0.79	*	ns	ns
	30	14.00	14.00	15.00				
	60	11.00	12.00	14.00				
	75	11.50	11.00	14.00				
Globulin					0.85	*	*	ns
	30	46.05^{ab}	45.00^{b}	47.75^{a}				
	60	48.00^{b}	48.00^{b}	51.00^{a}				
	75	46.05^{c}	49.00^{a}	48.70^{a}				
Bilirubin					0.94	*	ns	ns
	30	4.00^{b}	7.00^{a}	6.00^{a}				
	60	3.00^{b}	4.50^{a}	5.00^{a}				
	75	5.50	5.00	5.50				
Alanine aminotransferase (ALT)					1.82	*	ns	ns
	30	16.00^{b}	14.00^{b}	20.00^{a}				
	60	15.00^{b}	15.00^{b}	27.00^{a}				
	75	17.00^{b}	15.00^{b}	22.00^{a}				
Aspartate amino transferase (ALP)					3.91	*	ns	ns
	30	20.00^{b}	23.00^{b}	34.50^{a}				
	60	26.00^{b}	27.00^{ab}	33.00^{a}				
	75	25.50^{b}	34.00^{a}	34.50^{a}				
Cholesterol					0.23	**	ns	ns
	30	2.08^{a}	1.78^{ab}	1.49^{b}				
	60	1.40^{a}	1.28^{ab}	1.05^{b}				
	75	1.13	1.13	1.08				
Triglyceride					0.07	ns	ns	ns
	30	0.23	0.12	0.15				
	60	0.20	0.23	0.11				
	75	0.20	0.13	0.13				
High-density lipoprotein (HDL)					0.08	ns	ns	ns
	30	0.95	1.07	1.01				
	60	0.81	0.96	0.90				
	75	0.82	0.84	0.84				
Low-density lipoprotein (LDL)					0.13	**	**	**
	30	0.35^{c}	0.69^{b}	0.95^{a}				
	60	0.19^{b}	0.29^{b}	0.60^{a}				
	75	0.36^{b}	0.70^{a}	0.70^{a}				

ns, $P > 0.05$; *$P < 0.05$; **$P < 0.01$.
Abbreviations: T = treatment; D = day; W0 = *ad libitum* water intake; W70 = 70% of *ad libitum* water intake; W50 = 50% of *ad libitum* water intake.
[a,b,c] Means with different superscripts within a row are significantly different.

et al., 2020). This variation in water tolerance could be attributed to the water deprivation type adopted. Although the water stress effect was not significant on the final weight, significant losses were observed in the total gain/average daily gain of the Nguni goat. As observed in the study, water stress significantly declined feed intake. The need to survive requires compensating for the sub-optimum nutrient (feed) intake through fat mobilisation (depletion of body reserves) for energy metabolism (Jaber et al., 2004). This could have accounted for the total/average daily gain losses. According to Akinmoladun et al. (2019), the extent and nature of deprivation influence water-use abilities and tolerance to reduced intake in small ruminants.

Efficient digestion requires the supply of adequate water for the physical softening of feed as well as the biochemical digestion process. Hence, a close inter-relationship does exist between water fluxes and energy in mammals (Silanikove, 1989). As observed, the DM intake in this study decreases as the water restriction levels increase. Similar values were obtained in water-restricted groups compared to the *ad libitum* group. The similarity in DM intake in W70 and W50 could be attributed to efficient water-saving mechanisms that empower them to sustain their intake (Akinmoladun et al., 2019). Chief among the mechanisms is the rumen of small ruminants, which could conserve water (reservoir) to 15% of the animal's weight for use during scarcity. The effect of water restriction on voluntary feed intake reduction, as observed in this study, agrees with previous studies (Jaber et al., 2013; Akinmoladun et al., 2020a, and 2020b).

Elevated RcT is usually a response to heat or water stress. The similarity in RcT in the differently watered groups in this study indicates the adaptive capacity of Nguni goats to water stress. This finding agrees with other reports (Hamadeh et al., 2006). The FAMACHA score, when guided by the standard chart, provides a measure of assessing an anaemic animal. Besides the usual causative factors of anaemia, including gastrointestinal parasitism, thrombosis of the vena cava, haemorrhagic bowel syndrome, and abomasal ulcers, anaemia can also be caused by factors (e.g., iron absorption) that decrease the production of erythrocytes (Katsogiannou et al., 2018). Previous studies have shown that iron homeostasis was impaired under specific stress conditions, thus inducing a lack of haemoglobin and hence anaemia (Chen et al., 2009). The FAMACHA scores recorded in this study seem reasonably balanced, notwithstanding the effects of water limitation. As van Wyk and Bath (2002) conveyed, scores above 3 indicate severe anaemia and would require urgent veterinary attention. In this study, the FAMACHA values are $\leq$3 and within the permissible range. This suggests that the goats adapt well to the water stress effect and that iron metabolism was not seriously impaired to induce anaemia. The decreased BCs with increasing levels of water limitation in this study are attributed to a depletion of body reserves. However, the similarity in BCs in the water-stressed groups (W70 and W50) indicates that the goats can manage the depletion of body reserve even at W50. With the limitation of water intake, voluntary feed intake drops. Attempts by the animal to sustain homeostasis by maintaining a regular supply of energy result in the loss of body condition (Sejian et al., 2010; Akinmoladun, 2022). Similar outcomes were recorded in water-restricted Xhosa (Akinmoladun et al., 2020a) and summer heat-stressed goats (Pragna et al., 2018). When animal water intake decreases below the optimum requirement, ruminants decrease their metabolic rate to conserve energy (Rahardja et al., 2011). This new adjustment enhances the animal's capacity to survive under an extended period of water intake limitation (Akinmoladun et al., 2019). With increasing levels of water limitation, the RR in this study decreases. Similarly, the RR of Lacauna ewes was reduced when their water intake was reduced by 60 and 80% of the ad libitum water intake. As an adaptive instinct by small ruminants, respiratory activities decrease to prevent further water loss via pulmonary evaporation during suboptimum water intake (Casamassima et al., 2016).

The adaptive morphological changes due to stressors in animals are the most pronounced and efficient response to coping with the stressors. For example, breeds found in warmer ecological climes are predominantly smaller than in cooler regions with larger breed sizes (Verberk et al., 2021). According to Salako (2006), the heaviness of a particular small ruminant is determined when body proportions and contributions of body length, rump, chest and hip widths are considered. Unsurprisingly, the goats with unrestricted access to water had the highest body and rump lengths and hence the heaviest compared to the water-restricted but similar groups. This is consistent with their much higher BW. Water and feed intake are directly related (Akinmoladun et al., 2021). Hence, with higher feed intake, muscle deposition increases and, ultimately, slaughter weight and body proportions, particularly those around the muscle areas (rump width) (Mapiye et al., 2009; Akinmoladun et al., 2020b). Usually, a breed's functionality and balance can be assessed with the knowledge of its width slopes and length indices (Salako, 2006). Apart from the fact that the balance of the goats was not affected, the similarity in most of the linear body indices suggests the adaptive capacity of the goats to manage the loss of body conditions when water intake is limited.

An animal's metabolic status and biochemical composition are directly proportional to one another and are therefore used as an index when assessing their adaptive capacity to stressors. With water intake limitations, ruminants respond by withdrawing fluid from tissues to maintain normal blood volume (Radostits et al., 2006). The observed increase in osmolality reflects dehydration, consistent with several other reports in water-restricted goats (Mengistu et al., 2007). The increased Na+ reflects an increased aldosterone activity, which raises the concentration of Na+ in the kidney. A similar pattern is followed for Cl^- concentration due to their passive distribution according to electrical gradient and the active transport of Na+ (Tasker, 1980). The increased blood urea concentration with respect to water intake limitation could be due to a reduced blood flow towards the urinary apparatus as well as urea reabsorption in the kidney, while that of creatinine may be linked to an imbalance in the endogenous creatinine's clearance rate (Baxmann et al., 2008; Casamassima et al., 2016). Similar outcomes were reported by Qinisa (2010) and Akinmoladun et al. (2020a) following water restriction on goats. The decreased blood glucose concentration with respect to water restriction levels could be attributed to reduced feed intake. While the blood glucose of goats under water restriction in some studies remains unchanged (Alamer, 2006), other studies have reported a decline with increased levels of water deprivation (Abdelatif and Ahmed, 1994). The increase in blood biochemical indices (total protein, globulin, bilirubin, alanine aminotransferase, aspartate amino transferase and cholesterol) recorded in this study could be attributed to haemoconcentration due to the lower blood water levels (Alamer, 2006). The increased protein concentration was also reported in water-restricted Ethiopian-Somali (Mengistu et al., 2007) and black Morocco (Hossaini-Hilali et al., 1994) goats. This increased serum protein concentration suggests its important role as an osmotic pressure regulator of the blood in animals under water stress, as water loss results in increased concentration in smaller blood volume (Schalm et al., 1975; Mengistu et al., 2007). The decreased serum cholesterol with increased water restriction levels agrees with Kumar et al. (2016), who water-restricted Malpura ewes. However, other authors have reported higher plasma cholesterol as the water restriction levels increase in Yankasa and Awassi sheep (Igbokwe, 1993; Jaber et al., 2004) and attributed such to increased fat metabolism and decreased energy intake.

Conclusion

The present study reveals the impact of water stress on various physiological and body morphometrics of Nguni goats. The adaptive capacity of this breed to water stress was quickly shown in their BW, as values recorded among the groups remained unaffected. The decreased respiratory rates and haemoconcentration of blood metabolites are mechanisms adopted by the Nguni to cope with water stress and extend their survivability. Other variables tested, even at water intake of 50% *ad lib*, were not compromised as a similar effect was recorded with the 70% *ad lib*. The Nguni goat, an indigenous breed, holds much promise as an adaptable goat to water stress.

Ethics approval

The University Research and Ethics Committee approved the experimental protocol described in this study of the University of Fort Hare, South Africa (Ref. No: MUC011SAKI01).

Data and model availability statement

None of the data was deposited in an official repository. The data/models that support

the study findings are available from the authors upon request and after authorisation by

all authors.

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Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors did not use any artificial intelligence-assisted technologies in the writing process.

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