AMERICAN JOURNAL OF BIOLOGY AND NATURAL SCIENCES
https://biojournals.us/index.php/AJBNS
ISSN: 2997-7185

Comparative Physiological Responses of Sheep and Goats to Combined Heat Stress and Water Restriction: A Systematic Review of Adaptive Mechanisms and Evidence Gaps

Hawraa Hamza Abbas*

1. Open Education College_ Muthanna Study Center
*Correspondence: hawra.hamzah.abbas@ec.edu.iq

Citation: Abbas, H. H. Comparative Physiological Responses of Sheep and Goats to Combined Heat Stress and Water Restriction: A Systematic Review of Adaptive Mechanisms and Evidence Gaps. American Journal of Biology and Natural Sciences 2026, 3(11), 70-88.

Received: 25th Aug 2026
Revised: 27th Sept 2026
Accepted: 14th Oct 2026
Published: 17th Nov 2026

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Abstract: Background: Sheep and goats in arid regions often face high temperatures and limited drinking water at the same time, but it is unclear how the two stressors interact and whether the two species respond differently. This review examined the experimental evidence. **Methods:** We conducted the literature search using PubMed, Europe PMC, AGRICOLA, and OpenAlex on 26th October 2026 and adhered to PRISMA 2020 guidelines for conducting the literature search. Original experiments were eligible if sheep or goats had water restricted or withheld under imposed heat[Tier 1] or under heat documented by the authors[Tier 2]. Reports from the same animals were counted once. Since designs and outcomes varied, a narrative synthesis using the outcome-direction coding technique, description of reported changes, and exploratory sign tests was attempted. **Results:** The searches returned 502 records; after removing 61 duplicates, 441 were screened, and 66 reports were assessed in full text. Thirty-five reports describing 30 independent cohorts were included. Nine cohorts were Tier 1 and 21 were Tier 2; 12 used sheep, 14 goats, and 4 both species. Cohorts were small[median 9 animals, range 5–42]. The most consistent results were the decline in body weight in 11 cohorts and in feed intake in 10, and the increase in plasma osmolality in 7[hematocrit increase in 5]. Thermoregulation changed in 6 cohorts, didn't change in 3, and was mixed in 6, and rose in 4 and fell in 5 with respect to respiration rate. Four of these cohorts performed a direct comparison of sheep and goats, and the evidence does not indicate there was any consistently clear superiority of either species. **Conclusions:** The available evidence mainly describes dehydration-related changes under hot conditions rather than proven adaptation. Only a few experiments applied both stressors, sample sizes were too few, and some reports may have shared animals. Factorial studies with adequate sample sizes, comparable protocols, and standardized heat reporting are needed.

Keywords: sheep; goats; heat stress; water restriction; dehydration; thermoregulation; osmoregulation; systematic review.

Introduction

Heat stress and limited water availability are major environmental challenges affecting the physiological function, welfare, and productivity of small ruminants, particularly in arid and semi-arid regions[1]. Sheep and goats are important livestock species in these environments because of their contributions to meat, milk, and other animal products[2]. However, their ability to maintain physiological homeostasis under hot conditions depends on several factors, including environmental temperature, humidity, breed characteristics, nutritional status, and access to drinking water[3]. In hot environments with limited water supply, animals may suffer further from the encounter with an extra problem of watering the body and maintaining a certain temperature level[4].

Thermoregulation is a crucial physiological mechanism that aids animals in adjusting to a range of body temperatures that allows them to function effectively with changes in the environment[5]. Responses to heat exposure may include increased respiratory rate, changes in body temperature, sweating, and behavioral adjustments[6]. Water availability is closely associated with these responses because respiratory and cutaneous evaporation contribute to heat dissipation while also increasing water loss[7]. Consequently, water restriction during hot weather may alter both the capacity for evaporative cooling and the physiological mechanisms that conserve body fluids[8]. Experimental studies in goats and sheep have investigated changes in respiratory rate, rectal temperature, plasma electrolytes, endocrine indicators, and water balance under conditions of heat exposure and restricted water availability[9].

Although sheep and goats share several physiological characteristics, they may differ in their strategies for regulating body temperature and conserving water. A comparative experimental study involving fat-tailed sheep and Kacang goats under sunlight exposure and water restriction reported species-related differences in thermoregulation and water balance[10]. Such findings highlight the importance of examining species-specific responses rather than assuming that sheep and goats respond identically to environmental stressors[11]. Nevertheless, physiological responses may also vary according to breed, the severity and duration of exposure, nutritional conditions, physiological status, and experimental design[12].

The physiological responses to heat exposure and restricted water availability involve several interconnected domains, including thermoregulation, hydration and electrolyte balance, renal water conservation, endocrine regulation, metabolism, behavior, and productivity[13]. Relevant outcomes reported in the literature include rectal and body-surface temperatures, respiratory and heart rates, water intake, body-weight changes, plasma sodium and potassium concentrations, antidiuretic hormone and other endocrine indicators, and selected biochemical markers. However, the outcomes measured, the methods used to assess them, and the environmental conditions reported vary among studies. Differences in experimental protocols and comparator groups may therefore limit direct comparisons across studies and complicate the interpretation of the evidence.

Despite the relevance of this topic to small-ruminant production under hot and water-limited conditions, the available experimental evidence needs to be interpreted according to the nature of the exposure and the design of each study[14]. In particular, studies in which heat exposure and water restriction are both experimentally imposed should be distinguished from studies investigating water restriction under naturally hot environmental conditions[15][16]. This distinction is important because the latter can demonstrate responses under combined environmental circumstances but may not establish an independent interaction between heat and water restriction[17].

Therefore, this systematic review aims to critically synthesize experimental evidence on the physiological responses and adaptive mechanisms of sheep and goats exposed to water restriction or deprivation under heat-stress conditions. The review focuses on thermoregulatory responses, water and electrolyte balance, endocrine and metabolic changes, behavioral adaptations, and production-related outcomes. It also looks at sheep versus goat differences where comparable evidence is available, discusses methodological limitations that impact interpretation, and notes some areas that need to be addressed in ongoing, future research. By distinguishing controlled combined-exposure

experiments from studies conducted under naturally hot conditions, the review seeks to provide a transparent and appropriately qualified assessment of the available evidence.

Materials and Methods

1. Review Design and Reporting Framework

The purpose of this study was to systematically review the existing literature on heat stress and water restriction effects on the physiological response of sheep and goats and incorporate and discuss the findings with the goal of summarizing the available data. Special consideration was devoted to the physiological/ adaptive responses to combined thermal and water-related stress such as thermoregulation, hydration, electrolyte homeostasis, renal function, hematologic/bio-chemical responses, endocrine regulation, and metabolic adaptation.

This review was also intended to compare the sheep and goat responses where the evidence was available, and to understand current limitations and gaps in the literature. The review process was organized based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. Study identification, screening, eligibility assessment, and inclusion were documented using a PRISMA 2020 flow diagram.

2. Information Sources and Literature Search

A systematic literature search was conducted in four electronic databases: PubMed, Europe PMC, AGRICOLA, and OpenAlex. Searching was conducted by 1 researcher on 26/10/2026, and on 26/10/2026 all four databases were searched to locate studies examining the effects of heat exposure and limited water availability on sheep and goats.

The search strategy involved using keywords for both animal species, heat exposure, and water restriction or deprivation. The following general search string was used:

["sheep" OR "ovine" OR "goat" OR "caprine" OR "small ruminant*"] AND ["heat stress" OR "heat exposure" OR "thermal stress"] AND ["water restriction" OR "water deprivation" OR dehydration]

The search strategy was adapted to the search requirements of each database. Additional terms related to physiological and adaptive responses were considered where appropriate to identify relevant studies.

3. Eligibility Criteria

Eligibility criteria were established before screening to identify studies relevant to the physiological responses of sheep and goats to heat exposure and restricted water availability [Table 1]. Original research studies involving sheep and/or goats were considered eligible when they investigated water restriction or deprivation under heat exposure or documented hot environmental conditions and reported at least one relevant physiological or adaptive response. Studies were classified according to the nature of heat exposure and water restriction to distinguish direct evidence of combined stress from studies conducted under naturally hot conditions. Detailed inclusion and exclusion criteria are presented in Table 1.

Table 1. Eligibility criteria

Domain	Inclusion criteria	Exclusion criteria
Population	Sheep and/or goats, regardless of breed, age, or sex	Studies involving other animal species without separately extractable sheep or goat data
Exposure	Water restriction or deprivation under experimentally imposed heat exposure or documented hot environmental conditions	Studies investigating water restriction without relevant heat exposure, or heat exposure without water restriction
Study design	Experimental original research with	Studies lacking sufficient

	sufficient information on exposure conditions and study design	information to characterize the exposure conditions
Outcomes	At least one relevant physiological, thermoregulatory, hydration, renal, hematological, biochemical, endocrine, or metabolic outcome	Studies without relevant physiological or adaptive outcomes
Publication type	Original research articles reporting primary data	Review articles, editorials, letters, and other non-original publications
Evidence classification	Studies with controlled combined heat and water restriction, or water restriction under documented hot environmental conditions	Studies in which relevant heat exposure or water restriction could not be established

Relevant review articles were retained for background information and reference searching but were not included in the primary evidence synthesis.

4. Classification of Evidence

To distinguish the strength and context of the available evidence, the included studies were classified into two main evidence tiers.

Tier 1: Controlled combined exposure

This category included studies in which heat exposure and water restriction or deprivation were experimentally imposed or controlled. These studies provided the most direct evidence concerning physiological responses under combined thermal and water-related stress.

Tier 2: Water restriction under documented hot conditions

This category included studies investigating water restriction or deprivation under documented natural environmental heat or relevant hot study conditions, without a separately estimable experimental heat-by-water interaction. Tier 2 studies were retained because they provide relevant evidence concerning animal responses to restricted water availability under hot conditions. However, their findings were not interpreted as demonstrating an independent interaction between heat exposure and water restriction.

5. Study Selection Process

A total of 502 records were identified from four databases. After removing 61 duplicates, 441 records were screened based on their titles and abstracts. Following screening, 66 reports were selected for full-text assessment. Of these, 31 were excluded according to the eligibility criteria, leaving 35 reports representing 30 independent experimental cohorts for the final review.

6. Data Extraction

Relevant information was identified, abstracted, and arranged in a structured matrix of evidence from the reports supplied. The data obtained comprised the publication information, animal species and breed, sample size, heat exposure and water restriction procedures, experimental design, comparison strains, and reported physiological, biochemical and endocrine responses. The direction of responses was also noted, along with the main findings and the statistical significance of the findings. Any methodological limitations relevant to the main findings were also noted.

The outcomes that were extracted were then related to the various major physiological domains so that they could be compared between sheep and goats and the available evidence could then be synthesized.

7. Data Synthesis and Analysis

Selected results were distributed across seven physiological domains. A narrative synthesis was conducted because there was heterogeneity in the animals used, the environmental conditions,

environmental exposure studies, and measuring the outcomes. Responses were grouped into the following four categories: increased, decreased, unchanged, mixed, and not evaluable. Data have been compared descriptively between the physiological domains and between sheep and goats, where data were available. Reports from the same experimental cohort were linked to avoid double-counting.

Selected outcomes were subjected to exploratory exact two-sided sign tests to explore the consistency of directions of responses. These tests were described rather than treated as estimates of treatment effects. Meta-analysis was not performed because of insufficient comparability among study designs, exposure protocols, outcome definitions, and reported data.

Results

1. Study selection

A total of 502 records were identified through searches of four databases: PubMed [n = 102], Europe PMC [n = 272], AGRICOLA [n = 61], and OpenAlex [n = 67]. After removing 61 duplicate records, 441 unique records remained for screening. Of these, 375 were removed from consideration based on title and abstract screening and 66 reports were assessed by full-text. After assessing for eligibility, 31 reports were discarded and 35 studies were added to the review. The study selection process is presented in Figure 1.

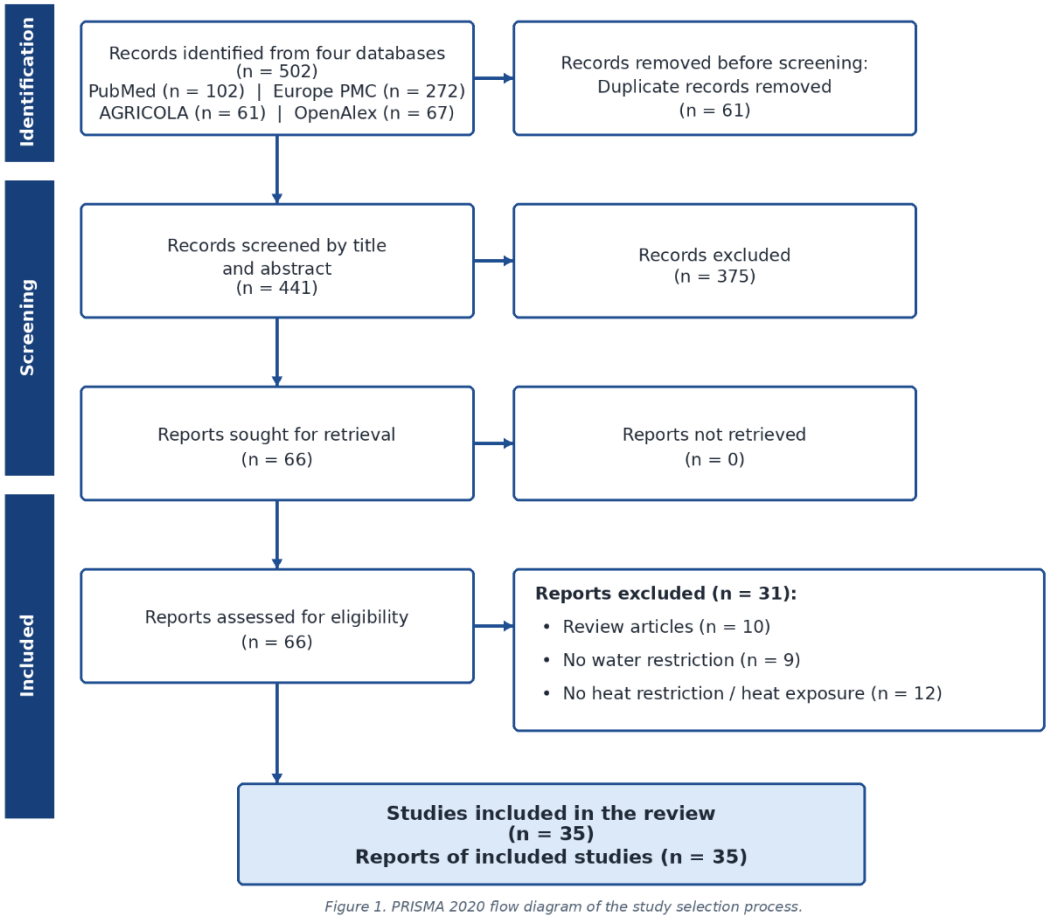


Figure 1. PRISMA 2020 flow diagram of the study selection process.

Figure 1. PRISMA 2020 flow diagram for the systematic review, including searches of databases.

2. Characteristics of the included cohorts

The final evidence base comprised 35 eligible reports representing 30 independent animal cohorts. Of these, 9 were Tier 1 and 21 were Tier 2. In terms of species distribution, 12 cohorts included sheep, 14 included goats, and four included both species. Reports derived from the same

experimental cohort were linked to avoid double-counting, while companion reports contributing distinct outcomes were retained in the synthesis.

The included studies were published between 1980 and 2026, indicating that the available evidence spans more than four decades.

Table 2. Composition of the included evidence base [independent cohorts].

Characteristic	Category	Tier 1[n]	Tier 2[n]	Total cohorts[n]
Animal species	Sheep	3	9	12
	Goats	4	10	14
	Sheep and goats	2	2	4
Evidence tier	Tier 1	9	—	9
	Tier 2	—	21	21
Total		9	21	30
Publication period	1980–1989	—	—	2
	1990–1999	—	—	4
	2000–2009	—	—	7
	2010–2019	—	—	12
	2020–2026	—	—	5

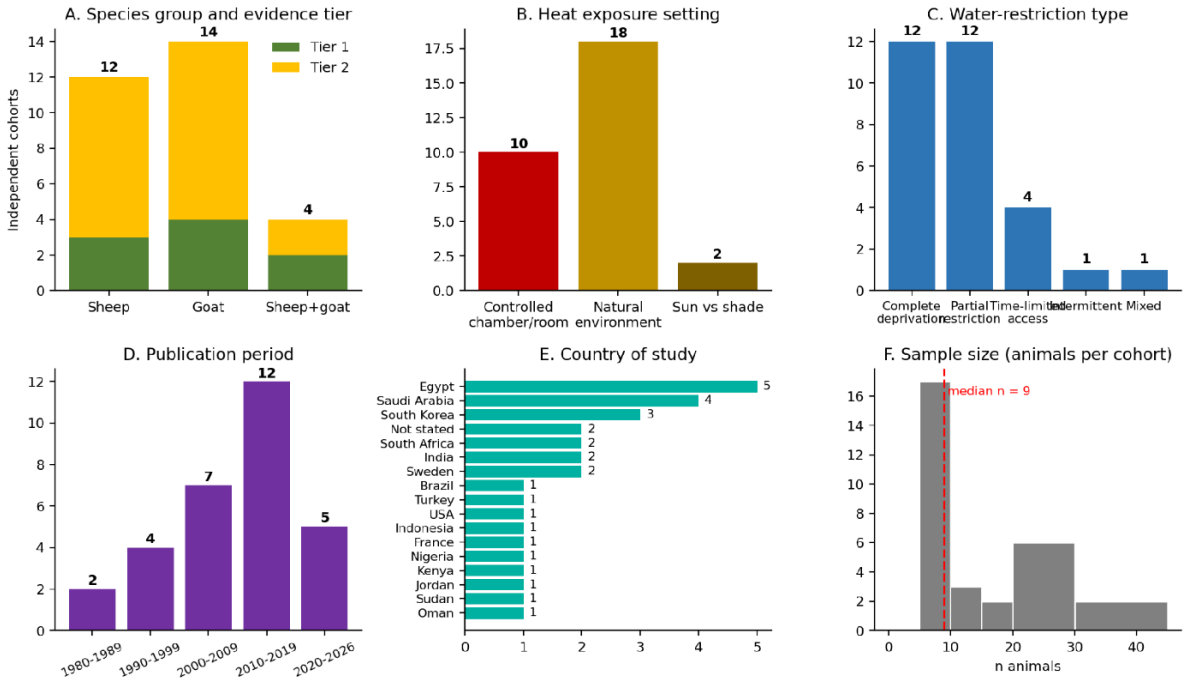


Figure 2. Distribution of the cohorts by species, heat setting, restriction type, publication period, country and sample size.

Table 3. Characteristics of the included studies

Study title	First author	Year	Animal species	Evidence tier
Physiological and Metabolic Responses to Water Restriction in Ewes Under Semi-Arid Conditions	Costa et al.	2025	Sheep	Tier 2

Study title	First author	Year	Animal species	Evidence tier
Proposing a Strategy Based on Body-Thermal Status to Improve the Welfare of Heat-Stressed and Water-Deprived Goats[Capra hircus]	Samara et al.	2024	Goat	Tier 2
Behavioral and Physiological Changes During Heat Stress in Corriedale Ewes Exposed to Water Deprivation	Ghassemi Nejad & Sung	2017	Sheep	Tier 2
Physiological and Behavioral Basis for the Successful Adaptation of Goats to Severe Water Restriction Under Hot Environmental Conditions	Kaliber et al.	2016	Goat	Tier 2
Wool Cortisol Is a Better Indicator of Stress Than Blood Cortisol in Ewes Exposed to Heat Stress and Water Restriction	Ghassemi Nejad et al.	2014	Sheep	Tier 2
Effects of Water Restriction After Feeding During Heat Stress on Nutrient Digestibility, Nitrogen Balance, Blood Profile and Characteristics in Corriedale Ewes	Ghassemi Nejad et al.	2014	Sheep	Tier 2
Effects of Dehydration and Rehydration on Thermoregulatory Sweating in Goats	Baker	1989	Goat	Tier 1
Applicability of Thermography as a Potential Non-Invasive Technique to Assess the Body-Thermal Status of Heat-Stressed and Water-Deprived Goats[Capra hircus]	Samara et al.	2024	Goat	Tier 2
Thermoregulation and Water Balance in Fat-Tailed Sheep and Kacang Goat Under Sunlight Exposure and Water Restriction in a Hot and Dry Area	Rahardja et al.	2011	Sheep + Goat	Tier 1
Mild Heat Stress and Short Water Restriction Treatment in Lactating Alpine and Saanen Goats	Jaber et al.	2019	Goat	Tier 2
Effect of Water Restriction on Lactation Performance of Aardi Goats Under Heat Stress Conditions	Alamer	2009	Goat	Tier 2
Physiological Responses, Feed Intake, Urine Volume and Serum Osmolality of Aardi Goats Deprived of Water During Spring and Summer	El-Nouty et al.	1990	Goat	Tier 2
Water Restriction in Goats During Hot-Dry Season in the Humid Tropics: Feed Intake and Weight Gain	Abioja et al.	2010	Goat	Tier 2
Effects of Water Restriction Following Feeding During Heat Stress on Behavior and Physiological Parameters of Corriedale Ewes	Ghassemi Nejad et al.	2015	Sheep	Tier 2
Determining the Minimum Time Interval for Completely Eliminating the Carryover Effect of Dehydration in Heat-Stressed Goats	Samara et al.	2024	Goat	Tier 2
Effects of Dehydration and Heat Stress on Food Intake and Dry Matter Digestibility in East African Ruminants.	Maloiy et al.	2008	Sheep + Goat	Tier 1
The Effects of Temperature Elevation and Water	Lowe et al.	2002	Sheep	Tier 1

Study title	First author	Year	Animal species	Evidence tier
Deprivation on Lamb Physiology, Welfare, and Meat Quality.				
Renal Efficiency Underlies Adaptive Heterothermy of Heat-Stressed Hypohydrated Goats.	Al-Tamimi et al.	2019	Goat	Tier 1
Effect of Water Scarcity During Thermal-Humidity Exposure on the Mineral Footprint of Sheep.	Ghassemi Nejad et al.	2020	Sheep	Tier 2
Response of Ossimi Sheep to Dehydration or/and Starvation for Different Periods Under Summer Conditions of Egypt	Abdel-Khalek et al.	2002	Sheep	Tier 2
Thermoregulation and Water Balance as Affected by Water and Food Restrictions in Sudanese Desert Goats Fed Good-Quality and Poor-Quality Diets	Ahmed & El Kheir	2004	Goat	Tier 2
Performance, Heat Tolerance Response, and Blood Metabolites of Water-Restricted Xhosa Goats Supplemented with Vitamin C	Akinmoladun et al.	2020	Goat	Tier 2
Effect of Water Restriction on Physiological Responses and Certain Reproductive Traits of Malpura Ewes in a Semiarid Tropical Environment	Kumar et al.	2016	Sheep	Tier 2
Physiological Responses of Indigenous Sheep Under Water Restriction	Gupta et al.	2016	Sheep	Tier 2
Major Plasma Cations and Aldosterone Concentration of Sheep and Goats as Affected by Some Environmental Conditions	Assimawy & Ibrahim	1999	Sheep + Goat	Tier 2
A Comparative Thermophysiological Study on Water-Deprived Goats and Camels	Samara et al.	2012	Goat	Tier 2
Dehydration Increases the Magnitude of Selective Brain Cooling Independently of Core Temperature in Sheep	Fuller et al.	2007	Sheep	Tier 1
Reproductive Period Affects Water Intake in Heat-Stressed Dehydrated Goats	Olsson et al.	1996	Goat	Tier 1
Effects of Season, Housing Environment and Water Deprivation on Rectal and Skin Temperature Regulation in Barki Desert Sheep	El-Zeiny	2011	Sheep	Tier 2
Feed Digestibility, Digesta Passage and Faecal Microbial Biomass in Desert-Adapted Goats Exposed to Mild Water Restriction	Ramadhan et al.	2021	Goat	Tier 2
Stress Hormone Responses of Sheep to Food and Water Deprivation at High and Low Ambient Temperatures	Parrott et al.	1996	Sheep	Tier 1
Physiological Responses of Desert Barki Sheep and Goats to Dehydration and Rehydration Under the Arid Conditions of North Coastal Zone of Egypt	Abdel Khalek et al.	2012	Sheep + Goat	Tier 2
Physiological Responses of Barki Sheep to Water Restriction Under Desert Conditions	Abdel-Fattah	2008	Sheep	Tier 2

Study title	First author	Year	Animal species	Evidence tier
Fluid Balance During Heat Stress in Lactating Goats	Olsson & Dahlborn	1989	Goat	Tier 1
Water Balance of Goats in Jeneponto – South Sulawesi Under Sunlight Exposure and Water Restriction	Rahardja	2007	Goat	Tier 1

3. Direction of the reported responses

Table 4 and Figures 3 and 4 summarise the direction of each outcome relative to the study's own water-adequate or euhydrated comparison. The most consistent patterns concerned hydration and intake: body weight decreased in 11 cohorts and feed intake in 10; water intake decreased in 7 cohorts, and plasma osmolality increased in 7. Thermoregulatory outcomes were heterogeneous: rectal or core temperature increased in 6 cohorts, was unchanged in 3 and showed a mixed response in 6; respiration rate increased in 4, decreased in 5, remained unchanged in 2 and was mixed in 2.

As an exploratory check of directional consistency, exact two-sided sign tests were applied to the seven indicators with at least four cohorts showing an increase or decrease [Table 4]. The tests indicated directional consistency for body weight [11/11 decreases, $p = 0.001$], feed intake [10/10 decreases, $p = 0.002$], plasma osmolality [7/7 increases, $p = 0.016$], and water intake [7/7 decreases, $p = 0.016$]. Rectal/core temperature also showed six increases among six directional cohorts [$p = 0.031$], whereas haematocrit/PCV showed five increases among five directional cohorts [$p = 0.063$]. Respiration rate was split [4 increases, 5 decreases; $p = 1.000$]. These tests ignore effect size and precision, assume independence between cohorts, exclude unchanged and mixed findings, and were not corrected for multiple testing. For rectal/core temperature, only 6 of 15 cohorts with an extractable contrast showed an increase; the remaining cohorts were unchanged or mixed.

Table 4. Outcome direction by indicator [unique independent cohorts], dominant direction and exploratory sign test.

Domain	Indicator	N coded	↑	↓	↔	Mixed	Dominant direction	Sign test p	Sheep[↑ ↓ ↔ M]	Goat[↑ ↓ ↔ M]
Thermoregulation	Rectal/core temperature	15	6	–	3	6	↑ 6/15	0.031	↑2 ↔2 M4	↑4 ↔2 M2
	Core temperature oscillation	1	1	–	–	–	↑ 1/1	–	–	↑1
	Respiration rate	13	4	5	2	2	↓ 5/13	1.000	↑2 ↓2 M2	↑2 ↓3 ↔2
	Heart rate	5	1	1	1	2	Mixed 2/5	–	↔1 M2	↑1 ↓1
	Skin/surface temperature	2	1	–	1	–	↑ 1/2	–	↔1	↑1
	Sweating rate	2	–	1	1	–	↓ 1/2	–	↔1	↓1
	Selective brain cooling	1	1	–	–	–	↑ 1/1	–	↑1	–
	Heat production	1	–	1	–	–	↓ 1/1	–	↓1	↓1
Water balance/hydration	Water intake	7	–	7	–	–	↓ 7/7	0.016	↓3	↓4
	Plasma/serum	8	7	–	–	1	↑ 7/8	0.016	↑1 M1	↑6

	osmolality									
	Plasma/serum sodium	3	3	–	–	–	↑ 3/3	–	↑1	↑3
	Plasma volume / total body water	2	–	2	–	–	↓ 2/2	–	↓2	↓2
	Water turnover / evaporative loss	3	–	3	–	–	↓ 3/3	–	↓1	↓2
	Urine output/frequency	3	–	3	–	–	↓ 3/3	–	↓1	↓2
	Fecal water/moisture	2	–	2	–	–	↓ 2/2	–	–	↓2
Hematology	Hematocrit / PCV	8	5	–	2	1	↑ 5/8	0.063	↑1 ↔2 M1	↑4 ↔1
	Hemoglobin	5	3	–	1	1	↑ 3/5	–	↑2 ↔1 M1	↑2
	Red blood cell count	3	3	–	–	–	↑ 3/3	–	↑2	↑1
	White blood cell count	2	1	–	1	–	↑ 1/2	–	↔1	↑1
Biochemistry / metabolic	Plasma urea / BUN	4	3	–	1	–	↑ 3/4	–	↑2 ↔1	↑1
	Total protein	3	3	–	–	–	↑ 3/3	–	↑2	↑2
	Glucose	2	–	1	1	–	↓ 1/2	–	↓1 ↔1	–
	Cholesterol	1	–	1	–	–	↓ 1/1	–	↓1	–
	Liver enzymes[ALT/AST]	2	1	1	–	–	↑ 1/2	–	↑1 ↓1	–
	Other electrolytes/minerals	2	–	1	1	–	↓ 1/2	–	↓1 ↔1	–
Endocrine	Cortisol[blood]	3	–	–	2	1	↔ 2/3	–	↔2	M1
	Cortisol[wool]	1	1	–	–	–	↑ 1/1	–	↑1	–
	ADH / vasopressin	2	2	–	–	–	↑ 2/2	–	–	↑2
	Other hormones	0	–	–	–	–	–	–	–	–
Behavior	Standing / walking time	2	–	2	–	–	↓ 2/2	–	↓1	↓1
	Sitting/lying time	2	2	–	–	–	↑ 2/2	–	↑1	↑1

	Drinking latency	1	–	1	–	–	↓ 1/1	–	–	↓1
Production/intake/ digestion	Feed / DM intake	11	–	10	1	–	↓ 10/11	0.002	↓2	↓9 ↔1
	Body weight/gain	13	–	11	2	–	↓ 11/13	0.001	↓4 ↔2	↓7 ↔1
	Digestibility	3	1	1	–	1	↑ 1/3	–	↓1 M1	↑1 ↓1
	Milk yield	2	–	1	1	–	↓ 1/2	–	–	↓1 ↔1

N coded = cohorts with an extractable direction[↑+↓+↔+Mixed]. Dominant direction = most frequent category / N coded. Sign test only where ≥4 cohorts showed ↑ or ↓. A sheep + goat cohort can appear under both species.

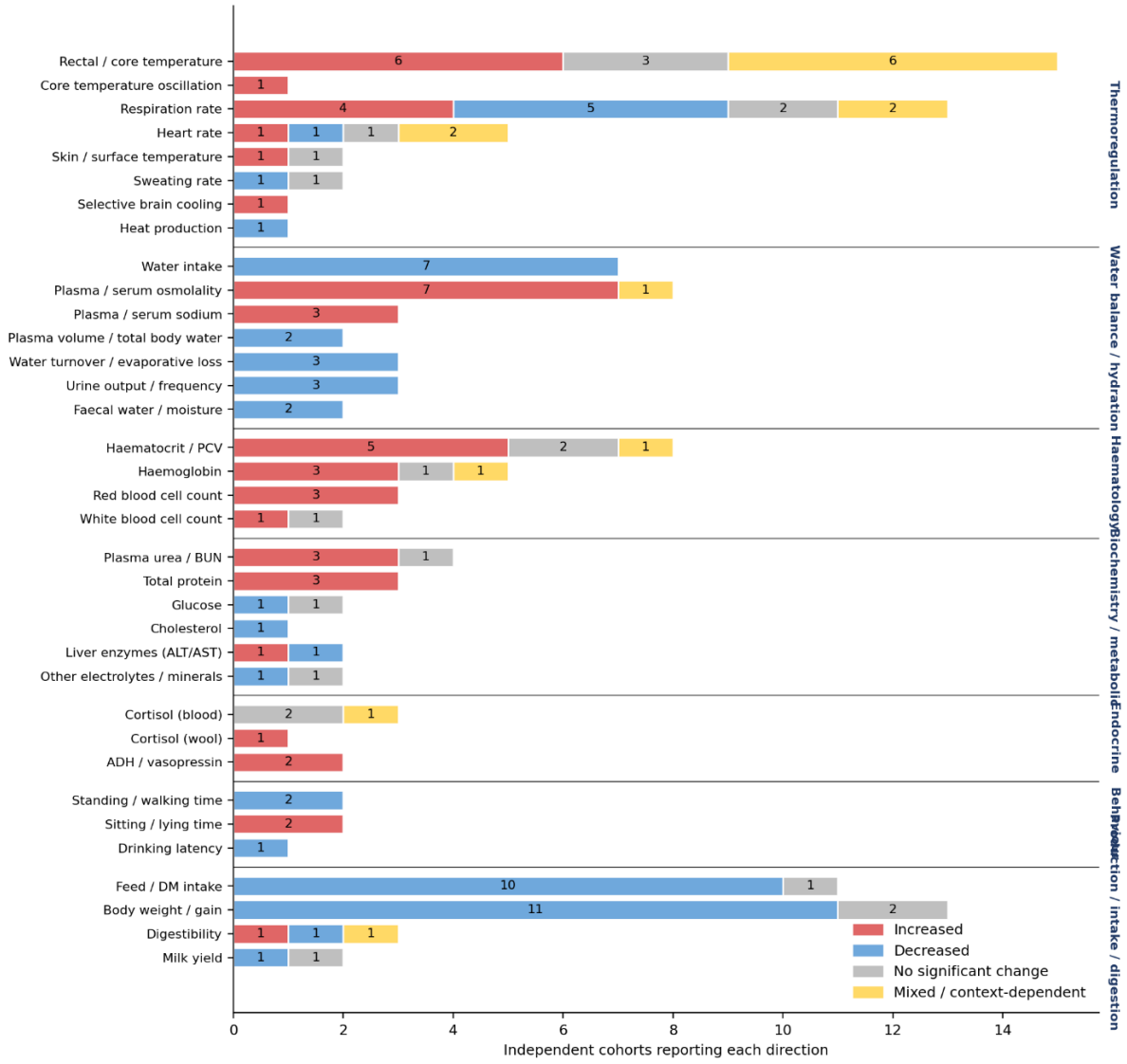


Figure 3. Evidence map: number of independent cohorts reporting each direction, by indicator and domain.

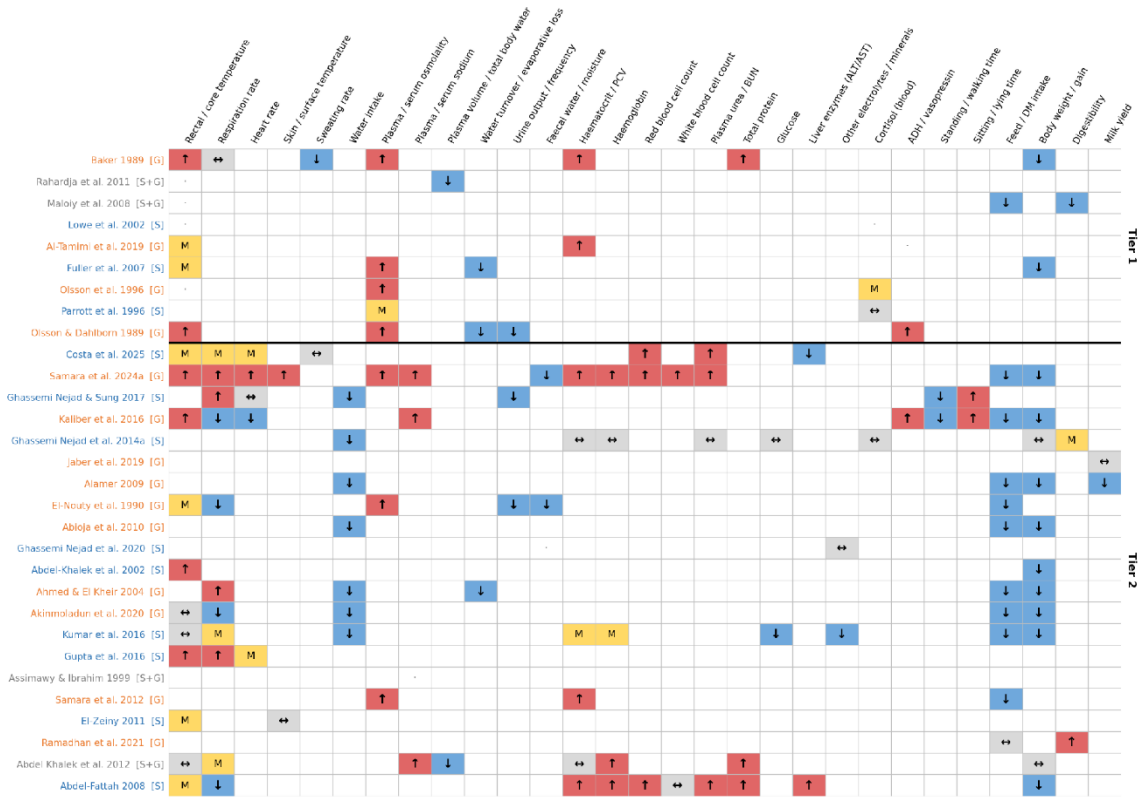


Figure 4. Effect-direction plot: direction of response by cohort and indicator[only indicators coded in ≥2 cohorts].

↑ increase, ↓ decrease, ↔ no significant change, M mixed/context-dependent. Label color: blue = sheep, orange = goat, grey = both. Cohorts sorted by tier then study.

4. Findings by outcome domain

Thermoregulatory responses varied across study protocols and measurement times. In Ahmed and El Kheir, water restriction during a hot dry summer increased afternoon respiratory rate, while rectal temperature responses depended on feed type and time of measurement[18]. Similarly, Lowe reported associations between respiratory rate, rectal temperature, and temperature-humidity index[19]. Other studies reported both increased and decreased respiratory rates, indicating considerable variation across exposure conditions.

Hydration-related changes were more consistent, with increased plasma or serum osmolality reported in several cohorts. Ahmed and El Kheir also documented reduced water turnover and evaporative water loss, while urinary and faecal losses varied with forage type. Feed intake decreased in 10 cohorts and body weight or gain in 11. In Abioja, daily weight gain declined across increasing water-restriction levels[20]. Digestibility responses were inconsistent: it decreased significantly in goats in Maloiy, whereas the reduction in sheep was not significant, and increased between two restricted-water levels in Ramadhan[21][22].

Endocrine and behavioral outcomes were reported less frequently. ADH increased in two cohorts, while blood cortisol was unchanged in two and showed mixed responses in another. Wool cortisol increased following a three-hour delay in water access in Ghassemi Nejad, although blood cortisol did not differ significantly[23]. Behavioral changes included reduced standing or walking, increased lying time, and shorter drinking latency in some cohorts.

5. Sheep and goats

Both sheep and goats exhibited changes in hydration, thermoregulatory, hematological, and production-related indicators in response to water restriction under hot environmental conditions. The direction and magnitude of these responses varied across studies and experimental protocols

[Table 5]. In sheep, respiration rate decreased in two cohorts and increased in two, whereas in goats it decreased in three cohorts and increased in two. Rectal temperature increased in four goat cohorts and two sheep cohorts, while unchanged and mixed responses were also reported, particularly in sheep.

Direct comparisons involving both species within the same experiment provided additional insights. In Rahardja, water restriction reduced water intake, urinary water loss, and evaporative water loss in both species, although sheep showed higher absolute water losses, with broadly comparable proportions of total water loss. Maloiy reported reduced intake in both species, while digestibility decreased significantly in goats and showed a less consistent response in sheep. Abdel Khalek found a significant reduction in respiration rate in sheep, whereas body water decreased and sodium concentrations increased in both species[24]. Overall, the reported findings demonstrate physiological and metabolic responses to water restriction in both sheep and goats, with variations across specific outcomes. Overall difference in response between the two species is suggested by the available comparisons, but is not consistently made.

Table 5. Direction counts by species[indicators coded in both species].

Indicator	Sheep cohorts[↑ ↓ ↔ Mixed]	Goat cohorts[↑ ↓ ↔ Mixed]
Rectal/core temperature	↑2 ↔2 M4	↑4 ↔2 M2
Respiration rate	↑2 ↓2 M2	↑2 ↓3 ↔2
Heart rate	↔1 M2	↑1 ↓1
Skin/surface temperature	↔1	↑1
Sweating rate	↔1	↓1
Heat production	↓1	↓1
Water intake	↓3	↓4
Plasma/serum osmolality	↑1 M1	↑6
Plasma/serum sodium	↑1	↑3
Plasma volume / total body water	↓2	↓2
Water turnover / evaporative loss	↓1	↓2
Urine output/frequency	↓1	↓2
Hematocrit / PCV	↑1 ↔2 M1	↑4 ↔1
Hemoglobin	↑2 ↔1 M1	↑2
Red blood cell count	↑2	↑1
White blood cell count	↔1	↑1
Plasma urea / BUN	↑2 ↔1	↑1
Total protein	↑2	↑2
Cortisol[blood]	↔2	M1
Standing / walking time	↓1	↓1
Sitting/lying time	↑1	↑1
Feed / DM intake	↓2	↓9 ↔1
Body weight/gain	↓4 ↔2	↓7 ↔1
Digestibility	↓1 M1	↑1 ↓1

6. Evidence for adaptive mechanisms

Several physiological and behavioral changes observed across the included cohorts were consistent with mechanisms involved in water conservation and thermoregulation. They consisted of decreased urinary water loss, endocrine and osmoregulatory changes, as well as respiration and

behavioral responses. These results must, however, be considered as physiological reactions, and not as guarantees of adaptation, because there are also physiological stress factors associated with dehydration. Table 6 differentiates between immediate outcomes that are measured directly and outcomes that are understood to be processes from which they arise or are produced.

Table 6. Mechanisms, number of supporting cohorts and strength of inference.

Mechanism	Cohorts	Type of evidence	Caution
Urinary/fecal water conservation	4	Measured outcomes[urine volume/frequency, fecal water]	Frequency is not volume in S003; measured at different times
Lower evaporative loss/water turnover/heat production	5	Measured[turnover, heat production, sweating]	Fuller/Strauss are one probable cohort; few cohorts
Changes in respiratory rate	5	Respiration measured; water saving is inferred	Respiration rose in 4 other cohorts; direction is context-dependent
Osmoregulatory/endocrine response[ADH, osmolality, sodium]	9	Measured	Also marks the dehydration load, not only adaptation
Selective brain cooling	1	Measured[Fuller 2007]; Strauss 2015 related report	One cohort; independence of the two reports unresolved
Reduced activity[less walking/standing, more lying]	2	Behavior measured; benefit inferred	Heat-saving effect not tested
Hemoconcentration/fluid shift	7	Measured	Reflects dehydration; not shown to be protective
Reduced intake and weight	14	Measured	Consequence and possible adaptation cannot be separated

Discussion

The present systematic review synthesized 35 reports representing 30 independent experimental cohorts to examine the physiological responses and potential adaptive mechanisms of sheep and goats exposed to water restriction or deprivation under hot environmental conditions. The results show that these stressors impact multiple interrelated physiological and productive systems, especially thermoregulation, hydration, and metabolism. However, the responses differed among studies, and thus it depends on exposure conditions, restriction protocols, and animal characteristics.

1. Thermoregulation Under Heat Stress and Water Restriction

Thermoregulatory responses were heterogeneous across the included cohorts. Six cohorts recorded a rise in rectal/core temperature, three had no change, and six had mixed responses. Similarly, four cohorts had a higher respiratory rate while five cohorts had a lower respiratory rate. This variation indicates that animals do not react to a reduced water supply in hot environments in a singular thermoregulatory manner.

Under heat exposure, respiratory and cutaneous evaporation contribute to heat dissipation but also increase body-water loss. The physiological challenge, then, to lower the body temperature through evaporative cooling, may be made challenging by restricted water availability. Respiratory, peripheral and behavioral adaptive responses can vary as a function of environmental heat load and magnitude and duration of water restriction.

Ahmed and El Kheir demonstrated this complexity, reporting increased afternoon respiratory rate under water restriction during a hot dry summer, whereas rectal temperature responses varied

according to feed type and measurement time. They also point to the need to separate out water restriction from food restriction since the water and food restrictions did not lead to the same thermoregulatory responses. Similarly, Lowe reported strong associations between respiratory rate, rectal temperature, and temperature-humidity index.

Reductions in respiratory rate observed in some cohorts, such as Kaliber and Abdel Khalek, may be due to variations in exposure, measurement time, and physiological status[25] . Thus, alteration of the respiratory rate does not necessarily reflect heat tolerance or decreased water needs. Rather, thermoregulatory responses need to be considered alongside hydration indicators and environmental conditions.

2. Hydration, Water Conservation, and Productive Responses

The changes in indicators of hydration were some of the most consistent findings in this review. Water intake decreased in all seven cohorts with an evaluable directional response, while plasma or serum osmolality increased in seven of eight cohorts. No control group and all three groups with evaluable directional findings observed an increase in plasma sodium. These changes as a whole represent a change in body-fluid regulation during limited water availability.

Reductions in water turnover, evaporative water loss, and urinary output reported in several studies suggest that water conservation may contribute to maintaining fluid balance. In particular, Ahmed and El Kheir demonstrated reductions in water turnover and evaporative losses, while urinary and fecal water losses were influenced by dietary conditions. These findings highlight the interaction between water availability and nutritional factors in determining overall water balance.

Hematocrit, packed cell volume, hemoglobin, and red blood cell counts increased in several cohorts. Such changes may partly reflect hemoconcentration associated with reduced plasma volume. Although these responses are compatible with physiological adjustments during dehydration, they should not be considered evidence of improved physiological function, as they may also indicate the burden of reduced body-water availability.

Restricted water availability was also associated with reduced feed intake in ten cohorts and reduced body weight or body-weight gain in eleven cohorts. These changes may reflect the combined consequences of altered hydration, reduced nutrient intake, and changes in body-water content. Consequently, body-weight loss during short-term water restriction should not be interpreted exclusively as tissue loss.

Digestibility responses were less consistent. Maloiy reported a significant reduction in dry-matter digestibility in goats, whereas the corresponding decrease in sheep was not statistically significant. In contrast, Ramadhan reported increased digestibility between two restricted-water levels, although this comparison did not establish an improvement relative to unrestricted water availability. Milk production findings were also variable: Alamer reported reduced milk yield, whereas Jaber found that milk production was maintained during their short restriction protocol despite changes in milk components[26][27]. These findings indicate that productive responses may depend on restriction severity, duration, dietary conditions, and physiological status.

3. Potential Adaptive Mechanisms

The following studies identified some physiologic or behavioral responses that may play a role in water conservation and thermoregulation: These included decreased evaporative water loss, alterations in urinary water loss, changes in osmoregulatory hormones and indicators, decreased physical activity, and alterations in respiratory responses. Osmoregulatory responses were particularly evident through increased plasma osmolality and sodium concentrations, together with increased antidiuretic hormone [ADH] in the two cohorts reporting this outcome. ADH contributes to renal water reabsorption and therefore represents a plausible component of the physiological response to reduced water availability. Conversely, decreases in water excretion can aid in preventing additional fluid loss. These responses, however, are also associated with changes in hydration status and are unable to make a stand-alone determination of successful adaptation.

Changes in evaporative water loss, sweating, respiratory rate, and heat production may also be involved in balancing thermal regulation with water conservation. However, the direction of the respiratory-rate responses did not always agree among different studies, suggesting that the decreased panting is not always present. Selective brain cooling, reported in a limited number of related publications, provides another potential thermoregulatory mechanism, although the evidence is insufficient to establish its broader contribution across sheep and goats.

Behavioral changes, including reduced standing and walking and increased lying time, may potentially reduce activity-related heat production. The studies included, however, failed to directly show that these changes resulted in an improvement in thermal balance or water-saving. Likewise, physiological responses to water restriction such as a decrease in feed intake and body weight cannot simply be assumed to be adaptive responses.

Overall, the evidence suggests that sheep and goats employ several physiological responses that may contribute to maintaining homeostasis under hot and water-limited conditions. However, a clear difference needs to be noted between a regulatory response which may save water and a physiological change that is a sign of dehydration or water reduction in productive performance. The effectiveness and long-term protective value of these mechanisms remain insufficiently established.

4. Comparative Responses of Sheep and Goats

Water restrictions in hot conditions resulted in changes in hydrometabolic and hematological responses, as well as productive performance, in both sheep and goats. However, the available findings did not establish a consistent overall advantage of either species.

Variations in the responses dependent upon the respiratory rate were observed in both species, and increases in rectal or core temperature were recorded in four cohorts of goats and two cohorts of sheep. Here, similarities and differences were drawn between the species at the physiological level. Rahardja found that water intake, urinary water loss, and evaporative water loss for both species decreased, but the absolute water loss varied. Maloiy reported reduced feed intake in both species, with a significant reduction in digestibility in goats but a less consistent response in sheep. Abdel Khalek also reported differences in respiratory-rate responses, while reductions in body water and increases in sodium concentrations were observed in both species.

The results are evidence that differences in the physiological effects measured might occur by species. However, no general pattern or conclusion can be drawn for tolerance between sheep and goats in regard to heat stress and reduced water availability. Variations in the breed, physiological state, environment, and experimental procedure should be taken into account and considered when interpreting the results.

5. Evidence Gaps and Future Research Directions

Despite the physiological information provided by the included studies, several important evidence gaps remain. First, most available studies investigated water restriction under naturally hot environmental conditions, whereas fewer studies experimentally controlled both heat exposure and water availability. Hence, the importance of these stressors for independence and their combined interaction is poorly understood. Factorial experimental designs incorporating separate heat-exposure and water-restriction conditions are particularly needed to establish whether their combined effects differ from their individual effects.

Second, there is limited evidence for some possible adaptive mechanisms. A comparatively small number of independent studies examined in-depth endocrine responses, selective brain cooling, behavioral adjustments, and direct water conservation measurements. Rarely integrated studies are needed for evaluation of the interaction between those mechanisms and the measure of physiologic benefits or not.

Third, direct comparisons between sheep and goats under well-controlled experimental conditions are still rather limited. Further research should continue on both species, in similar breeds

under similar nutrition conditions, heat loads, and restriction protocols to determine inter-species differences in water conservation and thermoregulation.

Additionally, there was also significant heterogeneity across studies in exposure methods, environmental reporting, outcome measurements, and the numerical data, which hampered the possibilities for comparison and quantitative meta-analysis. Information for detailed, specifically therapy comparisons was also limited in some reports.

Conclusion

This systematic review shows that there is a connection of multiple physiological responses between water restriction and hot environmental conditions in sheep and goats, which involves alteration of thermoregulation status, hydration status, and productive performance. Water intake, feed intake, and body weight appeared to be the most consistently decreased parameters, whereas plasma osmolality and hematological parameters were increased. Variation in thermoregulatory responses, however, did exist between studies, and there was no consistent overall difference in the thermoregulatory response of sheep when compared to goats, with the available evidence. There are several physiological and behavioral responses which can also aid in water conservation and thermal regulation, but not all these are proof of adaptation, since some also indicate the effects of dehydration. One such evidence gap is the limited number of available controlled combined-exposure studies. Comparative studies with factorial designs merit addressing under standardized conditions to make the deconvolution of the heat stress × water restriction interaction in these systems, as well as species differences, and differentiate potentially protective adaptive mechanisms from stress responses.

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