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Effect of Excessive Environmental Heat Load on Digestibility, Energy Balance, and Urea Recycling in the Mediterranean (Member) Goat

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Abstract— This study investigates the energy and nitrogen economy of the Mediterranean goat across diverse environmental conditions, emphasizing the influence of heat stress and shelter on animal productivity. Environmental factors such as water availability, food quality, and heat stress affect the animal's capacity to convert indigestible plant components into digestible food and sustain energy balance. In particular, heat stress causes a significant decrease in the goat's food by 27.49% and by 34.85% in alfalfa hay and wheat straw respectively, leading to a loss of body mass, even when offered high-quality food such as alfalfa hay. However, when sheltered from direct sunlight, the goat can maintain an energy balance on any diet, a significant decrease in body mass was recorded, with a reduction of 10.59% for alfalfa hay and 17.79 ± 3.0% for wheat straw. Heat stress also impairs the goat's ability to maintain a balanced nitrogen economy, reducing nitrogen loss through excretion during heat load conditions and high-protein food digestion. The study found that the average urea recycling rate in goats kept in a shelter was 36%, which was significantly higher than the rate observed in goats exposed to heat stress, which was only 19.6%. Moreover, the amount of recycled urea was also higher in the shelter at 91% compared to 69.9% in the reflected heat stress recorded when the goats were maintained on a diet of wheat straw.

As the goat cannot reduce its metabolic rate, a negative energy balance occurs, resulting in body mass loss. The quality of food and heat stress are critical determinants of the goat's food consumption, with high heat load reducing appetite. This study concludes that sheltered conditions, providing protection from direct sunlight, are necessary to sustain productivity and maintain a stable body mass on any diet. Furthermore, maintaining a balanced nitrogen balance can be challenging for animals consuming low-protein food, particularly under suboptimal feeding conditions. The study's findings have implications for the broader issue of global warming, as rising temperatures could increase heat stress and reduce food consumption and productivity in animals, with potentially negative consequences for agriculture and food security. Therefore, protecting animals from heat stress through adequate shelter and management practices is essential to mitigate the negative impacts of global warming on animal productivity, Animal husbandry, and human livelihoods.

Index Terms— Animal husbandry, heat stress, digestibility, Energy balance, Nitrogen metabolism, Urea recycling, Goat.

I. INTRODUCTION

Ruminants, in general, assume a pivotal function as primary consumers in the ecosystem. Additionally, small ruminants, such as goats, possess noteworthy importance due to their added contributions to meat and milk production in urban and rural areas [1]. In developing countries, goats hold substantial significance in terms of health and economic welfare, as they provide a source of high-protein nutrition and serve as a crucial component in improving the well-being and financial stability of impoverished populations with limited access to quality food [2-4]. In the nations situated within the eastern basin of the Mediterranean Sea, as well as in the northern region of the Land of Israel and throughout Syria, Lebanon, Iraq, Jordan, and Turkey, one may commonly observe a breed of goat recognized as the black Mediterranean goat (capra hircus mambrica). This species of the goat is regarded as a highly energetic creature, exhibiting mobility throughout the day that is twice that of cows. Furthermore, studies have revealed that the goat demonstrates superior adaptability to changes in diet when compared to other domesticated animals [5, 45]. Based on field observations, it has been observed that during the summer season, Mediterranean goats are typically watered only once per day, even during the hottest periods, and this occurs in the middle of the day. The goat also exhibits rest behavior during the hottest part of the day, followed by a resumption of grazing activity in the late afternoon. These observations offer valuable insight into the feeding behavior of Mediterranean goats during the summer season [5].

Additionally, it has been noted that this breed of goat is capable of grazing for several days without access to water sources. As a small ruminant, the black Mediterranean goat has earned a reputation for being selective in its dietary preferences, often targeting the higher portions of plants that are known to contain significant protein levels [6-7]. The black Mediterranean goat is known to possess a remarkable ability to efficiently consume and digest poor-quality food sources, such as shrubs, bushes, and herbaceous plants, which are typically less desirable for other ruminants. Moreover, it exhibits greater proficiency in utilizing the fibrous component of its diet when compared to other ruminant species [7-8].

The Mediterranean goat's distribution area is characterized by a Mediterranean climate that exhibits four distinct seasons throughout the year. The summer season is prolonged, hot, and arid, whereas the winter season is cold and rainy. Consequently, the survival challenges encountered by this goat vary between the two seasons. The vegetation growth in this climate is diverse, consisting of shrubs and grasses [9]. During the summer season, the environmental heat load intensifies, and prolonged radiation exposure induces significant changes in the flora, especially in the herbaceous plants. In such conditions, the quantity of vegetation decreases, and the high temperatures directly impact the structure of the plant, resulting in lower quality plants. Furthermore, the nitrogen content in the plant also decreases and terminal heat stress reduces wheat yield [10-12].

In summer, goats face heat stress and limited access to high-quality food, which can impact their health, productivity, and profitability. Effective management strategies are necessary to mitigate these challenges and ensure optimal performance. Physiological studies have shown that there is a reciprocal effect of the drinking regime on the energy economy, food consumption, its digestion and metabolic rate, and on the other hand, the water regime is affected by the energy economy [13]. Apart from energy, protein is also an irreplaceable nutritional component, it is accepted that the proper existence of Increased ruminative rumination depends on the fact that the protein content in the food should not be lower than 7% [14].

It is well-established that vegetarian animals possess the ability to subsist on low-protein diets by optimizing their nitrogen economy, rather than excreting urea, which represents a nitrogenous residue of catabolism. To recycle this protein, they absorb it back into the bloodstream via the kidney and subsequently direct it toward the digestive system. Intestinal microorganisms also participate in this process by utilizing non-protein nitrogen for the synthesis of bacterial protein, which is ultimately digested by the animal's own proteolytic enzymes. As a result, the animal receives additional protein from a microbial source [15].

In recent times, a disconcerting trend of climate change attributed to global warming has emerged, causing profound impacts globally, including in the Mediterranean basin. The repercussions of this climate shift extend to the inhabitants of the wild, encompassing both animals and plants, who are exposed to extreme heat and radiation. It is noteworthy that Heat stress imposes a significant impact on both producers and consumers due to their [16]. As a response, numerous initiatives have been undertaken to mitigate global warming and restrict its rise to 1.5 degrees, thereby averting catastrophic consequences [17]. There is a need to underscores the importance of enhancing feed efficiency in livestock production as a means to mitigate greenhouse gas emissions, emphasizing that it can reduce emissions by minimizing the amount of feed needed per unit of animal product [18].

Another concern is how heat stress affects dairy cow lactational performance, emphasizing its negative consequences on milk yield and overall welfare, advocating for heat abatement and further research to mitigate these issues in the dairy industry [19]. The objective of this study was to investigate the impact of rising heat stress on the digestibility, energy balance, and urea recycling in the Mediterranean goat.

II. MATERIAL AND METHODS DIET, FOOD CONSUMPTION AND APPARENT DIGESTIBILITY

The Member goats were subjected to a sequence of diets consisting of alfalfa hay (25% fiber, 18% CP) and wheat straw (35% fiber, 5% CP). The animals were given 3-4 weeks to adapt to each diet, feed, and water were offered ad libitum, and consumption was recorded daily. During a 10-day "balance period," urine and feces were collected, which were repeated 2-3 times for each diet. After the end of the balance period for one type of food, the food was gradually replaced with the other type for about three weeks, and another balance period was conducted for the second type of food after an acclimation period. Dry matter content was ascertained through the use of an oven, with a temperature set at 90°C until a constant weight was achieved. The energy content of both feed and fecal samples was evaluated by utilizing a Gal-lenkamp Ballistic Bomb Calorimeter. Resting animals' metabolic rate was assessed by measuring their oxygen consumption. Measurements were taken 12 hours post-feeding, with a duration of 4-5 hours for each session. This process was repeated 2-4 times for each of the two diets under consideration. Oxygen concentration was determined using a Taylor-Servomex Oxygen Analyzer, in an open flow system [20].

Food consumption and apparent digestibility were evaluated through the implementation of the balance method. This method involves measurement of the amount of food ingested, calculated as the variance between the weight of the food that was served and the residual food that remained unconsumed.

DM food intake = DM food offered - DM in orts

The amount of feces excreted daily during the balance period was also collected and kept frozen (-20 degrees Celsius) until analysis. The percentage of apparent digestibility of dry matter present in the food was determined using the subsequent formula:

$$DMD = \frac{\text{DM food intake} - \text{DM feces excreted}}{\text{DM food intake}} \times 100$$

DMD - Dry Matter Digestibility

The difference between the amount of food eaten (intake) and the amount excreted (excreted) is the amount apparently ingested.

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III. BODY TEMPERATURE

The rectal temperature of the goats was assessed through the utilization of a Wescor-type thermocouple. The initial measurement was conducted early in the morning, prior to sunrise at 5:00 am, whereas the final measurement was taken late in the evening at 10:00 pm. Corresponding to the rectal temperature readings, measurements of the ambient air temperature were also recorded hourly.

IV. NITORGEN METABOLISM AND UREA RECYCLING

The investigation of nitrogen metabolism was conducted by administering a single injection of 14C-urea, utilizing the method proposed by Cocimano and Leng [21]. A dose of 2-3 Ci/Kg of 14C-urea was administered through a jugular vein cannula. Blood samples were taken during an 8–10-hour period following the injection, while urine was collected continuously for 24 hours using a Foley Catheter inserted into the bladder on the morning of the experiment. The level of 14C activity was assessed using a liquid scintillation counter (Packard TRI-CARB 4530). The urea pool was calculated using the dilution method, while the urea entry rate was determined by measuring the rate at which 14C disappeared, in accordance with the technique suggested by Cocimano and Leng [21]. Urea recycling was assessed by deducting the rate of urea eliminated with the urine from the urea entry rate. Urea concentration in plasma and urine was analyzed calorimetrically [22].

V. STATISTICAL ANALYSIS

The significance of the differences observed under the influence of the different experimental conditions and the two types of food was determined through Two-Way Analysis of Variance (ANOVA) variance tests. Furthermore, to establish the statistical significance between the body temperature in the different foods under the experimental conditions of shelter and heat stress, paired comparison tests were conducted.

VI. FINDINGS

Food intake

Under summer shelter conditions when the goats were fed alfalfa hay, the average food consumption recorded was 89.13±2.74 g kg $^{-0.75}$ day $^{-1}$(Table I). In contrast, the consumption of the wheat straw diet was significantly lower at 37.90 ± 0.62 g kg $^{-0.75}$ day $^{-1}$, which amounted to only 42.5% of the consumption observed in the alfalfa hay diet ($p<0.01$). In unshaded environments, a significant decrease of 27.49% in food intake was observed when the goats were maintained on alfalfa hay, in comparison to shaded conditions. Similarly, when exposed to unshaded conditions and fed wheat straw, the decrease in food intake was even more pronounced at 34.85%. The apparent digestibility of dry matter in the alfalfa hay diet was found to be 68.92+1.86% under shaded conditions, which was significantly reduced by 8.11% in unshaded conditions. Similarly, transitioning from high-quality alfalfa hay to low-quality wheat straw led to a similar decrease of 6.79% in the apparent digestibility of dry matter from shaded to unshaded conditions. Notably, no significant changes were observed in the digestibility of Acid Detergent Fiber (ADF) when subject to variations in both diet and environmental conditions.

Table I. Consumption and digestibility of dry matter (DM) and Acid Detergent Fiber (ADF) in member goat fed either alfalfa hay or wheat straw and maintained during the summer either under a shaded or unshaded in sun.

Condition	Diet	Body mass Kg	Food Intake	ADF $gr \cdot Kg^{-0.75} \cdot day^{-1}$	Apparent DM%	Digestibility ADF%
Shaded	Alfalfa hay	32.38±2.37	89.13±2.74	27.01±0.83	68.92±1.86	53.62±3.89
Unshaded	Alfalfa hay	31.92±1.59	64.62±2.04	21.42±2.65	63.33±0.64	43.48±8.79
P		N.S	p<0.01	p<0.01	p<0.01	N.S
Shaded	Wheat straw	30.12±2.39	37.90±0.62	20.14±0.33	50.33±0.48	49.68±2.91
Unshaded	Wheat straw	26.24±1.30	24.69±2.82	15.41±0.33	46.91±0.93	45.17±9.32
P		N.S	p<0.01	p<0.01	p<0.01	N.S

Oxygen Consumption

To estimate the metabolic rate, oxygen consumption was measured under resting conditions. When the goats were fed alfalfa hay in sheltered conditions, the rate of oxygen consumption was calculated to be 19.34+1.03 ml.kg$^{0.75}$.day^{-1}. However, this rate decreased significantly by 36.74% upon switching to a wheat straw diet. Similarly, a comparable decrease of 35.55% was observed in unshaded conditions. Notably, the transition to heat load (unshaded) conditions did not result in a significant change in the rate of oxygen consumption, either in the case of alfalfa hay or wheat straw diets (Table II).

Table II. Oxygen consumption in member goats fed either alfalfa hay or wheat straw and maintained either under a shaded shelter or unshaded in the sun.

Environment	Alfalfa hay $ml \cdot day^{-1} \cdot Kg^{-0.75}$	Wheat straw $ml \cdot day^{-1} \cdot Kg^{-0.75}$	% of change	
Shaded	19.34±1.03	12.23±1.81	-36.74%	P<0.01
Un-shaded	17.72±2.02	11.42±1.21	-35.55%	P<0.01
	N.S	N.S		

Body Mass

Under the sheltered conditions and with a diet of alfalfa hay, the goats were able to maintain a consistent body mass (Fig.1). However, during the transition period to a low-quality diet of wheat straw, the goats experienced an average weight loss of 2.3±1.6% compared to their average weight in the alfalfa hay diet. Following this transition period, no significant change in body weight was observed during the

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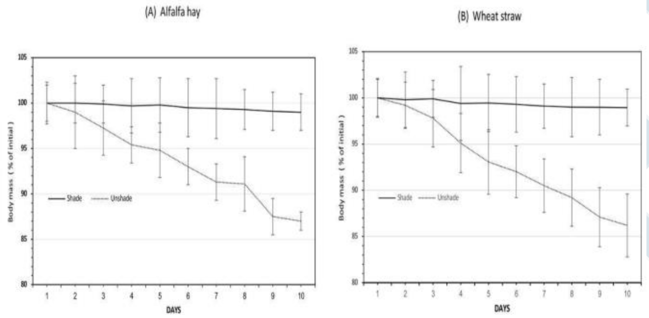
balance period. Upon exposure to a heat load (unshaded environment), a change in body mass was observed during the balance period for both experimental diets, as demonstrated in Figure 1. Specifically, when the goats were fed with alfalfa hay, a loss of 3.6±0.3 Kg was recorded over the balance period, representing a weight loss of 10.59% (P≤0.01) from the starting body mass of this period. Upon switching to a wheat straw diet, the goats lost an average of 17.79+3.0% (P≤0.01) of their mass recorded during the alfalfa feeding, and the weight loss continued during the balance period. The average loss per goat during the balance period was 3.81+0.43 Kg, representing a weight loss of 13.39% from the initial weight in this period. Moreover, it should be noted that under the conditions of heat stress, two goats were unable to cope with the environmental conditions and consequently ceased eating. Therefore, they have been removed from the experiment.

Fig. 1 Body mass of member goats maintained during the summer either in a shaded shelter (solid line) or unshaded (dotted line) and fed either alfalfa hay (A) or wheat straw (B)

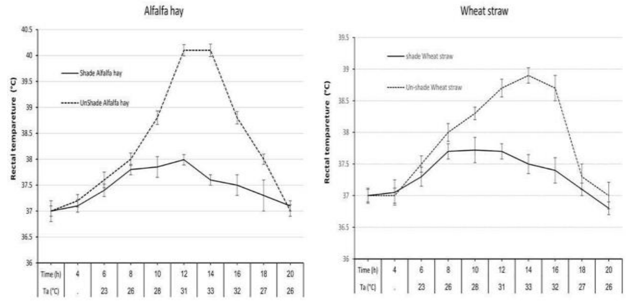


Changes In Body Temperature

In the experimental animals subjected to shelter conditions and two distinct diets, no significant fluctuation in body temperature was observed over the course of the day (Fig. 2). Specifically, the body temperature ranged from +37.1 +0.2°C to 38.5+0.2°C in alfalfa hay, and from 37.0+0.2°C to 38.0+0.2°C in wheat straw. Throughout this study, the ambient temperature ranged from 20-33°C, with relative humidity levels ranging between 55-90%.

Exposure to sunlight caused an increase in body temperature (Fig. 2), particularly in the afternoon, where the average solar radiation and relative humidity were recorded at 80%, and the ambient temperature was 32°C. The body temperature of the experimental animals fed with alfalfa hay increased from a minimum of 37.0+0.1°C in the morning to a maximum of 40.5+0.5°C (P<0.01) in the afternoon, while in wheat straw, it ranged from a minimum of 37.1+0.1°C to a maximum of 40.1+0.1°C(P<0.01). Notably, a significant difference in body temperature (P<0.05) was observed between the two diets during the hours of 13:00-15:00, under the conditions.

Fig. 2 Ambient temperature (Ta) and rectal temperature of member goats that maintained during the summer either in shaded shelter (solid line) or unshaded shelter (dotted line) and fed either alfalfa hay or wheat straw.



Nitrogen Balance

The determination of nitrogen balance in the human body involves subtracting the amount of nitrogen excreted from the amount of nitrogen ingested through food intake. Notably, the quantity of nitrogen in the food intake undergoes a significant reduction in both diets during the shift from sheltered conditions to the environmental heat stress. In particular, the average amount of nitrogen intake by goats that were fed with alfalfa hay was determined to be 3.05 $g.kg^{-075}.day^{-1}$. However, when these goats were exposed to sunlight, the amount of nitrogen intake declined to 1.99 $g.kg^{-0.75}.day^{-1}$ representing a decline of about 36% relative to sheltered conditions (Table III).

The consumption of nitrogen exhibited a significant decrease concurrent with the decline in food quality and protein concentration, across both experimental conditions. Specifically, in goats fed wheat straw and subjected to sheltered conditions, the average recorded intake was 0.18 $gr.kg^{-0.75}.day^{-1}$, However, when exposed to heat stress, the nitrogen consumption underwent a considerable decline of 35%. In circumstances where goats were nourished with alfalfa hay and maintained under sheltered conditions, a noteworthy disparity was observed between the amount of nitrogen intake and that excreted from the body, resulting in a positive protein balance. However, when the same goats were exposed to environmental heat stress conditions while consuming the same diet, a balanced nitrogen balance was recorded, indicating that the nitrogen intake and excretion were equilibrated.

Table III. D.M intake and nitrogen (N) balance in member goats fed either alfalfa hay or wheat straw and were subjected to summer conditions under either shaded or unshaded environments.

Diet and environment	D.M intake	N intake	Fecal N	Urine N	N retained
	$g/Kg^{0.75}/day$	— — — — — — mg / $Kg^{0.75}/day$ — — —			
Alfalfa hay					
Shade	89.13±2.74	3051.08±93.87	474.06±164.32	1953.66±250.59	604.59±134.42
Un-shade	64.83±2.30	1945.05±69.13	442.72±94.10	1503.32±55.90	-0.99±16.49
P	p<0.01	p<0.01	N.S	p<0.01	p<0.01
Wheat straw					
Shade	37.96±0.62	181.63±10.58	161.51±16.54	154.28±6.64	-134.17±20.05
Un-shade	24.69±1.77	116.66±12.25	145.11±31.27	177.88±44.62	-209.29±65.42
P	p<0.01	p<0.01	N.S	N.S	p<0.01

Kinetics of Nitrogen

The present research aimed to evaluate the potential impact of heat exposure on the N-urea pool of goats fed either alfalfa hay or wheat straw. Notably, the N-urea pool demonstrated no significant change during the transition from shaded to unshaded conditions in either of the diets studied. Specifically, the average N-urea pool in the body of goats fed alfalfa hay in sheltered conditions was recorded at 315.5±51.3 mg· $kg^{-0.75}$, which did not differ significantly from the unshaded conditions. On the other hand, when goats fed the same diet were exposed to heat stress, the N-urea pool was measured at 381.6±72 mg· $kg^{-0.75}$ (Table IV). Moreover, it was observed that a reduction in food quality led to a significant decrease in the body's nitrogen reserve in both shaded and unshaded environments goats. However, the N-urea pool reserve demonstrated no significant variation during the transition from shaded and unshaded conditions.

The findings of the present study indicate that the N urea entry rate in the liver remained relatively stable when the animals were fed alfalfa hay, despite transitioning from sheltered to sun-exposed conditions. Conversely, when goats were provided with suboptimal feed, the rate of N urea entry in the liver was observed to decline considerably in both shaded and unshaded conditions. Importantly, a change in climate conditions did not exert a significant effect on the dental health of the goats, even in the context of poor nutrition. The process of urea recycling involves the difference between hepatic urea production and the renal excretion of urea in urine, which indicates the amount of recycled urea returning to the digestive system. Notably, the rate of urea regeneration was significantly different in the two climate conditions. In particular, when goats were fed with alfalfa hay and kept in a shaded environment.

The study found that the average urea recycling rate in goats kept in a shaded environment was 36%, which was significantly higher than the rate observed in goats exposed to heat stress, which was only 19.6%. Moreover, the amount of recycled urea was also higher in the shelter at 91% compared to 69.9% in the reflected heat load recorded when the goats were maintained on a diet of wheat straw.

The urea turnover percentage showed a decrease in both diets during the transition from shaded conditions to heat stress conditions. Specifically, the decline was noted to be 47% in alfalfa hay and 24% in wheat straw. Notably, in both environmental conditions, the Urea cycle in protein-rich food exhibited a lower frequency when compared to protein-poor food.

Table IV. N urea Kinetics in member goats fed either alfalfa hay or wheat straw and maintained during the summer either under a shaded environment or unshaded environment.

Diet and environment	Urea pool	Urea entry rate	Urinary urea excretion	Urea recycling	% of entry rate
	mg· $kg^{-0.75}$	—— —— ——	mg· $kg^{-0.75}$ ·day^{-1}	—— —— ——	
Alfalfa hay					
Shade	315.09±51.38	1319.33±151.98	837.25±179.54	482.08±90.38	36.89±7.63
Un-Shade	381.59±72.27	1304.76±152.09	1045.11±89.38	259.62±78.56	19.64±3.87
P	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01
Wheat straw					
Shade	117.58±38.91	219.93±37.67	19.23±2.25	200.70±36.39	91.11±1.45
Un-Shade	141.42±77.94	355.95±114.49	103.06±27.43	252.88±98.72	69.94±6.97
P	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01

VII. DISCUSSION

The Energy Economy

Productive animals have the unique ability to convert energy that is not readily available for human consumption into digestible food. Ruminants hold a significant place in the human economy due to their remarkable ability to utilize energy from plant components that are indigestible to humans. The animal's intrinsic energy [23] and its capacity to mobilize energy for production processes are directly influenced by environmental conditions such as water availability, food quality, and heat stress. This article delves into various aspects of the energy economy, including efficiency rates, particularly during the summer period, and the impact of heat stress versus shelter conditions.

The quality of food is a crucial determinant of an animal's food consumption, recently it was reported Yaks need less energy to survive than cattle, making them better at eating low-energy diets in the harsh winters of the Qinghai-Tibetan Plateau [24]. However, it is not the sole factor influencing an animal's feeding habits, as heat stress also plays a significant role. In the literature, it is well-documented that high heat stress can considerably reduce an animal's appetite [12,23,25-28].

In Mediterranean goats that were fed on either alfalfa hay or wheat straw, exposure to heat stress led to a significant decrease in food consumption. Specifically, a reduction of 28% and 34% was observed for alfalfa hay and wheat straw diets, respectively. Notably, the heat stress did not impact the digestibility of either food type.

Despite the effect of the heat stress, the findings suggest that the quality of the food remained an essential factor in determining food consumption. Interestingly, both in sheltered and sun-exposed conditions, the consumption of wheat straw was notably lower (35% to 40%) compared to alfalfa hay. It can be concluded that the Mediterranean goat can maintain an energy balance and a stable body mass on any diet if it is provided with sheltered conditions that offer protection from direct sunlight.

Wheat straw has long been recognized as a food source that cannot sustain any domestic animal [14]. However, it has been observed that the Mediterranean goat can subsist on it if it is provided with shaded shelter. This finding suggests that goats possess the capacity to effectively utilize high-fiber, low-protein food and maintain a balanced energy budget. Similar abilities have been previously reported in desert herbivores like the antelope [29], donkey [30], and camel [31].

However, when exposed to the full environmental heat load, including direct exposure to solar radiation, as is typical during the summer season, the goat was unable to maintain a proper energy balance. This was demonstrated by a body mass loss of approximately 13% in each type of diet. Therefore, it can be concluded that the Mediterranean goat is sensitive to heat stress and unable to maintain a balanced energy economy under such conditions.

Another conclusion drawn from the study is that heat stress has a detrimental effect on the Mediterranean goat's ability to maintain a balanced heat economy, regardless of the type of diet. It was observed that the goat failed to maintain a proper heat balance in all holding regimes, resulting in a 3 °C increase in body temperature when fed wheat straw and a 3.5°C increase when fed alfalfa hay.

Heat sensitivity in domesticated ruminants has been well-documented in literature for several decades, with decreased food consumption and no change in the oxygen consumption posing a risk to the animal's life [32]. The most common response to heat exposure in ruminants is an increase in body temperature [33]. The ability of a productive animal to maintain a constant body temperature is essential for its effectiveness, and its resistance to heat stress is measured by its ability to do so [32,34]. In tropical areas, heat stress has mainly been observed in wild ruminants, with limited observations in domesticated animals such as cattle, deer, sheep, and goats [35-36]. In contrast, ruminants from temperate areas have been found to experience an increase in body temperature due to heat stress, even in domesticated animals [37-39].

The underlying cause of the negative energy balance and loss of body mass observed under heat stress conditions is the goat's inability to lower its metabolic rate as measured by oxygen consumption. This lack of adaptation to heat stress is also evident in hyperthermia and the inability to maintain proper heat balance. The increased internal heat production resulting from high metabolism under heat stress hinders effective thermoregulation by impeding the physiological mechanisms responsible for the release of heat (conductivity and evaporation). Hyperthermia due to high-quality food is also observed in various other animals [40].

The Nitrogen Economy

Management of nitrogen balance can be a formidable task for animals consuming low-protein food and exposed to heat stress conditions. Thus, it is of utmost importance to investigate the mechanisms utilized by the animals to achieve a stable nitrogen economy. The heat load that impacted food consumption in the Mediterranean goat had a consequential effect on nitrogen consumption. Specifically, under conditions of heat stress and digestion of alfalfa hay, a high-protein food, the quantity of protein ingested decreased due to the concomitant decrease in food intake. This decrease led to a parallel reduction in nitrogen loss through excretion.

Some advocate the use of urea nitrogen (UN) in animal nutrition to improve protein utilization, reduce costs, and improve feed efficiency, although it must be used alongside other indicators due to its limitations [41]. Notably, the Mediterranean goat exhibited a reduction in nitrogen loss only through the urinary pathway, which was diminished by a mere 23% compared to the level observed under sheltered conditions. Although the amount of nitrogen lost through urine was reduced because of heat exposure, there was no change in the quantity of nitrogen lost through feces. Under shelter conditions, the Mediterranean goat achieved a positive nitrogen balance, thanks to the abundant nitrogen supply derived from its diet. However, under heat stress conditions, despite receiving the same diet, the balance was barely sustained, primarily due to a reduction in the amount of nitrogen lost through urine.

When animals are fed low-quality food with low protein content, they face difficulties in maintaining proper nitrogen balance. This reduction in food quality leads to a decrease in consumption and consequently, a reduction in protein intake. In the case of the Mediterranean goat, both the channels of nitrogen absorption and loss exhibit low absolute amounts compared to protein-rich foods. This trend is also observed in other animals. Bedouin goats have a more efficient nitrogen economy than Swiss goats. The ibex recycled urea efficiently, with rates of 14%, 64%, and 74% on different feeds [29], and the Bedouin goats have higher nitrogen intake and entry rates, and they recycle more urea, resulting in an 87% higher nitrogen entry rate compared to Swiss goats [42].

A shift from alfalfa hay to wheat straw, under sheltered conditions, resulted in a decrease in the amount of nitrogen ingested by the Mediterranean goat. Furthermore, when the goats were exposed to heat stress conditions, this decrease in nitrogen intake persisted. The failure of the Mediterranean goat to maintain a balanced or positive nitrogen balance even when sheltered indicates an inherent difficulty in maintaining full function when fed a low-protein diet, resulting in a loss of mass. Efficient protein digestion and nitrogen conservation are key mechanisms for animals to maintain a positive nitrogen balance when fed low-protein diets. However, the Mediterranean goat did not exhibit a reduction in the amount of nitrogen lost through feces under low protein feeding conditions, indicating a limitation in this regard. In herbivorous mammals, urine represents the final nitrogenous product of protein metabolism occurring in the liver. This nitrogenous product is released from the liver into the bloodstream, with a fraction being excreted in the urine and the remainder returned to the digestive system. The latter can serve as a substrate for protein synthesis by microbial populations, with the resulting microbial protein being available for absorption and utilization by the host animal [29,43].

The nitrogen kinetics in the urine of the Mediterranean goat was investigated, and it was observed that the heat stress caused a significant reduction in the recycling of urinary nitrogen. Specifically, when digesting alfalfa hay, the heat stress led to a 17% decrease in the value recorded in the shelter. This decrease in the recycled urinary nitrogen is not attributed to its production in the liver but rather to the Mediterranean goat's inability to decrease the amount of nitrogen excreted in the urine under heat-stress conditions. When food is of low quality and high in cellulose, the protein content is often low, and consequently, preserving the nitrogen that is filtered by the kidney and returning it to the digestive system for use by the microbial population is a crucial process in maintaining a balanced nitrogen economy.

When the Mediterranean goat is fed a low-protein diet and kept under sheltered conditions, the rate of urinary nitrogen recycling reaches a high of 91%. However, exposure to heat stress results in a significant decrease in the recycling rate, with the Mediterranean goat showing a decrease of 23%. Exposure to the sun results in a significant decrease in nitrogen recycling and as a result damages the production of the vital protein. This decrease in urinary nitrogen recycling can be attributed to an increase in water consumption, leading to an increase in the amount of urine excreted and urinary nitrogen excretion. This failure to store nitrogen in the kidney and recycle it as efficiently as recorded in the sheltered conditions reduces the amount of nitrogen available to the microorganisms in the rumen, thus harming the production of the essential protein required for balancing the nitrogen economy, especially when the goat is fed with low-protein food. It is suggested that heat stress increases water consumption which affects the urine excretion, and increases the nitrogen loss in the urine. In addition to our findings, it is essential to recognize the significance of nitrogen recycling in the context of feed efficiency and animal selection. Nitrogen recycling has been shown to play a vital role and can be controlled within the digestive system and liver, particularly through mechanisms such as fermentative energy. While substantial research has been conducted on changing crude protein (CP) concentration in animal diets, other factors affecting nitrogen recycling, such as total fermentable energy, protein sources, genetic variation, and hormonal modulation, remain relatively unexplored [44].

The conclusion of this study is that the greenhouse effect poses a significant threat to the survival of animals, as exposure to heat stress can lead to a reduction in appetite and an inability to lower metabolic rates. In temperate regions, such as the habitat of the Mediterranean goat, animals lack the physiological mechanisms to mitigate the negative effects of heat stress, resulting in a significant loss of body mass and, ultimately, mortality. The conclusions drawn from this study suggest that the greenhouse effect has the potential to cause significant harm to both the food web in natural habitats and agricultural production, particularly in the case of ruminants like goats used for meat and milk. These findings highlight the urgent need for attention and awareness-raising among international organizations tasked with addressing climate change. This phenomenon is not limited to the Mediterranean goat; many animals in temperate regions face similar challenges due to their inability to regulate oxygen consumption and metabolism in response to heat stress, rendering them vulnerable to the negative effects of global warming. In contrast, desert animals possess the ability to maintain a stable body mass thus indicating their ability to cope with the adverse effects of heat stress, and even increase it when necessary, making them more resilient to the adverse effects of rising temperatures. To achieve more efficient animal selection and develop environmentally sustainable diets, it is imperative to further elucidate the complexities of nitrogen recycling.

This will not only improve our understanding of feed efficiency but also contribute to our wider goal of reducing the environmental impact of animal agriculture. Based on our findings, several questions arise for further investigation concerning the impact of climate change on animal husbandry, animal welfare, and agriculture. What economic consequences could the greenhouse effect have on livestock industries, particularly in regions where animals are susceptible to heat stress, such as in meat and dairy production? Additionally, what are the implications of climate change-induced heat stress on the distribution and abundance of diverse animal species, and how might it potentially impact conservation and biodiversity?

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