PHYSIOLOGICAL AND GENETIC ISSUES FOR TOLERANCE TO HEAT STRESS IN SUBTROPICAL SHEEP AND GOATS RAISED IN HOT DRY AREAS

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SUMMARY

Near East region is getting warm at a faster rate than the global average. Egypt is particularly vulnerable to the impacts of climate change (CC). Local livestock are facing significant challenges in regulating their physiological functions under stressful hot dry conditions. The present article reviews studies conducted on tolerance of subtropical Egyptian sheep and goats breeds to heat stress (HS) under different hot and dry regions.

Respiration rate (RR) increased significantly with HS and has been identified as a reliable measure for differentiating heat-tolerant local sheep. Changes in RR are less pronounced in local goats (which reflect better tolerance to HS) than sheep. Local goats adapt HS, primarily, by reducing their heat production, while local sheep rely on their respiration function to cope with HS. Body weight of subtropical sheep and goats are related to their thermoregulation capacity, heavy weight animals are less suited to hot dry environment.

Genomic analyses have identified several genomic regions associated with adaptation of local sheep and goats to hot dry conditions. Their adaptation is mediated by a complex network of genes that function together rather than relying on single candidate genes. Adaptation strategies to environmental stress in hot dry areas reported by the breeders, include precision feeding to enhance feed efficiency, improving farm facilities and innovative breeding promoting well adapted animals and enhance the resilience of local sheep and goats breeds in hot dry areas. Future research in arid areas, should emphasize their molecular mechanisms that underlie heat tolerance to hot dry conditions.

Keywords: Subtropical sheep and goats, heat stress tolerance, hot dry environments, physiological adaptations, genomic analysis

INTRODUCTION

Climatic change (CC) has introduced critical challenges to animal production in the hot dry areas, where livestock face significant environmental stress. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), the Near East (NE) region is expected to experience greater impacts from the CC than the global average. Egypt among the countries that is most vulnerable to these changes, as evidenced by decreasing precipitation, shifts in weather patterns, rising sea levels and increasing emission of CO_2, methane, and nitrous oxide (Gaughan *et al*., 2019).

Heat stress (HS) directly affects animal production and their welfare, HS reduced feed intake, decreased feed efficiency, along with disturbances in mineral balance, enzymatic function and hormonal activity, resulted ultimately in feed shortage and disease outbreaks (Holmes and Moore, 1981). Animals have developed physiological and biochemical mechanisms to cope HS, safe guard cell function, and recover from hyperthermic conditions (Ames, 1981). Under pastoral system, livestock are directly exposed to intensive solar radiation, high temperatures and drought, which degrade pasture and reduce animal performance. Furthermore, livestock contribute to global warming through greenhouse gas (GHG) emissions, accounting for around 18% of the total emissions (UNFECC,2018). This places livestock production under scrutiny for its environmental impact, particularly regarding GHG emissions (Maddison, 2007).

Gaughan *et al*. (2009) emphasized that heat and drought will be the predominant challenges facing animal production in hot dry regions over the next 30 years. These environmental stressors are characteristic of the extensive livestock systems, it have a profound negative impact on both animal performance and livelihoods of pastoral communities. In response to CC, pastoral breeding strategies focus on selecting heat-tolerant animals and excluding those negatively affected by environmental stressors. The ongoing challenge in these breeding programs is the trade-off between environmental tolerance and production performance.

Sheep and goats are the primary livestock raised in the NE's hot dry areas, where Bedouin and marginal communities rely on them for their livelihoods. The animals must regulate their physiological functions to cope with the challenging environmental conditions. Local breeds have developed unique adaptive characteristics, such as water conservation, lower metabolic rates, increasing respiration rates, elevated skin temperatures and stable cardiac output, which enabling them to thrive in these environments (Abdel-Samee, 1997;Dubeuf*et al*., 2004;Shkolnik and Choshniak, 2006; Dracan and Silanikove, 2017and Sejian *et al*., 2018). Notably, Shkolnik and Choshniak (2006) highlighted that local Sinai Black goats surpasses other Mediterranean animals in its ability to withstand hot dry desert conditions, owing to its efficient grazing skills, specialized anatomical and physiological features, extended digestion retention time, and enhanced cellulolytic activity in the rumen.

Local subtropical sheep and goat breeds are suited to low-input farming systems and resilient to various environmental stressors. The breeds produce animal products that cater to local consume preferences and hold cultural and traditional significance. In addition, they harbor valuable genetic resources that can be utilized in innovative breeding programs using both conventional and genomic techniques.

Genomic investigations for local sheep and goat breeds have discovered several genomic regions and candidate genes potentially linked to adaptation to the hot dry conditions (Kim *et al*., 2016 and Aboul-Naga *et al*., 2023). Many of these candidate genes are involved in multiple pathways and biochemical process, including thermoregulation, body development, energy, and digestive metabolism, all of which are crucial for surviving in the harsh environments.

The present review analyzes studies on adaptation of local Egyptian sheep and goat breeds to heat stress in various regions. The studies focused on the physiological changes under heat stress, genetic characteristics of local breeds, genomic analyses of heat tolerance, and the relationship between heat tolerance and production performance.

Climate profile in the studied areas and breeds investigated:

Egypt Climate profile:

Egypt's climate is characterized by warm winter with mild days and cold nights, hot summer with hot daytime and warm nights. Observations from the Mediterranean and Near East region between 1950 and 2000 indicated that the region has warmed more rapidly than the global average, with projected increase in future temperature to exceed the global trend (IPCC, 2014). Egypt is ranked the fifteenth among the most vulnerable countries to CC (Omran *et al*., 2020). The impacts of CC in Egypt include decreasing precipitation, steady increase in sea levels, and rising emissions of CO_2, methane, and nitrous oxide. It is projected that minimum temperature will increase by 1.09–1.32°C in 2030 and by 1.64–2.33°C in 2050. Solar radiation (SR) is high all the year-round, across Egypt (4500 KJ/m2) particularly in summer, reaching extreme levels in the desert areas (Wiersma,1990). Livestock in Egypt experience climate stress for approximately six months of the year, causing various physiological and biochemical changes. There is clear evidence that CC has negatively affected livestock performance in the hot dry areas of Egypt (Aboul-Naga *et al*., 2021a). The impact of HS on animal production varies depending on the specie, production system and animal characteristics, with an anticipated reduction in animal production due to CC by 25% by the end of the century (Kadah *et al*., 2008).

Studied hot dry areas: (Fig 1)

A) Coastal Zone of Western Desert (CZWD): Extending from Alexandria east to Saloum west, over 700 km on the Mediterranean Sea cost. CZWD is a hot dry area characterized by annual rainfall below140mm. The region has 2-3months of poor-quality ranges in winter and scarce vegetation in the long summer. The predominant agricultural system includes rain-fed barley, sheep and goats raising, along with figs and olives trees. The system has been shaped by the settlement policies of Bedouin communities, whose traditional values and institutions still prevail.

B) New Valley (NV): It is the largest governorate in Egypt, occupies >40 % of the country's land area. It extended from the Libyan border in the west to the Nile Valley in the east, and from Matruh Governorate in the north to the Sudanese border in the south. The region includes three large desert oases (Dakhla, Kharga, and Farafra). The NV experienced extreme environmental conditions, with summer temperatures reaching 50°C under shade, and winter nights dropping below zero. Rainfall is scarce (2-10 mm annually), and the diurnal temperature variation often exceeds 20°C.The region also characterized within tense SR (8.4Wh/M2), the highest in Egypt.

C) Upper Egypt (UE): Extending from Giza north to Sudanese border south (latitudes: 22o to 29o), Upper Egypt is known with very hot summer, cold winter nights, scarce rainfall (15 mm annually), and intense solar radiation. Ambient temperatures vary widely between day and night. The dominant farming system is intensive agriculture with more than one crop per year, in crop-livestock farming system. Livestock fed through cut-and-carry system, utilizing green fodder; such as clover in winter and green corn in summer, plus crop residues in between.

D) Red Sea, Hala'ib and Shaletien: This region encompasses Red Sea, Hala'ib and Shaletien triangle, and Eastern Desert. It is characterized by arid conditions, with rainfall ≤30 mm and scarce vegetation. Average summer temperatures is ≥32º C, and humidity levels ≥ 68%.

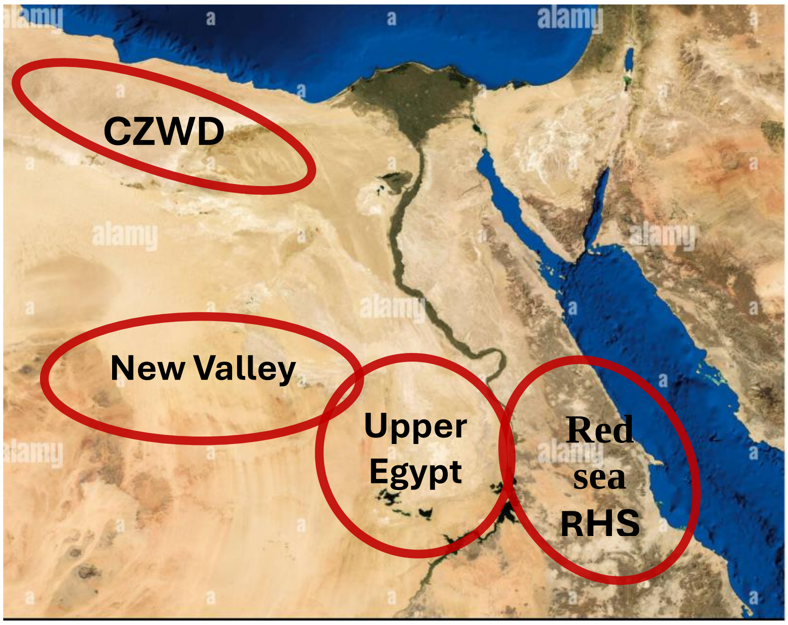

Figure 1: The Studied hot dry areas in Egypt.

Table 1. Climatic parameters reported by time of measurement in the studied areas+

Location	07:00am			02:00pm		
	AT* (°C)	RH (%)	THI	AT(°C)	RH (%)	THI
CZWD	27.4	73.0	71.9	45.5	25.3	105.8
Upper Egypt (UE)	28.5	53.8	75.8	45.5	22.7	107.2
New valley (NV)	33.0	40.0	81.1	48.0	25.5	110.0
Red sea, Hala'ib & Shaletien (RHS)	33.05	38.0	83.4	44.0	24.5	94.7

*AT, ambient temperature; RH, relative Humidity; THI: temperature humidity index.
+Cited from Aboul Naga *et al.* (2021a), Aboul Naga *et al.*(2021b) Aboul-Naga *et al.* (2021c), and Shaker *et al.* (2008)

Local sheep and goats breeds investigated:

A) *Barki sheep and Barki goats:* they have been raised for centuries in the Western Desert and are known with their adaptation to harsh desert conditions (Galal,2005; Aboul Naga *et al*., 2011 and Aboul-Naga and Abdel Sabour, 2023). Barki sheep have a well -proportioned body, long neck and legs, and small head with straight profile. Rams have large horns, while ewes are usually polled. They have a small triangular fat-tail, and their coat is white with brown or black head and legs, covered by coarse open wool. *Barki goats*, characterized by small head with straight profile, have horns in both genders, with medium-size ears, mostly black with white spots on the head and body, covered with long glossy hair. The animals are hardy and have good mothering abilities (Galal,2005 and Aboul Naga *et al*.,2021a).

B) *Wahati sheep and Wahati goats*: Native to the New Vally, Wahati sheep (known also as Farafra sheep) have a narrow body, medium-sized head with straight profile, mostly polled. They have white fleece with brown markings on the head, small ears, the fat-tail has a wide base and cylindrical end (El-Hamamsy *et al*., 2018; Elshazley and Youngs, 2019; Bashandy *et al*., 2020 and Aboul-Naga and Abdel Sabour, 2023). *Wahati goats* have small-bodied with medium-size ears, both sexes have relatively long spiraled horns. They are mostly black and covered with long glossy hair.

C) *Seidi sheep and Seidi goats*: They are indigenous to Upper Egypt, raised in small flocks, and are known by their tolerance to heat stress and hot dry environment (Galal *et al*., 2005 and Aboul-Naga *et al*.,2021d). Saidi sheep are considered one of the oldest Egyptian sheep breeds. They are highly fertile, with high losses of young lambs (EL-Hamamsi and Abdel-Hafiz, 1982; Guirgis, 1994 and Elshazly and Youngs, 2019). They are mostly dark in color, with open coarse fleece, although some individuals may have creamy or mixed colors. These sheep are also distinguished by their Roman nose, dewlap under the neck, and long tail (Ghanem, 1980). *Saidi goats* are mostly black, small size, with small to medium ears, and are widely distributed across Upper Egypt. hey are particularly known for their resilience to the challenging environmental conditions in this region.

D) Abou-deliek sheep: Native to the Abo-Ramada, Halaieb, and Shaletien triangle, these sheep are the smallest Egyptian breed, averaging 20 kg body weight. They have long black hair (occasionally red or white), long legs covered with short hair, convex nose, and polled heads in both genders. Their necks are often adorned with dewlap, their tail is long and cylindrical, reaching below the hocks. The breed is characterized by small or no bears, dark cream to dark brown coat, and rare wattles. They have good fertility but low milk yield (Desert Research Centre, 1996)

E) *Black Bedouin goats:* Little performance data is available for this breed; however, Black Bedouin goats are known to be hardy animals with small body sizes. They are extremely tolerant to thirst, drinking only once every two days and grazing far from water resources (Maltez and Shkolnik, 1979). Their ability to withstand water deprivation surpasses that of other desert animals in the Mediterranean region (Shkolnik and Choshniak, 2006).

Physiological response to heat stress (HS)and genomic analysis:

Physiological responses of different local sheep breeds:

(Barki, Wahati, Seidi, and Abu-Deliek) to HS are summarized in Table (2). Significant changes were observed in different physiological parameters, however, percentage of change varied greatly among parameters. The highest change was seen in the respiration rate and the lowest in there ctal temperature (Aboul Naga *et al*., 2021a). The authors pointed respiration rate as the most reliable indicator to differentiate the tolerant and non-tolerant animals and is easy to be measured by the breeder. The response to HS differed among breeds, Barki sheep showed the higher percentages of change, while Wahati and Abo-Deliek sheep showed less changes. According to Aboul Naga *et al*. (2021b) Wahati sheep exhibited better tolerance to HS and intense solar radiation than other local sheep breeds raised under hot dry conditions. Water scarcity significantly reduced respiration rate of Barki sheep (Abdelkhalek *et al*., 2012).

Response of different local goat breeds (Barki, Wahati, Seidi, and Black Bedouin) to HS is presented in Table (3).Wahati and Seidi goats showed little changes in their physiological response to HS, indicating that they are more tolerant to hot dry conditions than other local goat breeds. Changes in physiological parameters with HS are less pronounced in the local goat breeds than in the local sheep breeds raised in the same hot dry area, reflecting less effect of HS on local goats than local sheep, specie variations were the largest in the respiration rate (RR). Aboul Naga *et al.* (2021a) illustrated that local goats rely mainly on reducing their heat production when facing HS, while local sheep accelerate their respiration function to cope with HS and intense SR. If accelerating the respiration rate is insufficient to cope with the HS, animals practice deep breathing, increase their gas volume (GV) to avoid alkalosis (Hales, 1969). This was more recognized in sheep than in goats. Specie differences in the respiration mechanism to cope with HS was reported by Aboul Naga *et al.* (2011) for Barki sheep and goats. Dehydration and low water intake caused significant changes in the physiological responses of Barki sheep, but not in Barki goats (Abdelkhalek *et al*., 2012). These findings were confirmed by Shkolnik and Choshniak (2006) for Black Bedouin goats, which drink once every two days. They can withstand water deprivation better than other species in the Mediterranean.

Table 2. Physiological responses of local sheep breeds exposed to heat stress

Parameter	RT (^{0})	ST (^{0})	RR (min)	GV (l/min)	Reference
			Barki		
Pre-HS	39.2 ± 0.07**	36.3 ± 0.12**	31.6 ± 1.52**		El -beltagy *et al*. (2015)
Post-HS	40.10±0.09	39.4±0.16	91.2±5.52		
Dehy. (0) hours	39.6±0.16	35.5±0.86	46.0±3.98	2.30±0.24	Abdel khalek *et al*. (2012)
Dehy. (72) hours	39.5±0.08	37.1±0.66	34.0±3.54	1.97±0.16	
G 50% (76 days)	39.53		42.00		
At rest	$39.2^c \pm 0.07$	$36.6^b \pm 0.1$	$41.7^c \pm 2.31$	$2.1^c \pm 0.08$	Aboul-Naga *et al*. (2021a)
HS	$40.1^b \pm 0.07$	$39.5^a \pm 0.12$	$98.5^b \pm 4.63$	$2.9^b \pm 0.17$	
EHS	$40.6^a \pm 0.07$	$39.6^a \pm 0.18$	$144.7^a \pm 3.89$	$4.5^a \pm 0.19$	
Acute Heat	$40.1^b \pm 0.07$	$39.4^b \pm 0.16$	$90.7^b \pm 3.98$		
			Wahati (Farafra)		
At rest (7am)	$39.1^b \pm 0.05$	$35.0^b \pm 0.17$	$27.7^b \pm 0.55$	$2.5^b \pm 0.05$	Aboul-Naga *et al*. (2021b)
Noon (2pm)	$40.1^a \pm 0.05$	$44.5^a \pm 0.33$	$77.4^a \pm 2.19$	$4.6^a \pm 0.11$	
			Saidi		
At rest (7am)	$39.1^b \pm 0.06$	$33.9^c \pm 0.14$	$34.1^b \pm 1.31$	$2.2^b \pm 0.52$	Aboul-Naga *et al*. (2021d)
HS (2pm)	$39.4^a \pm 0.04$	$36.5^a \pm 0.15$	$70.2^a \pm 5.10$	$4.8^a \pm 0.79$	
At night(8pm)	$39.5^a \pm 0.05$	$34.4^b \pm 0.10$	$30.2^b \pm 1.01$	$2.4^c \pm 0.27$	
			Abou-Deleik		
Pre-exercise	$39.03^a \pm 0.030$	$36.02^a \pm 0.106$	$34.27^a \pm 0.977$		Shaker *et al*. (2013)
Post-exercise	$39.56^b \pm 0.030$	$37.17^b \pm 0.106$	$69.32^b \pm .977$		

*RT: Rectal temp.: SK: Skin temp. RR: Respiration rate, GV: Gas volume, G 50%=received 505 of water requirement; EHS: physical exercise under heat stress; Dehy: Dehydration.

**Changes with HS are highly significant (P≥0.001),*estimates followed by the same symbol don't differ significantly at 5%P.

Table 3. Physiological responses of local goat breeds exposed to heat stress

Parameter	RT (^{0})	ST (^{0})	RR (min)	GV (l/min)	Reference
			Barki		
At Rest	39.1 ± 0.05	37 ± 1.12	26.8 ± 8.30	2.77 ± 1.39	Aboul-Naga *et al*. (2021a)
Change with EHS	1.7**± 0.04	2.9** ±0.12	107.7**±3.1	6.33**±0.40	
Pre-HS	39.1±0.08	36.8±0.25	28.6±1.63		Elbeltagy *et al*. (2015)
Post-HS	40.0±0.10	39.6±0.18	51.8±4.23b		
Change%	2.3**	7.6**	81.1**		
Dehy.(0) hours	39.3±0.11	36.9±0.26	31.2±2.40	1.93±0.13	Abdel khalek *et al*. (2012)
Dehy.(72) hours	39.2±0.11	37.1±0.52	30.3±3.03	1.88±0.07	
At rest	39.3 ± 0.06^{c}	37.0 ± 0.14^{c}	32.6 ± 1.41^{c}	1.9 ± 0.05^{b}	Aboul-Naga *et al*. (2021a)
HS	40.0 ± 0.06^{b}	40.0 ± 0.17^{a}	64.0 ± 4.91^{b}	2.1 ± 0.09^{b}	
EHS	40.6 ± 0.08^{a}	36.0 ± 0.13^{b}	103.4 ± .06^{a}	2.6 ± 0.12^{a}	
At Rest	39.04±0.11^{c}	36.74±0.25^{b}	28.69±6.04^{c}		Aboul-Naga *et al*. (2011)
Acute H	40.05±0.11^{b}	39.59±0.25^{a}	51.54±6.04^{b}		
EHS	40.67±0.11^{a}	39.12±0.25^{a}	71.77±6.04^{a}		
			Wahati		
At rest (7am)	38.9^{b} ± 0.04	35.5^{b} ± 0.20	23.1^{b} ± 0.43	2.1^{b} ± 0.05	Aboul-Naga *et al*. (2021b)
Noon (2pm)	40.0^{a} ± 0.06	44.4^{a} ± 0.39	57.9^{a} ± 2.04	3.9a ± 0.11	
			Saidi		
At rest(7am)	39.2 ^{b} ± 0.07	34.9 ^{b} ± 0.18	20.8 ^{b} ± 0.86	1.6 ^{b} ± 0.11	Aboul-Naga *et al*. (2021d)
HS (2 pm)	39.8^{a} ± 0.07	36.9^{a} ± 0.06	47.8^{a} ± 4.56	3.3^{a} ± 0.23	
At night (8pm)	39.3^{b} ± 0.07	34.2^{c} ± 0.11	21.6^{b} ± 0.77	1.89^{c} ± 0.05	
			Black Bedouin		
Shaded: 08am	39.07^{a}	38.24^{a}	35.40^{a}		Shaker *et al*. (2008)
Shaded: 2pm	39.44^{b}	39.62^{b}	61.57^{b}		
Unshaded: 8.am	40.15^{a}	39.48^{b}	36.30^{a}		
Unshaded:2pm	41.41^{d}	41.52^{c}	68.20^{c}		
Summer 8am	38.53^{a}±0.11		29.14^{a}±0.97		Abdalla *et al*. (2005)
Summer 2pm	39.56^{b}±0.11		34.53^{b}0.97		
Winter 8am	38.25^{a}±0.11		19.24^{a}±0.97		
Winter 2pm	38.82^{b}±0.11		21.76^{b}±0.97		

RT: Rectal temp., SK: Skin temp,. RR: Respiration rate, GV: Gas volume, EHS: Exercise under heat stress, G 50%=50%of water requirement; Dehy: Dehydration

**Significant at 5 % probability. ** significan^{t} at 1 % probability; means followed by the same symbol don't differ significantly P≥5%

Several studies have examined the effect of HS on blood parameters such as total protein, albumin, hemoglobin, hematocrit, and mineral concentrations. The effects of HS on blood parameters are generally low, and less noticeable than the physiological parameters. The factor that causes significant changes in blood parameters was water deprivation (dehydration), but these changes were quickly reversed upon rehydration (Abdel khalek *et al*., 2012).

Correlation between heat tolerance and production performance:

Aboul Naga *et al*. (2021c) reported significant correlation estimates between changes in respiration rate (RR) and rectal temperature (RT) with economic traits in Barki sheep (p≥0.05). The estimates were insignificant for other physiological traits (Table 4). The authors highlight that the increase in RR and RT in the desert breeds, in response to HS appears to be associated with their body weight. Local goats, on the other hand, has low correlations between their physiological responses to HS and production performance, indicating that they perform well, under hot dry conditions. These suggested that tolerance to abiotic stress in the desert sheep and goat is not antagonistic with their economic traits.

In brief, physiological responses of local sheep and goat breeds changed significantly with HS, and rate of change differ across parameters. Respiration rate exhibited the highest rate of change, while rectal temperature showed the lowest. Respiration rate is a reliable measurement to differentiate between heat-tolerant and non-tolerant animals to HS. No antagonism was found between HS tolerance and the economic traits of local sheep and goat breeds.

Table 4. Correlation estimates between changes in physiological parameters with HS, and production performance of Barki sheep and goats

Traits	No.	RT	ST	RR	GV	MR	HT-Index
				Barki Sheep			
Bwt.	607	0.076*	0.099*	0.037	0.18**	− 0.084*	0.06
Wwt.	295	− 0.105	− 0.146*	− 0.052	0.071	0.040	− 0.04
Ywt.	297	0.133*	− 0.037	0.196 **	082	− 0.018	0.04
Fec.	174	0.262**	0.201*	0.126+	0.126	− 0.030	− 0.01
				Barki Goats			
Bwt.	232	0.126*	0.012	0.090*	0.176**	− 0.119	0.04
Wwt.	80	− 0.016	0.067	− 0.110	0.055	0.271*	0.07
Ywt.	80	− 0.009	0.257	− 0.001	0.269**	0.308**	0.06
Fec.	80	− 0.132	− 0.230	− 0.016	− 0.095	0.085	0.17

+Cited from Aboul-Naga et al.(2021c).

RT: Rectal temperature; ST: Skin temperature; RR: Respiration Rate; GV: Gas volume; MR: Metabolic rate; Bwt: body weight; Ww.t: weaning Weight; Ywt.: yearling weight; Fec.: fecundity.

* Significant at 5 % P. ** significant at 1 % probability; means followed by the same symbol don't differ significantly P≥5%

***Genomic analysis*:**

Genome-wide association analysis for local sheep breeds exposed to HS under hot dry conditions revealed several potential genomic regions that could be controlling their adaptation to HS. Aboul Naga *et al*. (2022) reported that the MYO5A gene, which belongs to the actin-based protein family involved in melanin production, had significant effect on tolerance of desert Barki sheep to HS. The GSTCD gene, associated with the respiratory function, also assists in controlling their response to HS(Table5). Gene analysis revealed further strong link between genes involved in fat deposition in the fat tail(STEAP3 and GPAT2) and tolerance to HS. The authors suggested that the relationship between genes associated with pigmentation, fat tail deposition, and heat tolerance in local Egyptian sheep breeds can explain why local sheep breeds have better tolerance to heat stress than the temperate ones under hot dry conditions. Kim *et al*. (2016) and Mwacharo *et al*. (2021) reported clear genetic differences between Egyptian sheep breeds and temperate European breeds (Figure 2). They attribute the differences to variations in their evolutionary, breeding, and management histories. The Egyptian desert breeds have been exposed to long period of natural selection in stressful environments. The authors proposed that natural selection and random mating shaped the genome of these breeds, maintaining high diversity within and between local breed populations.

Assessing the impact of HS on gene expression, MYO5A, PRKG1, GSTCD and RTN1 genes were significantly associated with heat tolerance in local desert sheep and goats (Aboul-Naga *et al*., 2023). The SNP OAR1_18300122.1, located in the ST3GAL3 gene, had the greatest positive effect on heat tolerance, the GWAS analysis identified SNPs associated with heat tolerance in the PLCB1, STEAP3, KSR2, UNC13C, PEBP4, and GPAT2 genes. Younis (2020) revealed that gene expression ofHSP70 and HSP90 were relatively up-regulated in Abou-Deleik sheep and down-regulated in Barki sheep, their expression patterns can serve as a reference point to identify breeding animals of genetic adaptability to arid areas.

The findings suggest that adaptation to hot dry environment is mediated by a complex network of genes acting in tandem, rather than the action of a single candidate gene. Lv *et al*. (2014) reported that the adaptation capacity to HS results from the interaction of multiple complex traits controlled by several genes. Therefore, it is not surprising that selection signatures span several candidate genes that directly or indirectly influence traits critical for survival in hot dry environment. Variations in body size were closely related to thermoregulation capacity, desert sheep and goat breeds are generally smaller in body size (McManus *et al*., 2011).

In brief, adaptation to hot dry environment is mediated by a complex network of genes working together, rather than acting as single candidate genes. The relationship between genes associated with pigmentation, fat tail deposition, and heat tolerance in subtropical sheep breeds may explain why these breeds have better adaptation to hot, dryconditions than temperate breeds, along with their small body size. Further research is needed to determine the molecular mechanisms managing the adaptability of local breeds to HS at the cellular level.

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Table 5. Genomic analysis of tolerance to HS in local sheep and goats breeds

Breed	Anim	Region	HS	Season	Tech.	Genes & SNPs	Author
				Sheep			
Barki	59 ewes	CZWD*	Air Temp. 28-35 °C	July /August	50K SNPChip	MAGI3, LAP3, CSN3, ARRDC3, MIR217, LKPDIA6, LMLNPCDH9, LYPLA1, ELF2, PGRMC2, BBS	El-Beltagy, *et al.*, (2016)
Barki	25 ewes	CZW & RHS	Air Temp.: 25–35◦C; Humidity:55–65%	March /May	qPCR	HSP70 HSP90	Younis, (2020)
Barki	291 ewes	CZWD	HS:12 to 3 pm EHS (Walk for 7 km 12 - 3 pm)	July /August	qPCR	LACT, BLF, HSP70, CAT GST, SOD	Aboul-Naga *et al.*, (2023)
Barki	83 ewes	CZWD	EHS (Walk for 7 km 12- 3 pm)	July /August	GWAS	19 chromosomes 31 gene & 46 SNP	Aboul-Naga, *et al.* (2022)
Barki	50 ewes	CZWD	Measures at 7 am and 3pm.	Summer /Winter	qPCR	HSP70, IL 2, IL 6, IL 12	Abu-Rawash, *et al.*, 2022
Barki	60 males	South Sinai	Measureat 6 am and 2pm	Summer	Seqenc.	HSP90AB1, HSF1, ST1P1, ATP1A1	Ibrahim, *et al.*, (2023)
Abou-Deleik	25 ewes	CZW & RHS	Air Temp.: 25–35◦C; Humidity: 55–65%	March /May	qPCR	HSP70 HSP90	Younis, (2020)
Abou-Deleik	60 males	South Sinai	Measured at 6 am and 2 pm	Summer	Sequen.	HSF1(3 SNP), ST1P1 (6 SNP), ATP1A1, HSPB6	Ibrahim, *et al.*, (2023)
Wahati	55 ewes	CZWD	EHS (Walk for 7 km 12 – 3pm)	July /August	GWAS	19 chromosomes 31 gene & 46 SNP	Aboul-Naga, *et al.*, (2021a)
Saidi	68 ewes	CZWD	EHS (Walk for 7 km 12- 3pm)	July /August	GWAS	19 chromosomes 31 gene & 46 SNP	Aboul-Naga, *et al.*, (2021b)
				Goats			
Barki	68 does	CZWD	Air Temperatures: 28 –35 °C)	July /August	50K SNP Chip	KNSTRN, PLEKHB2, TRHDE, ATP12A, PCDH9, BMP2RPL6, SUCLG2PAK1	El-Beltagy, *et al.*, (2016)
Barki	166 does	CZWD	HS: 12 to 3 pm EHS (Walk for 7 km 12 – 3pm)	July /August	qPCR	LACT, BLF, HSP70, CAT, GST, SOD	Aboul-Naga, *et al.*, (2023)
Barki	28 does	Siwa	Morning &Noon	Summer	Sequen.	21 SNP (RNF17)	Sallam, *et al.*, (2023)

*CZWD: Coastal Zone Western Desert, HS: Heat Stress, EHS: Exercise Heat Stress, qPCR: Quantitative PCR.

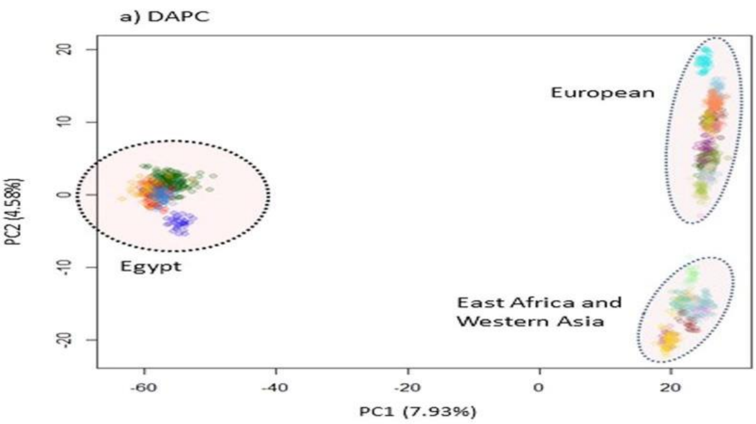

Figure 2. Discriminant analysis of principal components for genetic variation of different groups of sheep breeds *(Cited from Kim et al. 2016).*

Breeders' perception of adaptation strategies of local sheep and goats to HS:

Adaptation strategies to cope with CC are often implemented through top-down approach, which overlooked the fact that the real decisions are made at the breeder's level. Few studies explore breeders' knowledge and practical management of the climatic stress. Abdel-Sabour (2024) conducted interviews with breeders in three hot, dry agro-ecological zones (CZWD, NV, and UE) to assess the practices they implemented to adapt CC. The outputs reflect similar breeders' perceptions regarding the adaptive capacity of local sheep and goats at different regions. The breeders emphasized the complementary role that sheep and goats play to ensure the resilience of farming systems under hot dry environments, in terms of food security and income generation. According to the breeders the advantage of local sheep and goats comes from their ability to cope with hot dry conditions (≥50%). The second key advantage is their productivity and marketing value of their products, accounting for at least 25%. The adaptability of local breeds to feed shortages and poor-quality feeds was also highlight ted as crucial factors. These traits are essential for addressing environmental stress and economic uncertainty and highlight the importance of local knowledge in a sustainable livestock management in hot dry areas.

Table 6. Perception of breeders for the advantage of local sheep and goat breeds /farm type+ (%)

	Sheep			Goat		
Farm type	**Small***	**large**	**overall**	**Small**	**large**	**overall**
Adapted to desert conditions	11	30	17	12	23	19
Adapted to heat and drought	32	21	29	34	22	29
Adapted to walk and grazing	1	11	4	1	10	4
Adapted to feed shortage and low requirement	8	10	9	9	11	10
Adapted to disease	5	3	4	5	3	4
Good productivity	19	7	15	19	8	15
Good meat quality	3	10	5	2	10	5
Good market value	13	5	11	10	3	7
Cultural value	8	4	6	9	4	7

*Small: ≤6 acres, ≤100 small ruminant and ≤10arge ruminants, at poverty threshold, low potential of transmission for next generation; Large: ≥50 acres, ≥ 300 SR) ≥10 large ruminant, sustainable potential of transmission for next generation.
+Cited from Abdel Sabour (2024).

Management strategies for small ruminants in hot dry areas:

Effective managerial strategies are vital for minimizing the impact of environmental stress on sheep and goats' production at the hot dry areas (Giuseppe *et al*., 2016). These strategies include modifying housing systems, improving feeding techniques, innovative breeding methods, and promoting animal biodiversity. In addition, specific management practices such as improving reproductive efficiency, low water-requirement crops, shaded areas in the pastoral systems, and preventive measures for emerging diseases are crucial in mitigating the negative impacts of CC on small ruminants. Mitigating livestock environmental stress, through feeding adjustment and grazing system, reducing flock/herd sizes, are key elements in coping climatic stresses.

Many recent advances in precision feeding have been developed to address the challenges posed by the stressful climatic conditions. These advances aim to increase feed efficiency, improve farm profitability, and reduce environmental impacts. Identifying and selecting well-adapted animals is crucial for ensuring the sustainability and profitability of sheep and goats farming under hot dry conditions. Meteorological warning is necessary to mitigate the effects of severe weather events on livestock. Focus on sustainability, breeders can enhance resilience to climate change while maintaining farm productivity.

CONCLUSIONS

The most significant challenges of CC atthe hot dry areas are reducing livestock production due to the physiological disruptions caused by the HS. The ability of local sheep and goat breeds to adapt heat stress at hot dry environment, is largely governed by genetic factors mediated by a complex network of genes acting in concert, rather than the influence of single candidate genes. Genetic selection for heat tolerance could prioritize traits like respiration rate, which proved to be reliable in identifying heat-tolerant animals. Body weight of sheep and goats is closely related to their thermoregulation capacity, heavier animals are less suited to hot dry environments, an evolutionary response to the need for mobility and endurance searching for water and pasture. Adaptation strategies to environmental stress at the hot dry areas include precision feeding to enhance feed efficiency, innovative breeding that promotes well adapted animals. In additions, effective management practices, as adjusting flock size and optimizing feeding management, are essential in mitigating the effects of CC. Future research should focus on the molecular mechanisms that underlie heat tolerance to hot dry conditions, and refining livestock breeding programs in arid areas.

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Authors' contributions

AA-N contributed to the conception and design of the work, writing the manuscript, SM, RA and LG organized database and review of literature, MErevised the manuscript

Conflicts of Interest

The authors declare no conflicts of interest for the work.

Consent to participate and for publication:

All authors agreed to participate to the work. They approved the content of the manuscript and the submission for publication

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الجوانب الفسيولوجية والوراثية لتحمل الإجهاد الحراري في الأغنام والماعز شبه الاستوائية التي تربي في المناطق الجافة الحارة

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ترتفع درجة حرارة منطقة الشرق الاوسط بمعدل أسرع من المتوسط العالمي، وتعتبر مصر عرضة بشكل خاص لتأثيرات تغير المناخ. وتواجه الثروة الحيوانية بها تحديات كبيرة لتنظيم وظائفها الفسيولوجية في ظل الظروف الجافة الحارة المجهدة. وتستعرض المقالة الدراسات التي أجريت على تحمل سلالات الأغنام والماعز المصرية شبه الاستوائية للإجهاد الحراري في المناطق القاحله.

زاد معدل تنفس الحيوانات بشكل ملحوظ مع الإجهاد الحراري وتم تحديده كمقياس موثوق به للتمييز بين الأغنام المتحملة للحرارة والاغنام غير المتحملة. وكانت التغييرات في معدل التنفس أقل وضوحًا في الماعز المحلية، مما يعكس تحمل الماعزالمحليه لـلإجهاد الحراري بشكل أفضل من الأغنام. وتتكيف الماعز المحلية مع الإجهاد الحراري، في المقام الأول، عن طريق تقليل إنتاجها الحراري، بينما تسارع الأغنام المحلية في تنفسها للتعامل مع الإجهاد الحراري. ووجد ارتباط كبير بين التغييرات في معدل التنفس والأداء الاقتصادي للأغنام ويرتبط زيادة المعدل بحجم أجسامها.

حددت التحليلات الجينومية العديد من المناطق الجينومية المرتبطة بتكيف الأغنام والماعزالمحليه مع الظروف الجافة الحارة. وهذا التكيف يتم بواسطة شبكة معقدة من الجينات التي تعمل معًا بدلاً من الاعتماد على الجينات المحدده الفردية. وتؤكد استراتيجيات التخفيف من الضغوط البيئية على الأغنام والماعز في المناطق الجافة الحارة، على أهمية ممارسات الرعايه لزيادة قدرة الأغنام والماعز المحلية على الاقلمه في المناطق القاحله.