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Impact of the Temperature-Humidity Index on Body Temperature, Physiological Response, Lipid Profile, Thyroid Function, and Reproductive Performance of Damascus Goat Bucks

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ABSTRACT

A total of 17 Damascus bucks were exposed to different THI conditions during the experimental intervals covering THI of 14.06-21.29 in December (no HS), 22.28-25.14 in March (moderate HS), and 27.19-35.41 in July (severe-extreme HS). Temperature of hair, skin, rectum, and scrotum as well as pulse rate increased ($P<0.05$) under moderate HS compared to no HS, but further increase ($P<0.05$) was found in all under severe-extreme HS. Respiratory rate was higher ($P<0.05$) under severe-extreme HS than under absence or moderate HS. Increasing THI (severe-extreme HS) decreased ($P<0.05$) RBCs, WBCs, Hb, and Ht to the minimum values, compared to no HS. Plasma concentration of triglycerides, total cholesterol, and very LDL-cholesterol decreased ($P<0.05$) only under severe-extreme HS. Plasma T3 and T4 concentrations decreased ($P<0.05$) under severe-extreme HS compared to no or moderate HS. Reaction time was longer and plasma testosterone concentration was lower ($P<0.05$) under severe-extreme HS than no or moderate HS. Ejaculate volume, and percentages of sperm progressive motility, livability, normality, acrosome integrity, and sperm cell concentration were higher ($P<0.05$) under no or moderate HS than severe-extreme HS. Sperm output per ejaculate, as total, motile, live, and normal were higher ($P<0.05$) under no and moderate HS than severe-extreme HS. Body core and surface temperatures, hematology, lipid profile, thyroid function, and semen quality can be reliable monitoring tools for predicting heat stress in goat bucks.

Keywords: *Goat, THI, body temperature, thyroxin, semen quality.*

INTRODUCTION

Warming of the global climate is now unequivocal by increasing temperature and related climate phenomena, including an increase in the frequency and intensity of extreme weather events such as hot spells, droughts and floods (IPCC, 2013). Climatic factors, such as ambient temperature and humidity have been direct effects on reproductive performance, growth, and the animal production of milk, meat, and wool (Marai *et al*., 2001). Climate change has caused unprecedented alterations in recent decades (Hansen *et al.* 2010), which may predict future losses related to heat stress (HS) incidence in animal productive and reproductive performances (Upadhyay *et al.* 2012). Animal productivity is dependent on its ability to adapt to these stressors (Collier *et al.* 2008) and HS is an important factor affecting the animal subfertility. In mammal males, it was reported that HS elevates the respiration rate, pulse rate, and body temperature (Meyerhoeffer *et al*., 1985), disrupts spermatogenesis, and decreases sperm quality, testes volume, and testosterone concentration (Setchell, 1998; Alves *et al*., 2016).

The effect of the season can vary greatly among climatic zones; however, conflicted results have been obtained for the seasonal variation on semen quality of bulls (Malama *et al*., 2017; Sabes-Alsina *et al*., 2017) and males of small ruminants (El-Maghraby, 2007; Abdullah, 2019; Zanouny and Ashmawy, 2024). The thermal-humidity index (THI), first proposed by Thom (1958), is a marker used to determine the degree of HS in different conditions. However, there are no unified critical thresholds of THI for delineating different degrees of HS (Brown-Brandl *et al.* 2003; Broucek *et al.* 2009). THI, the value of the combined effects of ambient temperature and relative humidity, is an indicator of environmental conditions and is commonly used to evaluate the impact of HS (Dikmen and Hansen, 2009), and determine the comfort threshold value, mild HS, severe HS, and extreme HS (De Rensis *et al*., 2015; Herbut and Angrecka, 2018). In many areas of the Mediterranean basin, THI in summer is higher and affect negatively animal productivity and welfare (Segnalini *et al*., 2011), and THI value has been developed as a weather safety index to control and losses related to HS (Bohmanova *et al*., 2007).

Some authors have studied the impact of THI on fertility of bulls (Menegassi *et al*., 2016; Romanello *et al*., 2018), milk production in Egyptian buffaloes (El-Khashab *et al*., 2017), and physiological aspects in riverine buffaloes (Umar *et al*., 2021). The THI is a practical tool and a standard for several applications in animal biometeorology, particularly in summer condition all over the world to determine the impact of HS on animal performance to enhance the productivity by mitigating of impaired effects of HS. The physiological regulation of heat exchange is varying in goat from sheep in association with color of hair coat and skin, the efficiency of evaporation, and the ability of sweating glands (Apocrine) during different THI values.

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According to our knowledge, the researches published on the effect of THE variation on physiological response and reproductive performance of goats are rare. So, the heat regulation and the response to HS in goats would be different as compared to other animal species. Therefore, in this study, we aimed to identify the accurate THI range affecting semen quality and the physiological status to contribute to a better evaluating the impact of climate factors on the reproductive performance of Damascus goats.

MATERIALS AND METHODS

The present study was conducted within the framework of scientific cooperation between Animal Production Department, Faculty of Agriculture, Minia University and Animal Production Research Institute (APRI), Agricultural Research Center, Ministry of Agriculture, Egypt.

Meteorological characteristics:

The study was carried out at Sakha experimental station, Kafrelsheikh Governorate, belonging to Animal Production Research Institute, Agricultural Research Center, Egypt. The latitude and longitude of Kafrelsheikh, Egypt is: 31° 6' 42'' N and 30° 56' 45'' E, having a subtropical desert climate. In Kafrelsheikh, the summer is muggy, arid, and clear and the winter is cool, dry, and mostly clear. Over the year, the temperature typically varies from 49°F to 93°F and is rarely below 44°F or above 98°F (https://weatherspark.com/y/96439/Average-Weather-in-Kafr-ash-Shaykh-Egypt-Year-Round).

During the experimental intervals in December, March, and July covering a THI range from 14.06 to 35.41ºC, ambient temperature and relative humidity were daily recorded for the surrounding area of animals at 12 p.m. using a digital thermometer, while RH was measured by hygrometer, then THI was calculated (Table 1).

THI values were calculated according to Marai *et al.* (2001) using the following equation:

$$\mathbf{THI = db^0C - \{(0.31 - 0.31\ RH)\ (db^0C - 14.4)\}}$$

Where: **db^0C = dry bulb temperature (^0C) and RH = relative humidity/100.**

THI values of <22.2 were considered as HS absence. THI values ranging from 22.2 to more than 23.3 indicate mild or moderate HS. THI values ranging from 23.3 to more than 25.6 lead to severe and severe-extreme HS.

Table 1. Recorded averages of air temperature (ºC) and relative humidity (%), and calculated temperature-humidity index (THI) during different experimental intervals.

Heat stress	Ambient temperature (ºC)		Relative humidity (%)		THI value	
	Mean±SE	Range	Mean±SE	Range	Mean±SE	Range
No	18.25±1.51	14-22	58.75±3.69	50-70	17.82±1.36	14.06-21.29
Moderate	24.50±1.47	20-28	54.50±3.95	45-55	22.27±1.87	22.28-25.14
Severe-extreme	36.25±3.07	29-40	68.75±3.69	60-80	32.42±2.10	27.19-35.41

Animals:

All experimental animals were approved by the Institutional Animal Ethics Committee of APRI. From the herd of goats raised in Sakha station belonging to APRI, a total of 17 Damascus bucks were randomly chosen as experimental animals. The experimental bucks ranged from 42 to 52 kg as live body weight and 22-26 months of age. During the experimental months (December, March, and July), the experimental bucks were housed, fed, and managed under the same conditions, and sampled at the times. The sampled bucks were kept under a semi-intensive system in which they were stall-fed with fresh water available all-day time.

Feeding system:

The experimental bucks (n=17) were fed in group-feeding system on concentrate feed mixture (CFM) and berseem hay plus rice straw in July or CFM and fresh berseem and rice straw in December and March. The CFM contained 89.9% DM, 88.6% OM, 14.5% CP, 12.5% CF, 3.1% EE, 58.5% NFE, and 11.3%. Feeds were given to bucks at 6 a.m. and 4 p.m. and block minerals were licked *ad libitum*.

Experimental procedures:

The temperature of body weight regions including the top surface of hair (HT), skin of the median back (ST), rectum (RT), and scrotum (SCT) were measured at 3-day interval at noon., then average temperature degrees were computed for each buck during the experimental months. Each body temperature (HT, ST, and SCT) was recorded by a thermometer, while RT was recorded by insertion (5 cm in depth) of an electronic thermometer probe into the rectum. Respiratory rate (number of breaths/min) and pulse rate (number of pulses/min) were determined at the same time.

At the end of each experimental month, blood samples were collected from the jugular vein of 10 bucks into heparinized test tubes. Each blood sample was divided into two tubes, one (whole blood samples) for hematological parameters and another was centrifuged at 3000 *g* for 15 min to obtain blood plasma, which was stored at -20°C until biochemical analyses.

Analytical procedures:

Hematological parameters:

In whole blood samples, hematological traits including count of erythrocytes (ECs) and leukocytes (LCs), hemoglobin (Hb) concentration, and packed cell volume percentage (PCV%) were estimated utilizing an automated blood cell counter equipped with an Auto Hematology Analyzer (Sysmex F-800, Japan) (Buttarello, 2004).

Blood biochemicals and hormones:

Chemical kits sourced from Diamond Diagnostic Company, Egypt were used to analyze the concentration of lipid profile, including total lipids, triglycerides (Burtis *et al.*, 2006), total cholesterol, high-density lipoproteins (HDL-cholesterol, and low-density lipoproteins (LDL-cholesterol) in blood plasma samples (Henry, 1974), by enzymatic colorimetric method, using BT3500 Biotechnic Instruments. Very-LDL level was computed as triglycerides divided by 5 according to Liotta *et al.*, 2021).

According to the manufacturer's instructions ((DRG Diagnostics GmbH, Marburg, Germany), plasma triiodothyronine, tetra iodothyronine (thyroxin), and testosterone concentrations were assayed by the Enzyme-Linked Immunosorbent Assay (ELISA) using commercial kits.

Reproductive measurements:

Sexual desire:

Sexual desire parameters including reaction time, testicular volume, and testosterone profile were determined for each buck. The time-interval from introducing each buck to teaser until complete ejaculation was recorded as a reaction time. The testicular volume was determined by the water displacement volume of the testes (right and left) with their scrotum. The plasma testosterone concentration was assayed by the radioimmunoassay (RIA) technique using the coated tube kits (Diagnostic Products Corporation, Los Angeles, CA, USA).

Semen collection and evaluation:

Semen was collected individually from all bucks during different experimental months twice/week (8 ejaculate/month) using the artificial vagina of goats. Ejaculate volume (EV) was recorded after the collection of semen, then semen was placed in a water bath (37ºC) and transported to the laboratory for evaluation. All semen evaluations were run in 5 microscope fields with about 200-300 sperm cells in each.

In a sample of semen diluted with Tris-egg yolk-citrate extender, the count of sperm cells with progressive motility (forward movement in a long semi-arc pattern) was determined in a microscope field of about 200 sperm cells on a slide placed on the warmed stage of a phase contrast microscope (DM 500; Leica, Switzerland), and then the percentage of progressive motility was calculated.

Sperm livability and abnormality were measured in a smear of stained semen with 5% eosin and 10% nigrosine and examined at magnification ×400. The count of stained (dead) and unstained (live) spermatozoa was determined, and then the sperm livability percentage was computed. The count of spermatozoa with morphological abnormality patterns was recorded then the percentage of total abnormalities was calculated.

Acrosome status was examined in semen smear dried, fixed by 10% buffered formal saline for 15 min, and stained with Giemsa by a light microscope at 1000x (Brackett and Oliphant, 1975). Sperm cells with attached or detached acrosome was determined, and then the percentage of acrosome integrity was computed. Sperm cell concentration (SCC) was determined by hemocytometer.

Sperm production, in terms of the count of sperm cells per ejaculate presented as motile (MSC), live (LSC), normal (NSC), and total (TSC) was calculated as the following:

TSC/ejac. =EV (mL) x SCC(x10^9/mL),
MSC/ejac. =TSC x progressive motility/100,
LSC/ejac. =TSC x live sperm/100, and
NSC/ejac. =TSC x (abnormality -100)

Statistical analysis:

A one-way ANOVA procedure was used for the data statistical analysis to evaluate the effect of THI value on different parameters studied (SPSS, 2023). The significant differences of THI were separated by Duncan's Multiple-Range test procedure (Duncan, 1955) to clear the group differences. The obtained percentages were transferred to arc-sign pre-statistical analysis, then the true values were tabulated as means.

RESULTS AND DISCUSSION

Body temperature and physiological response:

The effect of THI on body temperature and physiological response parameters of bucks is shown in Table 2. Results revealed that the temperature of hair (HT), skin (ST), rectum (RT), and scrotum (SCT) increased (P<0.05) under moderate HS as compared to no HS condition, but further increase (P<0.05) was found in all body temperature degrees under severe-extreme HS condition, showing the highest values.

Regarding the physiological response parameters, pulse rate (PR) showed a similar trend to temperature degrees, however respiratory rate (RR) was higher (P<0.05) under severe-extreme HS than under no or moderate HS conditions (Table 2).

Table 2. Effect of THI on body temperatures, respiration rate, and pulse rate of goat bucks, as physiological response parameters.

Parameter	Heat stress condition (THI value)			P-value
	No(14.06-21.29)	Moderate(22.28-25.14)	Severe-extreme (27.19-35.41)	
Body temperature (ºC)				
Hair temperature	20.59±0.369^c	22.38±0.397^b	37.11±0.323^a	0.000
Skin temperature	32.52±0.124^c	33.28±0.255^b	35.42±0.183^a	0.031
Rectal temperature	37.54±0.145^c	38.13±0.217^b	39.43±0.270^a	0.007
Scrotal temperature	18.72±0.397^c	24.54±0.203^b	33.11±0.341^a	0.000
Physiological response				
Pulse rate (time/min)	78.33±0.636^c	85.21±0.458^b	97.21±1.214^a	0.003
Respiration rate (beat/min)	46.61±0.784^b	50.87±1.883^b	105.67±1.764^a	0.004

$^{a, b, and c}$: Differed superscripts within the same row indicate significant group differences at P<0.05.

These findings indicated that body temperature (HT, ST, RT, and SCT) and physiological response (PR) are more sensitive to THI values than RR with heat loss and body heat dissipation. Similar to our results, Abdullah (2019) found the highest HT, RT, ST, SCT, PR, and RR of goats in hot conditions compared to moderate or cold conditions in Egypt, associated with the highest THI values. Increasing RT and RR are important traits in response to HS conditions in goats and physiological response parameters (RT, RR and PR) are suitable parameters for measuring HS (Helal *et al.*, 2010). The alterations in body temperature and physiological response parameters are frequently used as markers of climatic adaptability in small ruminants (Adedeji, 2012).

According to our results, RR was affected only by exposing bucks to hot temperatures with severe-extreme HS (high THI). This finding was related to the gradient between RT and each of ST, HT, and SCT, which was higher under no or moderate HS conditions than under severe-extreme conditions, being 5.02, 16.95, and 18.82ºC under no HS, 4.85, 15.75, and 13.59ºC under moderate HS, and 4.01, 2.32, and 6.32ºC under severe-extreme HS condition. Increasing the gradients may indicate more heat loss by dissipation of body core heat to ST, HT, the surrounding environment.

These results indicated that the excess body heat dissipation was higher to negate the excessive heat loading by increasing water evaporation via the respiratory tract by increasing RR (panting) and sweating rate by the skin surface. This was due to that, environmental temperature approaches HT and ST (Caulfield *et al.,* 2014). The observed insignificant increase in RR under moderate HS conditions indicated a recruitment of evaporative processes, primarily sweating and less increased RR (Mortola and Frappell, 2000).

Hematological parameters:

The effect of THI on the count of erythrocytes (RBCs) and leukocytes (WBCs) as well as hemoglobin (Hb) concentration and hematocrit (Ht) percentage were significant (Table 3). Higher THI values under severe-extreme HS conditions decreased (P<0.05) all hematological parameters (RBCs, WBCs, Hb, and Ht) to the minimum values, as compared to no HS condition. However, moderate HS conditions showed insignificant differences in these parameters with no HS or severe-extreme HS conditions. In agreement with our results, Abdullah (2019) found that RBCs, WBCs, Hb, and Ht were the highest with low THI values in winter, moderate with mild THI values in spring, and lowest with high THI values in summer. However, Iyiola-Tunji *et al.* (2015) found that ambient temperature did not affect erythrocyte indices.

Table 3. Effect of THI on hematological parameters of goat bucks.

Parameter	Heat stress condition (THI value)			P-value
	No(14.06-21.29)	Moderate(22.28-25.14)	Severe-extreme(27.19-35.41)	
Erythrocytes, RBCs ($x10^6/mm^3$)	13.34±0.085^a	12.89±0.176^{ab}	12.13±0.068^b	0.042
Leukocytes, WBCs ($x10^3/mm^3$)	6.54±0.042^a	6.32±0.086^{ab}	6.09±0.033^b	0.037
Hemoglobin, Hb (g/dL)	12.63±0.081^a	12.40±0.167^{ab}	11.77±0.065^b	0.029
Hematocrit, Ht (%)	41.68±0.267^a	40.27±0.551^{ab}	38.84±0.214^b	0.046

$^{a\ and\ b}$: Differed superscripts within the same row indicate significant group differences at P<0.05.

The hematological parameters (WBCs, Hb, and Ht) are important for indicating the normal physiological condition of animals, evaluating the nutritional status and animal health (Opara *et al.,* 2010), and animal adaptability to prevailing climatic conditions (Kaushish *et al.*, 1976). In our study, the results indicated that THI affects the volume of blood/plasma and several environmental factors lead to variations in the hematological parameters of goats in different regions (Fasae *et al.*, 2011). In this respect, alteration in ambient temperature or relative humidity (THI) affect the animal biological systems, as physiological stressors (El-Nouty *et al.*, 1990), exerting marked effects on the hematological parameters of goat bucks (El-Nouty *et al.*, 1986). As found in our study, environmental ambient temperature was reported to affect all erythrocyte series in small ruminants (Tibbo *et al.*, 2008). In this context, increasing RBCs, Hb, and Ht in no or moderate HS condition may reflect good circulation of erythrocytes (Chineke *et al.*, 2006). Our results may suggest that decreasing WBCs, Hb, and Ht in the blood of bucks under severe-extreme HS conditions may be due to increasing water consumption in hot climates, leading to increasing blood plasma volume compared to low water consumption under no or moderate HS conditions. Generally, effect of THI on the hematological parameters of bucks is more prominent in improving health status under no or moderate HS conditions.

Lipid profile:

The effect of THI was significant on plasma lipid profile, in terms of decreasing (P<0.05) total lipid concentration under moderate HS, and another decrease with severe-extreme HS, as compared to no HS condition. However, the concentration of triglycerides, total cholesterol, and very LDL-cholesterol decreased (P<0.05) only under severe-extreme HS compared to no HS, and insignificant differences with under moderate HS conditions. On the other hand, concentration of HDL- and LDL-cholesterol were not affected by THI (Table 4).

Table 4. Effect of THI on lipid profile in blood plasma of goat bucks.

Parameter	Heat stress condition (THI value)			P-value
	No(14.06-21.29)	Moderate(22.28-25.14)	Severe-extreme(27.19-35.41)	
Total lipids (mg/dL)	213.6±1.795^a	204.2±2.736^b	194.5±1.453^c	0.009
Triglycerides (mg/dL)	26.32±0.223^a	25.20±0.461^{ab}	24.01±0.179^b	0.021
Total-cholesterol (mg/dL)	92.47±1.298^a	89.48±1.637^{ab}	85.23±0.637^b	0.033
HDL-cholesterol (mg/dL)	9.412±0.079	9.012±0.164	8.571±0.064	0.142
LDL-cholesterol (mg/dL)	78.89±0.662	75.43±1.380	71.86±0.537	0.215
Very LDL-cholesterol	5.26±0.041^a	5.04±0.054^{ab}	4.80±0.037^b	0.042

$^{a,\ b,\ and\ c}$: Differed superscripts within the same row indicate significant group differences at P<0.05.

These results indicated a pronounced effect of severe-extreme HS (THI 27.19) on lipid profile. Similarly, Abdullah (2019) found that total lipids, triglycerides, HDL-cholesterol, LDL-cholesterol, and very LDL-cholesterol concentrations in the plasma of goat bucks were significantly the lowest in summer (severe-extreme HS) as compared to other seasons. Also, Indu *et al.* 2014) showed increased cholesterol concentration in winter compared with summer. Moreover, Gudev *et al.* (2007) reported a decrease in plasma cholesterol concentration during exposure to direct solar radiation compared to the morning levels.

The existence of significant differences in total lipids, total cholesterol, triglyceride, and very LDL-cholesterol concentrations, reaching the minimum values under severe-extreme HS and the maximum values under both no and moderate HS conditions indicated a significant effect of THI on the lipid homeostasis. The obtained values of total cholesterol, triglycerides, and very LDL-cholesterol under all conditions in our study are within the physiological ranges reported on adult goats (Waziri *et al.*, 2010; Tharwat *et al.*, 2013; Karaþahin *et al.*, 2018), and the trend of change may be due to the impact of THI on the synthesis of triglycerides in the liver (Okonkwo *et al.*, 2010; Sharma *et al.*, 2015). In this line, decreasing in cholesterol concentration in the summer may be due to a marked reduction in feed intake (Indu *et al.*, 2014). Besides the effect of different THI values, the nutrition regime and managerial system may have an important role in the lipid profile of goats.

Thyroid function:

Results in Table (5) reveal that thyroid activity was affected significantly (P<0.009) by THI value. The concentration of plasma T_3 and T_4 decreased (P<0.05) under severe-extreme HS compared to no or moderate HS conditions. The results obtained from the goat bucks in the current study are in accordance with the reported physiological range (0.59–1.35 µg/dL for T_3 and 6.10–8.15 µg/dL for T_4, respectively (Todini, 2007). The present results of our study are in agreement with several authors, who found that T_3 and T_4 concentrations were increased in winter as compared to summer, being the lowest under hot condition (Gudev *et al.*, 2007; Banerjee *et al.*, 2015; Rathwa *et al.*, 2017; Abdullah, 2019).

Table 5. Effect of THI on concentration of thyroid hormones and cortisol in blood plasma of goat bucks.

Hormone	Heat stress condition (THI value)			P-value
	No	Moderate	Severeextreme	
Triiodothyronine (T3, ng/dL)	107.46±0.51[a]	106.26±1.28[a]	80.12±0.85[b]	0.009
Thyroxin (T4, µg/dL)	8.460±1.887[a]	8.015±4.768[a]	5.139±3.181[b]	0.012

[a and b]: Differed superscripts within the same row indicate significant group differences at P<0.05.

Ambient temperature is found to be the major exogenous regulator of thyroid function (Dickson *et al.*, 1993). There is an inverse relationship between environmental temperature and concentration of T_3 and T_4 concentration in goats (Colavita *et al.*, 1993) and sheep (Starling *et al.*, 2005). The observed reduction in T3 and T4 levels with severe--extreme HS conditions may be attributed to HS's direct influence on the activity of thyroid gland due to decreased feed consumption to avoid extra metabolic heat load (Banerjee *et al.*, 2015). Moreover, the reduction observed in the thyroid response to severe-extreme HS may be in relation to the regulation of energy homeostasis by decreasing the rate of metabolic heat production. The lowest T_3 and T_4 concentrations are probably due to a decrease in their demands and the requirements of low metabolic and oxidation rates, as reported in ruminant species (Todini *et al.*, 2007). These results indicated higher activity of the metabolic action of the thyroid gland in no or moderate HS than in severe- extreme HS conditions. Moreover, the thyroid gland exhibits a seasonal pattern of activity, showing maximal concentration in winter and minimal level in summer (Okab *et al.*, 1993; Menegatos *et al.*, 2006). It is of interest to note that the present results of thyroxin are in association with lipid profile. In this context, some reports indicated that thyroid hormones affect the metabolism of cholesterol (Mansourian, 2010) and the seasonal variation in blood total cholesterol, triglycerides, and very LDL-cholesterol may be partly affecting the thyroid function.

Reproductive performance parameters:

Sexual desire:

The results of sexual desire parameters, including testicular volume, reaction time, and plasma testosterone concentration of bucks as affected by THI are shown in Table 6. The effect of THI on testicular volume was not significant, but there was a trend toward decreased testicular volume in severe-extreme HS compared to no or moderate HS conditions. Abdullah (2019) reported similar results, founding a reduction to the minimal value of length and volume of the testes and circumference of the scrotum of goat bucks in summer as compared to other seasons.

Table 6. Effect of THI on testicular volume, reaction time, and testosterone concentration in blood plasma of goat bucks, as sexual activity parameters.

Item	Heat stress condition (THI value)			P-value
	No(14.06-21.29)	Moderate(22.28-25.14)	Severe-extreme(27.19-35.41)	
Testicular volume (mL)	50.4±1.17	50.7±1.08	47.5±1.24	0.093
Reaction time (second)	85.3±5.755[b]	107.3±9.37[b]	180.7±12.86[a]	0.004
Testosterone (ng/ml)	5.85±0.082[a]	6.11±0.207[a]	4.17±0.270[b]	0.043

[a, and b]: Differed superscripts within the same row indicate significant group differences at P<0.05.

On the other hand, both reaction time and plasma testosterone concentration were lower (P<0.05) and reaction time was longer (P<0.05) under severe-extreme HS conditions than no or moderate HS conditions (Table 6). Based on these results, Abdullah (2019) recorded the longest reaction time and lowest testosterone concentration of goat bucks in summer, while the shortest reaction time and highest testosterone level were recorded in winter and autumn. In Sannen goat bucks in England, Ahmad and Noakes (1995) found that reaction time was shorter in winter than in spring and summer. In Baladi goat bucks, reaction time was the longest in spring and the shortest in autumn (Ashmawy, 1978). On the contrary, Chehadeh (1996) found increased reaction time during spring and winter compared to autumn in the Zaraibi goat. On the other hand, season has been reported to have no impact on the sexual desire of Indigenous and crossbred goats in the Indian arid region (Mittal, 1987), and the dry and rainy seasons of woodless sheep (Freitas and Nunes, 1992). However, males of tropical origin showed their sexual desire all year round (Chemineau, 1986). Several authors have also found significant fluctuations in testosterone and libido of goat bucks in temperate regions during or outside of the breeding season (El-Saidy, 1988; Ahmad and Noakes, 1995).

Sexual desire is an important factor in assessing the reproductive capacity of males (Abdel-Rahman and Kandil, 1984). In different geographical areas, the intensity of sexual desire depends on the level of androgen and photoperiod, which directly affects the goat buck's sexual activity in temperate regions (Nunes, 1988). Therefore, reports on the effect of the season (with varying THI values, photoperiods, feeding regimes, and management factors) on sexual activity have shown contradictory effects. For example, the sexual desire of Sannen bucks declined steadily from February until reaching a complete cessation in May and reaching its highest levels in December (Ahmed *et al.*, 1997). Zaraibi bucks had higher sexual desire in February, March, April, and September compared to May, October, and December (Nelson *et al.*, 1987). According to our results and previous findings, the sexual desire of Damascus goat bucks is subjected to the influence of THI along with other environmental factors.

Physical semen characteristics:

Effect of THI on physical characteristics, including ejaculate volume (EJV), and the percentages of progressive motility (PRM), livability (LIV), abnormality (ABN), acrosome integrity (AIN), and sperm cell concentration (SCC) of sperm cells was significant (P<0.05, Table 7).

The results show that all semen characteristics were higher (P<0.05) under no or moderate HS than severe-extreme HS conditions, and no significant differences were found under no and moderate HS conditions (Table 7). The obtained values of most semen characteristics are within the normal range of Damascus goat bucks raised in Egypt (El-Saidy, 1993; El-Maghraby, 2007; Abdullah, 2019).

Table 7. Effect of THI on physical semen characteristics of goat bucks

Semen characteristics	Heat stress condition (THI value)			P-value
	No(14.06-21.29)	Moderate(22.28-25.14)	Severe-extreme(27.19-35.41)	
Ejaculate volume (mL)	0.84 ± 0.048^a	0.94 ± 0.066^a	0.68 ± 0.029^b	0.038
Sperm progressive motility (%)	71.7 ± 1.559^a	72.3 ± 1.637^a	65.3 ± 1.795^b	0.024
Live sperm (%)	78.8 ± 1.714^a	79.6 ± 1.800^a	71.9 ± 1.974^b	0.045
Abnormal sperm (%)	12.3 ± 0.649^b	14.2 ± 0.822^b	16.5 ± 0.554^a	0.049
Acrosomal damage (%)	12.1 ± 0.540^b	13.4 ± 0.825^b	19.1 ± 0.584^a	0.043
Sperm concentration ($x10^9$/ml)	2.83 ± 0.148^a	2.91 ± 0.157^a	2.39 ± 0.105^b	0.050

a, and b: Differed superscripts within the same row indicate significant group differences at P<0.05.

The results obtained are consistent with the lowest semen characteristics (EJV, PRM, LIV, ABN, AIN, and SCC) in summer and the highest ones in autumn (El-Maghraby, 2007; Abdullah, 2019). Incomparable with other reports, the highest sperm motility of goat buck semen was recorded in autumn (Ghallab, 1981; El-Saidy, 1988). Some authors found that SCC was lowest in summer for Damascus goats (Nebar, 1983; Miyamoto *et al.*, 1987), Baladi goats (Abdel-Rahman and Kandil, 1984; El-Saidy, 1988), and Alpin goats (Moussa, 1987). Abnormal sperm percentage decreased in summer as compared to other seasons in Damascus goat semen (El-Wishy *et al.*, 1971).

Our results for all semen characteristics (Table 7) are related to testosterone plasma concentration under different HS conditions (Table 6). Spermatogenesis and seminal plasma production (which represented the major part of the ejaculate) from the accessory sex glands are controlled by the level of testosterone. There is also a positive relationship between testosterone levels and most sperm variables, especially ejaculate volume (Hafez, 1986; Abdel-Khalek *et al.*, 2000). Besides the effect of THI (ambient temperature and relative humidity) on semen characteristics, Kang and Chung (1976) reported a negative relationship between seminal volume (EJV) and photoperiod (day length) in the semen of Korean goat bucks. In our results, higher THI values are in relation to longer photoperiod.

Sperm production:

As a result of improving semen volume in association with increasing PRM, LIV, and SCC, and decreasing ABN of sperm cells (Table 7), sperm counts per ejaculate, as total, motile, live and abnormal spermatozoa were higher (P<0.05) under no and moderate HS than severe-extreme HS conditions (Fig. 1).

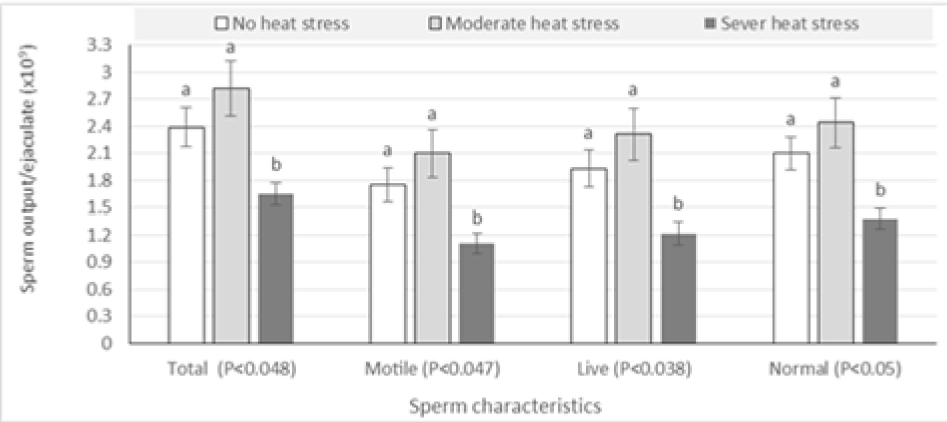

Fig. 1. Effect of THI on sperm output, as total, motile, live, and normal, per ejaculate of goat bucks, as sexual activity parameters. (a and b: significant differences at P<0.05).

In Damascus goats, Abdullah (2019) found that all sperm outputs (motile, live, normal, and total) per ejaculate were the lowest during summer and the highest in autumn. Also, the highest total sperm output per Damascus goat ejaculate was reported in autumn (El-Saidy, 1988; Eitedal, 2000). It is of interest to observe that the reduction in physical characteristics (Table 7) and sperm counts (Fig. 1) in the semen of bucks under severe-extreme HS conditions were mainly related to a reduction in sexual desire, in terms of decreased testosterone concentration and the testicular volume (Table 6) under these conditions, which had a negative impact of spermatogenesis (Massoud *et al.*, 1991, Abdel-Khalek et al, 2000), and due to the small size of the seminiferous tubules (Abdel-Khalek *et al.*, 2000).

CONCLUSION

In temperate or subtropical zones, THI can be used as an important metric, with season, to assess the impact of heat stress. According to the current study's results, a primary delineation of THI as an important metric of heat stress in goats would be THI 14.06-21.29 as the absence of heat stress, THI 22.28-25.14 as moderate stress, and THI ≥27.19 for severe-extreme heat stress. Core and surface body temperature, hematology, lipid profile, thyroid function, and semen quality can be reliable monitoring tools for predicting heat stress in goat bucks.

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تأثير مؤشر درجة الحرارة والرطوبة على درجة حرارة الجسم و الاستجابة الفسيولوجية و مستوى الدهون و وظيفة الغدة الدرقية والأداء التناسلي لذكور الماعز الدمشقي

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[2]معهد بحوث الانتاج الحيوانى - مركز البحوث الزراعية

الملخص

تعرضت مجموعه مكونة من 17 تيس من سلالة الدمشقى (42-52 كجم وزن وعمر 22-26 شهرًا) لظروف حرارة و رطوبة مختلفة خلال الفترات التجريبية من 14.06-21.29°م في شهر ديسمبر (بدون اجهاد حرارى) و من 22.28 - 25.14°م في مارس (اجهاد حرارى معتدل) ومن 27.19-35.41°م في يوليو (اجهاد حرارى شديد). زادت درجة حرارة الشعر والجلد والمستقيم وكيس الصفن وكذلك معدل النبض (P <0.05) في ظل حالة الاجهاد الحرارى المعتدلة مقارنة بعدم وجود حالة اجهاد حرارى ولكن تم العثور على زيادة أخرى (P <0.05) في جميع حالات الاجهاد الحرارى الشديدة. كان معدل التنفس أعـــــلى (P <0.05) في ظل الاجهاد الحرارى الشديد منه في حالة الغياب أو في حالة الاجهاد الحرارى المعتدلة. انخفض (P <0.05) كرات الدم الحمراء وكريات الدم البيضاء والهيموجلوبين والهيماتوكريت إلى الحد الأدنى من القيم مع ارتفاع الاجهاد الحرارى الشديد مقارنةً بعدم وجود حالة اجهاد حرارى. ومع ذلك أظهر الاجهاد الحرارى المعتدل اختلافات ضئيلة مع غيابه او الحالة الشديدة. انخفض إجمالي مستوى الدهون (P <0.05) في ظل الاجهاد الحرارى المعتدل وانخفاض آخر مع الاجهاد الحرارى الشديد مقارنة بغيابه. انخفض تركيز الدهون الثلاثية والكوليسترول الكلي والكوليسترول المنخفض الكثافة (P<0.05) فقط في ظل الاجهاد الحرارى الشديد. انخفضت تركيزات T3 و T4 فى البلازما (P<0.05) في ظل الاجهاد الحرارى الشديد مقارنةً بظروف الاجهاد الحرارى المعتدلة أو المعدومة. كان تركيز هرمون التستوستيرون في البلازما أقل (P <0.05) في ظل ظروف الاجهاد الحرارى الشديدة مقارنة بعدم وجود الاجهاد الحرارى أو المعتدل. كان حجم القذفة والنسب المئوية للحركة التقدمية والحيوانات المنوية الحية و الطبيعية وسلامة الاكروسوم وتركيز خلايا الحيوانات المنوية أعلى (P<0.05) فى عدم وجود الاجهاد الحرارى أو المعتدل مقارنة بالشديد. كان ناتج الحيوانات المنوية لكل قذفة كحيوانات منوية كلية ومتحركة وحية وطبيعية أعلى (P <0.05) في ظل عدم وجود الاجهاد الحرارى والمعتدل مقارنة بظروف الاجهاد الحرارى الشديدة. يمكن أن تكون درجات حرارة الجسم الأساسية والسطحية وقياسات الدم ومستوى الدهون ووظيفة الغدة الدرقية وجودة السائل المنوي أدوات مراقبة موثوقة للتنبؤ بالإجهاد الحراري في ذكور الماعز.