

# Negative Effects of Heat Stress on Physiological and Immunity Responses of Farm Animals

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## Abstract:

Numerous physiologic changes occur in the digestive system, acid-base chemistry, and blood hormones during hot weather. Neurons that are temperature sensitive are located throughout the animal's body and send information to the hypothalamus, which invokes numerous physiological, anatomical or behavioral changes in the attempt to maintain heat balance. In response of farm animals to heat stress, their activity, roughage intake and rumination decrease, while their water intake increase, evaporative loss through sweating, respiration, panting and rectal temperature increase in respective order. Regarding blood metabolites and biochemical changes, exposure to heat stress is accompanied by decline in concentrations of glucose, total protein, albumin, globulin, total lipids, cholesterol, red blood cells, hemoglobin and haematocrit. A decreasing in the level of blood hormones due to heat stress, especially, anabolic hormones such as growth hormone, insulin, triiodotyronine, thyroxin and aldosterone. However, the circulating blood cortisol, follicle stimulating hormone and estradiol showed conflicting results due to the duration of heat exposure, the intensity of environmental heat, species, breed and age of the farm animals.

## Keywords:

Heat Stress, Animal, Physiological Parameters, Immunity, Blood Components, Hormones

## 1. Introduction

Optimal climatic conditions for cattle, buffaloes, sheep goats, rabbits and poultry would be something like an air temperature of 13 to 20 °C, a wind velocity of 5 to 18 km/hr, relative humidity of 55 to 65% and a moderate level of sunshine. However, the summer in Egypt is characterized by high ambient temperature, intense solar radiation and high relative humidity. Therefore, farm animals rose to such a severe climatic stress for almost 6 months of the year. All farm animals become uncomfortable; they suffer extremely in production, reproduction and resistance to diseases and parasites [1]. Exposure of animals to heat stress evokes a series of drastic changes in the

biological functions, which include a decrease in feed intake, feed efficiency and utilization, disturbances in water, protein, energy and mineral balances, enzymatic activities, hormonal secretions and blood metabolites ending to impairment the productive and reproductive performance. Heat stress also lowers natural immunity making animals more vulnerable to disease [2]. In tropical and sub-tropical countries, climatic characteristic is the major constraint on animal productivity. Growth, milk production and reproduction are impaired as a result of the drastic changes in biological functions caused by heat stress. In response of farm animals to heat stress, their activity, roughage intake and rumination decrease, while their water intake increase, evaporative loss through sweating, respiration, panting and rectal temperature increase in respective order [3].

## 2. Negative Effects of Heat Stress on Physiological Response in Farm Animals

### 2.1. Negative Effects of Heat Stress on Thermoregulatory Parameters

The RR was significantly higher in summer than in winter and the increase values were 27.6, 45.0 and 48.5% in the first, second and third months, respectively [4]. The same authors found that the RT was significantly higher in summer than in winter and the increase values were 3.6, 3.6 and 3.8% in the first, second and third months, respectively (Table 1). The RR, RT, Skin temperature and Ear temperature of purebred and crossbred native calves values were significantly higher in summer than in winter and the increase values were 16.0, 2.0, 2.0 and 2.0%, respectively [5] (Table 2). The increase in RR in heat stressed animals is an attempt to increase respiratory evaporation [2]. The calf's body temperature as expressed RT will rise if these calves were unable to achieve thermal balance between body heat production and body heat loss and were unable to lose sufficient heat [2]. The RT values are consider a good indicator of the thermal stress and may be used to assess the response of the animals to exposure to the thermal environment [6].

**Table 1.** Respiration rate and rectal temperature in crossing native calves as affected by climatic conditions [4].

Climatic conditions	Respiration rate, rpm	Rectal temperature, °C	Skin temperature, °C	Ear temperature, °C
Mild climate	32.79 ±1.3	38.44 ±0.05	37.25 ±0.03	38.17 ±0.09
Hot climate	38.19 ±1.9	39.26 ±0.04	38.07 ±0.02	39.07 ±0.05
Change%	+16.0	+2.0	+2.0	+2.0
Significance	P<0.001	P<0.001	P<0.001	P<0.001

**Table 2.** Least squares means of respiration rate and rectal, skin and ear temperatures in young calves as affected by climatic conditions [5].

Climatic conditions	Respiration rate, rpm			Rectal temperature °C		
	1 <sup>st</sup> month	2 <sup>nd</sup> month	3 <sup>rd</sup> month	1 <sup>st</sup> month	2 <sup>nd</sup> month	3 <sup>rd</sup> month
Winter	30.30±0.9	27.29±2.3	25.96±2.0	38.8±0.04	38.8±0.05	38.8±0.05
Summer	38.39±1.1	39.70±2.7	38.6±2.4	40.2±0.04	40.2±0.05	40.3±0.06
Change (%)	+26.7	+45.0	+48.5	+3.6	+3.6	+3.8
Significance	P<0.01	P<0.01	P<0.01	P<0.001	P<0.001	P<0.001

### 2.2. Negative Effects of Heat Stress on Water and Feed Intake

#### 2.2.1. Water Intake

Water requirements are influenced by many factors such as species of animal, ambient temperature, body size, age, level of feed intake and daily milk yield. The water sources are free water, feed water and metabolic water (which is derived from oxidation of fat, carbohydrates and proteins). In a steady state, total water intake must balance water output. The water requirements are determined by the amount needed to give the proper osmotic concentration to body fluids, and to compensate total water loss. On the other hand, to maintain total body water content at a relatively constant level it is important that a continuous supply must be provided. Water requirements have not been extensively investigated because water is usually supplied in abundance.

Exposure to elevated ambient temperature is associated with increase in water intake in cattle [7, 8, 9], buffaloes [1, 10]. The first danger from heat stress is rapid dehydration and animals cool themselves by sweating and panting. Both of these methods of cooling require water. A calf needs to drink between 3 and 6 gallons of water per day, to replace the lost fluid. If this water is not available the animal will rapidly dehydrate in summer heat [11].

### 2.2.2 .Feed Intake

High environmental temperature decrease feed consumption, i.e., dry matter intake (DMI). El-Koja *et al.* [12] confirmed that high temperature resulted in a depression in DMI in lactating Holstein cows. Habeeb *et al.* [13] found that the overall average of DMI was significantly lower in summer than in winter. Bernabucci *et al.* [14] found that exposure to the hot environment reduced DMI and increased water intake. The heat stress progressively decreased significantly DMI (29%;  $P < 0.01$ ) in lactating Holstein cows [15]. Brien *et al.* [16] reported that heat stress reduced significantly DMI by approximately 12%. Similar results were recorded by [17, 18] who found that the immediate response to heat load decreased feed intake. From another point of view the studies on sheep [19] showed that DMI decreased significantly following exposure to heat stress in Croix, Karakul and Ram boulet. The daily feed intake and feed conversion also significantly decreased in Suffolk lambs under hot conditions in a climatic chamber (30.5 °C), compared to a group under shelter (19.3 °C) during spring [20]. In the same respect, Marai *et al.* [21] found that exposure of sheep to heat stress decreased feed intake and feed efficiency. Similarly, DMI per kilogram live weight was lower at high ambient temperature and the decrease in concentrate intake by rams was estimated to be approximately 13%, without altering the roughage consumption, at 35 °C in a climatic chamber [22]. Similar results obtained by [17] who observed that the heat stress decreased DMI in cows. Habeeb *et al.* [4] showed that DMI was significantly lower during summer than those during winter and the percentage decrease was 21.96% in purebred and was 24.09% in crossbred calves. DMI values were  $4.0 \pm 0.09$  and  $3.10 \pm 0.05$  kg/day in purebred calves and were  $4.24 \pm 0.07$  and  $3.19 \pm 0.07$  kg/day in crossbred calves during winter and summer seasons, respectively. DMI was significantly lower during summer than those during winter and the percentage decrease was 21.96% in purebred and was 24.09% in crossbred calves (Table 3).

**Table 3.** Comparison between purebred and crossbred bovine calves in dry matter intake during winter and summer seasons [4].

Items	Dry matter intake (kg/day)			
	Winter season		Summer season	
	Purebred	Crossbred	Purebred	Crossbred
X±SE	4.00±0.09	4.24±0.07	3.10±0.05	3.19±0.07
Change % due to season			-21.96 $P < 0.001$	-24.09 $P < 0.001$
Change% due to breed	Non-significant		Non-significant	

Depression in feed consumption is the most important reaction to heat exposure. High environmental temperature stimulates the peripheral thermal receptors to transmit suppressive nerve impulses to the appetite centre in the hypothalamus causing the decrease in feed consumption, i.e., dry matter intake [2]. In addition, animal decrease feed intake in an attempted to create less metabolic heat, as the heat increment of feeding, especially, in ruminants is a large portion of whole body heat production [23].

### **3. Negative Effects of Heat Stress on Biochemical and Hormonal Responses**

Regarding blood metabolites and biochemical changes, exposure to heat stress is accompanied by decline in concentrations of glucose, total protein, albumin, globulin, total lipids, cholesterol, urea nitrogen, creatinine, red blood cells, hemoglobin and haematocrit [24]. A decreasing in the level of blood hormones due to heat stress especially anabolic hormones such as growth hormone, insulin, insulin-like growth factor (IGF-2), triiodothyronine, thyroxin and aldosterone [2, 4, 24, 25, 26 and 27].

However, the circulating blood cortisol, follicle stimulating hormone and estradiol showed conflicting results due to the duration of heat exposure, the intensity of environmental heat, the species, breed and age of the experimental farm animals [28, 29].

#### **3.1. Negative Effects of Heat Stress on Triiodothyronine ( $T_3$ ) and Thyroxin ( $T_4$ )**

Hormonal secretions are known to be of major importance in body thermoregulation. The hormones connected with thermoregulation are thyroxin, cortisol, insulin and aldosterone. The anterior lobe of pituitary gland produces the hormone thyrotropin which acts primarily on the thyroid gland to produce  $T_4$  and  $T_3$  [30]. Thyroid hormones play a permissive role in growth regulation and are essential for maintenance of the basal metabolic rate [31]. Therefore, Normal growth and development occur only in presence of thyroid hormones, confirmed that hormones play a positive role in growth regulation. Thyroid hormones are classified as growth stimulators when present as optimal amounts and are essential for maintenance of the basal metabolic rate [2]. Thyroid hormones, either  $T_4$  or  $T_3$  also play an important role in animal adaptation to environment changes [32]. Exposure to elevated ambient temperature is associated with decrease in thyroid hormones, i.e. plasma  $T_3$  and  $T_4$  levels in cattle [1, 7, 29, 33 and 34] and buffalos [27, 35]. Silanikove [30] clarified that the response of  $T_3$  and  $T_4$  to heat stress is slow and it takes several days for the levels to reach a new steady state. It was also found that  $T_3$  is more concerned with thermogenesis and was found to decline significantly in heat stressed cattle [21]. In the long term,  $T_4$  hormone release decreases by up to 25% under heat stress conditions and the low plasma  $T_3$  concentration may well reflect the hormonal response of animals to prolonged heat exposure and to the marked decrease in feed intake, since  $T_3$  is more concerned with thermogenesis and declines significantly in heat stressed animals [36]. With prolonged heat exposure, the hypothalamic hormone releasing factors are suppressed. Consequently, the pituitary hormones and other hormones, either autonomous or pituitary controlled, are affected [32]. It is believed that not only the hormonal concentrations, but also the levels available for cellular metabolic activities and cellular multiplications are altered by high environmental temperature [2]. Kamal and Habeeb [37] confirmed that these hormones are the primary determinants of basal metabolic rate and have a positive correlation to weight gain or

tissue production. Several authors suggested a positive relationship between circulating thyroid hormones concentration and growth rate of the animal. El-Masry and Habeeb [38] also indicated that thyroxin is considered necessary for cellular metabolism of the mammary gland and energy utilization which could be considered as important factors in milk biosynthesis. In addition, thyroxin hormone as a growth promoter plays an important role in the metabolism of each of protein, fat, carbohydrate and minerals [2]. Similar results were obtained by Horowitz [39] and Habeeb et al. [26, 40] who found that  $T_3$  and  $T_4$  values in Frisian calves were found to be significantly lower in summer than in winter. Habeeb et al. [26] found in crossing bovine calves that  $T_4$ ,  $T_3$  and parathormone hormonal levels decreased and cortisol level increased significantly due to hot climate during summer season in Egypt (Table 4).

**Table 4.** Serum hormonal concentrations in crossing calves as affected by climatic conditions [26].

Items	$T_3$ (nmol/l)				$T_4$ (nmol/l)			
	Winter season		Summer season		Winter season		Summer season	
	Pure bred	Cross bred	Pure bred	Cross bred	Pure bred	Cross bred	Pure bred	Cross bred
X ±SE	6.22 ±0.37	5.94 ±0.13	4.77 ±0.22	4.92 ±0.19	91.69 ±4.97	96.13 ±5.20	78.13 ±4.02	81.49 ±4.43
Change% due to season			-23.3 P<0.001	-17.2 P<0.001			-14.79 P<0.05	-15.23 P<0.05
Change % due to breed	Non-significant		Non-significant		Non-significant		Non-significant	

Heat stress conditions of summer season affected significantly on each of serum  $T_4$  and  $T_3$  hormonal levels in buffalo calves. Under hot conditions, the levels of  $T_4$  and  $T_3$  were lower significantly by 13.8 and 24.8 % respectively, than under mild conditions.  $T_4/T_3$  ratio value also decreased due to heat stress of hot climate by 14.6% [41] (Table 5).

**Table 5.** Hormonal levels in buffalo calves as affected by different climatic period of the year [41].

Climatic conditions	Thyroid hormonal levels		
	$T_4$ (nmol/l)	$T_3$ (nmol/l)	$T_4/T_3$ ratio
Mild climate	98.31 ±3.54	3.71 ±0.20	26.50 ±1.1
Hot climate	84.73 ±3.41	2.79 ±0.14	30.37 ±1.3
Change, % and significance	-13.8 P<0.001	-24.8 P<0.001	-14.60 P<0.01

The  $T_3$  values were significantly lower in summer than in winter during the three months. The decrease values were 31.2, 29.4 and 21.4% in the first, second and third months, respectively [5]. Habeeb et al. [4] showed that  $T_3$  and  $T_4$  values were found to be significantly lower in summer (the average of ambient temperature and relative humidity were 35.25±0.72 °C and 55.6±1.03%, respectively) than in winter (average of ambient temperature and relative humidity were 21.8 ± 0.87 °C and 63.7±2.5%) and the percentage decrease in  $T_3$  was 23.3 and 17.2% and in  $T_4$  was 14.79 and 15.23% in purebred and crossbred calves, respectively. Averages of  $T_3$  values were 6.22 ± 0.37 and 4.77 ± 0.22 nmol /L in purebred calves and were 5.94 ±0.13 and 4.92 ± 0.19 nmol/L in crossbred calves during winter and summer seasons, respectively and concluded that crossbred calves were less affected by climatic condition in  $T_3$  than purebred calves although  $T_3$  level was not affected significantly due to breed of calves.

Habeeb et al. [4] found also that averages of T<sub>4</sub> values were 91.69±4.97 and 78.13±4.02 nmol/L in purebred calves and were 96.13 ±5.20 and 81.49 ±4.43 nmol/L in crossbred calves during winter and summer seasons, respectively. T<sub>4</sub> values decreased significantly due to heat stress conditions during summer seasons as compared with winter season and the percentage decrease was 14.79% in purebred and was 15.23% in crossbred calves (Table 6).

**Table 6.** Comparison between purebred and crossbred bovine calves in T<sub>3</sub> and T<sub>4</sub> levels during winter and summer seasons [4].

Climatic conditions	Hormonal levels			
	T <sub>4</sub> (nmo/l)	T <sub>3</sub> (nmo/l)	Cortisol (ng/dl)	Parathormone (pg/ml)
Mild climate	97.63±3.2	2.34 ±0.05	12.20 ±0.12	18.09 ±0.64
Hot climate	78.48±3.2	1.83 ±0.04	15.82 ±0.15	14.15 ±0.50
Change% & sign.	-20.0 P<0. 01	-22.0 P<0. 01	+30.0 P<0. 01	-22.0 P<0. 01

The changes in thyroid hormones are consistent with the decrease in metabolic rate, feed intake and growth under heat stress [42]. Exposure animals to severe heat stress conditions suppresses the production of hormone releasing factors from the hypothalamic centers causing a decrease in pituitary hormonal secretion and the decrease in thyroid stimulating hormone and consequently lowers the secretion of thyroid hormones [2]. In addition, the interaction between the thyroid and the adrenaline and noreadrenaline released in response to high temperature may contribute in thyroid depression in cattle [43]. Moreover, reduction in thyroid activity in animal under heat stress is the process of adaptation to its environment [30]. Thyroid hormones decline in response to heat stress is probably an attempt to reduce metabolic heat production [44]. As a function of heat stress, there was a decrease in each of daily body gain and thyroxin levels. Daily weight gain was correlated positively with thyroxin level either in mild or in hot climate [37].

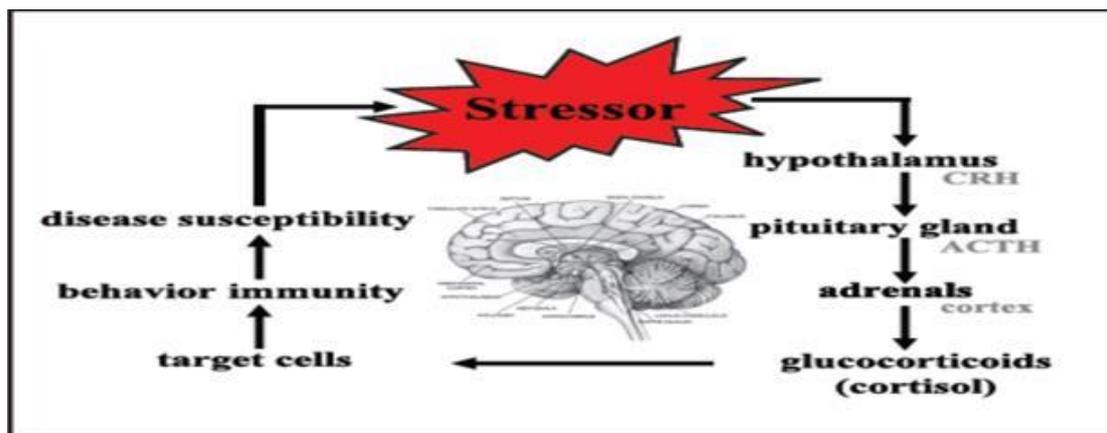
### 3.2. Negative Effects of Heat Stress on Cortisol

The secretion of cortisol stimulates physiological adjustments that enable an animal to tolerate the stress caused by a hot environment. Plasma cortisol may increase within 20 min of exposure to acute heat stress, and reach a plateau within 2h [45]. It is known that cortisol to suppress growth [46] and reproductive function in male mammals [46] by changes in photoperiod [48]. However, Habeeb *et al.* [2] observed that the literature dealing with the effect of hot climate on plasma cortisol level in cattle is rather conflicting. In some studies, heat stress increased plasma glucocorticoids and in other, either decreased significantly or unaltered. Exposure to elevated ambient temperature is associated with increase cortisol in cattle [26, 40, 49] and buffaloes [1, 35]. Similar results were recorded by Habeeb et al. [26, 40]. Habeeb et al. [4] found that averages of cortisol values were 42.83±2.16 and 56.42±2.34 nmol/L in purebred calves and were 43.84±2.33 and 55.68±3.34 nmol/L in crossbred calves during winter and summer seasons, respectively. Cortisol was significantly higher during summer by 31.7 and 25.0 % than those in winter in purebred and crossbred calves, respectively. Results also illustrated that crossbred calves were less affected by climatic condition in cortisol than purebred calves although cortisol level was not affected significantly due to breed of calves (Table 7).

**Table 7.** Comparison between purebred and crossbred bovine calves in cortisol level during winter and summer seasons [4].

Items	Cortisol hormone (nmol/l)			
	Winter season		Summer season	
	Purebred	Crossbred	Purebred	Crossbred
X±SE	42.83±2.16	43.84±2.33	56.42±2.34	55.68±3.34
Change % due to season			+31.7 P<0.001	+25.0 P<0.01
Change% due to breed	Non-significant		Non-significant	

The increase in cortisol level during acute heat stress may be attributed to the fact that the glucocorticoid hormones have hyperglycaemic action to increase gluconeogenesis and provide the expected increase in glucose utilization in heat stressed animals [32]. In addition, the increase in cortisol level, as a catabolic hormone, in the heat stressed animals may be also due to the effect of stressful conditions on adrenal gland [5]. On the other hand exposure to elevated temperature is associated with decrease in cortisol in cattle [51]. This depression may be due to the cortisol hormone is thermogenic and consequently the reduction of adrenocortical activity under thermal stress is a thermoregulatory protective mechanism for preventing metabolic heat production and hat conditions [52]. It has long been established that stress in the dairy cow activates the hypothalamic - pituitary – adrenal axis. Activation of this gland causes an increase in plasma glucocorticoids (cortisol) [53] Figure (1).



**Figure1.** Impact of stress on glucocorticoid release [53].

Acute exposure to high environmental temperatures has been shown to cause significant increases in plasma cortisol in dairy cows [27].

### 3.3. Negative Effects of Heat Stress on Glucose Concentration

Exposure to elevated ambient temperature is associated with decrease in glucose in cattle [1, 15, 16 and 26] and in buffaloes [27]. The glucose values were significantly lower in summer than in winter in the second and third months, but without significance differences due to season in the first month. The decrease values were 21.6, 24.4 and 43.1% in the first, second and third months respectively [5].

**Table 8.** Least squares means of glucose in young bovine calves as affected by summer season [5].

Season effect	Glucose (mg/dl)		
	1 <sup>st</sup> month	2 <sup>nd</sup> month	3 <sup>rd</sup> month
Winter	91.15±5.33	92.36±5.04	103.03±5.54
Summer	71.48±6.21	69.86±5.86	58.61±6.37
Change, % and significance	-21.6 P<0.05	-24.4 P<0.05	-43.1 P<0.01

Shaffer *et al.* [54] attributed the highly significant depression blood glucose levels with the elevation of temperature to the increase in respiration rate under hot climate, which caused a rapid utilization of blood glucose by the respiratory muscles resulting in decreased blood glucose content under heat stress. Such change in glucose level during heat exposure relates in part, to the decrease in concentrations of insulin and thyroxin which are closely correlated to the decrease in energy metabolism during heat exposure [24]. The decrease in plasma glucose could also be due to the marked dilution of blood and body fluids as a whole (due to increase in water intake under hot conditions) or to the increase in glucose utilization to produce more energy for greater muscular expenditure required for high respiratory activity [2]. The decrease of glucose level in heat stressed animals may be probably a result of the heat-induced increase in circulating basal insulin concentration [15, 16]. On the other hand Webster [55] showed that glucose concentration increase under heat stress conditions due to the decrease in glucose utilization, depression of both catabolic and anabolic enzyme secretions and subsequent reduction of metabolic rate. Either glucose utilization and gluconeogenesis or glycogenolysis and gluconeogenesis are increased with consequent decrease or increase in blood glucose concentration, respectively [2].

### 3.4. Negative Effects of Heat Stress on Urea-N and Creatinine Concentrations (Kidney Function)

The urea-N values were significantly higher in summer than in winter during the three months. The increase in urea values were 26.7, 21.9 and 42.1% in the first, second and third months respectively [5] (Table 9).

**Table 9.** Least squares means of urea-N in young bovine calves as affected by summer season [5].

Season effect	Urea-N (mg/dl)		
	1 <sup>st</sup> month	2 <sup>nd</sup> month	3 <sup>rd</sup> month
Winter	25.23±1.00	26.59±0.741	24.5±1.06
Summer	31.98±1.17	32.42±0.86	34.82±1.22
Change, % and significance	+26.7 P<0.01	+21.9 P<0.01	+42.1 P<0.01

Under hot conditions, serum concentrations of urea-N and creatinine increased significantly by 23.3 and 12.6 %, respectively, due to exposed the buffalo calves to heat stress conditions of summer season [41] (Table 10). El-Masry *et al.* [56] reported that heat stress increased the concentration of urea-N in crossbred and baladi cows. The same trend in buffalo calves was found by Habeeb *et al* [27]. Shwartz *et al.* [15] showed also that the heat stress increased plasma urea-N concentration in cows.

The increase in plasma urea nitrogen during heat stress may be due to an improved rumen nitrogen balance [57]. In addition, the increase in plasma urea-N in heat stressed animals may be due to increase in muscle breakdown [58].

The high level of urea in heat stressed animals may be due to low energy /protein ratio and to gluconogenesis by protein degradation in conditions of insufficient energy for growth [2, 59].

**Table 10.** Kidney function in buffalo calves as affected by different climatic period of the year [41].

Climatic conditions	Kidney function	
	Urea-N ( mg/dl)	Creatinine ( mg/dl)
Mild climate	32.87±2.3	1.11±0.11
Hot climate	40.53±3.1	1.25±0.02
Change, % and significance	+23.3 P<0.001	+12.6 P<0.05

### 3.5. Negative Effects of Heat Stress on Liver Function

Under hot condition of summer season, the activities of GOT and GPT increased significantly by 28.2 and 61.6 %, respectively, in buffalo calves [41].

**Table 11.** Liver function in buffalo calves as affected by different climatic period of the year [41].

Climatic conditions	Liver function	
	GOT (U/ml)	GPT (U/ml)
Mild climate	51.60±1.2	39.3±1.7
Hot climate	66.13±1.2	63.5±1.7
Change, % and significance	+28.2 P<0.001	+61.6 P<0.001

The same trend showed in buffalo calves by Habeeb *et al.* [27] and in cows by El-Masry *et al.* [56]. Marai and Habeeb [32] found that the blood enzymes are easily and often influenced by the external environment including feeding practices, type of shelter and many other aspects of hard management, since they are intimately related to metabolism.

### 3.6. Negative Effects of Heat Stress on Total Protein Fractions

Under hot conditions, the total protein and albumin concentrations decreased with 11.5% and 15.6%, respectively as compared with under mild conditions [41].

**Table 12.** Protein fractions concentrations in buffalo calves as affected by different climatic period of the year [41].

Climatic conditions	Total proteins (g/dl)	Albumin (g/dl)	Globulin (g/dl)
Mild climate	8.51±0.18	4.63±0.12	3.88±0.02
Hot climate	7.53±0.11	3.91±0.11	3.62±0.04
Change, % and significance	-11.51 P<0.001	-15.6 P<0.001	- 6.7 P>0.36 Non-significant

The decrease in serum protein and its fractions under heat stress conditions may be due to the decrease in feed nitrogen intake which occurs under heat stress conditions [26] and decrease of protein synthesis as a result of the depression of anabolic hormonal secretion like T<sub>4</sub> or T<sub>3</sub> and insulin [38].

### 3.7. Negative Effects of Heat Stress on Lipid Fractions

Under hot conditions, the concentrations of serum total lipids and total cholesterol decreased significantly by 9.9 and 9.3 %, respectively, due to exposed the buffalo calves to heat stress conditions of summer season (Table 13) [41].

**Table 13.** Lipid fractions in buffalo calves as affected by different climatic period of the year [41].

Climatic conditions	Lipids fractions concentrations	
	Total lipids (g/dl)	Total Cholesterol( g/dl)
Mild climate	5.35±0.11	104.5±2.5
Hot climate	4.82±0.11	94.8±2.5
Change, % and significance	-9.9 P<0.01	-9.3 P<0.01

The decline of serum total lipids and total cholesterol concentrations due to exposure the calves to high ambient temperature may be attributed to the increase in body water content (hemodilution). Moreover, the decline in cholesterol concentration during exposure to heat stress may be due to the decrease in acetate concentration on which is the primary precursor for the synthesis of cholesterol [32]. As a general, Habeeb *et al.* [2] reported that reductions in total lipids and cholesterol

levels may be due to the decrease in feed intake or increase in water intake and consequent dilution of the blood components that occur under heat stress conditions.

### 3.8. Negative Effects of Heat Stress on Minerals Content

Under hot conditions, serum calcium and inorganic phosphorus concentrations in buffalo calves were significantly lower than the mild climate. The percentage decreases were 11.9 and 22.3 %, respectively (Table 14) [41].

**Table 14.** Calcium and inorganic phosphorus concentrations in buffalo calves as affected by different climatic period of the year [41].

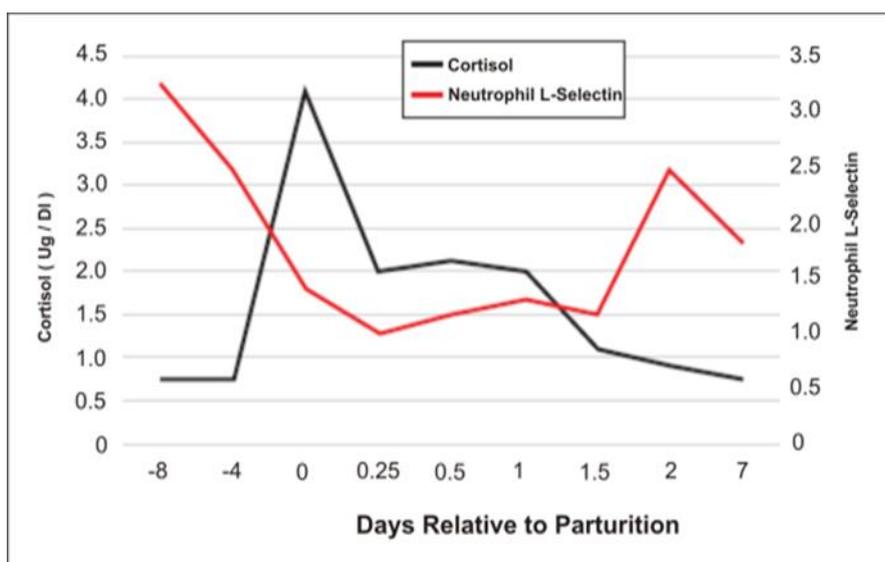
Climatic conditions	Minerals concentrations	
	Ca (mg/dl)	Pi (mg/dl)
Mild climate	9.98 ±0.22	4.13 ±0.12
Hot climate	8.79 ±0.14	3.21 ±0.11
Change, % and significance	-11.9 P<0.01	-22.3 P<0.001

Habeeb *et al.* [2] suggested that the decrease of blood minerals in heat stressed animals may be a decrease in aldosterone and parathormone hormone secretions with associated with a rise in urinary mineral excretion at one side and the increase in the body fluids and water turnover rate which dilute the absolute quantities of plasma minerals and help in washing out these minerals during heat stress. The body needs a continuous supply of fluids and electrolytes, chemical ions which balance the body fluids in and around the cells. Without the key electrolytes Sodium Na<sup>+</sup>, Potassium K<sup>+</sup> Chloride Cl<sup>-</sup> and Bicarbonate HCO<sub>3</sub><sup>-</sup>, it is impossible to balance the internal environment. When an animal is under stress, particularly heat stress, acid concentration increases, the body's balance is upset and economic loss will follow. Before that situation is reached, before animals start to be distressed a control and treatment strategy must be put in place.

## 4. Negative Effects of Heat Stress on Immune Function

The effects of heat stress are estimated to cost the dairy industry \$897 million annually [60]. Primary losses are associated with, but not limited to, lowered milk production, increased metabolic disorders, poor reproduction and reduced immune function [61].

Most dairymen, veterinarians and dairy nutritionists understand the impact that heat stress can have on milk production and dry matter intake, the most common symptoms for cows experiencing moderate heat stress. With the development of gene expression microarrays, dairy scientists are now able to study the impact that heat stress has at the cellular level. Acute exposure to high environmental temperatures has been shown to cause significant increases in plasma cortisol in dairy cows [27]. It is also well documented that increases in circulating plasma cortisol result in down regulation or suppression of L-selectin expression on the surface of neutrophils [62] (Figure 2).



**Figure 2.** Relationship between cortisol and neutrophil L-selectin, a marker of immune function [62].

Neutrophils are considered to be the first line of defense against invading pathogens and L-selectin is a marker of innate immunity in dairy cows [63]. Reduced L-selectin expression causes neutrophils to function poorly by failing to move into tissue being invaded by pathogens. This has a dramatic negative impact on the immediate response of the immune system to disease challenges and the clinical outcome following exposure to an infective organism [64]. Neutrophils harvested from dairy cows exposed to heat stress during the dry period and at the time of calving demonstrated reduced oxidative burst and phagocytic activity at 20 days postcalving compared to cows that had been cooled, indicating a carryover effect of heat stress on immune function into lactation [65]. The transition period of animal immunity is one of the most challenging times for the dairy cow's immune system. Reduced immune function associated with failure of neutrophils to move into tissues being invaded by pathogens and reduced capability of neutrophils and other immune cells to effectively carry out phagocytosis and killing mechanisms for pathogens allow the dairy cow to be highly sensitive to infectious disease [66]. This can occur not only at the time of calving but at other times throughout the lactation cycle when dairy cows may be exposed to other types of stress, such as heat stress, which also compromises animal immunity. Management strategies to improve neutrophil function during times of stress will likely improve immune function and aid in disease resistance [62]. Additionally, increases in circulating cortisol as a response to heat stress cause an increase in cellular levels of other markers of immunity known as heat shock proteins (HSP) [67]. Heat shock proteins (HSPs) function to fortify and protect cells during a stressful event and have been shown to increase at the onset of hyperthermia. HSPs function as a danger signal to the immune system to encourage increased killing of pathogenic bacteria by neutrophils and macrophages, innate immune cells and the first line of defense against invading bacteria [68].

HSP is increased when the cells are exposed to elevated temperatures or exposure to different kinds of environmental stress conditions. HSPs genes are induced by the denatured proteins that are produced during elevation of body temperature and other stresses [69]. Cattle exposed to high heat show elevated levels of HSPs in their cells or antibodies against heat stress proteins in blood serum and when the cell is exposed

to a temperature a few degrees above body temperature, it will start producing large amounts of this protein [70].

Habeeb et al [71] showed that averages HSP70 in 10 Buffalo calves during SHS, HS, THN and MC conditions were 5.94, 3.1, 1.3 and 1.0, respectively; indicating that increase in the ambient temperature is followed by significantly increasing levels of the HSP70 in serum of buffalo calves. When considered mild climate as comfortable condition, the heat induced significantly increase in HSP70 by 494, 210 and 30% due to exposure of the Buffalo calves to SHS, HS and THN, respectively (Table 15 and Figure 3).

**Table 15.** Heat shock proteins HSP70 in buffalo calves exposed to different ambient temperatures [71].

Heat stress conditions	Heat shock proteins, HSP70	Significant
Mild climate, MC (18 °C)	1.0±0.0	Control
Thermo neutral, THN (24 °C)	1.3 ±0.07	P<0.05
Heat stress, HS (32 °C)	3.1±0.21	P<0.01
Severe heat stress, SHS (36 °C)	5.94 ±0.43	P<0.01

Ambient temperatures

MC (18 °C)

THN (24 °C)

HS (32 °C)

SHS (36 °C)



**Figure 3.** View larger version of heat shock protein in Egyptian buffaloes calves exposed from right to left to different ambient temperatures (36 °C, 32 °C, 24 °C & 18 °C) under the natural climatic conditions [71].

## 5. Conclusions

Farm animals raised under severe climatic stress for almost 8 months of the year during hot period of the year in Egypt and become uncomfortable suffering extremely in production and reproduction. Exposure of farm animals to heat stress evokes a series of drastic changes in the biological functions, which include a decrease in feed intake, feed efficiency and utilization, disturbances in water, protein, energy and mineral balances, enzymatic activities, hormonal secretions and blood metabolites ending to impair the productive and reproductive performance. Heat stress also lowers natural immunity making animals more vulnerable to disease.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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