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Adaptability of *Bos taurus* Cattle Under Hot Arid Conditions

I. Fayez M. Marai[1] and A. Alnaimy M. Habeeb[2]
[1]*Department of Animal Production, Faculty of Agriculture, Zagazig University, Zagazig, Egypt*
[2]*Department of Radiobiological Applications, Division of Radioisotopes Applications, Nuclear Research Centre, Atomic Energy Authority, Cairo, Egypt*

Abstract: Climatic heat is the major constraint on *Bos taurus* cattle production in hot arid zones due to the drastic changes that occur in their biological functions. Appetite, feed intake, feed efficiency and feed utilization are impaired. At the same time, disturbances in metabolism of water, protein, energy and minerals occur. Similar disturbances occur in enzymatic reactions and hormonal secretions. Such disturbances lead to depression in some of the blood metabolites. The final result of all these changes is the impairment of growth, milk yield and reproduction. The possible mechanisms of these changes are reviewed.

Key words: *Bos taurus*, hot arid conditions, adaptability.

In hot arid environment, *Bos taurus* cattle production is faced with many problems. These problems are heat stress, poor quality food and drinking water (saline), diseases and parasites, of which heat stress is the most important, since it evokes a series of changes in the animal's biological functions ending with impairment of their productive and reproductive traits.

The present article highlights the difficulty of reconciling *Bos taurus* as cattle of potential for high production with conditions of hot arid conditions.

Bos Taurus Cattle Performance as Affected by Hot Arid Conditions

Productive performances

Growth: Growth is controlled genetically and environmentally by well balanced available nutrients, hormones and enzymes. However, the data in literature regarding the effects of elevated temperature on growth performance are conflicting.

Some studies showed that growth performance, i.e., growth rate, daily gain weight, dry body weight (total body solids), solids daily gain and live body weight are impaired at elevated temperatures in Brown Swiss, Holstein and Jersey calves (Kamal *et al.*, 1962), Holstein and Hereford calves (Thompson *et al.*, 1963), Friesian heifers (Kamal and Seif, 1969) and Friesian calves (Habeeb, 1981 and Marai *et al.*, 1995, 1997c). The calculated loss in body solids due to heat stress conditions was found to be 23% in Friesian heifers (Kamal and Seif, 1969), 14-29% in Guernsey cattle (Kamal and Johnson, 1971) and 17% (Habeeb, 1987) and 10.0% (Marai *et al.*, 1995) in Friesian calves. In solids daily gain, the loss values in Friesian calves were 51% (Habeeb, 1987) and 46% (Daader *et al.*, 1989 and Marai *et al.*, 1995). The effects of elevated temperature on growth performance are the products of the decrease in anabolic activity and increase of tissue catabolism. The decrease of anabolism is essentially caused by the decrease in voluntary feed intake of essential nutrients (Morrison and Lofgreen, 1979), particularly metabolizable energy for both maintenance and gain weight. This causes loss of production per unit of food under heat stress conditions (Ames and Brink, 1977 and Kamwanja *et al.*, 1980). The increase of tissue catabolism occurs mainly in fat depots and/or lean body mass (Kamal and Johnson, 1971). Specifically, there is a reduction in body amino-N (El-Fouly *et al.*, 1978) and endogenous DNA and RNA purine catabolism (El-Fouly and Kamal, 1979) as a result of the increase in catecholamines and glucorticoids.

The other studies showed no appreciable change in live body weight (Habeeb, 1981) with rising temperature.

The contradictory response of live body weight under heat stress may be due to the interaction between tissue destruction and water retention. The increase in total body water could be less than, equal to, or more than the loss in total body solids, thus resulting in a decrease, no change or increase in live body weight, respectively. Kamal and Johnson (1971) found that heat-stressed calves lost 10.6 kg body fat and gained 0.6 kg lean mass solids with a net total body solids loss of 10 kg, in three days. This loss was replaced by extra body water retained during these three days without a significant change in body weight. From another point of view, the conflicting responses of animals' live body weight under hot conditions could be attributed to the differences in exposure periods and to breed, and stage of maturity of the treated animals (Habeeb *et al.*, 1992).

Milk yield and composition: Milk production was found to be significantly impaired in hot climates (Habeeb *et al.*, 1989, 1991, 1993; Marai *et al.*, 1997a. b and Yousef *et al.*, 1996). The rise in temperature averages by 1.6, 3.2 and 8.8°C above normal (21°C) results in the decrease in daily milk yield averages by 4.5, 6.8 and 14%, respectively, and a decline in the daily temperature by 7°C below normal resulted in an increase in the daily milk yield by 6.5% in dairy cattle (Petkov, 1971). At 30°C, the high producing animals showed a mean reduction of 2.0 kg day^{-1} compared to a reduction of only 0.65 kg day^{-1} for the low producing animals (Vanjonack and Johnson, 1975). In the hot climate (38°C), the reduction in the average milk yield in Friesian cows was lower by 30% than in the mild climate (18°C) (Kamal *et al.*, 1989b). Milk production of imported pure breeds from mild climates to the humid tropics rarely exceeded 12-15 kg day^{-1} and most usually was less than 10 kg day^{-1} (Raun, 1976). The reaction of the lactating cows to hot environments seemed to be related to stage of lactation, since Bober *et al.* (1980) reported that milk production in early, mid and late lactation decreased by 25, 41 and 47%, respectively, at 72 h after the beginning of heat exposure.

Milk constituents are also greatly affected by hyperthermia. Friesian cows maintained under 38°C showed lower averages of total solids, fat, protein, ash and lactose yields than when the same animals were maintained under thermoneutral environmental temperatures (Habeeb *et al.*, 1989). The reduction percentages were 28, 27, 7, 22.7 and 30, respectively. Rodriguez *et al.* (1985) demonstrated that fat and protein percentages declined between 8 and 37°C and protein to fat ratio decreased at temperatures above 29°C, while chloride content increased above 21°C, in Friesian cows. Similar reduction values in milk constituents were reported by Habeeb *et al.* (1993, 1996), Yousef *et al.* (1996) and Marai *et al.* (1997a, b).

Average of phosphorus and magnesium values were also found to be less in summer. Citric acid and calcium contents decreased during early lactation, while potassium decreased in all lactation stages at high temperatures (Kamal *et al.*, 1962).

The decrease in yield and constituents of milk of dairy cattle as a result of exposure to high environmental temperature might be due to the disturbance in each of carbohydrate, lipids, minerals and vitamins metabolism which leads to a negative balance in each of nitrogen (Kamal *et al.*, 1962), energy (McDowell *et al.*, 1969) and minerals (Kamal *et al.*, 1984) resulting in low protein turnover, less heat production and fewer minerals for biosynthesis of milk. The depression in many hormone levels in heat-stressed cattle, especially the thermogenic hormones such as insulin (Habeeb, 1987), thyroxine (El-Masry and Habeeb, 1989), and cortisol (Kamal *et al.*, 1989a, b) may also be responsible for the decrease in milk production, as well as, milk composition. Upper critical temperatures for milk production and growth rates of *Bos taurus* cattle are in the range 21-27°C and 24-30°C, respectively.

Feed utilization: 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. Thus, fewer substrates become available for enzymatic activities, hormone synthesis and heat production (Kamal, 1975). Production of hormone releasing factors by the hypothalamic centre is also suppressed causing decrease in pituitary hormonal secretions (Johnson, 1974), insulin (Habeeb, 1987) and thyroxine (El-Masry and Habeeb, 1989). The metabolic pathways slow down, causing drastic impairment of protein utilization due to shortage of energy, substrates, hormones and enzymes, and a dramatic decrease in apparent digestibility, volatile fatty acids production, rumen pH and electrolyte concentrations in the rumen fluids (Niles *et al.*, 1980). Under these conditions, the protein synthesis becomes unable to counteract the protein catabolism which leads to a negative nitrogen balance. The destruction in protein tissues is due to the increase in glucocorticoid hormones (proteolytic hormones) responsible for protein catabolism.

The increase in glucocorticoid hormones may occur through the increase in gluconeogenisis which delivers the amino acids to their corresponding α-keto acids (Alvarez and Johnson, 1970) or in the hepatic capture of blood amino acids (Noall *et al.*, 1957) or through inhibiting the oxidation of glucose which is essential for providing the energy required for peptide synthesis (Welt *et al.*, 1952). The increase in catecholamines (lipolytic hormones) (Winegrad, 1962) or the decrease in insulin responsible for protein anabolism (Habeeb, 1987) may also contribute to tissue destruction.

The nitrogen balance in young animals decreases significantly under high temperature, but it does not reach the negative nitrogen balance found in older animals. This phenomenon may be due to the fact that heat-induced protein catabolism is not high enough to offset the well-known high rate protein synthesis in young animals.

Reproduction

Reproductive functions of cattle are unfavourably affected by high environmental temperature or by the rapid and sudden fluctuations of temperature that often occur in many parts of the subtropics (Abdel-Samee and Marai, 1997 and Abdel-Samee *et al.*, 1997). In the following we may refer to that occurs in other animals than cattle as well.

Reproductive traits in males: Most of anabolic and thermogenic hormones such as thyroxine, triiodothyronine, insulin, growth hormone, cortisol and aldosterone decrease appreciably under hot climatic conditions in an attempt by the animal to decrease its endogenous heat production to tolerate heat. The adrenal function is also reduced in heat- stressed animals and this may allow the animal to cope with the environment because of the calorigenic actions of glucocorticoids (Gwazdauskas, 1985). Regarding male sex hormones, Gomes *et al.* (1971) and Rhynes and Ewing (1973) estimated the decrease in testosterone concentration with one-third of that of the control after 2 weeks of exposure to high ambient temperature. This reduction is due to the damage and accordingly, the detrimental function of leydig cells that results from deterioration of each of testicular testosterone tissue, spermatic venous testosterone and biosynthesis of testosterone. This was confirmed by incorporation of less labelled precursors (Cholesterol and Pregnenolone) into testosterone in testes tissue of stressed animals (Gomes *et al.*, 1971). Prolactin, generally, increases significantly following heat exposure (Schams *et al.*, 1980). The highest levels of prolactin were found in summer and the lowest in winter season. The increase of prolactin influences the number of spermatozoa produced (Ravault, 1976).

Socrtal circumference and testicular consistency, tone, size and weight, which are excellent indicators of sperm producing capacity and spermatogenic functions, decrease in hot summer in the sub- tropics to the extent that they become lower than those of the same breeds reared under temperate environmental conditions (Fields *et al.*, 1979; Finch, 1986 and Yarney *et al.*, 1990). In this connection, Mikelsen *et al.* (1981) recorded the highest scrotal circumference values in the month of October. The reduction in testicular measurements (testes weight and length) by exposure to heat stress is due to degeneration in the germinal epithelium and to a partial atrophy in the seminiferous tubules (Chou *et al.*, 1974), that are reflected in the adverse effects on the average number of testicular cells, especially the secondary spermatocytes and spermatids of types B, C and D, the ratio of steroli cells to other cells and the diameter of the seminiferous tubules (El-Sherry *et al.*, 1980). However, Hafez (1965) reported that the testes of farm animals do not undergo marked seasonal changes in size.

High temperature usually affects inversely the processes of spermatogenesis and metamorphosis of sperms that cause semen degeneration (Coser *et al.*, 1979) and accordingly, impairment of each of fertility power of spermatozoa and their ability to produce viable embryos (Wildeus and Hammond, 1993). Particularly, Sahni and Roy (1967) suggested that maximum and minimum temperatures for optimum spermatogenesis were 29.4 and 15.6°C, respectively. Seasonal differences, with minimal spermatogenesis occurring during summer months that is usually referred to as ''summer sterility'' (Akpokodje *et al.*, 1985), are attributed to reduction of steroidgenic function of the testes and to the decrease of the blood flow through the testes (Setchell, 1970).

Sexual desire (*libido*) is negatively affected by high environmental temperature, despite the thermoregulatory mechanism of the testes. Such phenomenon, altogether with the adverse effects on ejaculate volume, live sperm percentage, sperm concentration, viability and motility (Gamcik *et al.*, 1979), reduce conception and fertility rates of male, i.e., reduce the male fitness. The reaction time (*libido*) was reported to be generally shorter in summer and autumn seasons than during winter and spring seasons (El-Saidy, 1988). However, El-Sherbiny (1987) mentioned that it was significantly longer in summer season than in the other seasons of the year. The optimum climatic conditions for sexual activity were found to be either during autumn or spring season (Hafez, 1968 and Ziedan, 1989) and the lowest sexual activity was shown to be during summer season (Zeidan, 1989).

Semen characteristics: The quantity and quality of semen vary with season of the year. However, degrees of response to seasonal effects vary according to species, breed and locality. The physical and chemical characteristics of semen as affected by elevation of temperature, are shown below.

Physical characteristics of semen: Results of the influence of high environmental temperature on semen-ejaculate volume of males, are conflicting. The studies of Zeidan (1989) and Marai *et al.* (1996) showed that semen-ejaculate volume decreased, while studies of Fawzy (1982) showed remarkable increase with heat elevation. The above confliction may be due to type and duration of heat exposure, intensity of environmental heat, species and breed and age of the experimental animals. Testes histological examination suggests that only spermatogenic elements disappear and that interstitial material remain unchanged or increase in number and volume as a function of exposure to heat stress (Gomes *et al.*, 1971).

The results of the studies on the effects of season on motility of spermatozoa were also conflicting. Some studies showed that the initial motility of spermatozoa decreased in hot climate conditions (Ax *et al.*, 1987 and Zeidan, 1989). Other studies indicated that motility of spermatozoa either increased or did not show any change due to elevation of temperature. The former studies were carried out by Oloufa *et al.* (1959) and El-Azab (1980) and the latters were conducted by Silva *et al.* (1991).

Percentage of live spermatozoa decreases remarkably due to exposure to high ambient temperature in cattle bulls (Tomar *et al.*, 1966; Ross and Entwistle, 1979 and Zeidan, 1989). However, some other reports indicated either an increase in live spermatozoa in summer season than in winter (El-Azab, 1980) or no significant differences between seasons (Ibrahim, 1969).

Percentages of abnormal spermatozoa vary with changes in ambient temperature. Heat causes detrimental effects even on indigenous stock in hot climate regions, including abnormalities in head, mid-piece, tail or proximal cytoplasmic droplets (Akpokodje *et al.*, 1985; Chase *et al.*, 1991 and Wildeus and Hammond, 1993). However, some other studies showed no significant differences due to season of the year in the mentioned trait (Tomar and Kanaujia, 1970). The critical temperature that inhibits spermatogenesis in dairy bulls was estimated to be 29.4°C under conditions of continuous exposure (Rhynes and Ewing, 1973). Viability and true acrosome reaction of bovine spermatozoa are impaired at 40°C (Lenz *et al.*, 1983).

Results of the concentration for spermatozoa as affected by exposure to high ambient temperature, are conflicting. Some studies showed detrimental effects with heat elevation (Tucker and Oxender, 1980 and Zeidan, 1989). In contrast, others recorded the highest sperm-cell concentration during summer season and the lowest during winter season (Everett *et al.*, 1978 and Osman, 1988), while Kapoor (1982) reported that season of the year had no effect on sperm-cell concentration.

Total sperm-output was found to be adversely affected in summer season (El-Shamaa, 1983 and Zeidan, 1989). However, other studies recorded the highest total sperm-output during summer season (Everett *et al.*, 1978).

Chemical characteristics of semen: Seminal plasma contains many organic compounds which are not found elsewhere in the body at such high concentrations. Such compounds are fructose, citric acid, total phosphorus, total nitrogen, sodium, potassium, calcium, sorbitol and spermine. These substances are produced by various accessory glands in response to testosterone. Their estimation in ejaculated semen or directly in the glands can be used as an index of the accessory gland functions.

Hydrogen ion concentration (pH) in semen shows significant differences between seasons of the year (Kapoor, 1973 and Zeidan, 1989), but with high correlation coefficients with environmental temperatures (0.73 to 0.83). However, some studies showed no such significant correlations (Gili *et al.*, 1974 and Osman, 1988).

Initial fructose concentration shows seasonal, as well as, monthly variations. Some studies revealed that fructose concentration decreased (Wildeus and Hammond, 1993), while others recorded either an increase (El-Shamaa, 1983 and Zeidan, 1989) or no significant change by exposure to high environmental temperature (Dojeseva *et al.*, 1979).

Total phosphorus concentration in semen was found either to decrease significantly (Fawzy, 1982 and El-Shamaa, 1983) or increase significantly (Oloufa *et al.*, 1959), during summer season. Ei-Keraby *et al.* (1980) found that the highest value of total nitrogen in semen was in spring and the lowest in autumn.

Citric acid concentration was found to decrease significantly as a result of exposure to high environmental temperatures (Amir and Volcani, 1965).

Sodium and potassium cation concentrations were found to decrease in summer than in winter season (El-Shamaa, 1983 and Zeidan, 1989), while Fawzy (1982) found that they were significantly higher during summer than in the other seasons of the year. Total calcium concentration in seminal plasma was found either to increase (Marai *et al*., 1991) or decrease (El-Azab, 1980) in summer than in winter or not significantly affected (El-Keraby *et al*., 1980) by season of the year. Zeidan (1989) reported that the highest calcium concentration was found in spring and the lowest in winter season.

In conclusion, elevation of ambient temperature affects male reproductive functions deleteriously, leads to testicular degeneration and reduces percentages of normal and fertile spermatozoa in the ejaculate of males. The ability of the male to mate and fertilize is also affected. The biological backgrounds of such phenomena include disturbances in each of sexual activity, endocrine and testes functions, spermatogenesis and physical and chemical characteristics of semen.

Reproduction in females: Comparison between seasons of the year shows that ovarian activity decreases in hot summer and increases during winter and spring, i.e., when ambient temperature decreases. The percentage of heat (oestrus) with strong symptoms is also lower in the hot season than in the cold season.

In the following, effects of elevated temperature on reproductive functions in females, are reviewed in details.

Oestrous cycle is suppressed (Williamson and Payne, 1971) and anoestrum is produced (Bond *et al*., 1960) by heat stress. This could be attributed to reduction in ovarian function (El-Sawaf and Schmidt, 1962) and immense irreparable damage (El-Sawaf *et al*., 1979) which results in complete ovarian inactivity in heat-stressed animals. Concurrently, the decline in throxine and feed intake reduces the quantity and quality of feed available, specially with respect to protein, vitamin A and phosphorus, aggravate the negative influence on the adenohypophysis. Less gonadotrophic hormone release results in weak heat and/or anaoestrum (El-Sawaf *et al*., 1979). Incidence of anoestrum due to increase in plasma corticoids and progesterone (Abily, 1974) and shortening of duration of oestrus and decrease in intensity of oestrous expression (Bianca, 1985) with exposure to heat stress, could be another explanation for that phenomenon. Gwazdauskas *et al*. (1981) and Drost and Thatcher (1987) confirmed that slight elevation in each of proestrous estradiol, progesterone and corticoid concentrations during the luteal phase were detected in heifers and cows upon exposing to heat stress. The difference in both proestrous estadiol/progesterone ratio and luteal progesterone concentrations may be correlated with the quality of the developing preovulatory follicles, the intensity of oestrous behaviour and subsequent microenvironment of the oviduct and uterus (Drost and Thatcher, 1987).

Pregnancy rates drop significantly and do not recover until November, in lactating dairy cows (not in heifers), during summer months in subtropical regions such as Florida (Thatcher and Collier, 1986). The highest first service conception rate (CR) was shown by females inseminated in winter (Azzam *et al.*, 1989). The cow and bull contribute to the low CR in the subtropics, but the female was the major contributor (Stott *et al.*, 1972). The high adverse effects in females are shown on the ova, their fertilization and development (Neville and Neathery, 1974). Drost and Thatcher (1987) reported that, since the temperature of the blood is cooler than that of the uterus, the consequent reduction in blood flow to the uterus allows the uterine temperature to rise. The decrease in estrogen concentration as a function of heat stress and, consequently, the sufficient alteration of the environment in the follicle suppresses normal maturation of the egg, in addition to, depression or postponing of the "ovulatory spurt" of LH. However, Drost and Thatcher (1987) reported that fertilization rates may be normal in heat-stressed cows, but embryonic death may increase in either the zygotes or in the early developing embryos when the embryos are still in the oviduct or after they arrive in the uterus, i.e., before maternal pregnancy recognition (days 15 to 17). From another point of view, the adverse effects of heat stress at the time of insemination or during the first few days after breeding, affect pregnancy rate. In Florida, pregnancy rates ranged between 10 to 15% following artificial insemination during heat stress (Gwazdauskas *et al.*, 1973 and Badinga *et al.*, 1985). Gwazdauskas *et al.* (1975) revealed that rising ambient temperature from 12.5 to 35°C was accompanied by decline of CR of cattle from 40 to 31%. In other words, an increase in rectal temperature of 1°C at 12 hr post-insemination was associated with a decrease of CR in cattle (45 vs 61%) (Ulberg and Burfening, 1967). Likewise, increase in uterine temperature of 0.5°C on the day of, and day after insemination, was associated with decline in CR of 13 and 7%, respectively (Gwazdauskas *et al.*, 1973). Particularly, Gwazdauskas *et al.* (1975) found that when solar radiation increased from 300 to 800 langleys (langley = 19 calorie per square centimetre), CR dropped from 39.5 to 26.0%. In general, Biggers *et al.* (1987) reported that seasonal variations in CR were closely correlated with climatological factors such as temperature, humidity, solar radiation, atmospheric pressure, perspiration and day length. Conclusively, depression of reproductive efficiency through reduced pregnancy rate caused by an unfavourable thermal environment may be related to the direct effect of the increase of uterine temperature on embryo development or indirectly through a modification in the endocrine of the dam.

Early embryonic development and survival are affected when exposed acutely to high environmental temperature during the period of rapid conceptus development and maternal recognition of pregnancy (Dutt and Jabaro, 1976). Conceptus size and weight are reduced with exposure to heat stress (Biggers *et al.*, 1987). Such phenomenon may be explained by that the conceptus metabolic rate, nutrients uptake and growth are altered by elevated uterine temperature. The increase in conceptus metabolic rate, as well as, the possible decrease in nutrient secretion by the uterus may result in retarded conceptus development. The increase in body temperature accompanied with low progesterone concentration may also alter endometrial secretion, forming an unfavorable environment for conceptus growth (Thatcher *et al.*, 1985).

Thermal stress adverse effects on reproductive performance are not limited to the initial stages of gestation. This is evidenced by the lower birth weight of Holstein calves during hot summer months than during cool winter months (difference range is 6 kg) in the subtropical environment of Florida (Collier *et al.*, 1980), in addition to the low weight of the foetal membranes collected within 24 hours of parturition during July and August (from Holstein and Jersy cows) than of those collected during the remaining months of the year (Head *et al.*, 1981). The calf birth weight of heat-stressed cows was found to be associated with a lower mean prepartum concentration of estrone sulfate in maternal plasma which may be an indication of reduced conceptus function during thermal stress, since estrone sulfate is produced by the foetal placenta (cotyledon) (Thatcher and Collier, 1986).

Restoration of normal post-partum uterine function which is a prerequisite for normal cyclicity is affected by pre-partum environmental influences, since Lewis *et al.* (1984) found that the rate of uterine involution and post-partum plasma concentration of $PGF_{2\alpha}$ increase in cows exposed to heat stress pre-partum. Post-partum peripheral concentration of $PGF_{2\alpha}$ increases and CL diameter reduces with pre-partum heat stress (Lewis *et al.*, 1984). The decrease in CL size may be due to heat-induced partial regression of CL attributed to greater uterine secretion of $PGF_{2\alpha}$ (reflected by greater concentrations of systemic PGF) in heat-stressed animals, since maintenance of luteal function is associated with decrease in endometrial $PGF_{2\alpha}$ secretion. The increase in endometrial protaglandin secretion rate in response to heat stress may compromise CL function, initiate partial or complete luteal regression and contribute to pregnancy failure. Oxytocin induces a rapid increase in luminal and myometrial secretion rates of PGF by endometrium from heat-stressed pregnant cows, as well as, from endometrial tissue of cyclic cows (Oyedipe *et al.*, 1984), although an attenuated increase exist in secretion of prostaglandins in response to oxytocin during early pregnancy in cattle (Lafrance and Goff, 1985 and Gross *et al.*, 1988). Collectively, environmental heat stress during late gestation has pronounced effects on the conceptus and dams subsequent post-partum performance.

In summary, high environmental temperature suppresses oestrus resulting in periods of anoestrus which interfere with ovulation. Hyperthermia can also interrupt early pregnancy by causing death and resorption of embryos and abortion of well grown foetuses. Oestrous cycle length, duration of oestrus, incidence of abnormalities in the ova, embryonic mortality, fetal death rates, gestation length, fetal size, incidence of oestrus with weak signs, percentage of silent heat, ovulation failure, interval from parturition to conception and the number of services per conception may increase. The frequency of ovulatory oestrus, fertilization rate and neonatal survival may decrease as a function of heat stress. Heat stress also causes loss of libido and reduction in ovarian activity and conception rate.

In conclusion, the detrimental effects of the hot climate on animal's reproductive performance are a result of the drastic changes in its biological functions. These are controlled by the external environment through a chain of reactions involving thermoreceptors, photoreceptors, sensor capacities, the hypothalamus, central nervous system, endocrine glands and gonads.

Physiological Backgrounds

Thermoregulatory function

In a wide range of environmental temperatures within the thermoneutral zone, a balance between heat gain and heat loss is needed to make the animal's life comfortable. Animals maintain their heat balance through vasomotor control by regulating the amount of blood flowing through the cutaneous vessels by either vasodilation or vasoconstriction. Vasodilation stimulates the pilomotor centre to flatten the hair cover to allow better heat dissipation through conduction, convection and radiation (sensible means). In addition, some heat is lost by evaporation through the lungs and also from the surface of the body as a result of diffusion of water through the skin as insensible perspiration (Kamal, 1975 and Habeeb *et al.*, 1992).

As the ambient temperature increases, the amount of water lost by insensible perspiration increases slightly. The circulation of blood transfers heat from the core to the periphery. Increased respiration rate is the first reaction when animals are exposed to environmental temperatures above the thermoneutral zone (Kamal, 1975). This response ensures direct heat stimulation of the peripheral receptors which transmit nervous impulses to the heat centre in the hypothalamus. The cardiorespiratory centre is stimulated to send impulses to the respiratory activity. Specifically, in Holstein and Jersey cows, respiration rate begins to increase at about 16 and 21°C, respectively (Kibler *et al.*, 1949). With increasing environmental temperature, the respiration rate continues to rise linearly until a certain temperature, where the rate of increase in respiration rate slows, then it almost levels off or slightly decreases (Kibler, 1962 and Bianca, 1963). At that point, respiration becomes much more shallow to permit an efficient ventilation of the upper respiratory tract without undue over-ventilation of the lungs themselves (Shafie and Abdelghany, 1978). At this level, the respiratory muscles reach a threshold of maximum activity and thus the respiration rate cannot increase further. Specifically, the respiration rate of *Bos taurus* cattle never exceeds 50 respirations/minute at all temperatures below 26°C (Dobinson, 1952). The significance of the increase of the respiration rate under heat stress is that it enables the animals to dissipate the excess of body heat by vaporizing more moisture in the expired air which accounts for about 30% of the total heat dissipation (McLean, 1963). However, the excessive respiratory activity may cause respiratory alkalosis as a result of excessive CO_2 respiration and consequently loss of blood alkali reserve.

The onset of sweating is the next rapid reaction of animals to heat exposure and this increases linearly with the increase in the ambient temperature (Habeeb *et al.*, 1992). This increase in sweating is also controlled by the hypothalamus which is stimulated by the peripheral receptors. The heat loss by sweating represents 60% of the total heat loss when the ambient temperature reaches 37.8°C, at which the thirst, vasomotor and pilomotor centres are unable to respond further (McLean, 1963). When the surrounding environmental temperature is equal to or above the animal's body temperature, the evaporative cooling (respiration and sweating) system represents the only means of heat dissipation. The importance of sweating in dissipating heat load is due to the high thermal capacity of water (4.2 J g^{-1} $°C^{-1}$ at 30°C) and its high heat of evaporation (2.4 k J g^{-1}).

The pulse rate reflects primarily the homeostasis of circulation along with the general metabolic level. It increases on exposure of the animals to high environmental temperature (Salem, 1980 and Daader *et al.*, 1989) to increase blood flow from core to surface to give a chance for more heat to be lost by sensible and insensible ways. At very high temperature, it may decrease (Yousef and Johnson, 1966) due to the decrease in metabolic rate of the animals under heat stress.

As water is lost through urine, skin and respiratory vaporization under heat stress, a temporary water deficit ensues, altogether with the increase in body fluids concentration (blood hypertonicity) that stimulates the hypothalamic thirst centre to increase water consumption. The increase in water consumption causes an increase in each of blood volume, hydrostatic pressure in blood vessels and water flux from the blood vessels to the surrounding tissues that causes an increased body water content in animals. The water retained in the animal under heat stress increases the heat dissipaton by assisting evaporative cooling via sweating, respiration and non-evaporative cooling via diuresis. However, although the increase in body water content is considered as an adaptive reaction to alleviate heat stress, it is thought that heat-tolerant animals are those which manifest the least changes in most of the physiological functions, including body water content, when subjected to hot climate (Kamal, 1975). Researchers show that body water content increases by different percentages when different animals are exposed to hot conditions. The increment values in body water content have been recorded as 26% in Friesian heifers (Kamal and Seif, 1969) and 8% in Friesian calves (Habeeb, 1987 and Marai *et al.*, 1995), although under thermoneutral conditions, water intake equals water loss in the normal adult animal.

When the animal can not sustain homeothermy, it reduces the heat production using internal physiological means to help in re-establishment of the thermal balance. Feed consumption and thermogenic hormone secretions decrease to lower the basal metabolism resulting in a rapid decline in productivity.

The body temperature rises and the animal enters an acute phase of heat stress, if all the above mentioned physiological mechanisms fail to balance the excessive heat load. At the same time, such increase coincides with impulses transmitted by peripheral thermal receptors to stimulate the central receptors of the hypothalamus to induce thermal polypnoea and sweating to increase heat loss (Kamal, 1975). If heat production exceeds heat dissipation, which may be caused by failure in proper response of the peripheral receptors, hypothalamus, neutrohumora, nervous system, endocrine glands or enzymes, rectal temperature rises. The rise in rectal temperature occurs above 21-26°C in *Bos taurus* cattle and above 32°C in Zebu cattle, and younger cattle are affected at lower temperatures than old ones (Bianca, 1963).

If the mentioned systems still fail to stop elevation in body temperature, the animal succumbs with heat stroke and dies.

Regarding the acute phase, it normally occurs within few days of encountering the high temperature and is accompanied by a rapid decline in productivity. If the ambient conditions remain the same and are not severe (or the exposure to stressful heat is intermittent) a rapid acclimation to the conditions takes place and the animal returns to the chronic phase of heat stress (adaptation). This results in better productivity which eventually stabilizes at a level greater than that observed during the acute phase, but lower than the normal level. Some of these changes may occur rather rapidly (days), whereas others may require a longer period (weeks). When more favourable climatic changes occur, the performance is improved and a compensatory response occurs quite often, resulting in a return to productive levels above the normal ones (Ames and Ray, 1983 and Habeeb *et al.*, 1992). Yousef (1985) clarified that the physiological adaptations to hot environmental conditions in the large part are due to changes in hormonal activity, particularly the decrease in thyro-adrenal activity. However, some physiological adaptations vary between species, between breeds within species and between individuals within breeds (forming the basis for the development of a new adapted breed). Natural selection for physiologically adaptive features with some assistance by good management (Marai and Habeeb, 1997), helps in manifestation such adaptations. Changes in the behaviour of livestock are important in assisting adaptation, as well. In the tropical environment, livestock become more sluggish in their movements, thus reducing muscular heat production, besides that it adapt an extended position when lying down. *Bos taurus* cattle seek shade more often during the day and graze at night and all livestock drink and use more water, under the same conditions. Intermittent heat stress between day and night and/or between seasons helps adaptation than more moderate continuous one, although it is difficult for the cattle to adapt themselves to environments where the mean annual temperatures are above 18°C (65°F). However, the heat tolerant animals are those which manifest the least changes in most of the physiological functions when subjected to hot climate and the good management is that aims to facilitate adaptation (Marai and Habeeb, 1997).

Mineral balance and blood minerals concentrations

The maintenance of mineral balance in animals is of profound importance for their milk production and reproduction due to their role in bone and teeth formation, blood clotting, proper functioning of nerve tissue, regulation of osmotic pressure in body fluids, maintenance of homeostasis in the acid-base balance and acting as co-factors of enzymes or as catalysts in enzymatic reactions.

Thermal stress induces alterations in electrolytes and a negative mineral balance. High environmental temperature (32 to 39°C) induces significant decreases in the retention of Na (23%), K (37%), Ca (20%), P (20%) and Zn (24%) in *Bos taurus* cattle (Kamal and Johnson, 1977 and About-Naga, 1983). At 39°C, Aboul-Naga (1983) also recorded a decrease in the retention of each of Mg, Fe and Co in heat-stressed Friesian heifers of 28, 43 and 22%, respectively. At the same time, total excretion of all minerals increases significantly. On the other hand, high environmental temperatures induce a decrease in the intake of each of most minerals (Aboul-Naga, 1983).

With regard to the concentrations of blood electrolytes, it was found significantly lower values in serum Na, K, Ca and Zn (4, 10, 7 and 12%, respectively) in lactating Friesian cows at 28°C (Kamal *et al.*, 1989a) and in serum Na, K, Ca, P, Mg, Fe, Zn and Co (3, 10, 7, 13, 13, 13, 11 and 16%, respectively) in Friesian calves at 36°C (Aboul-Naga, 1987). However, some studies showed that cattle maintain fairly normal electrolyte balances and others showed either no marked changes in plasma Na, K (Blincoc and Brody, 1951) and Ca (Kamal and Abdelaal, 1972; Shaffer *et al.*, 1981 and Kiatoko *et al.*, 1982) or significant increase in plasma P (Kamal and Abdelaal, 1972) and serum Na, K and Ca (Shebaita and Pfau, 1982) under heat stress conditions. These different effects may be due to difference in availability of the diets rich in particular minerals to the heat-stressed animals.

The decrease in aldosterone and parathyroid hormones secretion in heat-stressed cattle is probably associated with rise in urinary minerals excretion and increase in body fluids and water turnover rate that dilute the absolute quantities of plasma minerals and help in washing out these minerals. These hormones may contribute to the reduction of blood electrolytes. In addition, the decrease in feed intake, especially roughages and the catabolic processes may also contribute to that phenomenon. The increase of glucocorticoid hormones leads to tissues destruction, thereby eliminating minerals from the body in the urine and faeces. The increase in glomerular filtration rate in the kidney may also have a role in that respect.

Immune function

White blood cells (WBCs), red blood cells (RBCs), haemoglobin (Hb), haematocrit (Ht) and globulin as indicators of body immunity are, in general, adversely affected by exposure to heat stress.

The white blood cells (leucocyte) count values increase by 21-26% in Friesian cattle (Abdel-Samee, 1987), under heat stress conditions due to thyromolymphatic involution.

The red blood cells (erythrocyte) count was found to decrease significantly by 12-20% in cattle under heat stress conditions (38°C) (Salem, 1980 and Habeeb, 1987) due to destruction of erythrocytes (Shaffer *et al.*, 1981) and haemodilution effect.

Haemoglobin concentration decreases during heat stress (Daader *et al.*, 1989; Yousef, 1990 and Marai *et al.*, 1995) due to depression of haematopoiesis and to haemodilution (Shebaita and Kamal, 1973).

Haematocrit percentage (packed cell volume) decreases in heat stressed animals (Kappel *et al.*, 1984 and Marai *et al*,, 1995, 1997 a, b) due to red cell destruction and/or to haemodilution (Shebaita and Kamal, 1975).

Blood metabolites

Results of the studies of the effect of the high ambient temperature on plasma glucose content, are conflicting. Some studies showed that blood glucose decreased significantly with different percentages in animals exposed to heat stress conditions. The decrease was found to be 24% in Friesian cows (Shaffer *et al.*, 1981), 18% in lactating Friesian cows (Kamal *et al.*, 1989b), 13% in Holstein, Brown Swiss and Jersey heifers (Kamal *et al.*, 1962), 10% in Holstein heifers (Segura *et al.*, 1979) and 8% in Friesian calves (Habeeb, 1987). Such change in glucose level during heat exposure relates in part to the decrease in concentrations of insulin (Herbein *et al.*, 1985 and Habeeb, 1987) and thyroxine (El-Masry, 1987), which are correlated closely to the decrease in energy metabolism during heat exposure. The decrease in plasma glucose could be also due to the marked dilution of blood and body fluids as a whole or to the increase in glucose utilization to produce more energy for greater muscular expenditure required for high respiratory activity (Habeeb *et al.*, 1992) in the heat-stressed animals. Moreover, the decrease in production of propiontic acid in the rumen (Kelley *et al.*, 1968) and the decrease in roughage intake (Colditz and Kellaway, 1972), as well as, the decrease in hepatic capacity for gluconeogenesis (Sano *et al.*, 1983), would also be reasons of such phenomenon in heat-stressed animals. Other studies show that glucose concentration may increase under heat stress conditions (Webster, 1976 and Collier *et al.*, 1982), due to the decrease in glucose utilization, depression of both catabolic and anabolic enzyme secretions and subsequent reduction of metabolic rate (Webster, 1976), or to the rapid panting which results in increased breakdown of glycogen into free glucose by the increase in glucocorticoid hormones (Thompson, 1973). The conflict shown above may be because the high environmental temperature that affects blood glucose content by altering the hormonal balance (i.e., insulin, adrenaline, glycogen, thyroxine and adrenocorticotrophic hormone balances). Thus either the glucose utilization and glucogenesis or glycogenolysis and gluconeogenesis are increased with consequent decrease or increase in blood glucose concentration, respectively.

Plasma protein content is negatively correlated to environmental temperature (Kamal *et al.*, 1962). Serum protein, particularly albumin concentration, usually decreases under heat stress by about 10% (Marai *et al.*, 1996 and Yousef *et al.*, 1996), while globulin concentration increases. The significant decline in serum protein with rising temperature seems to be due to dilution of plasma proteins, decrease of protein synthesis as a result of the depression of anabollic hormonal secretion (El-Masry and Habeeb, 1989) and the increase in the catabolic hormones such as glucocorticoids and catecholamines (Alvarez and Johnson, 1973). The decrease in serum protein may also be due to the decrease in feed nitrogen and mineral intake which occurs under heat stress conditions. The plasma protein provides an efficient way of transferring the heat from inside the body to the outer surface in the skin for heat dissipation by non-evaporative processes during heat stress, since it holds an adequate percentage of water in the intravascular fluids and maintains the viscosity of the blood (Kamal *et al.*, 1962).

Serum total lipids concentration decreases significantly in ruminants with prolonged exposure to high environmental temperature (Marai *et al.*, 1995, 1997a, b; Habeeb *et al.*, 1996 and Yousef *et al.*, 1996 and 1997). Such phenomenon may be due to the increase in either body water content or utilization of fatty acids for energy production as a consequence of the decrease in glucose concentration. The cholesterol concentration also decreases markedly with the high environmental temperature (Shaffer *et al.*, 1981; Abdel-Samee, 1987, Marai *et al.*, 1995, and Habeeb *et al.*, 1996). The marked decrease in cholesterol concentration may be due to the increase in total body water or to the decrease in acetate concentration which is the primary precursor for the synthesis of cholesterol. The marked increase in glucocorticoid hormone level in heat-stressed cattle may be another factor causing the decline in blood cholesterol.

Kidney function

Blood urea-N level was found to decrease by 16% in heat-stressed Friesians (El-Masry, 1987 and Kamal *et al.*, 1989a), 28% in lactating cows (Aboul-Naga, 1987) and 30% in claves (Habeeb, 1987). The depression in blood urea-N associated with heat stress in animals may be due to more resorption of the urea-N from the blood to the rumen to compensate for the decrease in ruminal ammonia-N as a result to the decrease in feed intake (El-Fouly *et al.*, 1978 and Yousef *et al.*, 1996). In addition, the increase in urinary nitrogen excretion under severe heat stress conditions as indicated by a negative nitrogen balance (Kamal *et al.*, 1962), may also contribute to the decrease of serum urea level under such conditions.

Creatinine was also found to decrease by different percentages in *Bos taurus* cattle due to exposure to high ambient temperature. The decrease in creatinine concentration was estimated to be 19% in Friesian calves by Marai *et al.* (1995, 1997a,b).

Liver function

Most researchers show that the serum transaminase activities increase with increase in environmental temperature, in *Bos taurus* cattle. Heat stress causes increase in activities of serum glutamic oxaloacetic transaminase (SGOT) and serum glutamic pyruvic transaminase (SGPT) due to increase in stimulation of gluconeogenesis by corticoids (increase in cortisol, cortisone or adrenocorticotrophic hormone) (Thompson, 1973; Hebeeb, 1987; Kamal *et al.*, 1989b and Marai *et al.*, 1995).

Alkaline phosphatase enzyme was mostly found to decrease significantly (Peterson and Waldern, 1981; Shaffer *et al.*, 1981; Aboul-Naga, 1987 and El-Masry, 1987) by heat stress. This may be attributed to reduction in thyroid hormones which takes place under heat stress. With regard to acid phosphatase level, Roussel and Stallcup (1966) and Aboul-Naga (1987) reported that it was not affected in heat-stressed cattle.

Generally, the blood enzymes are easily and often influenced by the external environment including feeding practices, type of shelter and many other aspects of herd management, since they are intimately related to metabolism. Accordingly, seasonal changes of the enzymes are very important and must be considered. In addition, it is also important to control carefully all experimental conditions, especially environmental ones, when measuring the enzyme activity in any animal (Boots *et al.*, 1969).

Endocrine functions

Hormonal secretions are known to be of major importance in body thermoregulation. 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. 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 (Habeeb *et al.*, 1992). The hormones connected with thermoregulation are numerous: insulin, thyroxine, cortisol and aldosterone.

The studies on *Bos taurus* under heat stress conditions, showed that plasma insulin decreased significantly by 33, 54 and 30% in Holstein cows (Herbein *et al.*, 1985 and Abdel-Samee *et al.*, 1989), Friesian heifers (Sejrsen *et al.*, 1980) and Friesian calves (Habeeb, 1987), respectively, to decrease heat production. However, McVeigh and Tarrant (1982) noticed no significant differences between stressed- and unstressed-Friesian bulls in plasma insulin concentration.

Thyroid hormones, either thyroxine (T_4) or triiodothyronine (T_3) are known to play an important role in the animal's adaptation to environmental changes. However, T_3 is more concerned with thermogenesis and was found to decline significantly in heat-stressed cattle (Marai *et al.*, 1995, 1997a, b; Habeeb *et al.*, 1996 and Yousef *et al.*, 1997). In the long term, thyroxine hormone levels decrease by upto 25% (Vanjonack and Johnson, 1975; Collier *et al.*, 1982; Magdub *et al.*, 1982 and Habeeb *et al.*, 1997), under heat stress conditions. However, the decrease does not occur abrupty, but takes at least 72 hours to reach the peak and may then decline. The reduction has been found to be 15 and 37% after 48 and 72 hours of heat exposure, respectively, in Friesian cows (Kamal and Ibrahim, 1969). In summer, Kamal and Ibrahim (1969) reported that the thyroid activity decreased by 16% relative to winter in Friesian cows. The decrease in thyroid hormones is due to the decrease in each of basal metabolic rate and muscle activity which leads to decrease of heat production.

Activation of the hypothalamic-pituitary-adrenal axis and the consequent increase of plasma glucocorticoid concentrations are perhaps the most important responses of animals to stressful conditions. Adrenal corticoids, mainly cortisol, elicit physiological adjustments which enable animals to tolerate stressful conditions (Christison and Johnson, 1972). However, the literature dealing with the effect of hot climate on plasma cortisol level in cattle, is rather conflicting. The studies show that plasma glucocorticoids either increase (Satterlee *et al*., 1977 and Yousef *et al*., 1997), decrease significantly (Lee *et al*., 1976; Niles *et al*., 1980; Collier *et al*., 1982; Kamal *et al*., 1989a, b and Yousef *et al*., 1996) or not significantly affected (El-Nouty *et al*., 1980 and Gwazdauskas and Vinson, 1979), by heat stress. The above contradiction may be attributed to the difference in duration of exposure to heat stress, since Alvarez and Johnson (1973) found that glucocorticoids increased by 38% after 1 h and 62% after 2 h of exposure of animals to hot conditions reaching a peak of 120% at 4 h, then declined gradually to values not different from normal at 48 h and remained at or below this level for the rest of the exposure duration. The basal cortisol concentrations vary greatly so that its values may not be reliable indicators of an animal's ability to adjust to short (acute) or long (chronic) stressful conditions (Willet and Erb, 1972 and Rudson *et al*., 1975). However, it can be concluded that plasma cortisol level increases during acute heat stress and decreases during the chronic phase. The increase of plasma cortisol level during acute heat stress is 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. However, it is possible to consider the initial reactions of the animal to acute heat stress as an emotional rather than a thermoregulatory response (Collins and Weiner, 1968). The decline which occurs during the chronic heat stress is attributed to the fact that cortisol is thermogenic in animals and, consequently, the reduction of adrenocortical activity under thermal stress is a thermoregulatory protective mechanism preventing metabolic heat production in a hot environment. This indicates the role of the adrenal cortex gland in adpatation to stress (Alvarez and Johnson, 1973). Particularly, the response of cortisol level in the blood due to heat exposure may be affected by the physiological status of animals, since Yousef *et al*. (1996) found that cortisol level decreased in Friesian cows, while Yousef *et al*. (1997) found that cortisol level increased in Friesian calves.

Plasma aldosterone concentration decreases significantly in *Bos taurus* cattle under high environmental temperature (El-Noutry *et al*., 1980; Niles *et al*., 1980 and Aboul-Naga, 1987) due to the large decrease in potassium retention under heat stress conditions (Kamal *et al*., 1962). With prolonged heat exposure, mineralocorticoids seem to decrease due to the change in blood electrolytes. The increase in body fluids which occurs in heat-stressed cattle may also be partly responsible for this decrease, since the increase in the extracellular fluids volume decreases the aldosterone secretion.

Evaluation of *Bos taurus* Adaptability to Hot Arid Conditions

The suitable stock for the tropics or sub-tropics should be morphologically and physiologically equipped to withstand heat and drought. Accordingly, adaptability of the animals to hot climate could be evaluated on morhplogical basis and/or on physiological basis. This could be achieved according to morphological characteristics that can assist to adapt to hot climate and/or according to physiological parameters such as the actual response or adaptability to hot climate after testing the animals under the hot climate conditions.

Evaluation based on the morphological characteristics

Morphological characteristics of animals suitable to hot climate should include large skin area in relation to unit of live weight, shielded eyes, pigmented skin and eyelids (to lessen susceptibility to eye cancer) and short sleek light coloured hair. The ability of animals to shed their coats early in spring, walk long distances, use low water intake, high intake of salts (either in drinking water or in forages) and poor quality food, afford harsh treatment and resist ticks (animals with long or woolly coats pick up a large number of larval ticks than animals with short sleek coats) and other pests, should be involved.

With such information in mind, *Bos taurus* with permanent short coats can be used in fairly hot rather humid regions and those with heavy coat, but shed early and decisively in the spring, can be used in regions that are fairly hot and humid in summer. However, the spread of breeds to new areas may often be either a matter of chance or just trial and error owing to the great complexity of the environment and the unexplained idiosyncrasies of breed in respect to things like terrain.

Evaluation based on physiological prarameters

Proper and more accurate evaluation could be based on the ability of the animals to maintain expression of their inherited functional potential during their life-time when raised under hot conditions (which is the typical definition of adaptability or heat tolerance). The relative changes in thermal, water and/or nitrogen balances of the animals under the conditions which they have to live could be used in estimating parameters for detection of their adaptability as shown below (Habeeb *et al.*, 1997). The chosen breed for hot arid region should manifest the least changes in most of the physiological functions and consequently in the productive and reproductive traits. However, the possibility of a breed to fit in a certain region can be predicted by constructing climographs (Wright, 1946, 1954) using climate data collected from both the original and new environments, by plotting the means of monthly air temperatures against the means of monthly relative humidities in the two localities. Similarity of each of position, shape and area of the two patterns so formed after joining the twelve points, indicates such possibility. However, disease and parasite criteria, the feed situation, prices of inputs and products and the market situation also have to be considered, in this respect.

Evaluation based on changes in thermal balance: Various indices have been used to evaluate the thermal balance

Iberia heat tolerance index (IHT; Rhoad, 1944): The test is carried out by keeping the animal in a cattle chute exposed to direct sunlight on a bright calm summer climate for three consecutive days with ambient temperature in shade between 29 and 35°C. Averages of daily rectal temperatures (RT) and respiration rates (RR) measured at 10.00 and 15.00 h, are calculated. The IHT is estimated by the following equation: IHT = 100-10 (RT - 101), where 101 = the average normal °F of rectal temperature in cattle. If two groups show the same coefficient, the one which has lower RR is considered higher in heat tolerance.

Lee and Phillips (1948) made an improvement in IHT test by using a heat chamber to obtain standard conditions of temperature and humidity at which the animals are exposed for six hours.

Bonsma (1955) proposed that between breeds, there are significant differences in the standard temperatures of the body fixed by Rhoad as 101°F and indicated that IHT is valuable in selection within breed for heat tolerance:

Benezra index (BI, Benezra, 1954): The test is carried out by using RT and RR as shown in the following equation: BI = RT/38.3 + RR/23. The values obtained above or below 2 represent lower or higher, respectively, heat adaptability than normal.

McDowell *et al.* (1955) used RT and RR responses during 6 h hot room test in estimating the relative response in cattle. The trapezoidal mean (TM) of RT or RR during a 6 h period = (05 t_0 + t_1 + t_2 + t_3 + t_4 + t_5 + 0.5 t_6)/6, where t_0 + t_1 + t_2 + t_3.... etc. = RT or RR recorded after 1, 2, 3, ... etc., h of exposure.

Bianca (1963) used the average final RT as heat tolerance coefficient (HTC) as follows: HTC = 100 -18 (Tr - 38.3), where Tr = (Average RT at comfort + Average RT at hot temperature)/2. In this index, the decrease in the final RT is accompanied with the increase in heat adaptability. However, Brown *et al.* (1969) indicated that the rate of RT rise is definitely related to heat sensitivity, and multiple measurements could be used as a test for heat sensitivity of individual animals.

Evaluation based on thermal and productive responses: Milk yield (M), magnitude of RT and feed energy intake (F) could be used in an index for productive adaptability (PA) according to Johnson *et al.* (1988) as follows: PA = (% increase in RT) (% decrease in M + % decrease in F). Negative value indicates heat sensitivity and is shown when percentage increase in RT is 2.4 or more and percentage decrease in M is 28 or more, while positive value indicates heat tolerance and is shown when percentage increase in RT is 1.2 or less and percentage decrease in M is 8 or less. The PA index is more accurate estimation for the relative level of production potential in adverse hot climate and can provide a scientific basis for establishment of improved strains for adverse climatic zones.

Evaluation based on changes in water balance: The body water and its turn over raw has been used for physiological evaluation:

Total body water: Habeeb (1981) used the percentage increase in total body water (TBW) due to heat exposure as index for HTC as follows: HTC = 100 - [(TBW_2-TBW_1) x 100/TBW_1], where TBW_1 = TBW at comfort and TBW_2 = TBW at hot conditions. Kamal (1982) found a significant positive correlation between this index and the percentage increase in body weight gain, during hot summer climate.

Total evaporative rate: Yeck and Kibler (1958) used the ratio of total evaporative rate (TER) as index for HTC as follows: HTC = TER at 26.7°C: TER at 10°C. The most tolerant animal is that shows the highest ratio. since evaporation is considered the sole mean of dissipating body heat at high ambient temperatures.

Water turnover rate: Kamal *et al.* (1978) used the percentage increase in water turnover rate (WTR) in estimating THC as follows: HTC = 100 - [WTR_2 - WTR_1) x 100/WTR_1], where WTR_1 = WTR at comfort, WTR_2 = WTR at hot conditions, WTR = Total body water (tritiated water space) x (0.693/$T_{1/2}$ x 24 h of day). $T_{1/2}$ (biological half-life time of tritiated water; ^{3}TOH or ^{3}HOH = the time needed in days to remove half total exchangeable body water pool and 0.693 = the tritiated water exponential disappearance rate constant. The most heat tolerant animals are those with the highest values, and that index has proved to be more accurate in determination of adaptability of animals than total vaporization.

Biological half-time of tritiated water ($T_{1/2}$): Abdel-Samee (1982) used the percentage decrease in biological half-life ($T_{1/2}$) of tritiated water space (^{3}HOH) due to hot conditions as an HTC index (because $T_{1/2}$ in animals depends on WTR, i.e., WTR increases and $T_{1/2}$ decreases as the ambient temperature increases), i.e., HTC = 100 - [(T_1 - T_2) x 100/T_1], where T_1 = $T_{1/2}$ of ^{3}HOH at comfort and T_2 = $T_{1/2}$ of ^{3}HOH at hot conditions.

Parameters based on changes in protein balance: Protein turn over and its balance has been utilized for evaluation purposes.

Nitrogen retention (NR): Kamal *et al.* (1962) used the percentage decrease in nitrogen retention as HTC index as follows: HTC = 100 - [(NR_1 - NR_2) x 100/NR_1], where NR_1 and NR_2 are nitrogen retention at comfort and hot conditions, respectively, NR = (N intake x digestion coefficient) - N excretion and N = nitrogen. The most heat tolerant animals are those with the highest values.

Lean mass: Kamal and Johnson (1970) used the loss in lean mass estimated by the loss in the amount of radioactivity naturally occurring in ^{40}K in the body as a simple index for heat adaptability (HTRC). The amount of ^{40}K is counted for few minutes in the whole body counter before and after 3 days of heat exposure. From the ^{40}K loss, the amount of lean mass loss can be known. i.e., HTRC = 100 - [Body ^{40}K at comfort - Body ^{40}K at high temperature) x 100/Body ^{40}K at comfort]. The animals which loose less lean mass at high ambient temperature are considered as heat tolerant.

Total body solids: Kamal and Johnson (1971) used the loss in total body solids (TBS) that include lean body mass and body fat as heat tolerance index (HTC). Total body water is determined before and after three days of heat exposure and each value is subtracted from the corresponding live body weight to obtain TBS at comfort and hot climate, i.e., HTC = 100 - [(TBS at comfort - TBS at high temperature) x 100/TBS at comfort].

Protein catabolism: El-Fouly and Kamal (1979) used urea entry rate (urea pool size x ^{14}C-urea exponential disappearance rate) in blood as indication for protein catabolism in heat-stressed animals and as index for heat adaptability, since these values increase with different percentages in heat-stressed animals.

Kamal (1976) used ^{15}N-urea as an indication to protein catabolism instead of hazardous ^{14}C-urea. Such method is quicker and more accurate than nitrogen retention methods.

Other parameters: Shebaita and Kamal (1973) showed differences in heat tolerance between species and breeds due to differences in changes in blood volume and red blood cells volume in hot climate using radioactive soidum chromate.

In conclusion, *Bos taurus* cattle production in hot environment is faced with many problems of which the heat stress is the most important. Under such conditions, drastic changes in animal's biological functions occur and end with impairment of its growth, milk yield and reproduction. The most adaptable *Bos taurus* animals to such conditions are those which manifest the least deviations in their traits when introduced to such conditions. Selection of high productive animals that own such criteria, will be of a great benefit to mankind, either in hot climate areas or in any other area of the world, since such animals will face the expected increase in the global atmosphere temperaturic as a result to the greenhouse effect.

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