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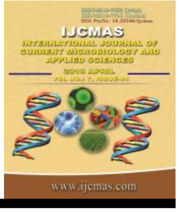

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# Advances in Stress Physiology and Bioenergetics of Farm Animals: An Overview

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## ABSTRACT

Livestock sector play a major economic and cultural influence throughout the world. The changing scenario of climate is a threat for sustainability of this sector. Climatic events such as rising temperatures are detrimental to the productive capacity of livestock under tropical climatic conditions. Heat stress due to rise in temperature affect the high producing animals more than low producing animals due to more metabolic heat productions. Countries which are under tropical and sub-tropical region are more sufferer of climate change. The energy metabolism and heat production of animals is highly variable, depending on the activity of the animal, its diet, thermoregulatory functions, sex, reproductive condition, time of day and year hair or feather characteristics, weather, parasites and pathogens, and various social and psychological effects. However, Knowledge and understanding of characteristics that directly used as a marker of heat stress includes coat, hide, skin, enzymes, hormones and hematological attributes may be helpful in combating the effect of harsh environment.

**Keywords**

Bioenergetics, Heat, Production, Stress, Temperature

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## Introduction

Livestock sector play a major economic and cultural influence in many communities throughout the world. However, the changing of climate scenario is a threat to sustainable agriculture in the world. Climatic events such as rising temperatures are detrimental to the productive capacity of livestock under tropical climatic conditions. Heat stress due to rise in temperature affect the high producing animals more than low producing animals due to more metabolic heat productions. However, the present scenario demands the food security for growing population. These impacts of climate change will pose additional burden on dairy farmers who operate on small profit margins. Countries which are under tropical and sub-tropical region are the major sufferer of global warming due to climate change. Livestock sector contributes a major role in agriculture which accounts for 40% of world's gross domestic product (GDP) with a value of at least 1.4 trillion dollars. It employs more than one billion people and thus creates a livelihood for people living in poverty (Steinfeld *et al.,* 2006). The comfortable range of ambient temperature for better performance varies from 15 to 25°C for crossbred cattle and 15-28°C for indigenous cattle (Singh and Upadhyay, 2009). When the ambient temperature rises from the comfortable temperature the productivity of farm animals compromised. The energy metabolism and heat production of animals is highly variable, depending on the activity of the animal, its diet, thermoregulatory functions, sex, reproductive condition, time of day and year hair or feather characteristics, weather factors, parasites and pathogens, and various social and psychological effects.

The harsh effect of climate change is expected to have maximum impact on extensive livestock production systems. Questions arise concerning options and strategies for reducing vulnerability and building resilience among these livestock communities. However, objective measurements of characteristics that directly used as a marker of heat stress includes coat, hide, skin and hematological attributes.

## Morphological and physiological characteristics

The breeds of animal having small size and low body weight with small barrel shaped body, slender legs and hump and dewlap are more suitable in tropical climatic condition. They held their head high and developed long legs with articulate joints which provide ample capacity to run and swiftly move under moist soils. The balanced fore and hind body quarters help them in propelling body and moving forward with loads at moderate speeds. Balanced body is mainly due to small size and low volume of internal organs. Small sized rumen, reticulum, omasum and abomasum, do not distend down belly of heat tolerant draught breeds contrary to heavy bodied in Taurine breeds. The animals well adapted to hot dry desert conditions are able to reduce their metabolic requirements to minimum and conserve energy for diversion to production (milk and /or work) without extra energy expenditure.

## Physiological responses

The physiological responses are important to cope the animals to the environments. The respiration rate (RR), heart rate (HR), pulse rate (PR) rectal temperature (RT) and skin temperature are recorded higher in crossbred cattle as compared to Zebu cattle. The relationship between behavioural and physiological indicators can be used to evaluate the adaptive capacity and consequently the “welfare” of animals in relation to different conditions (Broom and Johnson, 1993). Stressors of some systems are detectable as modifications of respiratory or heart rates, which are a valid index of social stress (Guyton, 1995). Sharma (1974) reported positive correlation between temperature, relative humidity and rainfall with that of pulse rate, respiration rate and body temperature in cattle. This increase in respiration rate may be used as an index of discomfort in large animals (Bhattacharya et. al. 1965). Singh and Upadhyay (2009) observed higher respiration rate and rectal temperature in Karan Fries than Sahiwal cattle during heat stress. McDowell (1972) and Gaughan *et al.,* (1999) reported a low respiratory rate under hot weather identifies animals with lesser discomfort. Pandey *et al.,* (2017b) also found higher values of physiological responses of Tharpakar and Karan Fries heifer’s expoxed to temperature of 42ºC and $CO_2$ levels of 600 ppm in climatic chamber. Energy levels of feed affect the physiological responses; it was found that increasing the energy content of feed by 15% increased the RR by 6% and in Sahiwal and 8.22% in KF heifers (Kumar *et al.,* 2017).

This fact is evident when comparing respiration rates of Bos taurus versus *Bos indicus* under hot summer weather conditions where *Bos indicus* (Zebu) cattle maintain lower respiration rate.

## Low metabolic rate

Low metabolic rate is advantageous if the availability of feed quality and/ or quantity is low. The quality and quantity of feed is affected during extreme climatic stress. However, the crossbred animal cannot able to maintain their production performance, which reduced drastically during extreme climatic stresses. The mRNA expression of metabolism related genes (Dio2, TRIP11) lower in Tharparkar cattle than Karan fries cattle during hot humid season (Naidu, 2016). The thyroid hormone, skin temperature and rectal temperature were positively correlated with the expression level of deiodinase type2 (Dio2) gene in PBMC (Naidu, 2016). The magnitude of TRIP11 gene expression was higher in Karan Fries heifers than Tharparkar heifers (Naidu, 2016). Thyroid Hormone Receptor Interacting Protein 11 (TRIP11) is found to positively correlate with cortisol, rectal temperature, pulse rate, respiration and skin temperature (Naidu, 2016). This characteristic makes them better adaptability under tropical climatic condition.

## Peripheral blood flow

The nourishment of the skin is received from the blood (peripheral circulation) carrying essential nutrients. The blood flow in the periphery is not only important for nourishment but also sufficient exchange of heat dissipation from internal to the surface of the body and to the environment. The peripheral blood flow increases to release the heat via conduction and convection. During summer, the mean blood flow was 4.71±0.49, 14.85±1.63 and 16.72±1.47 PU; whereas, during winter, it was low, 1.10±0.16, 8.96±0.58 and 12.16±0.95 PU at dorsal, abdomen and middle ear in buffaloes, respectively (Singh *et al.*, 2014). The blood flow was positively correlated with the temperature of the body parts and it varied in different seasons.

## Sweating

Cattle indigenous to tropical regions had a relatively thin hair follicle depth and very often a simple sac-like sweat gland (Jenkinson and Nay, 1975). *Bos indicus* cattle have looser and thicker skin, larger ears, and prominent hump and live in the hot and humid climates. Bos taurus, on the other hand, lack all of these characteristics (except for the thick hide) and are more adapted to cooler and drier climates. Heat stress activates various physiological functions to decrease the heat and enhance the heat release via conduction, convection, radiation and evaporation. Evaporation involves in sweating rate and respiratory minute volume (Al-Haidary *et al.*, 2001). Evaporation is one of the best ways of heat relief. However, it needs energy for its function. Therefore, proving easily digestible diet is recommended during summer to the animals for energy requirement. Approximately 70-85% of heat loss was estimated via evaporation from sweating and respiration (Kibler and Brody, 1952; Finch, 1986). When the air temperature reaches the skin temperature, evaporation becomes the major route for heat exchange with the environment. Evaporative cooling by sweating and panting is the most important mechanism for body heat dissipation under elevated hot climates (Collier, 2008). However, heat loss by panting becomes effective if the excess heat is not dissipated successfully by sweating and its capacity is impacted by the genetic makeup of cattle (Robertshaw, 1985). McLean and Calvert (1972) found that 84% of heat was lost by evaporation, of which 65% was lost by sweating and 35% was lost by panting. Cattle utilize evaporative cooling in the form of both sweating and panting in an effort to get rid themselves of excess body heat when environmental temperatures begin to exceed 35°C and THI of 90 (Collier, 2008). The ability of farm animal to maintain body temperature depends on their capacity of thermoregulation based on the balance of heat gain and heat loss through: conduction, convection, radiation, and evaporation (Kadzere *et al.,* 2002). *Bos indicus* cattle, with their higher sweat gland density, tend to have higher sweating rate (Schleger and Turner 1965). The sweat glands of *Bos indicus* are baggy-shaped, higher in volume (Pan, 1963), and closer to the skin surface (Nay and Hayman 1956) than those of Bos taurus. Comparative studies found that *Bos indicus* are more dependent upon increased sweating to dissipate excess body heat based on higher sweating rates, lower rectal temperature and lower respiration rate, while Bos taurus are more likely to utilize an increase in respiration rates to dissipate heat based on higher respiration rate and higher rectal temperature (Koatdoke, 2008). Sweating rate was found to be increased with increasing THI and was more prominent in Sahiwal than HF and the crossbreds.

## Coat colour

The hair and skin pigmentation is one of the adaptive mechanisms of farm animals during heat stress. Less pigmentation of melanin was observed during summer compared to winter in Tharparkar cattle which help to reduce the heat absorption from solar radiation. Melanin pigmentation helps in adaptive mechanism and act as an antioxidant. Studied also revealed that the skin pigmentation (melanin) is higher in Tharparkar than Karan fries cattle (Maibam *et al.,* 2014a). The basis of coat colour in mammals including cattle is the presence or the absence of melanin pigment (eumelanin and pheomelanin). Eumelanin is responsible for black and brown colours and pheomelanin for reddish brown (Simon and Peles, 2010**).** Melanocortin 1 receptor (MC1R) gene is responsible for pigmentation differences in mammals (McRobie *et al.*, 2014). Acquisition of a highly stable MC1R allele promotes black pigmentation which helps in protection from UV damage (Greave, 2014). Another gene, premelanosome (PMEL), encodes a transmembrane protein called pre-melanosomal protein. PMEL is a melanocyte protein necessary for eumelanin deposition (McGlinchey, 2009). Therefore, the above mentioned genes (MC1R and PMEL) divert the pathway of melanin synthesis towards eumelanin (true melanin) rather than pheomelanin. The rate limiting enzyme for melanin synthesis is tyrosinase (Zhang *et al.*, 2010). Eumelanin intensifies skin pigmentation and thus helps in photoprotection because of its efficiency in blocking ultraviolet rays (UV) and scavenging reactive oxygen species (Klungland *et al.*, 1995). The expression of skin colour related genes (MC1R and PMEL) in lymphocytes and plasma tyrosinase activity were found to be significantly higher in Tharparkar than Karan Fries cattle. It shows that the ability of Karan Fries cattle to protect themselves from the harmful UV radiation by melanisation was significantly less compared to Tharparkar and it was found to be declined with heat stress (Uttarani *et al.*, 2014a, b).

It is a familiar observation that different ecotypes of cattle, whether they are distinguished as species, breeds, or strains, show marked contrasts in coat cover. These differences follow the principle, dignified by Wright (1954) as “Wilson’s Rule”, of a gradient from thick, woolly coats in cold climates to short coats with bristly hairs lying sleekly against the skin in hot climates. Individual animals also grow shorter coats when transferred from a cold to a hot environment (Berman and Volcani, 1961). The fact that coat genotype seems to have changed fairly rapidly in breeds introduced to the tropics confirms the importance of this trait to adaptation. Dowling (1956) associated the heat tolerance and performance of different strains of cattle with their coat characters, and Turner and Schleger (1960) measured the degree of variability of coat type within herds, and assessed the proportion of the variation in growth rate that is accounted for by variation in coat type. Coat characteristics are associated with heat tolerance and performance of animals (Dandage *et al.*, 2010; Collier and Collier, 2012). Skin colour is also associated with the health condition of the individual (Stephen *et al.*, 2011). In animals, hair and skin pigmentation is a highly visible trait. Under tropical condition with high levels of solar radiation, animals with a light coloured hair coat and darkly pigmented skin are better adapted (Finch *et al.*, 1984). The light cows show lesser alterations in physiological variables than did cows with less white.

## Oxidative stress and thermal stress

Under heat stress, free radicals are produced in the body and are neutralized by intracellular antioxidant enzymes produced in the different tissues of the body depending upon their metabolic activity. An increase in the reactive oxygen species (ROS) production and the promotion of cellular oxidation were observed under heat stress conditions (Kim *et al.*, 2005). The increase in ROS reflects increased level of thermal stress. Keller *et al.*, (2004) also observed that exposure of animals to elevated temperatures accelerated mitochondrial respiration and increased mitochondrial ROS formation. ROS, being cellular toxicants (Davidson *et al.*, 1996), can be induced through hyperthermia (Flanagan *et al.*, 1998). Excess ROS production by intensively respiring mitochondria induces cellular damage (Abele *et al.*, 2002). ROS formation in fibroblast of cattle decreased at lower temperature (25$^{o}$C) than control (37 $^{o}$C), but increased at 40 and 44$^{o}$C. At 40 and 44 $^{o}$C, ROS formations were observed to be more in Karan-Fries cattle than Tharparkar (Singh *et al.*, 2014). The levels of the ROS are associated with the susceptibility of dermal fibroblasts to different environmental stresses. The major defense in detoxification of superoxide anion and hydrogen peroxide resulted from oxidative stress, are Super Oxide Dismutase (SOD), Catalase and Glutathione peroxidase (McCord and Fridovich, 1969). Erythrocytic SOD and Catalase increased significantly after 3h of exposures in climatic chamber (Lallawmkimi *et al.*, 2012). Kumar (2005) observed a significant positive correlation of THI with the erythrocyte SOD and Catalase activity in Murrah buffalo and KF cattle. The highest increase was registered in KF followed by Murrah. Pandey *et al.*, (2017a) reported higher values of SOD, GPx and catalase in treatment group of Tharpakar and Karan Fries heifers kept in climatic chamber at 42ºC temperature and 600 ppm of $CO_2$ levels compared to control group.

## Stress indicator hormone (cortisol)

Activation of hypothalamo-pituitary adrenal axis and the consequent increase of plasma cortisol level is the most prominent response to stressful conditions. This increase in cortisol level stimulates physiological adjustments that enable the animal to tolerate the stress caused by a thermal stress (Christison and Johnson, 1972). Plasma cortisol rises markedly when cattle are acutely exposed to high environmental temperatures (Habeeb *et al.*, 1992). Francisco *et al.*, (1992) also reported significant increase in plasma cortisol concentration in heat stressed cows as compared to unstressed cows. Chandrabhan *et* *al.*, (2013) reported higher plasma cortisol levels in KF compared to Zebu cattle during different seasons but the peak level of cortisol was observed when animal were exposed to higher temperature. The higher cortisol level in crossbred cattle during heat stress indicates that they are in greater stress on exposure to heat (Maibam *et al.*, 2016). Pandey *et al.*, (2017a) showed the significantly higher levels cortisol in treatment group of Tharpakar and Karan Fries heifers kept in climatic chamber at 42ºC temperature and 600 ppm of $CO_2$ levels than the control unexposed group.

## Heat shock proteins (HSPs)

Due to changing climatic conditions, a more lucid understanding of the mechanisms of thermal stress in livestock species has become imminent (Crozier *et al.*, 2008). Different attempts had been made to find out the levels of thermotolerance of cattle and buffaloes based on physiological and cardinal reactions. The levels of animal's heat tolerance can be assessed by a group of protein family known as Heat Shock Proteins (HSPs). Stressful conditions in animals elicit HSP synthesis especially the HSP 70. HSP 70 functions as molecular chaperones in restoring cellular homeostasis and promoting cell survival (Collier *et al.*, 2008). Therefore intracellular levels of HSPs were suggested as indicators of thermotolerance in livestock species.

Heat stress also initiates a complex program of gene expression and biochemical adaptive responses (Fujita, 1999). Heat shock proteins (HSPs) involved in these responses are highly conserved and these molecular chaperones encompass several families, play important physiological roles and help cope with heat stress (Parsell and Lindquist, 1993). HSPs have been considered to play crucial roles in environmental stress tolerance and in thermal adaptation (Sorensen *et al.*, 2003). Studies of Daugaard *et al.*, (2007) demonstrated that some of the cytosolic HSP70 family members deal with the cellular stress response and others are involve in tissue- specific and housekeeping biological tasks. Several studies in bovine and human cells gave evidence that constitutive elevation of the inducible HSPs levels in gene and protein expression provides cytoprotection upon thermal stress (Collier *et al.*, 2006).

Among HSPs family, HSP70 transcription is increased by heat shock as well as other stress stimuli such as oxidative stress, ischemia, inflammation, or aging (Favatier *et al.*, 1997). However, continuous temperature rise does not protect cellular damage due to an imbalance between various physiological and cellular functions (Patir and Upadhyay, 2010). Among members of the HSP family, HSP70i (namely, HSPA1A and HSPA2) is the most temperature sensitive and induced by various physiological stressors, pathological stressors, and environmental stressors (Beckham *et al.*, 2004; Kumar *et al.*, 2015). The expression of HSP70i is stress inducible and can only be detected following a significant stress upon the cell or organisms (Satio *et al.*, 2004). HSPA1A and HSPA2 play a crucial role in guiding conformational status of the proteins during folding and translocation (Arya *et al.*, 2007).

In the hot environmental niche, a greater amount of constitutive HSP70.8 (HSPA8) is found during non-stress conditions (Singh *et al.*, 2014). The HSPA8 assists in the day to day cell functions of protein folding and unfolding, prevention of polypeptide aggregation, disassembly of large protein complexes, and aid in the translocation of proteins between cellular compartments (Gething, 1997). The HSP72 mRNA expressions increased significantly after end of 3 h of exposures in growing and heifers of Murrah buffaloes during both exposure I (38±1°C with 50±2%RH) and II (42±1°C with 40±2% RH) whereas in lactating buffaloes the HSP72 mRNA expressions increased during first 2 h of exposures and later on a declining trend was observed at third hour (Lallawmkimi *et al.,* 2012). The levels of HSP 72 mRNA expression and antioxidant enzymes increased with the increase in temperature indicating an oxidative stress (Lallawmkimi *et al.,* 2012). The expression of HSP70 family genes increased significantly in heat stress exposed goat blood mononuclear cells (PBMC) as compared to un-stress cells (Mohanarao *et al.*, 2013).

Microarray analysis revealed that a total 460 transcripts were differentially expressed with a fold change of P2 in peripheral blood leukocytes of heat exposed (42 °C, 4 h) Tharparkar (*Bos indicus*) cattle and the heat stress affects expression of significant number of genes in peripheral blood leukocytes (Kolli *et al.*, 2014).

## Bioenergetics

Basal metabolism has been defined as the minimal energy loss when an animal is at rest in a thermoneutral environment and in a post-absorptive condition (Brody 1945). The measurement does not represent the minimum rate of metabolism needed to support life. The post-absorptive condition is necessary to reduce as much as possible any heat production that can be attributed to the heat of fermentation of food or the heat of nutrient metabolism. The energy required to maintain life at the basal metabolic rate provides for circulation, excretion, secretion, respiration activities, and the maintenance of muscle tone. Crampton and Harris (1969) estimated that 75% of the energy of basal metabolism is spent in maintaining muscle tone and body temperature, while, 25% being used in circulation, excretion, secretion and respiration.

## Measurements of basal metabolic rate

### Direct methods

Direct measurements of the metabolic rate involve the measurement of the actual heat production by the animal. Lavoisier done by placing a guinea pig in a closed box surrounded by ice and recording the amount of ice that melted in a specified period of time. Keeping in mind that about 80 calories of energy are required to melt one gram of ice, then calculated the amount of heat energy released by the animal. Now a day the early direct methods of Lavoisier are used in calorimetry chambers.

### Indirect methods

Indirect measurements of heat production are simple and less expensive than the direct methods. These indirect methods are based on the amount of oxygen consumed and the amount of carbon dioxide produced by the animal. The advantages of indirect methods are that the animal need not be confined in a small chamber.

The oxygen and carbon dioxide content of the air leaving the chamber is measured and is compared with the air entering the chamber. The differences are attributed to the metabolic processes of the experimental animal. The chamber can be equipped with temperature controls system, so that experiments on metabolic responses to changes in chamber temperature can be measured.

## Calculation of metabolic heat production

Metabolic heat production (kcal) can be determined from equation given by Brody (1945).

$$H = 3.866\times O_2 + 1.200\times CO_2 - 0.518\times CH_4 - 1.431\times N$$

Where, H=Heat production (H, kcal), $O_2$=Oxygen consumption (L), $CO_2$=Carbon dioxide (L) $CH_4$=Methane production (L), N = Quantity of urinary nitrogen excreted (g).

The R.Q. is the ratio of moles or volumes of $CO_2$ produced to moles or volumes of $O_2$ consumed. If the non-protein R.Q. were less than 1.00, it would indicate that some fats had been consumed. The R.Q. values for mixed fats are 0.71 and for short-chain fatty acids nearer to 0.8 (Brody 1945). The calories per litre of oxygen consumed ranges from 4.686 to 5.047. The mean value is about 4.86, and this occurs at an R.Q. of 0.85. The R.Q. of protein is 0.82, so the rate of heat production can be calculated by multiplying the litres of oxygen by 4.82 to 4.85 without correcting for protein metabolism.

## Metabolic rates of ruminants

### Relationships to body weight

The relationship between heat production and body weight has been determined for a variety of species. The heat production per unit weight of a small animal is far greater than the heat production per unit weight of a large animal.

The basal heat production can be calculated from formulae $70W_{kg}^{0.75}$ kcal per day (NRC, 1966). It is assumed that the mean standard metabolic rate of mammals is seventy times the three-fourth power of their body weight (in kg) per day, or about three times the three-fourth power of their body weight (in kg) per hour.

### Fasting Metabolism of Domestic Ruminants

The basal heat production of sub adult sheep has been measured by, Ritzman and Benedict (1930). The metabolic increment (Im) over the basal metabolic rate varies from 3 at one week of age to 1.4 at 16 weeks of age. The decline in heat production with age is linear indicating that heat production decreases per unit metabolic weight as the lambs grow.

## Factors influencing energy metabolism and heat production

The energy metabolism and heat production of free-ranging animals is highly variable, depending on the activity of the animal, its diet, thermoregulatory functions, sex, reproductive condition, time of day and year (daily and seasonal rhythms occur), hair or feather characteristics, weather factors, parasites and pathogens, and various social and psychological effects.

## The relationship between heat production and surface area

Heat loss from any object is proportional to surface area. In a homeothermic animal, heat production is also directly proportional to heat loss for maintenance of homeothermy. Therfore, heat production must be proportional to surface area. Under a low ambient temperature heat loss occur mainly as sensible (conduction convection and radiation) heat due to the increasing temperature difference However, when the environment is characterised by intense solar radiation, the body gains large amounts of heat by radiation (daSilva, 2000). In this condition the ability of the animal to withstand its environment is proportional to its ability to dissipate heat by insensible mode (evaporation from the skin respiratory surface) as a result of sweating (Finch *et al.*, 1982) or from the respiratory system by panting (Stevens 1981). Surface area is one of the important parameters that must be considered in the calculation of heat loss because according to Bergmann's rule, the body size of mammals are large in cold climates and smaller in warm climates. Smaller bodies have a larger surface area to volume ratios, which help in dissipation of heat load. Thermal loss is prevented by insulation. If two animals with equal surface areas are exposed to identical thermal conditions, the one with the higher insulation will lose less heat, and this heat will in maintaining the body temperature. The body insulation correlates the Wilson's rule which states that insulation (a combination of fur length and adipose tissue thickness) is greater in cooler climates (McLean, 1972). Another factor entering into the relationship between surface area and heat production is the variability in the surface area participating in heat exchange between an animal and its environment.

This factor can be explained by Allen rule who stated that endothermic vertebrates from colder climates have shorter appendages than closely related species from warmer climates, revealed that shorter appendages conserve heat and longer appendages are more effective in dissipating heat. A greater surface area is exposed when an animal is standing than when it is lying down. A living animal can change its surface area thereby accordingly its heat production, evaporative heat loss, muscular activity, diet, hair insulation through piloerection, and other characteristics to maintain homeothermy (Moen, 1968).

## Heat increments due to diet

An animal on feed has a greater heat production than it does in a post-absorptive state. The difference between heat production on feed and on fast is called the heat increment. This heat increment results from the release of heat during fermentation in the gastrointestinal tract and from the heat of nutrient metabolism in the assimilation of body tissue. This heat increment can be beneficial for animal living in colder weather for maintaining a balance between heat production and heat loss. That's why ruminants during winter season have higher dry matter intake than summer season. During summer season the heat increment represents a quantity of heat that must be dissipated to prevent a rise in body temperature. Benedict and Ritzman (1923) found that steers on timothy hay produced heat @ 50% greater than the fasting metabolic rate, while steers on an alfalfa diet produced heat @ 60% greater than the fasting rate. This shows clearly that food can be important in the maintenance of homeothermy. Kumar *et al.*, (2016) found significantly increase in metabolic heat production from 4.06±0.11 to 4.70±0.17 (kcal/min) and 5.31±0.21 to 5.99±0.21 (kcal/min) in Sahiwal and Karan Fries heifers respectively, when the energy levels of feeds increased by 15%.

## Heat increments due to activity

Heat production increases when an animal is active. Benedict and Ritzman (1923) stated that the activity of steers in the stall increased heat production by 15% over basal rates. Ritzman and Benedict (1931) consider the heat produced while standing compared with lying to be 15% greater for sheep and 17% greater for cattle. Hall and Brody (1932) found an energy increment of standing over lying of 9% for cattle, with a 13% increment for one very fat steer. The energy requirements for maintenance can be estimated by multiplying the basal metabolic rate by 1.33 (Crampton and Harris, 1969).

## Non-shivering thermogenesis

Homeotherms have the physiological capability of increasing their heat production without overt activity. Newborn lambs can increase their heat production up to five times the basal rate without muscular activity. In these thermogenic hormones like epinephrine, nor epinephrine, growth hormone, thyroid hormone plays major role.

## Sex differences

There are differences in heat production among sexes which attributed to effects of gestation and lactation. Reproductive cycle breeding, gestation, and lactation have effect on energy metabolism. Male ruminants expend a large amount of energy during the breeding season, and this activity is accompanied by a reduction in forage intake and a marked weight loss. The increase in energy expenditure is most likely due to the increase in the overt activity of the animal rather than to changes in the rate of tissue metabolism per se. The female must expend additional energy during gestation to maintain the uterus, for fetal growth, for the increased demands on the circulatory, respiratory, and excretory systems, and to handle the endocrine influences on her own metabolism (Brody, 1945). During the stage of rapid fetal growth, elevated metabolism may result when the growth processes demand additional energy for synthesis of fetal tissue. The heat production of cattle during peak lactation is approximately 100% above the non-lactating level and is associated with the higher food consumption and milk production rather than with muscular activity. The increase is directly proportional to milk production (Brody, 1945). When feed intake was held constant, wool growth during lactation ceased. Dolge (1963) reports that dairy cattle fed at a high grain level (challenge feeding) showed a marked increase in milk production but lost an average of 61 pounds of body weight during the 70-day test period. This indicates the high cost of lactation as body reserves were mobilized to meet the demands for energy and other nutrients. Egg production by female birds has the same effect on the annual cycle of energy costs as gestation and lactation in mammals. West (1968) has studied the bioenergetics of willow ptarmigan (*Lagopus lagopus*) throughout the year, finding that egg-laying females had a higher energy requirement than non-laying but molting females and males.

## Rhythmic changes in the basal metabolic rate

Marked changes occur in the rate of metabolism during a 24-hour period. Nocturnal animals have a low BMR during the daytime (Benedict 1938). Thus the diurnal variation is an important consideration when interpreting variations in the metabolic rates, both within and between species. Seasonal variations may also occur. The heat production during summer season is higher than tharmoneutal and followed by winter season.

## Pathogens and parasites

Whenever an organism supports the life processes of another organism living upon or within it, the energy requirements of the host increased Odum (1959).

## Social and psychological effects on heat production

Sociological and psychological interactions influence heat production in the mammals such as confinement versus natural range, herd versus individual response, numbers per group, space per animal, noise level, and other disturbances as factors that affect the heat production of domestic animals Pfander (1963). Voles kept in groups of two to four animals, lowered their daily metabolism rate by 13.3% (Gorecki, 1968). Noise from cars, tractors, snowmobiles, and other sources affects the heat production of deer. The effect of confinement on the psychology of the animal is very difficult to quantify, however, well-trained wild animals appear to be calmer. Moen (1967) showed a steady increase in rectal temperature from 26 °C to 39 °C in deer due to presence in the room but the animal did not show any overt signs of fear. The increase in the rectal temperature indicates that heat production was increased by the fear response.

There are certain significant differences in the parameters related to thermal stress. The ability of animals to protect themselves from the harmful radiation of sunlight by melanisation was significantly increased and it was found to be declined with heat stress. The resistance of dermal fibroblasts to thermal stress differed between different breeds of animals. Sweating rate is significantly higher in zebu than exotic cattle. Inducible HSPs expression, plasma cortisol level and ROS formation on exposure to heat stress were comparatively lower during winter. With the advancement of molecular biotechnologies, efforts in selecting animals till now have been primarily preoccupied toward productive traits. From now, it should essentially be oriented toward suitability and fitness, above all adaptability to heat stress. In this way, molecular biology allows to directly achieve genotypes with the necessary phenotypic characteristics. The energy metabolism and heat production of animals is highly variable, depending on the activity of the animal, its diet, thermoregulatory functions, sex, reproductive condition, time of day and year hair or feather characteristics, weather factors, parasites and pathogens, and various social and psychological effects. Therefore, it may be concluded that above mention characteristics contribute to their superior adaptability to tropical climatic condition with high solar radiation. However, many other mechanisms are likely to contribute to the difference in thermotolerance of different farm animals. Animal sector and agriculture will eyewitness more harsh challenges in countless fields in the 21st century. Decision makers, extension services and research institutions have to support and encourage livestock activities to handle as best as possible with less loss in production, abating of animal products, expansion of land desertification and the worsening of animal health under the effects of the climate change we expect in the coming decades.

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