

THERMAL STRESS IN DAIRY CATTLE

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ABSTRACT

Crosses of temperate cattle reared in tropical ambience lapse in heat tolerance, fertility and disease resistance. However, cross breeding zebu with high yielding exotic cattle seems necessary to meet the need for enhanced composite milk production per unit in view of food security. Thermal stress is considered as the main factor responsible for reduction of milk yield in tropical climate. Any model for the study of thermal stress in dairy cattle should encompass related effect of ambient parameters of temperature, humidity, wind speed and solar radiation as the stressor and behavioural, autonomic, neuroendocrine and immunological endpoints as responses. The responses reach different response states depending on the severity of the stressor. Response measurements are at behavioural, physiological, biochemical and cellular level, which also include hormone, protein and gene expression assays. By fitting these measurements to the described model we can work out the biological and economic cost of thermal stress and the level of adaptation of the

dairy animal in question. Such studies taking in to consideration the diverse nature of climatic factors is imperative for finding ameliorative measures to reduce the thermal stress experienced by the existing cattle population and for the possible genetic and management strategies for evolving and maintaining a climatically adapted dairy stock in a state like Kerala. This review analyses suitable model for climatic adaptation studies in the hot and humid climate especially in small holder production systems.

INTRODUCTION

Challenge before the scientific community of the tropical world is to find ways to enhance milk production in the prevailing climatic conditions. Historically the traditional livestock production largely depended on heat tolerant native breeds that produced less milk compared to temperate exotic breeds. The dairy sector now largely comprises of extensive and expanding crossbred population in Kerala. For crossbreds, increased air temperature, and humidity measured as Temperature Humidity Index (THI) above critical thresholds are related to low dry matter intake (DMI) and to reduced efficiency of milk production (West, 2003).

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The Zone of Thermoneutrality (Fig. 1) with in which no additional energy above maintenance is expended to heat or cool the body (for livestock it is between -0.5 to 20°C) and the upper critical temperature (B on the right side) may reach to 25-26°C (West, 2003). The ambient temperature of hot humid region is above this critical temperature during several months of each year. Effective environmental temperature is a combined effect of ambient temperature and humidity. The combined effect is quantified as Temperature Humidity Index (THI). The normal THI to maintain production in dairy cattle is 72. In our state, during most days in a year it is hot and humid and hence the THI is high enough to cause significant heat stress.

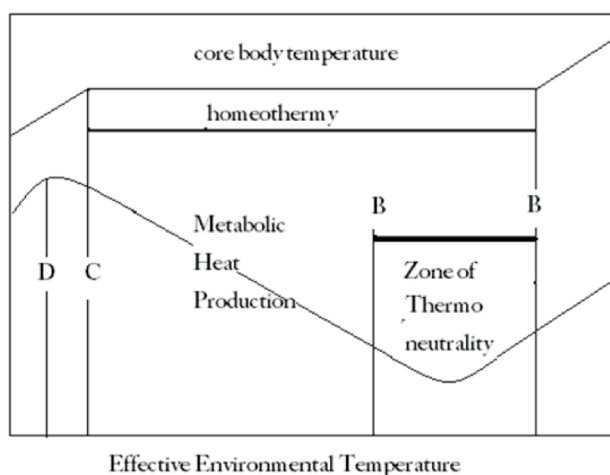


Fig.1 Kleiber's law of metabolic heat production and core body temperature as influenced by environment temperature. C = lower critical temperature D= point of reduction of metabolic heat. B on the left side = lower point of zone of thermal neutrality below which chemical regulation is needed to maintain homeothermy. B on the right side = upper critical temperature.

So the dairy cattle especially those with exotic blood cannot express its optimum production potential. Constant exposure of cattle

to high temperature causes a rise in its rectal temperature, a decline in feed intake, increase in water intake, a decrease in production of milk, changes in milk composition, reduction in growth and even a loss in body weight. This is the reason for deterioration in the performance of temperate dairy cattle when introduced into tropical countries. (Sastry and Thomas, 2005).

The extent of reduction in feed intake is proportional to the thermal stress i.e. how long and how much the cow is subjected to temperature beyond thermo neutral zone. VFA is reduced in summer, especially acetic acid. Feed efficiency is considerably reduced. Digestible energy utilization was 60 percent at 21°C but only 40 percent after 7 days exposure to 32°C and 31 percent after 14 days exposure (Jones and Stallings, 1999). High ambient temperature and humidity causes depression in yield of fat and SNF. Lactose percentage is also depressed when cows are exposed to high ambient temperature.

Genetic potential of well adapted local breeds that can be maintained without special feed concentrates or preventive health care are being increasingly recognized in this context. The prevailing harsh climate and the anticipated future climatic changes are real threats to the sustainability of the sector. An exact understanding of the impact of thermal stress on dairy cattle and possible ameliorative measures are thus extremely important. Thermal stress alone does not act separately in reducing the productivity of the animal, but multiple stresses act on the animal when nutrition is compromised (Sejian *et.al.* 2012). Since, interpretation of the effect of multiple stressors are difficult, multiple responses of the thermal stress alone is discussed here.

'Stress' conceptual clarity

The word 'stress' is perceived by different people differently. Even among animal scientists, different disciplines approach stress in different angles. Here an attempt is made to elucidate the word stress in the context of thermal stress in dairy cattle. Stress is a part of life. All life forms have evolved mechanism to cope with the stresses of their lives. Moberg and Mench (2000) defined stress as the biological response elicited when an individual perceives a threat to its homeostasis. The threat is the stressor. When stress response truly threatens the animal's well-being then the animal experience distress.

The stressor in our context is the effective environmental temperature represented by the temperature, solar radiation, humidity and air movement in the immediate vicinity of the dairy cow. Our challenge is to determine when their stress becomes distress and to determine how to measure stress and distress in animals.

Evolving a model for assessing thermal stress in dairy cattle

Moberg (2000) divided stress response in to three general stages

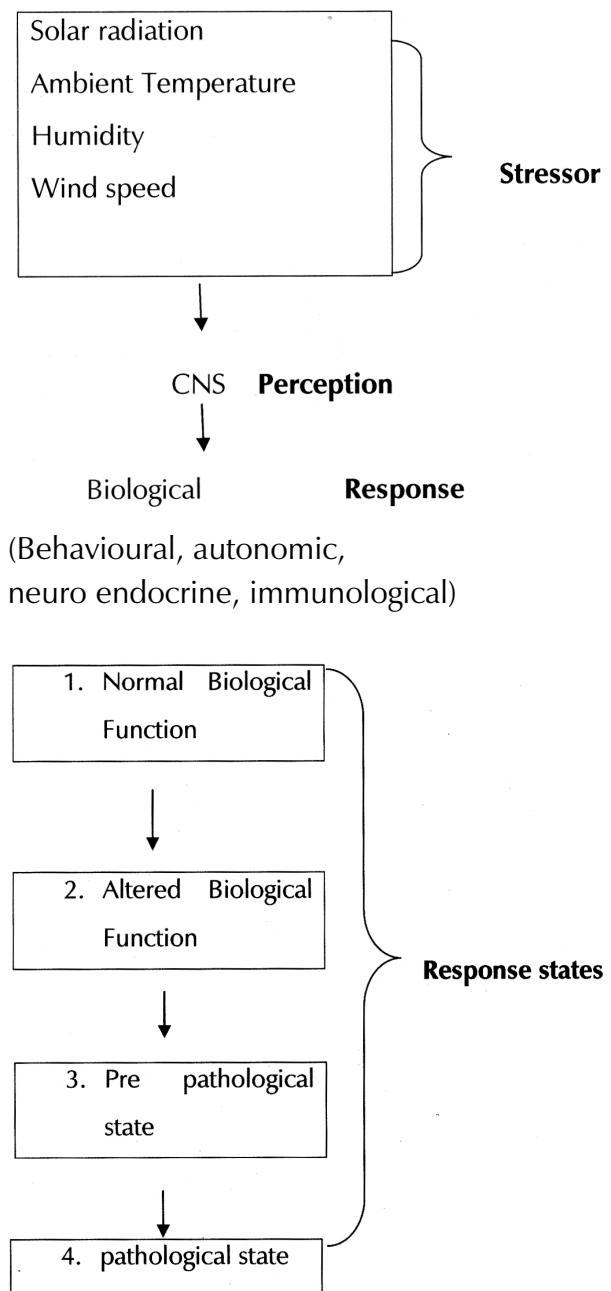
1. Recognition of a stressor
2. Biological defense against the stressor and
3. Consequence of the stress response.

A stress response begins with the CNS perceiving a potential threat to homeostasis. Then the cow develops biological response or defense that consists of four general biological defense responses

1. Behavioural

2. Autonomic nervous system
3. Neuro Endocrine
4. Immune response

Now let us attempt to evolve a model for thermal stress in dairy cattle which better clarifies our problem and will help in attempting to assess it scientifically.



Challenges in measuring thermal stress

Scientists rely on a variety of endocrine, behavioural, autonomic nervous system and immunological end points to measure stress. Unfortunately, none of these measures has proved to be a litmus test for stress. Further, complicating is inter animal variability in stress response. The above model demonstrates that all the responses to the perceived stressor can reach any one of the response state depending the severity of the stressor and the vulnerability of the animal. The vulnerability depends upon the modifiers of the responses. Modifiers which shape animal's organization of its biological defenses are early experience, genetics and age. The responses are not mutually exclusive but need to be measured independently for better assessment. After assessing them independently measures related to each response must be compared with normal values to arrive at the respective response state. As any one single response cannot be considered to be exclusively due to stress, the non parametric approach of considering the mode of response states for the entire array of tests may be taken as the animal's thermal stress level. Different responses and possible measurements are explained below and illustrated in Fig. 2.

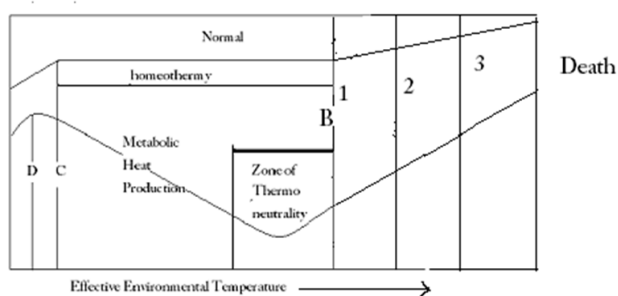


Fig. 2. Extrapolation of Fig 1 to depict the response states of the animal when subjected to effective temperature above the upper critical temperature. (The column 1 - altered, 2- pre pathological and. 3- pathological response states.

Behavioural response

A cow seeking shade during direct solar exposure is an example. But in case of dairy cattle behavioural response options are limited by confinement. When the severity of the stressor increases, this response can manifest as altered behaviour, pre pathological behaviour and even pathological behaviour. But all the animals will not show same degree of alterations in behaviour to the same degree of stressor.

Autonomic nervous system response

During thermal stress the autonomic nervous system affects a diverse number of biological systems including the cardiovascular, gastro intestinal, exocrine glands and adrenal medulla. The results are altered heart rate, blood pressure and gastrointestinal activity. But stress activation of autonomic nervous system is of relatively short duration. According to the grade of the stressor and the animal's vulnerability each of the autonomic nervous system responses also differs.

Neuro endocrine

Hormones secreted from hypothalamic pituitary system have a broad long lasting effect on the changes induced by body stress. The secretions of pituitary hormones have been implicated in failed reproduction, altered metabolism, immune competence and behaviour. The hypothalamic - pituitary- adrenal (HPA) axis has been primary neuroendocrine axis. However, the secretion of prolactin and somatotropin has proven to be equally sensitive to stress and has considerable economic importance. Likewise, thyroid stimulating hormone and gonadotropins (LH and FSH) are either directly or indirectly modulated by thermal stress.

Increased secretion of the adrenal glucocorticoids and cortisol has been found to be associated with stress and investigators frequently cite an increase in circulating cortisol as a proof of stress. Colborn *et.al.*, (1991) found that stallions secreted similar amounts of cortisol whether the stallions were restrained, exercised or permitted to mate with a mare. Serum cortisol concentrations are often used to evaluate stress, but due to the marked variability, faecal corticosterone has been used to evaluate stress in cattle (Morrow *et.al.*, 2002). Dairy cattle secretes cortisol during restrained and when they are approached by strangers. So it is difficult to simply use secretion of cortisol or any other hormone to differentiate between non threatening stress and distress. Even among the same breed, some cows may produce more cortisol to the same amounts of thermal stressors.

Immune response

We have long attributed the increased incidence of disease in cows suffering from thermal stress. Immune system in its own right is one of the major defense systems responding to stressor (Dunn, 1988). Measurement of immune competence offers us a potentially powerful tool for evaluating the disease components of distress. According to Kumar *et.al.*, (2011) heat stress is one of the wide varieties of factors which cause oxidative stress *in-vivo*. Reactive oxygen species (ROS), constantly generated *in vivo* as an integral part of metabolism cause oxidative stress when their level exceeds the threshold value. Superoxide ions, hydrogen peroxide and hydroxyl ions (ROS) produced as a result of heat stress are highly reactive and they cause damage to the polyunsaturated fatty acids of lipoprotein layer of cell membrane. This lipid peroxidation leads to the formation of lipid peroxides which are again

harmful to the cell components. The amount of lipid peroxides is measurable and hence can be used as reliable indicator of level of thermal stress. Reduced glutathione present in the animal acts as an anti oxidant by getting itself oxidized. So in a distressed animal the amount of reduced glutathione will be low.

The heat shock response is a highly conserved cascade of altered protein and gene expression in animals. The altered intracellular proteins secretion is due to the concerted action of physiological stress response which constitutes a system wide gene network coordinated across a variety of cells and tissues to minimize effects of adverse environmental conditions. Endocrine and metabolic responses are as result of gene expression changes that include (1) activation of heat shock transcription factors (HSFs), (2) Increased expression of HSPs and deviated expression and synthesis of extra proteins, (3) Increased protein, glucose and amino acid oxidation and reduced fatty acid metabolism, (4) Endocrine system activation and (5) Immune system activation (Richter *et.al.*, 2007).

Diverse physiological stresses (thermodynamics, mutant proteins and oxidative injury) produce multiple changes in a cell that ultimately affect protein structures and function. Cells from different phyla initiate a cascade of events that engage essential proteins, the molecular chaperones, in decisions to repair or degrade damaged proteins as a defense strategy to ensure survival. Molecular chaperones such as the heat shock family of stress proteins (HSPs) actively participate in an array of cellular processes, including cytoprotection. The versatility of the ubiquitous HSP family is further enhanced by stress-inducible regulatory networks.

Biological cost of thermal stress

Whether or not the stress altered functions are beneficial in helping the cow to cope is not our immediate concern. The changes in biological function during stress result in a shift of biological resources away from biological activities occurring before the stressor. For example, energy originally utilized for growth or reproduction might be needed by animal to cope with stress. This change in biological function during stress is the biological cost of stress. During prolonged stress or when stress is severe the biological cost is significant and the work of stress becomes a significant burden to the body. It is during such stress that the animal enters the next stages of stress pre pathology and pathology.

In a hot humid climate like the one in Kerala, the dairy cows suffer from chronic distress which is the sum total of all the compensations or displacements caused by the thermal stress applied. This chronic distress represents the totality of discomfort, felt by the cow in a hot environment. The cows under this chronic distress will have reduced feed intake and increased water consumption. The body temperature will rise often stabilizing at a higher level. There will be shift in body water from intra cellular to extra cellular and extracellular to vascular space which will be mobilized to effect evaporative thermal cooling from skin and respiratory tract.

Increased respiratory activity leads to excessive blowing out of carbon dioxide through the expired air thus upsetting carbonic acid bicarbonate buffer system. In order to maintain acid base balance, bicarbonate, mainly in the form of sodium bicarbonate or potassium bicarbonate is excreted through urine. Excessive loss of sodium

from body triggers corticosteroid hormone. Ultimately acid base and mineral balances are disturbed. Excessive moisture through evaporative channels can cause dehydration. Under hot condition, when subjected to water scarcity, energy utilization efficiency is reduced and reproductive efficiency is progressively affected.

Acclimation and adaptability factor

Acclimation is within life time phenotypic response to environmental stress and is a homeothermic process driven by endocrine system, whereas, adaptability involves evolutionary changes that occur over time scales covering multiple generations. Alterations in gene expression and changes in cellular signaling are key components of adaptability. The changes in gene expression mainly include that of HSPs. The major symptom in crossbred cattle is reduced feed intake, when the animals are under heat stress. Even if they are fed ad libitum, that too high quality feed, the animals do not take feed. This may be due to oxidative cellular stress that leads to cell starvation. Cell starvation often leads to inability of the cells to utilize glucose and other energy releasing molecules. When the cells are under starvation, growth, production and reproduction are compromised first, and then the vital functions of body. All these changes are associated with altered nutrient partitioning that accounts for production loss. In the acclimated state, metabolism is adjusted to minimize detrimental effects of increased thermal loads. We have to determine the basis of altered energy metabolism during thermal stress in exotic and indigenous animals which may lead to opportunities for improved animal performance via altered breeding strategies.

What contributed more to the natural selection are the fitness traits such as fertility and viability. The cattle breeds evolved in temperate and tropical climate are adapted to respective climate in terms of these fitness traits. When they are taken to alternate conditions fitness traits are maintained whereas production traits are compromised. So it is not possible to get a high production from these breeds in alternate conditions (i.e. temperate breeds in tropical climate and tropical breeds in temperate climate).

CONCLUSION

Thermal stress is a major threat to the viability and sustainability of milk production around the world, especially in tropical climate. The Inter-governmental Panel on Climatic Change (IPCC) has forecasted global warming leading to rise in average temperature by 1.8-4^o C by the year 2100. Thus, the deteriorating prevailing condition is going to be aggravated unless measures to alleviate the thermal strain are addressed at appropriate level. For suggesting genetic, nutritional and management measures to overcome this challenge, scientific operational definition of thermal stress elucidated through suitable models are imperative. The model suggested in the present study is based on various reviews on different aspects of the subject. The model depicts the different levels of stress response to the perceived stressor and various methods to measure the responses. This model will also help in determining the level of acclimation and adaptability of cattle.

REFERENCES

Colborn, D. R., Thomson, D. L., Roth, T. L.,

- Capehart, J. S. and White, K.L.1991. Response of cortisol and prolactin to sexual excitement and stress in stallions and geldings *J. Anim. Sci.*69:2556-2562.
- Hutcheson, D.P. and Cole, N.A. 1986. Management of transit stress syndrome in Cattle: Nutritional and Environmental Effects. *J. Anim. Sci.* 62:555-560.
- Jones, G.M. and Stallings, C.C. 1999. Reducing Heat Stress for Dairy Cattle. Virginia Cooperative Extension, Dairy Publication, 404-200.
- Kumar, S.B.V., Ajeet, K and Meena, K. 2011. Effect of heat stress in tropical livestock and different strategies for its amelioration. *J. Stress Physiol. Biochem.* 7 (1): 45-54.
- Moberg, G. P and Mench, J. A. 2000. The Biology of Animal Stress Basic Principles and Implications for Animal Welfare, CABI Publishing
- Morrow, C. J., Kolver, E. S., Verkerk, G. A. and Matthews, L.R. 2002. Faecal glucocorticoid metabolites as a measure of adrenal activity in dairy cattle. *Gen. Comp. Endocrinol.* 126: 229-241.
- Rao, G.S.L.H.V.P. 2003. Agricultural Meteorology Kerala agricultural University, Thrissur, Kerala, India, p.231.
- Richter, K., Haslbeck, M. and Buchner, J. 2010. The heat shock proteins: Life on the verge of death. *Molecular cell.* 40:253-266.
- Sastry, N. S. R and Thomas, C. K. 2005. Livestock Production Management (4th ed.). Kalyani Publishers, New Delhi, pp. 13-15.
- Sejian, V., Naqvi, S. M. K., Ezeji, T., Lakritz, J and Lal, R. 2012. Environmental stress and amelioration in livestock production. Springer, Newyork . pp 129-144.
- West, J. W. 2003. Effects of heat stress on production in dairy cattle *J. Dairy Sci.* 86:2131-2144