International Journal of Bio-resource and Stress Management 2016, 7(1):174-183 DOI: HTTPS://DOI.ORG/10.23910/IJBSM/2016.7.1.1355

Review Article

Heat Stress in Livestock: Impacts and Ameliorative Strategies—a Review

Lalrengpuii Sailo[1*] and Ramendra Das[2]

[1]Animal Genetics Division, ICAR-Indian Veterinary Research Institute, Izatnagar, Uttar Pradesh (243 122), India
[2]Dairy Cattle Breeding Division, ICAR-National Dairy Research Institute, Karnal, Haryana (132 001), India

Article History

Manuscript No. AR1355
Received in 25th March, 2015
Received in revised form 24th January, 2016
Accepted in final form 5th February, 2016

Correspondence to

E-mail: lrp.sailo@gmail.com

Keywords

Livestock, heat stress, impacts, cooling, nutrition, genetic selection

Abstract

Heat stress is one of the most important climatic conditions which adversely affects agricultural and livestock production worldwide. High ambient temperature with direct and indirect solar radiation, wind speed and relative humidity impose thermal stress in animals. The foremost reaction of animals under thermal weather is increased respiration and pulse rate, and rectal temperature. It directly affects feed intake thereby, reduces growth rate, milk yield, reproductive performance and even death in extreme cases. Heat stress suppresses the immune system thereby enhances susceptibility of an animal to various diseases. It is very important to control the impacts of thermal stress for sustainable dairy farming. Advances in environmental modifications and nutritional management in part alleviate the impact of thermal stress on animal performance during the hotter seasons. However, long-term strategies have to be evolved for adaptation to climate change. Differences in thermal tolerance between livestock species provide clues to select thermotolerant animals using genetic tools. There are heat shock gene related to thermotolerance that was identified and being used as marker in marker-assisted selection and genome-wide selection to develop thermotolerant bull that is used in breeding program. The present review collates and synthesizes information pertaining to thermal shock and possible ameliorative strategies to combat the impacts in livestock.

1. Introduction

Climate change represents a critical challenge to both livestock and human. The Inter-governmental Panel on Climate Change (IPCC) has forecasted global warming leading to rise in average temperature by 0.2 °C decade^{-1} and the global average temperature is predicted to be increased by 1.8-4 °C by the year 2100 with more floods, intense storms, heat waves and droughts by the end of century (IPCC, 2007). The impacts of climate change on agriculture and livestock are being witnessed all over the world, but developing countries are much more vulnerable as a large section of the population depends on agriculture for livelihood (Singh et al., 2011). It is believed that the livestock system based on grazing and mixed farming system will be more affected by global warming than an industrialized system. This will be due to the negative effect of high temperature, solar radiation, low rainfalls and droughts which adversely affect crops and pasture land (Nardone et al., 2010).

Farm animals are homeotherms as they can keep relatively constant core body temperature within a narrow range. In order to maintain homeothermy, an animal must be in their thermoneutral equilibrium with its environment. When the environmental temperature reaches value that surpasses the upper limit of the thermoneutral zone, animals enter a condition known as heat stress. This prompts physiological and behavioral responses to increase heat loss and reduce heat production in an attempt to maintain body temperature within the range of normality. The animal response to heat stress by increasing water intake, sweating and respiration rates, reduced heart rate and feed intake (Ayo et al., 2014). Heat stress impairs production and reproduction performance, metabolic, health status and immune response. In addition, the economic viability of livestock production systems is affected. Problems due to heat stress are particularly evident for high producing dairy cows, because animals of a better genotype have a greater metabolic activity and encounter more difficulties in maintaining an optimal thermal equilibrium in hot environments (Hansen, 2004). The negative effects of heat stress will become more apparent in the future if climate change continues as most predicted. Moreover, due to the close relationship between metabolic heat generation and production level, development in the genetic programs that enhance production traits may increase an animal's susceptibility to high environmental temperatures (Nardone et al., 2010).

It is very important to control the impacts of thermal stress for sustainable dairy farming. Advances in environmental modifications and nutritional management in part alleviate the impact of thermal stress on animal performance during the hotter seasons. However, long-term strategies have to be evolved for adaptation to climate change. Differences in thermal tolerance between livestock species provide clues to select thermo-tolerant animals using genetic tools. There are heat shock gene related to thermo-tolerance that was identified and being used as marker in marker-assisted selection and genome-wide selection to develop thermo-tolerant bull that is used in breeding program. This paper reviews literature pertaining to thermal shock and possible ameliorative strategies to combat the impacts in livestock.

2. Impact of Heat Stress

2.1. Health

High ambient temperatures directly and indirectly affect the health status of farm animals (Gaughan et al., 2009a). Direct effects of heat stress include temperature-related illness, morbidity and even death of animals. Indirect impact includes increase of micro-organisms, vector-borne diseases, food-borne diseases and shortages in food and water (Yatoo et al., 2012). The immediate response to heat stress includes increase in respiration rate, rectal temperature, pulse rate, water intake and changes in hormonal signals that affect target tissue responsiveness to environmental stimuli. The decrease in energy intake due to reduced feed intake results in a negative energy balance (NEB), leading to loss of significant amounts of body weight and body score when subjected to heat stress. Health problems in heat-stressed ruminants may also be a consequence of nutritional and metabolic acclimation. In particular, due to increased maintenance requirements for thermoregulation and lower feed intake, summer transition dairy cows are more likely to experience subclinical or clinical ketosis and are under higher risk of liver lipidosis (Basirico et al., 2009). High temperatures may cause heat stroke, heat exhaustion, heat syncope, heat cramps and ultimately organ dysfunction, and these heat-induced complications occur when the body temperature raises approximately 38-48 °C (Vitali et al., 2009). Bernabucci et al. (2010) reported that in dairy cow, the maximum and minimum THI values are 80 and 70 respectively, above which heat-induced death rate increases. In addition, 87 and 77 are the daily upper critical maximum and minimum THI, respectively, above which the risk of heat-induced death becomes maximum. A series of studies have described a higher risk of mortality during the hottest months (Vitali et al., 2009; Bernabucci et al., 2010; Basirico et al., 2011).

2.2. Production

Heat stress is a major source of production loss in the dairy industry (Nardone et al., 2010; Baumgard and Rhoads, 2013). Milk production in *Bos taurus* cow is reduced in warm compared to temperate climates (Nassuna-Musoke et al., 2007) despite the net production potential of heat-stressed *Bos taurus* is greater than that of a *Bos indicus* (Hansen, 2004). The negative effect of heat stress on milk production is primarily explained by reduced nutrient intake and a decrease of nutrient uptake by the portal-drained vein (McGuire et al., 1989). Rhoads et al. (2009) in a study using pair-feeding techniques showed that the reduced feed intake accounts for as much as 35% of the milk production decline under heat stress. Johnson et al. (1962) showed a linear reduction of dry matter intake (DMI) and milk yield when THI exceeded 70. There is a negative correlation between milk yield and daily THI (r=-0.76). In particular, milk yield decreased by 0.41 kg cow^{-1} day^{-1} for each THI unit increase of above 69. Heat stress also negatively affects the quality of milk (Hamzaoui et al., 2013). Milk protein contents decline, whereas the response of milk fat content seems delayed and results are contradictory when THI is above 72 (Bernabucci et al., 2010). A reduction in casein percentage and casein index was found in summer (2.18% vs 2.58% and 72.4% vs 77.7%, respectively) compared to spring season. The stage of lactation is an important factor affecting dairy cows' responses to heat. The mid-lactating dairy cows were the most heat sensitive compared to early and late lactating. The decline in milk production due to heat stress is 14% in early lactation and 35% in mid-lactation in dairy cows (Bernabucci et al., 2010; Basiricò et al., 2011). Decline in milk production (-38%) was observed in mid-lactating cows when the animals were exposed to heat (Chauhan and Ghosh, 2015).

2.3. Reproduction

Heat stress has a negative effect on reproduction by compromising the oocytes growth by altering progesterone, secretion of luteinizing and follicle-stimulating hormone and dynamics during the estrus cycle (Baumgard and Rhoads, 2013). A reduction in pregnancy rate is observed when THI is equal or exceeds 72.9 (Amundson et al., 2006). On average, conception rate drops by 20-27% during summer time (Bernabucci et al., 2010) or a decrease in 90-day non-return rate to the first service in lactating dairy cows (Al-Katanani et al., 1999). Fertility is reduced because heat stress can damage both the oocyte and early embryo. The early embryo, too, can be damaged by heat stress but soon acquires biochemical mechanisms that protect it from elevated temperature (Hansen, 2013). Thus, heat stress at day-1 after estrus reduced embryonic development but heat stress at day-3, 5 and 7 had no effect (Ealy et al., 1993). Heat stress during pregnancy slows down the growth of foetus and could increase foetal loss, although active mechanisms attenuate changes in foetal body temperature when mothers are thermally stressed. Impairment of embryo development and increased embryo mortality are also increased at elevated temperature (Hansen , 2007; Wolfenson , 2009). In bulls, semen concentration, number of spermatozoa and motile sperms ejaculation^{-1} are lower in summer than in winter and spring (Nichi et al., 2006). Exposure to elevated ambient temperatures resulted in decreased bull semen quality as evidenced by reduction in motile sperm percentage and sperm output with an increased percentage of abnormal and aged sperm (Meyerhoeffer et al., 2004).

3. Strategies to Mitigate Heat Stress

The effects of heat stress are costly to dairy farmers in hot and humid climatic regions, but there are opportunities to recover from the effect of heat stress. Physical modifications of environment, nutritional management and genetic development of breeds that are less sensitive to heat are the three major key components to sustain dairy production in hot environment.

3.1. Environmental Modifications

Environmental conditions such as high temperature, humidity, and solar radiation compromise the ability of dairy animals to dissipate heat, resulting in heat stress (Hammami et al., 2013). The primary approach for modifying the environment include the provision of house or shade (along with feed and drinking water), evaporative cooling system with water in the form of fog, mist or sprinkling with natural or forced air movement, and possibly cooling ponds (Collier et al., 2006; Atrian and Shahryar, 2012). The incorporation of these methods into an integrated environmental management system protects livestock from the primary sources of heat gain from the environment, and enhances evaporative heat loss.

For outdoors animals, provision of shade (natural or artificial) is one of the simplest and cost-effective methods to minimize heat from solar radiations. Trees are very effective and natural shading materials providing shade to the animals combined with beneficial cooling as moisture evaporates from the leaves. Artificial shades have been used with success for heat-stressed animals in confinement or in intensive situations (West, 2003). Artificial shades can be used to protect from the effects of solar radiation in absence of natural shade. Various types of roofing materials can be used from metal to synthetic materials for shade structures. However, the most effective in terms of reducing heat load is a reflective roof such as a white galvanized or aluminum roof (Blackshaw and Blackshaw, 1994). The total heat load could be reduced from 30 to 50% with a well-designed shade. Various studies comparing cows in a shade versus non-shade environment showed lower rectal temperatures and respiratory, as well as improved milk yield and reproduction when shaded. Shade ameliorates heat load of cattle and reduces mortality in extreme weather conditions (Gaughan et al., 2010).

Various cooling systems have also been evaluated. Evaporative cooling systems use energy from the air to evaporate water and evaporation of water into warm air reduces the air temperature while increasing relative humidity. This system needs fans, evaporative cooling pads, and pumps for circulation of water to the pads. Other evaporative cooling methods include mist, fog, and sprinkling systems. Fogging system sprays small water droplets into the air and cools the air as the droplets evaporate. When an animal breathe in the cooled air it exchange heat with the air and remove heat from the body (Bucklin et al., 2008). High pressure foggers disperse a very fine water droplet which quickly evaporates and cools air while raising the relative humidity (RH). These systems are most effective in dry areas but can also be used in high humid regions during daytime hours when RH is low (Bucklin et al., 1991). Use of misting systems is difficult under windy conditions or in combination with fans. Moreover mist droplets are too large to fully evaporate before settling to the ground, and bedding or feed become wet. Hence an insulating layer of air can be trapped between the skin and the layer of water if a misting system does not wet the hair coat through the skin which will block the evaporative heat loss and can cause a harmful heat buildup. With pad cooling system, the ambient air within the building is cooled down forcing air into the building through a wet pad. Therefore, a fine mist injection apparatus that injects water under high pressure into a stream of air can replace this wet pad (Renaudeau et al., 2011). Sprinkling system is an alternative to misting and fogging systems. This system uses a large droplet size to wet the hair coat to the skin of the animal, and then water evaporates and cools the hair and skin. Therefore, this system was found to be very useful and effective to reduce the high ambient temperature especially when RH was low (Atrain and Shahryar, 2012). The effects of sprinkling on dairy cow and beef performance have been extensively studied. Dairy cattle allowed access to sprinklers (with and without forced ventilation) have increased milk production (Renaudeau et al., 2011), improved reproduction and improved conversion of feed to milk (Wolfenson, 2009). Comparable economic benefits of cooling feedlot cattle are less evident, likely because of the ability of heat-stressed cattle to exhibit rapid compensatory growth following heat stress (Davis et al., 2003). Intermittent partial surface sprinkling is useful in poultry as a support for eliminating heat stress, especially when relative humidity is low (Renaudeau et al., 2011).

3.2. Nutritional Management

There are several key areas of nutritional management which should be considered during hot weather. The feeding behavior of most of the animals changes during summer and they tend to consume more feed during cooler periods of the day, i.e. evening hours (Atrian and Shahryar, 2012). Increasing the feeding frequency will also help to minimize diurnal fluctuations in ruminal metabolites (Soto-Navarro et al., 2000) and increase feed utilization efficiency in the rumen. Feeding regimen could be altered to enhance animal's ability to cope with metabolic and climatic heat load during summer (Nesamvuni et al., 2012).

3.2.1. Dry matter intake

When environmental temperatures exceed 25 °C, dry matter intake (DMI) starts to decline and increases maintenance expenditures (NRC 1981). Since heat production is highly associated with metabolism of acetate compared with propionate, there is a logical rationale for the practice of feeding low fiber rations during hot weather (Atrian and Shahryar, 2012). Ruminant diets with grain and low in fiber cause less heat stress for lactating cows because of their lower heat of digestion. Minimum quantity of good quality roughage should be fed to prevent rumen acidosis. Hence, feeding more concentrate at the expense of fibrous ingredients will not only increase the energy density of rations, but will also reduce heat increment. DMI and milk yield increased in cows fed with diets containing 14% versus 17 or 21% acid detergent fiber (ADF). However, milk yield was less sensitive to change in dairy temperature for cows fed with 14% ADF diet (West, 2003). Feeding of diets containing minimum amounts of roughage (NDF) during 3-week pre-partum period may minimize the decrease in DMI and lipid metabolization and thus limits the effects of heat stress on peri-parturient cows (Kanjanapruthipong et al., 2010). Adin et al. (2008) observed that diet containing 12% NDF as compared to 18% NDF improved DMI and milk yield of cows fed total mixed ration (TMR) under heat condition. Therefore, feeding a minimum but adequate amount of total and effective fiber should be the objective during summer month.

3.2.2. Protein

Overfeeding of protein during hot weather should be avoided because it requires energy to excrete excess nitrogen. Raising the protein content with highly degradable materials apparently stresses the cows further. Rations usually should be 18% protein or less on a dry basis. Also, rations containing more than 65% of the total protein as rumen degradable protein should be avoided because the kidney have to excrete the excess nitrogen produced. Therefore, it is best to feed a ration balanced for ruminal and post-ruminal digestion. Improve milk production is shown by feeding of low degradable protein during heat stress, provided the undegradable protein is of good quality (Taylor et al., 1991). Both the quality and quantity of protein in the diet needs to be considered when feeding heat stressed cows (Linn, 1997).

3.2.3. Fat

Feeding dietary fat remains an effective strategy of providing greater energy density and the potential to reduce heat increment of high-fat diets particularly beneficial during hot weather. Fats have a low heat increment as compared to other feeds. High yielding cows require fat supplementation of 6-7% of diet dry matter (Choubey and Kumar, 2012). Sources of fat supplements are cottonseeds or soybeans, oil seeds, tallow and protected fat products. Different results have been reported from several studies regarding the effect of fat supplementation on milk production during hot season. Increasing dietary fat content enhanced milk production efficiency and yield in the warm season (Linn et al., 2004). However, another study did not find change in milk production in hot condition when 5% of fat was supplemented in the diet (Knapp and Grummer, 1991). The difference in results could be attributed to variations in heat stress intensity or to other factors such as milk production potential and the nature of fat supplementation.

3.2.4. Mineral

The negative effects of heat stress are associated with changes in mineral metabolism. Electrolyte minerals, sodium (Na) and potassium (K) play an important role in the maintenance of water balance, ion balance and acid-base status of heat stressed cows (Ahmad et al., 2008). Large amounts of K are lost by sweat of heat-stressed cows. Increase in the concentration of dietary K to 1.2% or more result in 3-9% increase in milk yield and DMI. Likewise, increase in the concentration of Na from NRC recommended level of 0.18-0.45% or more in the diet improved milk yield by 7-18% (Sanchez et al., 1994). Thus sodium bicarbonate and magnesium oxide have proven very effective in alleviating to some extent the drop in milk fat associated with heat stress conditions (West et al., 1999). Sodium bicarbonate also increases ruminal pH providing more favorable environment for fiber digestion (Santra et al., 2003). The level of dietary Cl should not exceed 0.35% of dry matter (Sanchez et al., 1994). Therefore, a diet with high chlorine content decreased DMI and was associated with low blood pH and reduced blood buffering (Hu et al., 2005).

3.2.5. Antioxidants

Antioxidants are those nutrients which are required to cleanse cells of reactive oxygen species (ROS) with important consequences over the vital function, life and death of the affected cells. Treatment of buffaloes with antioxidant (viteselam) before the beginning summer and also during the summer period enhance the pregnancy rate, correct the infertility due to heat stress through the decrease in cortisol secretion and decrease in oxidative stress (Megahed et al., 2008). Supplementation of vitamin C and E have a negative effect on cortisol levels during heat stress, which relieved the severity of heat stress in goats (Shivakumar et al., 2010). The reduction in cortisol levels by vitamin E and C is not yet fully understood but may be achieved by reducing the synthesis and/or secretion of cortisol or by breaking it down (Webel et al., 1998). Supplementation with vitamin E and selenium is beneficial in reducing oxidative stress in dystocia-affected buffaloes in the immediate post-partum period (Sathya et al., 2007). Some antioxidants (Sakatani et al., 2007) and dithiothreitol (de Castro e Paula and Hansen, 2008) but not all vitamin E (Paula-Lopes et al., 2003), glutathione and glutathione ester (Ealy et al., 1993) reduced the effects of elevated temperature on development of embryos. Arechiga et al. (1998) found that cows supplemented with β-carotene at the rate of 400 mgday^{-1} for at least 90 days from about day-15 after calving increased the proportion of cows that were pregnant at 90 days postpartum during the summer but not during the winter. In heat-stressed laying hens, beneficial effects of vitamins A and C in the water are not clearly investigated, whereas the positive effect of vitamin E supplementation is observed on egg production (Lin et al., 2006). Zhao and Guo, (2005) showed that selenium and vitamin E complementation improved the resistance of pigs against heat stress.

3.2.6. Yeast culture

Yeast product supplementation plays an important role in digestibility of nutrient by altering the volatile fatty acids production in the rumen, decrease the production of ruminal ammonia and increase in ruminal microorganism population (Hua et al., 2010; Hillal et al., 2011). Live yeast was also reported as beneficial to small ruminant nutrition and production. Supplementation of live yeast to early lactation dairy cows increased feed consumption, feed efficiency and milk production during the hot season and similar results were reported in dairy goats but others reported no response in milk yield (Stella et al., 2007). In general, greater milk production in response to yeast products supplementation was accompanied by greater feed intake (Stella et al., 2007), whereas no response in production was accompanied by no effect on feed consumption (Schingoethe et al., 2004). The mixed results in intake and production might be partially attributable to the different condition in which these studies were performed with respect to stage of lactation, diet characteristics, and season.

3.3. Genetic Selection

Selection of thermotolerant animal has traditionally been counterproductive in domestic animal production. One of the challenges associated with managing high producing cattle in a hot environment is that selection for increased performance is often in conflict with maintaining homeothermy (Bernabucci et al., 2010; Scholtz et al., 2013). Genetic selection for milk and meat production has reduced heat tolerance (Nardone et al., 2006, Gaughan et al., 2009b). The identification of heat-tolerant animals within high-producing breeds will be useful only if these animals are able to maintain high productivity and survivability when exposed to heat stress conditions (Gaughan et al., 2009a). However, the likelihood of improving resistance among domestic animals to environmental stress through new genomic technologies without interferingtheir productive capability is achievable. Possibly improved herds could be developed when selected for milk yield and heat tolerance under local conditions. Improving animal adaptation to climatic stress can be achieved either by selection in stressed conditions or by introgressing 'heat adaptation' genes from a local breed into a commercial breed. In contrast to production traits, the inheritance of traits related to heat tolerance is poorly described. Among them, the rectal temperature reflects the animals' ability to maintain thermal equilibrium. It is the only parameter for which heritability has been ascertained with a rather good accuracy. The heritability estimates for rectal temperature have been found to be moderate, between heritability 0.15 and 0.31 in cattle (Seath, 1947). Genetic and phenotypic correlations between rectal temperature and productive and reproductive traits have been reported (Nardone et al., 2010).

The heritability of some anatomical and morphological traits, i.e. sweat glands density and function, hair coat density and thickness, hair length and color and skin color has been reported in ruminants (Nardone, 1998). Thus, hair density directly affects the number of sweat glands, and hair diameter and length affect evaporative heat loss (Bernabucci et al., 2010). Cattle with shorter hair, hair of greater diameter and lighter coat color are more adapted to hot environments than those with longer hair coats and darker colors (Gaughan et al., 2009b; Bernabucci et al., 2010). This phenotype has been characterized in *B. taurus* tropical cattle (Eg. Senepol and Carona), and this dominant gene is associated with an increased sweating rate, lower rectal temperature and lower respiration rate in homozygous cattle under hot conditions (Mariasegaram et al., 2007). In a Florida study using cows characterized as greater than 70% white or greater than 70% black, white cows had slightly lower body temperatures and greater milk yield, regardless of whether they were in shade or no shade conditions (Bertipaglia et al. 2005; Gaughan et al. 2008). Though coat color is heritable, it is not clear if it is useful to select for color. Perhaps the greatest benefit would be derived when cows are exposed heavily to radiant energy, such as in a grazing situation. In Georgia, when THI was near 72, variance for heat tolerance was zero, but when THI was 86 (equivalent to 36 °C and 50% humidity) the additive variance for heat tolerance was as large as the general variance. Because the genetic correlation between production and heat tolerance was approximately -0.3, the continued selection for production ignoring heat tolerance result in decreasing heat tolerance (Ravagnolo and Misztal, 2000). However because the correlation is small, a combined selection for production and heat tolerance is possible. Additional studies are needed to examine variability in heat tolerance of high yielding animals. Presently, functional genomics research via the identification of genes that are upregulated or downregulated during thermal stress can provide new knowledge about the impact of heat stress on production and reproduction systems. These involve variation in the expression of genes that are coordinated among cell types and tissues (Collier et al., 2008). Many transcripts and of the entire known transcriptome can be assessed simultaneously with the help of microarray technology (Rival and Jaligot, 2011). This will provide a wide variety of information useful in determining key metabolic pathways involved in acclimation. Another approach may be the use of consomic lines with single gene deletions exposed to a defined thermal environment. This permits the identification of those genes that are involved in key regulatory pathways for thermal resistance and thermal sensitivity. Finally, the gene knockout models in single cells may also allow better description of cellular metabolic machinery required for acclimation to thermal stress (Collier et al., 2005). Then, the associated genes will be mapped to their chromosomal location and the sequence of these genes will be determine to identify single nucleotide polymorphisms (SNPs) that are associated with changes in the coding for gene expression or protein function.

3.3.1. Heat shock proteins (Hsps)

Hsps are group of highly conserved proteins that are induced in both prokaryotes and eukaryotes by elevated temperatures or a variety of cellular stresses (Ross et al., 2003). As the name implies, heat shock proteins protect cells when stressed by elevated temperature. The thresholds for expression of Hsps are correlated with levels of stress naturally undergone by the animals (Ellis, 2006). Major families of Hsps are Hsp100, Hsp90, Hsp70, Hsp60, Hsp40 and the small Hsps (so-called Hsps of sizes below 30 kDa) (Feder et al., 1997). Hsps have a critical role in the recovery of cells from stress and in cytoprotection, guarding cells from subsequent insults (Nollen and Morimoto, 2002). They involved in a variety of cellular processes, including protein regulation, control of apoptosis, and signal transduction in the stress response (Richter and Buchner, 2001). In doing so, chaperones hold, translocate or refold stress denatured proteins and prevent their irreversible aggregation with other proteins in the cell (Hartl and Hayer-Hartl, 2002). Recently, the focus of Hsp research has progressed. In farm animals and chickens, associations of SNP in the Hsp70 genes with stress response and tolerance to heat were reported (Adamowicz et al., 2005; Banks et al., 2007). Hsp70.1 and Hsp70.2 are highly polymorphic, potentially accounting for variation in their functions and susceptibility to stress tolerance (Zhou et al., 2005). Cheng et al. (2009) reported a genetic polymorphism of Hsp70.1 gene and its association with resistance to mastitis in Chinese Holstein. Several studies have shown the association of Hsp90ab1 gene with thermo tolerance in Thai indigenous cattle (Charoensook et al., 2012), Sahiwal and Frieswal cattle (Deb et al., 2014; Sajjanar et al., 2015) and jersey-crossbred cows (Sailo et al., 2015). Many studies have also report the association of Hsp gene thermo tolerance *viz*. Hsf1 gene (Li et al., 2011a), Hsp70a1a gene (Li et al., 2011b) and Hsbp1 [Wang et al., 2013] in Chinese Holstein cattle. There are also non-Hsps genes which play an important role in relation to heat-resistance. Wang et al., 2011 reported the association of ATP1B2 gene with heat-resistance in Chinese Holstein cows. Das et al., 2015 also reported the association of ATP1A1 gene with heat-tolerance in jersey crossbred cows. Therefore, identification of SNPs that are associated with variation in animal resistance or sensitivity to thermal stress permits screening of animals for the presence or absence of desirable or undesirable alleles. These 'markers' will aid in selection of thermotolerantanimals.

4. Conclusion

Heat stress negatively affects animal performance in tropical, subtropical and temperate countries during summer seasons. Improved knowledge of the functional relationship between animals and their environment and of the physiological mechanisms of adaptation to environmental stresses may contribute to the adoption procedures to improve the welfare and efficiency of production and reproduction. The potential to select thermotolerant animal that can transmit gene associated with thermotolerance must be considered to propagate thermal adaptable as future generation to achieve optimum profits under global warming scenario.

5. References

Adamowicz, T., Pers, E., Lechniak, D., 2005. A new SNP in the 3-UTR of the Hsp 70-1 gene in Bos Taurus and Bos indicus. Biochemical Genetics 43, 623−627.

Adin, G., Solomon, R., Shoshani, E., Flamenbaum, I., Nickbachat, M., Yosef, E., Brosh, A., Mabjesh, SJ. ,Miron, J., 2008. Heat production, eating rations differing in roughage content and digestibility under heat load condition. Livestock Science 119, 145−153.

Ahmad, T., Khalid, T., Mushtaq, T., Mirza, M.A., Nadeem, A., Babar, ME., Ahmad, G., 2008. Effect of potassium chloride supplementation in drinking water on broiler performance under heat stress conditions. Poultry Science 87, 1276‒1280.

Al-Katanani, Y.M., Webb, DW., Hansen, P.J., 1999. Factors affecting seasonal variation in 90-day non-return rate to first service in lactating Holstein cows in a hot climate. Journal of Dairy Science 82, 2611‒2616.

Amundson, J.L., Mader, T.L., Rasby, R.J., Hu, Q.S., 2006. Environmental effects on pregnancy rate in beef cattle. Journal of Animal Science 84, 3415‒3420.

Arechiga, C.F., Staples, C.R., McDowell, L.R., Hansen, P.J., 1998. Effects of timed insemination and supplemental beta carotene on reproduction and milk yield of dairy cows under heat stress. Journal of Dairy Science 81, 390‒402.

Atrian, P., Shahryar, H.A., 2012. Heat stress in dairy cows. Research in Zoology 2(4), 31‒37.

Ayo, J.O., Egbuniwe, I., Kawu, M.U., Sinkalu, V.O., 2014. Ameliorative effects of betaine and ascorbic acid administration to broiler chicken during the hot dry season in Zaria. African Journal of Biotechnology 13, 2295‒2306.

Banks, A., Looper, M.L., Reiter, S., Starkey, L., Flores, R., Hallford, D., Rosenkrans, C.J., 2007. Identification of single nucleotide polymorphisms within the promoter region of the bovine heat shock protein 70 gene and associations with pregnancy. In: Proceeding of American Society of Animal Science, Southern Section Meeting 85(Suppl. 2), 10.

Basirico, L., Bernabucci, U., Morera, P., Lacetera, N., Nardone, A., 2009. Gene expression and protein secretion of apolipoprotein B100 (ApoB100) in transition dairy cows under hot or thermoneutral environments. Italian Journal of Animal Science 8(2), 592‒594.

Basirico, L., Morera, P., Primi, V., Lacetera, N., Nardone, A., Bernabucci, U., 2011. Cellular thermotolerance is associated with heat shock protein 70.1 genetic polymorphisms in Holstein lactating cows. Cell Stress Chaperones 16(4), 441‒448.

Baumgard, L.H., Rhoads, J.R.P., 2013. Effects of heat stress on postabsorptive metabolism and energetics. Annual Review of Animal Bioscience 1, 311‒337.

Bernabucci, U., Lacetera, N., Baumgard, L.H., Rhoads, R.P., Ronchi, B., Nardone, A., 2010. Metabolic and hormonal acclimation to heat stress in domesticated ruminants. Journal of Animal Science 4, 1167‒1183.

Bertipaglia, E.C.A., Silva, R.G., Maia, A.S.C., 2005. Fertility and hair coat characteristics of Holstein cows in a tropical environment. Animal Reproduction 2(3), 187‒194.

Blackshaw, J.K., Blackshaw, A.W., 1994. Heat stress in cattle and the effect of shade on production and behaviour: a review. Australian Journal of Experimental Agriculture 34, 285‒295.

Bucklin, R.A., Bray, D.R., Beede, D.K., 2008. Methods to Relieve Heat Stress for Florida Dairies. CIR782, Agricultural and Biological Engineering Department, UF/IFAS Extension, http://edis.ifas.ufl.edu.

Bucklin, R.A., Turner, L.W., Beede, D.K., Bray, D.R., Hemken, R.W., 1991. Methods to relieve heat stress for dairy cows in hot climates. Applied Engineering in Agriculture 7, 241‒247.

Charoensook, R., Gatphayak, K., Sharifi, A.R., Chaisongkram, C., Brenig, B., Knorr, C., 2012. Polymorphisms in the bovine HSP90AB1 gene are associated with heat tolerance in Thai indigenous cattle. Tropical Animal Health and Production 44, 921‒928.

Chauhan, DS., Ghosh, N., 2015. Impact of climate change on livestock production. Journal of Animal Research 4(2), 223‒239.

Cheng, W.J., Li, Q.L., Wang, C.F., Wang, H.M., Li, J.B., Sun, Y.M., Zhong, J.F., 2009. Genetic polymorphism of Hsp 70-1 gene and its correlation with resistance to mastitis in Chinese Holstein. Yi Chuan 31, 169‒174.

Choubey, M., Kumar, A., 2012. Nutritional interventions to combat heat stress in dairy animals. Vetscan 7(1), 19‒27.

Collier, R.J., Collier, J.L., Rhoads, R.P., Baumgard, L.H., 2008. Gene involved in the bovine heat stress response. Journal of Dairy Science 91, 445‒454.

Collier, R.J., Dahl, G.E., VanBaale, M.J., 2006. Major advances associated with environmental effects on dairy cattle. Journal of Dairy Science 89,1244‒1253.

Collier, R.J., Kobayashi, Y., Gentry, P., 2005. The use of genomics in genetic selection programs for environmental stress tolerance in domestic animals. In: Proceedings of the AMS 15th Biometeorology and Acrobiology Conference, 27 October-1 November, Kansas, 54‒58.

Das, R., Gupta, I.D., Verma, A., Singh, A., Chaudhari, M.V., Sailo, L., Upadhyay, R.C., Goswami, J., (2015) Genetic polymorphisms of ATP1A1 gene and their association with heat tolerance in Jersey crossbred cows. Indian Journal of Dairy Science 68(1), 50‒54.

Davis, M.S., Mader, T.L., Holt, S.M., Parkhurst, A.M., 2003. Strategies to reduce feedlot cattle heat stress: effects on tympanic temperature. Journal of Animal Science 81, 649‒661.

de Castro e Paula, L.A., Hansen, P.J., 2008. Modification of actions of heat shock on development and apoptosis of cultured preimplantation bovine embryos by oxygen concentration and dithiothreitol. Molecular Reproduction and Development 75, 1338–1350.

Deb, R., Sajjanar, B., Singh, U., Kumar, S., Singh, R., Sengar, G., Sharma, A., 2014. Effect of heat stress on the expression profile of Hsp90 among Sahiwal (*Bos indicus*) and Frieswal *(Bos indicus*×*Bos taurus*) breed of cattle: A comparative study. Gene 536, 435–440.

Ealy, A.D., Drost, M., Hansen, P.J., 1993. Developmental changes in embryonic resistance to adverse effects of maternal heat stress in cows. Journal of Dairy Science 76, 2899–2905.

Ellis, R.J., 2006. Protein misassembly: Macromolecular crowding and molecular chaperones. In: Csermely, P., Vígh, L., (Eds) Molecular Aspects of the Stress Response: Chaperones, Membranes and Networks. Springer Science Plus Business Media, New York, 2–13.

Feder, M.E., Blair, N., Figuras, H., 1997. Natural thermal stress and heat-shock protein expression in Drosophila larvae and pupae. Functional Ecology 11, 90–100.

Gaughan, J.B., Bonner, S., Loxton, I., Mader, T.L., Lisle, A., Lawrence, R., 2010. Effect of shade on body temperature and performance of feedlot steers. Journal of Animal Science 88(12), 4056–4067.

Gaughan, J.B., Mader, T.L., Holt, S.M., Lisle, A., 2008. A new heat load index for feedlot cattle. Journal of Animal Science 86(1), 226–234.

Gaughan, J., Lacetera, N., Valtora, E., Khalifah, H.H., Hahn, L., Mader, T., 2009a. Response of domestic animals to climate challenges. In: Ebi KL, Burton I and McGregor GR (Eds) Biometeorology for Adaptation to Climate Variability and Change. Springer, Aukland, New Zealand, 131–170.

Gaughan, J.B., Mader, T.L., Holt, S.M., Sullivan, M.L., Hahn, GL., 2009b. Assessing the heat tolerance of 17 beef cattle genotypes. International Journal of Biometeorology 54(6), 617–627.

Hammami, H., Bormann, J., Mhamdi, N., Montaldo, H.H., Gengler, N., 2013. Evaluation of heat stress effects on production traits and somatic cell score of Holsteins in a temperate environment. Journal of Dairy Science 96, 1844–1855.

Hamzaoui, S., Salama, A.A.K., Albanell, E., 2013. Physiological responses and lactational performances of late-lactation dairy goats under heat stress conditions. Journal of Dairy Science 96, 6355–6365.

Hansen, P.J., 2004. Physiological and cellular adaptations of zebu cattle to thermal stress. Animal Reproduction Science 82-83, 349–360.

Hansen, P.J., 2007. Exploitation of genetic and physiological determinants of embryonic resistance to elevated temperature to improve embryonic survival in dairy cattle during heat stress. Theriogenology 68, 242–249.

Hansen, P.J., 2013. Cellular and molecular basis of therapies to ameliorate effects of heat stress on embryonic development in cattle. Animal Reproduction 10, 322–333.

Hartl, F.U., Hayer-Hartl, M., 2002. Molecular chaperones in the cytosol: From nascent chain to folded protein. Science 295, 1852–1858.

Hillal, H., El-Sayaad, G., Abdella, M., 2011. Effect of growth promoters (probiotics) supplementation on performance, rumen activity and some blood constituents in growing lambs. Archiv Tierzucht 54(6), 607–617.

HuWL, Liu., JX, Ye., JA, Wu., YM, Guo., YQ. 2005. Effect of tea saponin on rumen fermentation in vitro. Animal Feed Science and Technology 120, 333–339.

Hua, P., Jia-qi, W., Deng-pan, B. 2010. Effects of Feed Additives on Rumen Fermentation. Annual Review of Ruminant Nutrition (2008-09) II. State Key Laboratory of Animal Nutrition, Institute of Animal Science, Chinese Academy of Agricultural Sciences, Beijing.

IPCC. 2007. Climate change: Synthesis report. www.ipcc.ch/pdf/assessment report/ar4/syr/ar4_syr_sym.pdt.

Johnson, H.D., Ragsdale, A.C., Berry, I.L., Shanklin, M.D., 1962. Effects of various temperature-humidity combinations on milk production of Holstein cattle. University of Missouri Agricultural Experiment Station. Research Bulletin, 791.

Kanjanapruthipong, J., Homwong, N., Buatong, N., 2010. Effects of pre-partum roughage neutral detergent fiber levels on peri-partum DMI, metabolism and lactation in heat stressed dairy cow. Journal of Dairy Science 93, 2589–2597.

Knapp, D.M., Grummer, R.R., 1991. Response of lactating dairy cows to fat supplementation during heat stress. Journal of Dairy Science 74, 2573–2579.

Li, Q., Han, J., Du, F., Ju, Z., Huang, J., Wang, J., Li, R., Wang, C., Zhong, J., 2011b. Novel SNPs in HSP70A1A gene and the association of polymorphisms with thermo tolerance traits and tissue specific expression in Chinese Holstein cattle. Molecular Biology Reports 38, 2657–2663.

Li, Q.L., Ju, Z.H., Huang, J.M., Li, J.B., Li, R.L., Hou, M.H., Wang, C.F., Zhong, J.F., 2011a. Two novel SNPs in HSF1 gene are associated with thermal tolerance traits in Chinese Holstein cattle. DNA Cell Biology 30,247-254.

Lin , H., Jiao, H.C., Buyse, J., Decuypere, E., 2006. Strategies for preventing heat stress in poultry. World's Poultry Science Journal 62, 71–86.

Linn, J.G., 1997. Nutritional management of lactating dairy cows during periods of heat stress. University of

Minnesota Dairy Update 125, 25‒27.
Linn, J., Reath-Knight, M., Larson, R., 2004. Managing heat stressed lactating dairy cows. Hubbard Feeds Inc. 26, 9‒10.
Mariasegaram, R., Chase, C.C., Chaparro, J.X., Olson, T.A., Brenneman, R.A., Niedz, RP., 2007. The slick air coat locus maps to chromosome 20 in Senepol-derived cattle. Animal Genetics 38, 54‒59.
McGuire, M.A., Beede, D.K., DeLorenzo, M.A., Wilcox, C.J., Huntington, G.B., Reynolds, C.K., Collier, R.J., 1989. Effects of thermal stress and level of feed intake on portal plasma flow and net fluxes of metabolites in lactating Holstein cows. Journal of Animal Science 67, 1050‒1060.
Megahed, G.A., Anwar, M.M., Wasfy, S.I., Hammadeh, M.E., 2008. Influence of heat stress on the cortisol and oxidant-antioxidants balance during oestrous phase in buffalo-cows thermo-protective role of antioxidant treatment. Reproduction in Domestic Animal 43, 672‒677.
Meyerhoeffer, D.C., Wettemann, R.P., Coleman, S.W., Wells, M.E., 2004. Reproductive criteria of beef bulls during and after exposure to increased ambient temperature. Journal of Animal Science 60(2), 352‒357.
Nardone, A., 1998. Thermoregulatory capacity among selection objectives in dairy cattle in hot environment. Livestock and Animal Nutrition 24, 297-308.
Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S., Bernabucci, U., 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Science 130, 57‒69.
Nardone, A., Ronchi, B., Lacetera, N., Bernabucci, U., 2006. Climatic effects on productive traits in livestock. Veterinary Research Communications 30(1),75‒78.
Nassuna-Musoke, G.M., Kabasa, J.D., King, M.J., 2007. Lactation curve of temperate Friesians on smallholder farms in tropical central Uganda. Journal of Animal and Veterinary Advances 6(8), 950‒954.
Nesamvuni, E., Lekalakala, R., Norris, D., Ngambi, J.W., 2012. Effects of climate change on dairy cattle, South Africa.African Journal of Agricultural Research 7(26), 3867‒3872.
Nichi, M., Bols, P.E.J., Zuge, R.M., Barnabe, V.H., Goovaerts I.G.F., Barnabe, R.C., Cordata, C.N.M., 2006. Seasonal variation in semen quality in *Bosindicus* and *Bostaurus* bulls raised under tropical conditions. Theriogenology 66, 822‒828.
Nollen, E.A.A., Morimoto, R.I., 2002. Chaperoning signaling pathways: Molecular chaperones as stress-sensing 'heat shock' proteins. Journal of Cell Science 115, 2809‒2816.
NRC. 1981. Effect of environment on nutrient requirements of domestic animals. National Academy Press, Washington, DC. www.nap.edu/openbook.php?isbn=0309031818.
Paula-Lopes, F.F., Al-Katanani, Y.M., Majewski, A.C., McDowell, L.R., Hansen, P.J., 2003. Manipulation of antioxidant status fails to improve fertility of lactating cows or survival of heat-shocked embryos. Journal of Dairy Science 86, 2343‒2351.
Ravagnolo, O., Misztal, I., 2000. Genetic component of heat stress in dairy cattle, parameter estimation. Journal of Dairy Science 83, 2126‒2130.
Renaudeau, D., Gourdine, J.L., St-Pierre, N.R., 2011. A meta-analysis of the effect of high ambient temperature on growing-finishing pigs. Journal of Animal Science 89, 2220‒2230.
Rhoads M.L., Rhoads, R.P., VanBaale, M.J., Collier, R.J., Sanders, S.R., Weber, W.J., Crooker, B.A., Baumgard, L.H., 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. Journal of Dairy Science 92, 1986‒1997.
Richter, K., Buchner, J., 2001. Hsp90: Chaperoning signal transduction. Journal of Cell Physiology 188, 281-290.
Rival, A., Jaligot, E., 2011. Oil palm biotechnologies are definitely out of infancy.Oléagineux Corps grasLipides 17(6), 368‒374.
Ross, O.A., Curran, M.D., Crum, K.A., Rea, I.M., Barnett, Y.A., Middleton, D., 2003. Increased frequency of the 2437 T allele of the heat shock protein 70-Hom gene in an aged Irish population. Experimental Gerontology 38, 561‒565.
Sailo, L., Gupta, I.D., Verma, A., Singh, A., Chaudhari, M.V., Das, R., Upadhyay, R.C., Goswami, J., 2015. Single Nucleotide Polymorphism In Hsp90ab1 Gene And Its Association With Thermo-Tolerance In Jersey Crossbred Cows. Animal Science Reporter 9(2),43‒49.
Sajjanar, B., Deb, R., Singh, U., Kumar, S., Brahmane, M., Nirmale, A., Bal, S.K., Minhas, P.S., 2015. Identification of SNP in HSP90AB1 and its association with relative thermo-tolerance and milk production traits in Indian dairy cattle, Animal Biotechnology 26(1), 921‒928.
Sakatani, M., Suda, I., Oki, T., Kobayashi, S., Kobayashi, S., Takahashi, M., 2007. Effects of purple sweet potato anthocyanins on development and intracellular redox status of bovine preimplantation embryos exposed to heat shock. Journal of Reproduction and Development 53,605‒614.
Sanchez, W.K., McGuire, M.A., Beede, D.K., 1994. Macromineral nutrition by heat stress interactions in dairy cattle: Review and original research. Journal of Dairy Science 77, 2051‒2079.

Santra, A., Chaturvedi, O.H., Tripathi, M.K., Kumar, R., Karim, S.A., 2003. Effect of dietary sodium bicarbonate supplementation on fermentation characteristics and ciliate protozoal population in rumen of lambs. Small Ruminant Research 47, 203−212.

Sathya, A., Prabhakar, S., Sangha, S.P., Ghuman, S.P., 2007. Vitamin E and selenium supplementation reduces plasma cortisol and oxidative stress in dystocia-affected buffaloes. Veterinary Research Communications 31, 809−818.

Schingoethe, D.J., Linke, K.N., Kalscheur, K.F., Hippen, A.R., Rennich, D.R., Yoon, I., 2004. Feed efficiency of mid-lactation dairy cows fed yeast culture during summer. Journal Dairy Science 87, 4178−4181.

Scholtz, M.M., McManus, C., Leeuw, K.J., Louvandini, H., Seixas, L., de Melo, C.B., Theunissenm A., Neser FWC. 2013.The effect of global warming on beef production in developing countries of the southern hemisphere. Natural Science 5(1A), 106−119.

Seath, D.M., 1947. Heritability of heat tolerance in dairy cattle. Journal of Dairy Science 30, 137−144.

Singh, S.V., Upadhyay, R.C., Ashutosh Hooda, O.K., Vaidya, M.M., 2011. Climate change: Impacts on reproductive pattern of cattle and buffaloes: Review. Journal of Animal Science 578, 199−208.

Shivakumar, A.V.N., Singh, G., Varshney, V.P., 2010. Antioxidants supplementation on acid base balance during heat stress in goats. Asian Australian Journal of animal Science 11, 1462−1468.

Soto-Navarro, S.A., Krehbiel, C., Duff, G.C., Galyean, M.L., Brown, M.S., Steiner, R.L., 2000. Influence of feed intake fluctuation and frequency of feeding on nutrient digestion, digesta kinetics, and ruminal fermentation profile in limit-fed steers. Journal of Animal Science 78, 2215−2222.

Stella, A.V., Paratte, R.,Valnegri, L., Cigalino, G., Soncini, G., Chevaux, E., Dellorto, V., Savoini, G., 2007. Effect of administration of live *Saccharomyces cerevisiae* on milk production, milk composition, blood metabolites, and faecal flora in early lactating dairy goats. Small Ruminant Research 67, 7−13.

Taylor, R.B., Huber, J.T., Gomez-Alarcon, R.A., Wiersma, F., Pang, X., 1991. Influence of protein degradability and evaporative cooling on performance of dairy cows during hot environment temperatures. Journal of Dairy Science 74, 243-249.

Vitali, A., Segnalini, M., Bertocchi, L., Bernabucci, U., Nardone, A., Lacetera, N., 2009. Seasonal pattern of mortality and relationships between mortality and temperature humidity index in dairy cows. Journal of Dairy Science 92, 3781−3790.

Wang,Y., Huang, J., Xia, P., He, J., Wang, C., Ju, Z., Li, J., Li, R., Zhong, J. and Li, Q. 2013. Genetic variations of HSBP1 gene and its effect on thermal performance traits in Chinese Holstein Cattle. Molecular Biology Report, 40,3877−3882.

Wang, Z., Wang, G., Huang, J., Li, Q., Wang, C. and Zhong, J. (2011) Novel SNPs in the ATP1B2 gene and their associations with milk yield, milk composition and heat-resistance traits in Chinese Holstein cows. Molecular Biology Report, 38,1749−1755.

Webel, D.M., Mathan, D.C., Johnson, R.W., Baker, D.M., 1998. Pretreatment of young pigs with vitamin E attenuates the elevation in plasma interleukin-6 and cortisol caused by a challenge dose of lipopolysaccharide. Journal of Nutrition 128, 1657−1660.

West, J.W., 2003. Effects of heat-stress on production in dairy cattle. Journal of Dairy Science 86, 2131−2144.

West, J.W., Hill, G.M., Mandebvu, P., Fernandez, J.M., Mullinix, B.G., 1999. Effects of dietary fiber on intake, milk yield, and digestion by lactating dairy cows during cool or hot, humid weather. Journal of Dairy Science 82(11), 2455−2465.

Wolfenson, D., 2009. Impact of heat stress on production and fertility of dairy cattle. In: Proceedings of the 18thAnnual Tri-State Dairy Nutrition Conference. Fort Wayne, USA, 21-22 April, 55−59.

Yatoo, M.I., Kumar, P., Dimri, U., Sharma, M.C., 2012. Effects of climate change on animal health and diseases. International Journal of Livestock Research 2(3), 15−24.

Zhao, H.J., Guo, D.Z., 2005. Effects of selenium and vitamin E on the free radical metabolism of pigs suffering from heat stress. Chinese Journal of Veterinary Science 25, 78−80.

Zhou, F., Wang, F., Li, F., Yuan, J., Zeng, H., Wei, Q., Tanguay RM and Wu T. 2005. Association of hsp70.2 and hsp-hom gene polymorphisms with risk of acute high-altitude illness in a Chinese population. Cell Stress Chaperones 10, 349−356.