International Journal of
Dairy Science

ISSN 1811-9743

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS International Journal of Dairy Science

ISSN 1811-9743
DOI: 10.3923/ijds.2017.1.11

Review Article
Heat Stress and Dairy Cow: Impact on Both Milk Yield and Composition

[1,2,3]Prathap Pragna, [1,2,3]P.R. Archana, [1,2,3]Joy Aleena, [1]Veerasamy Sejian, [1]Govindan Krishnan, [1]Madiajagan Bagath, [4]A. Manimaran, [2]V. Beena, [3]E.K. Kurien, [2]Girish Varma and [1]Raghavendra Bhatta

[1]Indian Council of Agricultural Research, National Institute of Animal Nutrition and Physiology, Adugodi, 560030 Bangalore, India
[2]Centre for Animal Adaptation to Environment and Climate Change Studies, Kerala Veterinary and Animal Sciences University, Mannuthy, Thrissur, Kerala, India
[3]Academy of Climate Change Education and Research, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala, India
[4]Southern Reginal Station, National Dairy Research Institue, Adugodi, 560030 Bangalore, India

Abstract
Heat stress is one of the major concerns which affect the production potential of dairy cattle almost in every part of world. Elevated temperature and humidity negatively affects feed intake leading to negatively affecting the reproductive potential which ultimately decrease milk production. High yielding cows more susceptible to heat stress than the low yielders. Heat stress can increase body temperature which may affect the fat synthesis in mammary gland. Apart from reducing the milk production, heat stress can also reduce the quality of milk. Internal metabolic heat production during lactation can further reduce the resistance of cattle to high ambient temperature, resulting in altered milk composition and reduction in milk yield. Heat stress can affect the various components of milk such as fat (%), solid-non-fat, protein, casein and lactose content. Heat stress can increase the somatic cell count indicating the reduction in quality of milk produced. Further, heat stress can also cause endocrine disbalance such as altering the levels of prolactin, thyroid hormones, glucocorticoid, growth hormone, estrogen, progesterone and oxytocin which ultimately affects the milk production. Heat stress through higher udder temperature may also cause mastitis in dairy cows. In addition, heat stress during dry period in particular might trigger mammary gland involution accompanied with apoptosis and autophagy, decreased amount of mammary epithelial cells can ultimately cause decline in milk yield. It may be concluded from this review that heat stress is considered to be adversely impacting both quantity as well as quality of milk produced. Heat stress brings about these impacts through reduced feed intake, altered hormone concentration and pathological changes in udder during mastitis.

Key words: Dairy cow, heat stress, mastitis, prolactin, SNF, udder health

Received: July 04, 2016 Accepted: August 12, 2016 Published: December 15, 2016

Citation: Prathap Pragna, P.R. Archana, Joy Aleena, Veerasamy Sejian, Govindan Krishnan, Madiajagan Bagath, A. Manimaran, V. Beena, E.K. Kurien, Girish Varma and Raghavendra Bhatta, 2017. Heat stress and dairy cow: Impact on both milk yield and composition. Int. J. Dairy Sci., 12: 1-11.

Corresponding Author: Veerasamy Sejian, Animal Physiology Division, National Institute of Animal Nutrition and Physiology, Adugodi, 560030 Bangalore, India Tel: +91-9740726121 Fax: +91-080-25711420

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Livestock is a main source of income for the poor people which caters their day-to-day social and economic needs. It provides employment for more than 1.3 billion people and contributes around 40% in the world's agricultural Gross Domestic Product (GDP)[1,2]. However, the demand for milk is in an increasing trend which is highly influenced by environmental factors and management practices. The changes in the environmental facors like ambient temperature, relative humidity, wind speed and solar radiation causes stresses in lactating cattle. The heat stress adversely affects both the quantity and quality of milk during first 60 days of lactation and high yielding breeds are more susceptible than the low yielding breeds.

Heat stress is of major concern among livestock owners in almost all parts of the world. Cattles that are affected by heat stress show reduction in feed intake and milk yield and shift metabolism, which in turn reduces their milk production efficiency[3]. Heat stressed cattle may try to reduce the body heat through thermoregulatory mechanisms which in turn affect feed conversion efficiency and lead to decreased milk production. Quality of colostrum and transfer of maternal IgG's to colostrum are reduced if the heat stress is felt close to calving[4,5]. Heat stress also impacts the mammary glands and the changes can be visualized through histological changes in the udder. Over 50% of the cattle population is located in the tropics and it has been appraised that heat stress causes severe economic loss in approximately 60% of the dairy farms around the world[6,7]. Further, very few studies are available quantifying the reduction in milk production as a result of heat stress in lactating cows. Hence, this review is an attempt to collate and synthesis information pertaining to heat stress impact on milk production in dairy cattle. Efforts were made to review the economic consequences due to heat stress in dairy production and also emphasis were given to addresss salient amelioration strategies to counter the adverse impact of heat stress on dairy cows.

ECONOMIC CONSEQUENCES OF HEAT STRESS IN LIVESTOCK PRODUCTION

Livestock economy is one of the major economy of the world, which satisfies nutritional requirements of the world through high quality milk and meat. It not only gives milk and meat but also manure, skin, horn, bone etc[8]. Increasing population, urbanization and improved wealth may increase the need of milk and other livestock products. With the population increase which is estimated to reach 9.6 billion by 2050, the global demand for livestock products is projected to increase[9] by 70%.

Elevated temperature and humidity negatively affects feed intake ultimately leading to decreased milk production. It has been observed that heat stress can create a significant economic burden to dairy industry to a tune of about $900 million per year[10,11]. Further, during heat stress, decline in milk production are a common phenomenon and the reduction was recorded[11,12] to be between 30-40%. St-Pierre *et al.*[10] in their study established the impact of heat stress on dairy cattle and estimated the annual economic loss to be 897-1,500 million dollars to US dairy industry. In an another study it was established that severe heat stress caused a loss of $800 million dollars to the US dairy industry[13]. Further, it was also reported that the Californian dairy farmers lost more than 1 billion dollar of milk and animals during 2006 heat wave[14]. In addition, heat stress is estimated to have lowered annual milk production in the average dairy by about $39,000, totalling $1.2 billion loss of production for the entire US dairy sector[15].

Heat stress impact on lactating cattle: Heat stress is one of the major concern which affect the production potential of cattle. Heat stress may lead to reduced dry matter intake, productivity, increased rectal temperature, increased respiration rate and panting to maintain body temperature. Decreased dry matter intake and alterations in physiological activities can adversely affect milk production[16,17]. Elevated core body temperature will reduce milk output, percentages of milk protein, fat, solids and lactose[15]. High temperature and low relative humidity are the critical parameters contributing to heat stress. Per unit increase in Temperature Humidity Index (THI) beyond 72, 0.2 kg reduction in milk yield was recorded in dairy cows[4,18]. For each point increase in the value of THI beyond 69, milk production drops by 0.41 kg per cow per day in the Mediterranean climatic regime[19,20]. Further, for every 1°C in air temperature above thermal neutral zone cause 0.85 kg reduction in feed intake, which causes ~36% decline in milk production[4,21]. Also heat stress can lead to higher udder temperature which may ultimately affect the udder leading to mastitis[22]. Further, heat stress also can cause immunosuppression by inhibiting rumination thereby leading to more chances of disease occurrence in dairy cattle[23]. In addition, it was established that during severe heat stress conditions mammary gland use a negative regulatory feedback mechanism to reduce milk production[24,25]. Heat stress may also offset the genetic progress achieved in increasing milk yield. Genetic advancement in milk production is linked to the feed intake. High yielding cows are more susceptible to heat stress than low yielding cows, as feed intake and milk production increases thermoneutral zone shifts to lower temperature. Hence, heat stressed cow activates its physical and biochemical process to counter stress and to maintain thermal equilibrium. Regulations made by cow includes heat dissipation to the environment and reduced production of metabolic heat[26]. In non-cooled farms heat stress can cause 40-50% decline in milk yield while in cooled farms it can go up to 10-15%[4,27]. Heat stress affects reproduction by inhibiting the synthesis of gonadotropin-releasing hormone and luteinizing hormone which are essential for oestrus behaviour expression and ovulation[23]. Further, only fewer standing heats are observed during heat stress which may ultimately lead to decreased pregnancy rate. Body temperature greater than 39°C may have a negative impact on the developing embryo from day 1-6 and lead to loss of pregnancy. Heat stress during late gestation, may also lead to cows calving 10-14 days before their due date[28]. The decreased milk production during heat stress can be due to dwindled nutrient uptake by portal drained viscera of the cattle and decreased nutrient uptake[20].

Impact of heat stress on milk yield in cattle: Heat stress can makes changes in the feeding pattern, rumen function and udder health ultimately leads to decreased milk production. Figure 1 describes the impact of heat stress on milk production in dairy cattle. Most livestock species perform well in the temperature range of 10-30°C, beyond this limit cattle tend to reduce milk yield and feed intake[29-31]. Temperature above 35°C may activate thermal stress in animals directly reducing the feed intake of animal thereby creating an negative energy balance which ultimately affects synthesis of milk[32,33]. Heat stress negatively affects milk yield in cattle[4,34,35]. Rejeb *et al.*[36] studied heat stress in response to milk yield on 13 Holstein cows and recorded reduction in milk yield during summer compared to spring and they attributed this reduction to changes in metabolism, physiology and feed intake. Heat stress can cause yield loss up to 600 or 900 kg milk per cow per lactation[4]. Heat stress can alter metabolic activity and reduce feed intake which may ultimately culminate in reducing the milk yield[21,37]. Cows in hot humid climatic regime show a decreased milk yield and feed intake because of their continuous exposure to high humidity and high air temperature[4]. Further, decline in milk production was recorded for body temperature higher than 39°C[38,39]. In addition, elevated temperature was found to decline milk yield by 0.38 kg[36,40]. It has been established that only 35% of the reduction in milk yield is due to decreased feed intake remaining 65% reduction is due to direct physiological effect of heat stress[21]. Decreased nutrient absorption, alteration in rumen function and hormonal imbalance are other factors which contributes to reduced

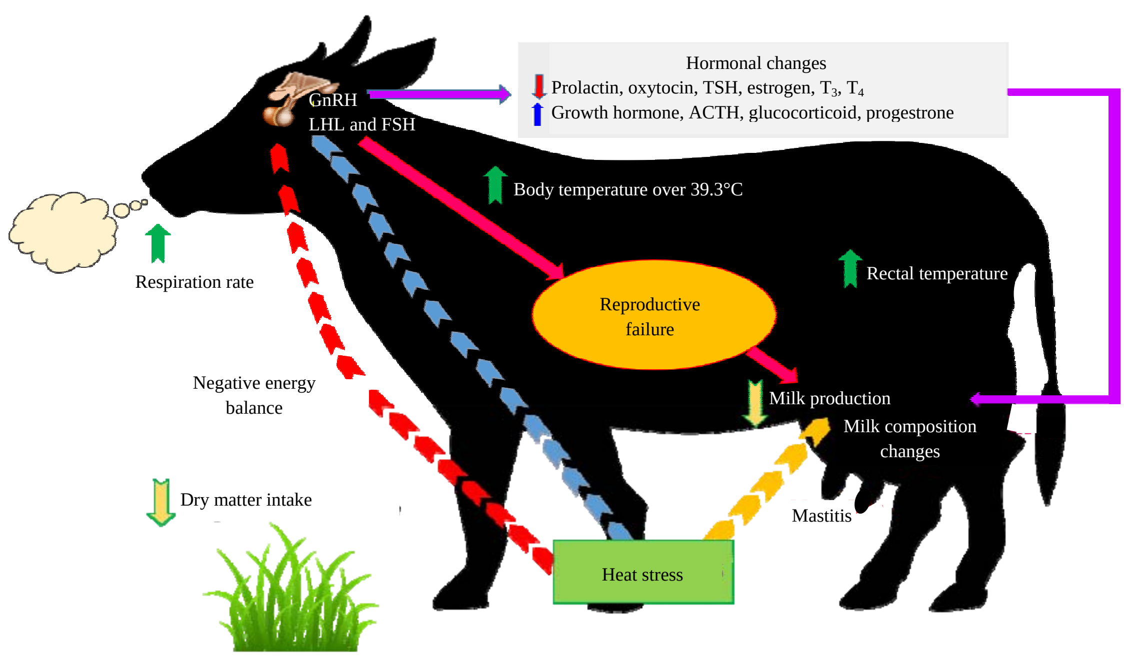

Fig. 1: Pictorial representation of heat stress impacting milk production in dairy cattle

milk production during heat stress[41]. The above consequences of heat stress are harmful to high yielding cows that are already under huge metabolic strain[37]. Holstein cows show more yield reduction than Jersey[42,43]. There are also reports suggesting that cattles which are conceived during heat stress also show a decline in milk production[44,45]. Further, in a study Dikmen *et al*.[46] observed that cows calved during heat stressed summer season showed reduced milk production than the cows that are calved during winter. Holstein lactating cows exposed to short term heat stress showed significant reduction in milk production of 1.7±0.32 kg. However, during recovery phase, milk decline was recorded to be much lesser of about 1.2±0.32 kg[44]. Further, heat stressed Holstein cows with high rectal temperature showed reduction in milk yield and reduced reproductive efficiency[47]. In an experiment on Holstein cows to assess the decrease in milk yields due to heat stress in tropical conditions, a yield loss of 0.23 kg day^{-1} was observed for unit rise of THI above 66[48]. In addition in another experiment in southern Brazil, Garcia *et al*.[49] observed 21% milk yield loss in commercial heard of Holstein cows due to heat stress. Similarly in an experiment conducted in Missouri on Holstein cows showed 0.56 milk yield decline for the temperature range 24-35°C[50]. Likewise in another experiment conducted in Tunisia on Holstein cows it was reported that for THI values above 68-78 a yield loss of 4 kg was recorded[19]. The reason for reduced milk production is the negative energy balance as the the animal try to maintain homeostasis to avoid hyperthermia[51,52]. Decrease in milk yield gets further intensified, due to reduced feed intake by the cattle to counter the heat stress[45]. Further, heat stress causes decline in the level of non-esterified fatty acid and hepatic glucose leading to reduced supply of glucose to the mammary glands which in turn negatively affect lactose synthesis leading to reduced milk yield in Holstein cows[32]. It has been observed that milk yield starts declining by 0.2 kg for every unit rise in THI value[18,53-55] above 72. There are further reports establishing the negative correlation between THI values and milk yield[17,33,34]. Reduced milk yield and milk protein fraction was also recorded in cattle exposed to heat stress[56]. For every 1°C in temperature above 21-27°C a production decline of approximately 36% was recorded in dairy cattle[21,33]. Heat stress during dry period also affect mammary gland development before parturition which ultimately leads to reduced milk yield in subsequent lactation[57]. High yielding cows are most affected due to heat stress than low yielding cows. High yielding cows have to consume more feed to meet their dietary requirements, reduced feed intake during heat stress may curb the cow to meet its dietary requirement for milk synthesis. When THI exceeds above 65-73, a milk yield reduction of 5 pounds per cow per day is observed, for a herd of 150 cow's loss can go up to $3375 per year[53]. Cowley *et al*.[58] estimated a reduction in milk yield, milk protein and casein concentration due to heat stress. There is a negative relationship between milk yield and RT.

Impact of heat stress on milk composition in cattle: Heat stress apart from affecting the milk yield can also influence milk composition and milk yield especially in high yielding breeds[20,33,59]. Internal metabolic heat production during lactation can reduce the resistance of cattle to high ambient temperature, resulting in altered milk composition and reduction in milk yield[60,61]. When the temperature rises above the zone of thermal neutrality milk composition changes[26,62]. Heat stress was found to reduce the protein and fat content[36,40,61]. Heat stress reduced milk protein, milk fat, solids-not-fat (SNF) in dairy cows[26]. Further, heat stress reduced milk fat, protein and short-chain fatty acids while increased the long chain fatty acids in the milk[26,63]. In an other study, decreased milk protein, lactose and fat values were recorded during the summer[39,64]. The declined protein concentration during heat stress could be attributed to the specific down thermoregulation activity of mammary protein synthesis[58]. In an experiment on Holstein heifers to heat stress Nardone *et al*.[65] observed reduction in percentages of total protein, fat casein, lactose, lactalbumin, short and medium-chain fatty acids, IgG and IgA for the first four lactations. Further, the elevated heat load index was correlated with decline in lactose, protein and fat concentration in milk[66]. Elevated temperature and humidity can reduce the ability of cattle to dissipate excess heat which can ultimately lead to heat stress and associated physiological changes such as reduced milk fat and protein[67]. In addition, milk solid, fat and protein concentrations in Holstein-Friesian (HF), New Zealand Jersey (NZJ) and HF×NZJ cows tend to decline for THI vales of 64.3, 66.7 and 73.3, respectively[68]. Heat stress can increase body temperature which may affect the fat synthesis of mammary gland[69]. From an experiment Gorniak *et al*.[70] estimated a reduction in milk fat and protein content for THI values above 60 in dairy cattle. Table 1 describes the impact of heat stress on milk yield and composition in different breeds of dairy cattle.

Impact of heat stress on udder health in cattle: Heat stress can cause adverse effects in udder thereby reduce milk yield. Cows are more prone to mastitis during summer season. Heat stress during dry period can adversely affect mammary gland development ultimately lead to subsequent milk yield[74]. Heat

Table 1: Species wise changes in milk composition and milk yield due to heat stress

Species	Milk production level	Milk composition	References
Jersey	Milk yield decreased	Reduction in milk protein and fat	Bandaranayaka and Holmes[63] and Kadzere *et al.*[26]
Holstein-Friesian	Milk yield decreased	Reduction in protein concentration casein number and casein concentration	Cowley *et al.*[58]
Zebu cattle (*Bos indicus*)	No significant yield reduction	No significant change in milk composition	Hansen[71]
Jersey	Increase in milk yield compared to Holstein	Reduction in fat and protein content	Smith *et al.*[72]
Tharparkar	No significant yield reduction	No significant change in SNF and fat	Alhussien *et al.*[73]

stress during dry period may trigger mammary gland involution accompanied with apoptosis and autophagy, decreased amount of mammary epithelial cells which can cause decline in milk yield[75]. Heat stress can weaken immune system of the cattle which will eventually facilitate mastitogenic udder infection[76]. Mastitis can spread from cow to cow via milking equipment and milker's hands[77]. The regenerative mammary gland involution which is vital for optimal cell proliferation will be compromised by alterations in autophagic activity induced by heat stress[75]. Cows dried off in summer months are more prone to mastitis than cows died off in cool months[74]. Further, heat stress can inhibit the flow of glucose to mammary glands[32]. Heat stress was found to influence oxidative glucose metabolism fluctuations and thereby control secretory cell number and level of secretory activities and secretory epithelium integrity of the udder. High temperature and humidity are very much favourable for the growth of mastitis causing bacteria like streptococci and coliforms less immunity during heat stress can increase possibility of diseases attack[78]. In a study about strength and weakness of dairy management at farm level, it was found that dairy cows with high Somatic Cell Count (SCC) (1.3 million cells mL^{-1}) had a severe udder infections[77,79]. The SCC was established to be a good indicator of udder health. During severe heat stress cows wallow in mud to regulate body temperature and usually such muddy udders are washed and milking such wet udder makes the animal more susceptible to intermammary diseases[80]. Further it was also established in dairy cattle that udder are very much sensitive to the variations in the THI[69]. In addition, it was also established that heat stressed dairy cows shows impaired mammary gland development during late gestation[81]. It has also been observed that even in adapted breeds like Tharparker cows showed mastitis during high temperature and humidity condition[73]. Also in another study, it was established that heat stress increased the frequency of mastitis in Karan Fries, Karan Swiss, Sahiwal and Tharparkar cows[82]. The incidence of mastitis in cows increases significantly with raise THI in comparison to Murrah buffaloes[82]. The higher frequency of mastitis in dairy cows during heat stress could be the reason that high temperatures facilitate the survival and multiplication of pathogenic vectors population associated with hot-humid conditions[33].

Histological changes in udder during heat stress: Heat stress can change the mammary histology of cow. Mastitis affected cows show drastic changes in the cell histology. From an experiment Kheira and Abdellatif[83] observed numerous inflammatory lesions on the affected udder quarter along with the disappearance of alveolar lumen, fibrosis and complete destruction of parenchyma. In the *Staphylococcus aureus* affected supramammary lymph node a sub capsular interstitial edema, suppurative lymphadenitis and hemorrhagic exudates were observed[84]. Mastitis affected cattle exhibited a lower macrophages, lymphocytes count and higher neutrophil count than the unaffected cattle. Mastitis cattle exhibited a variation in alveolar number, diameter and alveolar epithelial cell population than the healthy cattle[85]. Structural integrity loss of alveoli cells in the mammary gland are observed along with the damaged epithelium. The *S. aureus* affected mammary cells showed a reduction in milk secretion and synthesis, more inter alveolar stroma and less alveolar luminal space involuting alveolar epithelium than healthy cattle. All these changes are due to replacement of secretory tissue with non-secretory tissue[86,87]. Further in *E. coli* affected mammary cells, cellular wreckage with thick strand of fibrin and alveoli filled with caseated milk was observed[84]. In addition, mastitis affected tissues showed an irregular arrangement of nuclei along with changes in cell element. Major cell element established was fibrocytes along with some plasma cells and leucocytes[88]. Mycoplasma affected tissues showed inflammations in interlobular connective tissues and in the interalveoli and around large ducts in mastitis affected udder. Further histiocyte, fibroblast proliferation during mastistis may lead to broadening of inter alveolar stroma. Infiltration of plasma cells, eosinophils and mononuclear cells are generally visible in the infected quarters[89]. Mammary tissue of mastitis affected cattle showed a low protein staining and increased alkaline phosphate activity than healthy cattle[85]. Further, vaccular degeneration of mammary epithelial cells was observed in cattle affected with coagulase negative *Staphylococcus* mastitis, depletion of sub capsular edema and destruction of lymphoid center[84]. In addition, apoptosis may be identified by a characteristic pattern of morphological changes, including nuclear and cytoplasmic condensation, nuclear fragmentation and formation of apoptotic bodies in the infected udders[90].

Impact of heat stress on hormones controlling milk production: Various hormones contribute to the milk production in livestock. Heat stress can create a total imbalance in the endocrine system of cattle[91,92]. Heat stress can cause changes in hormone profiles like prolactin, thyroid hormones, glucocorticoid, growth hormone, adrenocorticotropic hormone (ACTH), oxytocin, estrogen and progesterone[92,93].

Prolactin is an essential hormone for lactogenesis and mammogenesis in cattle[94]. Any change in prolactin concentration during dry period can have negative impact in subsequent lactation[81,95]. Changes in the prolactin secretion during heat stress was correlated with body temperature changes with increased rectal temperature reducing the prolactin concentration[96]. It was generally observed that plasma prolactin concentration was found to increase during heat stress condition[92,97]. The increased prolactin was believed to be involved with meeting increased water and electrolyte demands of cattle that are affected by heat stress[92,98]. A threefold increase in prolactin level was observed for an air temperature rise from 18-32°C[96,99]. Further in another study, a 44% increase in prolactin concentration was observed in Holstein heifers for a temperature rise from 21-31°C. Conversely a 55-80% decline in serum prolactin was observed for a decline in temperature from 20-21 and 4-7°C[96,100,101]. The increased cortisol concentration in heat stressed dairy cattle was found to be associated with reduced milk production[102,103]. This could be attributed to the fact of deviation of available energy for coping up mechanisms to heat stress challenges.

Further, heat stress can also decrease the secretion of estradiol and luteinizing hormone. Lower concentration of estradiol in the follicular fluid of dominant follicles was estimated during summer season[104,105]. Estradiol is the hormone responsible for estrus expression. In a study conducted in Florida about 76-82% undetected estrus events are recorded during summer months than the average of 44-65% from October-May. Reduced concentration of estradiol was observed for an ambient temperature of 41°C due to the reduced expression of 17α-hydroxylase during heat stress[105]. The reduced estradiol concentration may lead to reduction in milk production throughby bringing about reduced reproductive efficiency in dairy cattle. Heat stress can also increase the secretion of progesterone when the dairy cows are exposed to 41°C. Bovine follicle cells usually exhibits endocrinological changes after LH or FSH surge *in vivo* with decreased production of androstenedione and increased progesterone secretion from theca cells whereas, decreased aromatizing capacity and increased progesterone and oxytocin is exhibited by granulosa cells. The increased progesterone concentration was also associated with reduced milk production in dairy cattle[105-108].

Plasma thyroxine and triiodothyronine level is found to be decreasing during heat stress than in normal thermoneutral conditions[109]. During heat stress concentrations of plasma T_3 and T_4 found to be decreasing[91,103,110] up to 25%. The reduced plasma thyroid hormone concentration may lead to reduced milk production by causing reduced feed intake. The reduced feed intake may lead to negative energy balance making energy level not sufficient for normal milk synthesis. Further, a decline in Growth Hormone (GH) was also observed for THI values beyond 70 in dairy cattle. This decline in GH was attributed to the suppressed hormone production to counter metabolic heat in dairy cows[4,22]. It has been observed that long term heat stress can decrease the circulating levels of growth hormone thereby reducing the milk production by causing negative energy balance[22,111].

Strategies to reduce negative impact of heat stress on milk production: The effect of heat stress on milk production may be reduced by providing suitable shelter, changing micro-environments and through nutritional supplementation[112]. Proper nutritional management may also be adopted by supplying of high energy feeds along with bypass protein, which will help animals to sustain their productivity under heat stress conditions[113]. Dairy cows are subjected to heat stress must be cooled to allow this heat exchange between the cow and her environment to occur and to prevent or at least minimize, increases in a cow's core body temperature[114]. By providing dairy cows shade increased ventilation and cooling of the surrounding air by fans alone or in combination with sprinklers, dairy cows are better able to minimize the detrimental effects of heat stress on milk production, reproduction and their immune system[113,115].

Dietary manipulation to alter microbutrients can also make a huge impact in reducing the negative impact of heat stress on milk production[116]. The appropriate concentrate and roughage ration should be maintained. The essential micronutrient consisting of mineral mixtures and antioxidants supplementation can yield a better result in ameliorating the heat stress induced reduction in milk production[115]. Efforts need to be made to increase the energy content of the diet by adding fat and high quality forages. Further, yiest supplementation also was found to reduce the negative effect of heat stress on dairy cows[113]. Optimization of ruminally undegraded protein improves milk yield in hot climates. The dry matter intake and milk yield increases for cows fed with diets containing 14% of acid detergent fiber. Further, increasing the dietary fat content also augments milk production efficiency and yield in the heat stressed dairy cows[33].

CONCLUSION

Heat stress is considered to be the primary factor reducing milk production in dairy cows which ultimately culminates in severe economic loss to livestock farmers around the world. Heat stress not only reduces the milk production but also affects the quality of milk by altering various components of milk. This review provides a clear insight into how heat stress affects milk production and elucidates the mechanisms through which the reduced milk production is brought about while an animal is exposed to heat stress challenges. Genetic potential of an animal plays an important role in deciding the reduction percentage of milk. The high producing dairy cows seems to be more affected for the heat stress effects than the low producing one. Further, extensive studies are required though to clearly identify the exact loss of milk production incurred throughout the world.

ACKNOWLEDGMENT

The authors greatly acknowledge the support received from director NIANP for permitting this review article.

REFERENCES

1. Gaughan, J.B., T.L. Mader, S.M. Holt, M.L. Sullivan and G.L. Hahn, 2010. Assessing the heat tolerance of 17 beef cattle genotypes. Int. J. Biometeorol., 54: 617-627.
2. Sejian, V., 2012. Introduction. In: Environmental Stress and Amelioration in Livestock Production, Sejian, V., S.M.K. Naqvi, T. Ezeji, J. Lakritz and R. Lal (Eds.). Springer, Germany, pp: 1-18.
3. Dahl, G.E., S. Tao and A.P.A. Monteiro, 2016. Effects of late-gestation heat stress on immunity and performance of calves. J. Dairy Sci., 99: 3193-3198.
4. West, J.W., 2003. Effects of heat-stress on production in dairy cattle. J. Dairy Sci., 86: 2131-2144.
5. Daramola, J.O., M.O. Abioja and O.M. Onagbesan, 2012. Heat Stress Impact on Livestock Production. In: Environmental Stress and Amelioration in Livestock Production, Sejian, V., S.M.K. Naqvi, T. Ezeji, J. Lakritz and R. Lal (Eds.). Springer, Germany, pp 53.
6. Wolfenson, D., Z. Roth and R. Meidan, 2000. Impaired reproduction in heat-stressed cattle: Basic and applied aspects. Anim. Reprod. Sci., 60: 535-547.
7. Pegorer, M.F., J.L. Vasconcelos, L.A. Trinca, P.J. Hansen and C.M. Barros, 2007. Influence of sire and sire breed (Gyr versus Holstein) on establishment of pregnancy and embryonic loss in lactating Holstein cows during summer heat stress. Theriogenology, 67: 692-697.
8. Herrero, M., P.K. Thornton, A. Notenbaert, S. Msangi and S. Wood *et al*., 2009. Drivers of change in crop-livestock systems and their potential impacts on agro-ecosystems services and human well-being to 2030. CGIAR Systemwide Livestock Programme, ILRI, Nairobi, Kenya, pp: 1-114.
9. FAO., 2015. Livestock and the environment. http://www.fao.org/livestock-environment/en/
10. St-Pierre, N.R., B. Cobanov and G. Schnitkey, 2003. Economic losses from heat stress by US livestock industries. J. Dairy Sci., 86: E52-E77.
11. Baumgard, L.H., R.P. Rhoads, M.L. Rhoads, N.K. Gabler and J.W. Ross *et al*., 2012. Impact of Climate Change on Livestock Production. In: Environmental Stress and Amelioration in Livestock Production, Sejian, V., S.M.K. Naqvi, T. Ezeji, J. Lakritz and R. Lal (Eds.). Springer-Verlag, Germany, pp: 413-468.
12. West, J.W., 1999. Nutritional strategies for managing the heat-stressed dairy cow. J. Anim. Sci., 77: 21-35.
13. Ziggers, D., 2012. Heat stress in dairy cows review. AllAboutFeed.net, 20: 26-27.
14. Collier, R.J. and R.B. Zimbelman, 2007. Heat stress effects on cattle: What we know and what we don't know. Proceedings of the 22nd Annual Southwest Nutrition and Management Conference, February 22-23, 2007, Tempe, AZ., USA.
15. Key, N., S. Sneeringer and D. Marquardt, 2014. Climate change, heat stress and U.S. dairy production. A Report Summary from the Economic Research Service, United States Department of Agriculture. http://www.ers.usda.gov/media/1679930/err175.pdf
16. Ray, D.E., T.J. Halbach and D.V. Armstrong, 1992. Season and lactation number effects on milk production and reproduction of dairy cattle in Arizona. J. Dairy Sci., 75: 2976-2983.
17. Spiers, D.E., J.N. Spain, J.D. Sampson and R.P. Rhoads, 2004. Use of physiological parameters to predict milk yield and feed intake in heat-stressed dairy cows. J. Thermal Biol., 29: 759-764.
18. Ravagnolo, O., I. Misztal and G. Hoogenboom, 2000. Genetic component of heat stress in dairy cattle, development of heat index function. J. Dairy Sci., 83: 2120-2125.
19. Bouraoui, R., M. Lahmar, A. Majdoub, M. Djemali and R. Belyea, 2002. The relationship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate. Anim. Res., 51: 479-491.

20. Gantner, V., P. Mijic, K. Kuterovac, D. Solic and R. Gantner, 2011. Temperature-humidity index values and their significance on the daily production of dairy cattle. Mljekarstvo, 61: 56-63.
21. Rhoads, M.L., R.P. Rhoads, M.J. VanBaale, R.J. Collier and S.R. Sanders *et al*., 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism and aspects of circulating somatotropin. J. Dairy Sci., 92: 1986-1997.
22. Igono, M.O., H.D. Johnson, B.J. Steevens, W.A. Hainen and M.D. Shanklin, 1988. Effect of season on milk temperature, milk growth hormone, prolactin and somatic cell counts of lactating cattle. Int. J. Biometeorol., 32: 194-200.
23. Temple, D., F. Bargo, E. Mainau, I. Ipharraguerre and X. Manteca, 2015. Heat stress and efficiency in dairy milk production: A practical approach. The Farm Animal Welfare Fact Sheet No. 12, Farm Animal Welfare Education Centre. http://www.fawec.org/media/com_lazypdf/pdf/fs12-en.pdf
24. Silanikove, N., F. Shapiro and D. Shinder, 2009. Acute heat stress brings down milk secretion in dairy cows by up-regulating the activity of the milk-borne negative feedback regulatory system. BMC Physiol., Vol. 9. 10.1186/1472-6793-9-13.
25. Baumgard, L.H. and R.P. Rhoads, 2012. Ruminant nutrition symposium: Ruminant production and metabolic responses to heat stress. J. Anim. Sci., 90: 1855-1865.
26. Kadzere, C.T., M.R. Murphy, N. Silanikove and E. Maltz, 2002. Heat stress in lactating dairy cows: A review. Livestock Prod. Sci., 77: 59-91.
27. Baumgard, L.H., J.B. Wheelock, G. Shwartz, M.O. Brien and M.J. van Baale *et al*., 2006. Effects of heat stress on nutritional requirements of lactating dairy cattle. Proceedings of the 5th Annual Arizona Dairy Production Conference, October 10, 2006, Tempe, AZ., pp: 8-17.
28. Morrill, K., 2011. Heat stress-impact on lactating cattle. Cornell University Cooperative Extension. http://www.ccenny.com/wp-content/uploads/2011/12/Heat-Stress-Part-impact-lactating-cows.pdf
29. Collier, R.J., R.B. Zimbelman, R.P. Rhoads, M.L. Rhoads and L.H. Baumgard, 2009. A re-evaluation of the impact of temperature humidity index (THI) and black globe humidity index (BGHI) on milk production in high producing dairy cows. Proceedings of the 24th Annual Southwest Nutrition and Management Conference, February 26-27, 2009, Tempe, Arizona, pp: 113-125.
30. Allen, J.D., S.D. Anderson, R.J. Collier and J.F. Smith, 2013. Managing heat stress and its impact on cow behavior. Proceedings of the Western Dairy Management Conference, March 6-8, 2013, Reno, NV., pp: 150-162.
31. Thornton, P.K., R.B. Boone and J.R. Villegas, 2015. Climate change impacts on livestock. Working Paper No. 120, CGIAR Research Program on Climate Change, Agriculture and Food Security, Denmark.
32. Wheelock, J.B., R.P. Rhoads, M.J. VanBaale, S.R. Sanders and L.H. Baumgard, 2010. Effects of heat stress on energetic metabolism in lactating Holstein cows. J. Dairy Sci., 93: 644-655.
33. Das, R., L. Sailo, N. Verma, P. Bharti, J. Saikia, Imtiwati and R. Kumar, 2016. Impact of heat stress on health and performance of dairy animals: A review. Vet. World, 9: 260-268.
34. Broucek, J., J. Novak, J. Vokralova, M. Soch, P. Kisac and M. Uhrinca, 2009. Effect of high temperature on milk production of cows from free-stall housing with natural ventilation. Slovak J. Anim. Sci., 42: 167-173.
35. Zhu, W., B.X. Zhang, K.Y. Yao, I. Yoon, Y.H. Chung, J.K. Wang and J.X. Liu, 2016. Effects of supplemental levels of *Saccharomyces cerevisiae* fermentation product on lactation performance in dairy cows under heat stress. Asian-Aust. J. Anim. Sci., 29: 801-806.
36. Rejeb, M., T. Najar and M.B. M'Rad, 2012. The effect of heat stress on dairy cow's performance and animal behaviour. Int. J. Plant Anim. Environ. Sci., 2: 29-34.
37. Brown, B.M., J.W. Stallings, J.S. Clay and M.L. Rhoads, 2015. Periconceptional heat stress of holstein dams is associated with differences in daughter milk production and composition during multiple Lactations. PLoS ONE, Vol. 11. 10.1371/journal.pone.0133574.
38. Ravagnolo, O. and I. Misztal, 2000. Genetic component of heat stress in dairy cattle, parameter estimation. J. Dairy Sci., 83: 2126-2130.
39. Joksimovic-Todorovic, M., V. Davidovic, S. Hristov and B. Stankovic, 2011. Effect of heat stress on milk production in dairy cows. Biotechnol. Anim. Husbandry, 27: 1017-1023.
40. Arieli, A., G. Adin and I. Bruckental, 2004. The effect of protein intake on performance of cows in hot environmental temperatures. J. Dairy Sci., 87: 620-629.
41. Bernabucci, U., N. Lacetera, L.H. Baumgard, R.P. Rhoads, B. Ronchi and A. Nardone, 2010. Metabolic and hormonal acclimation to heat stress in domesticated ruminants. Animal, 4: 1167-1183.
42. Sharma, A.K., L.A. Rodriguez, G. Mekonnen, C.J. Wilcox, K.C. Bachman and R.J. Collier, 1983. Climatological and genetic effects on milk composition and yield. J. Dairy Sci., 66: 119-126.
43. Bajagai, Y.S., 2011. Global climate change and its impacts on dairy cattle. Nepalese Vet. J., 30: 2-16.
44. Ominski, K.H., A.D. Kennedy, K.M. Wittenberg and S.A. Moshtaghi Nia, 2002. Physiological and production responses to feeding schedule in lactating dairy cows exposed to short-term, moderate heat stress. J. Dairy Sci., 85: 730-737.
45. Nardone, A., B. Ronchi, N. Lacetera, M.S. Ranieri and U. Bernabucci, 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Sci., 130: 57-69.

46. Dikmen, S., F.A. Khan, H.J. Huson, T.S. Sonstegard, J.I. Moss, G.E. Dahl and P.J. Hansen, 2014. The SLICK hair locus derived from Senepol cattle confers thermotolerance to intensively managed lactating Holstein cows. J. Dairy Sci., 97: 5508-5520.
47. Dikmen, S., X.Z. Wang, M.S. Ortega, J.B. Cole, D.J. Null and P.J. Hansen, 2015. Single nucleotide polymorphisms associated with thermoregulation in lactating dairy cows exposed to heat stress. J. Anim. Breed Genet., 132: 409-419.
48. Santana, Jr. M.L., A.B. Bignardi, R.J. Pereira, A. Menendez-Buxadera and L. El Faro, 2016. Random regression models to account for the effect of genotype by environment interaction due to heat stress on the milk yield of Holstein cows under tropical conditions. J. Applied Genet., 57: 119-127.
49. Garcia, A.B., N. Angeli, L. Machado, F.C. de Cardoso and F. Gonzalez, 2015. Relationships between heat stress and metabolic and milk parameters in dairy cows in Southern Brazil. Trop. Anim. Health Prod., 47: 889-894.
50. Reinemann, D.J., T.R. Smith, M.B. Timmons and A.P. Meyers, 1992. Cumulative effects of heat stress on milk production in Holstein herds. ASAE Technical Paper No. 924027, American Society of Agricultural Engineers, June 21-24, 1992, Charolette, North Carolina, pp: 1-6.
51. Nardone, A., B. Ronchi, N. Lacetera and U. Bernabucci, 2006. Climatic effects on productive traits in livestock. Vet. Res. Commun., 30: 75-81.
52. Renna, M., C. Lussiana, V. Malfatto, A. Mimosi and L.M. Battaglini, 2010. Effect of exposure to heat stress conditions on milk yield and quality of dairy cows grazing on Alpine pasture. Proceedings of the 9th European IFSA Symposium on Climate Change: Agriculture, Food Security and Human Health, July 4-7, 2010, Vienna, Austria, pp: 1338-1348.
53. Donnelly, M., 2012. Economic impacts of heat stress. University of Minnesota Dairy Extension. http://www.extension.umn.edu
54. Hill, D.L. and E. Wall, 2015. Dairy cattle in a temperate climate: The effects of weather on milk yield and composition depend on management. Animal, 9: 138-149.
55. Noordhuizen, J. and J.M. Bonnefoy, 2015. Heat stress in dairy cattle: Major effects and practical management measures for prevention and control. SOJ J. Vet. Sci., 1: 1-7.
56. Bernabucci, U., L. Basirico, P. Morera, D. Dipasquale, A. Vitali, F.P. Cappelli and L. Calamari, 2015. Effect of summer season on milk protein fractions in Holstein cows. J. Dairy Sci., 98: 1815-1827.
57. Tao, S., J.W. Bubolz, B.C. do Amaral, I.M. Thompson, M.J. Hayen, S.E. Johnson and G.E. Dahl, 2011. Effect of heat stress during the dry period on mammary gland development. J. Dairy Sci., 94: 5976-5986.
58. Cowley, F.C., D.G. Barber, A.V. Houlihan and D.P. Poppi, 2015. Immediate and residual effects of heat stress and restricted intake on milk protein and casein composition and energy metabolism. J. Dairy Sci., 98: 2356-2368.
59. Berman, A., 2005. Estimates of heat stress relief needs for Holstein dairy cows. J. Anim. Sci., 83: 1377-1384.
60. Chebel, R.C., J.E.P. Santos, J.P. Reynolds, R.L.A. Cerri, S.O. Juchem and M. Overton, 2004. Factors affecting conception rate after artificial insemination and pregnancy loss in lactating dairy cows. Anim. Reprod. Sci., 84: 239-255.
61. Hossein-Zadeh, N.G., A. Mohit and N. Azad, 2013. Effect of temperature-humidity index on productive and reproductive performances of Iranian Holstein cows. Iran. J. Vet. Res., 14: 106-112.
62. Coppock, C.E., 1978. Feeding Energy to Dairy Cattle. In: Large Dairy Management, Coppock, C.E. (Ed.). University Presses of Florida, Gainesville, pp: 265-268.
63. Bandaranayaka, D.D. and C.W. Holmes, 1976. Changes in the composition of milk and rumen contents in cows exposed to a high ambient temperature with controlled feeding. Trop. Anim. Health Prod., 8: 38-46.
64. Gaafar, H.M.A., M.E. El-Gendy, M.I. Bassiouni, S.M. Shamiah, A.A. Halawa and M.A. El-Hamd, 2011. Eefect of heat stress on perfprmance of dairy Friesian cows 1-milk production and composition. Researcher, 3: 85-93.
65. Nardone, A., N. Lacetera, U. Bernabucci and B. Ronchi, 1997. Composition of colostrum from dairy heifers exposed to high air temperatures during late pregnancy and the early postpartum period. J. Dairy Sci., 80: 838-844.
66. Van Laer, E., F.A.M. Tuyttens, B. Ampe, B. Sonck, C.P.H. Moons and L. Vandaele, 2015. Effect of summer conditions and shade on the production and metabolism of Holstein dairy cows on pasture in temperate climate. Animal, 9: 1547-1558.
67. Novak, P., J. Vokralova, I. Knizkova, P. Kunc and J. Roznovsky, 2007. The influence of high ambient temperatures in particular stages of lactation on milk production of Holstein dairy cows. Proceedings of the International Scientific Conference on Bioclimatology and Natural Hazards, September 17-20, 2007, Slovakia.
68. Bryant, J.R., N. Lopez Villalobos, J.E. Pryce, C.W. Holmes and D.L. Johnson, 2007. Quantifying the effect of thermal environment on production traits in three breeds of dairy cattle in New Zealand. N. Z. J. Agric. Res., 50: 327-338.
69. Hammami, H., J. Vandenplas, M.L. Vanrobays, B. Rekik, C. Bastin and N. Gengler, 2015. Genetic analysis of heat stress effects on yield traits, udder health and fatty acids of Walloon Holstein cows. J. Dairy Sci., 98: 4956-4968.
70. Gorniak, T., U. Meyer, K.H. Sudekum and S. Danicke, 2014. Impact of mild heat stress on dry matter intake, milk yield and milk composition in mid-lactation Holstein dairy cows in a temperate climate. Arch. Anim. Nutr., 68: 358-369.

71. Hansen, P.J., 2004. Physiological and cellular adaptations of Zebu cattle to thermal stress. Anim. Rep. Sci., 82-83: 349-360.
72. Smith, D.L., T. Smith, B.J. Rude and S.H. Ward, 2013. Comparison of the effects of heat stress on milk and component yields and somatic cell score in Holstein and Jersey cows. J. Dairy Sci., 96: 3028-3033.
73. Alhussien, M., P. Manjari, S. Mohammed, A.A. Sheikh, S. Reddi, S. Dixit and A.K. Dang, 2016. Incidence of mastitis and activity of milk neutrophils in Tharparkar cows reared under semi-arid conditions. Trop. Anim. Health Prod., 48: 1291-1295.
74. Tao, S., E.E. Connor, J.W. Bubolz, I.M. Thompson, B.C. do Amaral, M.J. Hayen and G.E. Dahl, 2013. Effect of heat stress during the dry period on gene expression in mammary tissue and peripheral blood mononuclear cells. J. Dairy Sci., 96: 378-383.
75. Wohlgemuth, S.E., Y. Ramirez-Lee, S. Tao, A.P.A. Monteiro, B.M. Ahmed and G.E. Dahl, 2016. Effect of heat stress on markers of autophagy in the mammary gland during the dry period. J. Dairy Sci., 99: 4875-4880.
76. Giesecke, W.H., 1985. The effect of stress on udder health of dairy cows. J. Vet. Res., 52: 175-193.
77. Lam, V., K. Ostensson, K. Svennersten-Sjaunja, L. Norell and E. Wredle, 2011. Management factors influencing milk somatic cell count and udder infection rate in smallholder dairy cow herds in southern vietnam. J. Anim. Vet. Adv., 10: 847-852.
78. Nickerson, S.C., 2014. Management strategies to reduce heat stress, prevent mastitis and improve milk quality in dairy cows and heifers. UGA Extension Bulletin. http://extension.uga.edu/publications/detail.cfm?number=B1426
79. Lam, V., E. Wredle, N.T. Thao, N. van Man and K. Svennersten-Sjaunja, 2010. Smallholder dairy production in Southern Vietnam: Production, management and milk quality problems. Afr. J. Agric. Res., 5: 2668-2675.
80. Vermunt, J.J. and B.P. Tranter, 2011. Heat stress in dairy cattle and some of the potential risks associated with the nutritional management of this condition. Proceedings of the Australian Veterinary Association Conference, March 25-27, 2011, Australia, pp: 212-221.
81. Tao, S. and G.E. Dahl, 2013. Heat stress effects during late gestation on dry cows and their calves. J. Dairy Sci., 96: 4079-4093.
82. Jingar, S.C., R.K. Mehla and M. Singh, 2014. Climatic effects on occurrence of clinical mastitis in different breeds of cows and buffaloes. Archivos Zootecnia, 63: 473-482.
83. Kheira, G. and N. Abdellatif, 2014. Impact of subclinical mastitis on the health of the mammary gland. Global Veterinaria, 12: 193-196.
84. Abeer, E.E.M. and A.E.A. Hanaa, 2008. Mastitis pathogens in relation to histopathological changes in buffalo udder tissues and supramammary lymph nodes. Egypt. J. Comp. Pathol. Clin. Pathol., 21: 190-208.
85. Hussain, R., M.T. Javed, A. Khan, F. Mahmood and R. Kausar, 2012. Mastitis and associated histo-pathological consequences in the context of udder morphology. Int. J. Agric. Biol., 14: 947-952.
86. Nickerson, S.C. and C.W. Heald, 1981. Histopathologic response of the bovine mammary gland to experimentally induced *Staphylococcus aureus* infection. Am. J. Vet. Res., 42: 1351-1355.
87. Zhao, X. and P. Lacasse, 2008. Mammary tissue damage during bovine mastitis: Causes and control. J. Anim. Sci., 86: 57-65.
88. Yamagiwa, S., T. Ono, T. Uemura and T. Ida, 1957. Histopathological studies on bovine mammary gland I: Histological findings of mastitis. Jpn. J. Vet. Res., 5: 141-165.
89. Van der Molen, E.J. and G. Grootenhuis, 1979. An investigation of the pathology of Mycoplasma mastitis in the cow. Vet. Quart., 1: 126-133.
90. Strange, R., F. Li, S. Saurer, A. Burkhardt and R.R. Friis, 1992. Apoptotic cell death and tissue remodelling during mouse mammary gland involution. Development, 115: 49-58.
91. Beede, D.K. and R.J. Collier, 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. J. Anim. Sci., 62: 543-554.
92. Farooq, U., H.A. Samad, F. Shehzad and A. Qayyum, 2010. Physiological responses of cattle to heat stress. World Applied Sci. J., 8: 38-43.
93. Akers, R.M., D.E. Bauman, A.V. Capuco, G.T. Goodman and H.A. Tucker, 1981. Prolactin regulation of milk secretion and biochemical differentiation of mammary epithelial cells in periparturient cow. Endocrinology, 109: 23-30.
94. Tucker, H.A., 2000. Hormones, mammary growth and lactation: A 41-year perspective. J. Dairy Sci., 83: 874-884.
95. Wall, E.H., T.L. Auchtung, G.E. Dahl, S.E. Ellis and T.B. McFadden, 2005. Exposure to short day photoperiod during the dry period enhances mammary growth in dairy cows. J. Dairy Sci., 88: 1994-2003.
96. Alamer, M., 2011. The role of prolactin in thermoregulation and water balance during heat stress in domestic ruminants. Asian J. Anim. Vet. Adv., 6: 1153-1169.
97. Wettemann, R.P. and H.A. Tucker, 1974. Relationship of ambient temperature to serum prolactin in heifers. Exp. Biol. Med., 146: 908-911.
98. Collier, R.J., S.G. Doelger, H.H. Head, W.W. Thatcher and C.J. Wilcox, 1982. Effects of heat stress during pregnancy on maternal hormone concentrations, calf birth weight and postpartum milk yield of Holstein cows. J. Anim. Sci., 54: 309-319.
99. Ronchi, B., G. Stradaioli, A.V. Supplizi, U. Bernabucci and N. Lacetera *et al*., 2001. Influence of heat stress or feed restriction on plasma progesterone, oestradiol-17β, LH, FSH, prolactin and cortisol in Holstein heifers. Livestock Prod. Sci., 68: 231-241.

100. Smith, V.G., R.R. Hacker and R.G. Brown, 1977. Effect of alterations in ambient temperature on serum prolactin concentration in steers. J. Anim. Sci., 44: 645-649.
101. Wettermann, R.P., H.A. Tucker, T.W. Beck and D.C. Meyerhoeffer, 1982. Influence of ambient temperature on prolactin concentrations in serum of holstein and brahman x hereford heifers. J. Anim. Sci., 55: 391-394.
102. Abilay, T.A., R. Mitra and H.D. Johnson, 1975. Plasma cortisol and total progestin levels in Holstein steers during acute exposure to high environmental temperature (42°C) conditions. J. Anim. Sci., 41: 113-117.
103. Silanikove, N., 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livestock Prod. Sci., 67: 1-18.
104. Wolfenson, D., B.J. Lew, W.W. Thatcher, Y. Graber and R. Meidan, 1997. Seasonal and acute heat stress effects on steroid production by dominant follicles in cows. Anim. Reprod. Sci., 47: 9-19.
105. Bridges, P.J., M.A. Brusie and J.E. Fortune, 2005. Elevated temperature (heat stress) *in vitro* reduces androstenedione and estradiol and increases progesterone secretion by follicular cells from bovine dominant follicles. Domest. Anim. Endocrinol., 29: 508-522.
106. Berndtson, A.K., S.E. Vincent and J.E. Fortune, 1995. Effects of gonadotrophin concentration on hormone production by theca interna and granulosa cells from bovine preovulatory follicles. J. Reprod. Fertil.
107. Komar, C.M., 1998. Effects of the Luteinizing Hormone Surge on the Capacity of Preovulatory Follicles to Secrete Steroids and Oxytocin and the Molecular Mechanisms that Mediate Periovulatory Changes in Steroidogenesis in Cattle. Cornell University, USA., Pages: 127.
108. Komar, C.M., A.K. Berndtson, A.C.O. Evans and J.E. Fortune, 2001. Decline in circulating estradiol during the periovulatory period is correlated with decreases in estradiol and androgen and in messenger RNA for P450 aromatase and P450 17α-hydroxylase, in bovine preovulatory follicles. Biol. Reprod., 64: 1797-1805.
109. Aggarwal, A. and R. Upadhyay, 2013. Heat Stress and Animal Productivity. Springer, New York, USA., ISBN: 9788132208792, Pages: 188.
110. Magdub, A., H.D. Johnson and R.L. Belyea, 1982. Effect of environmental heat and dietary fiber on thyroid physiology of lactating cows. J. Dairy Sci., 65: 2323-2331.
111. Mitra, R., G.I. Christison and H.D. Johnson, 1972. Effect of prolonged thermal exposure on Growth Hormone (GH) secretion in cattle. J. Anim. Sci., 34: 776-779.
112. Maurya, V.P., R. Reshma, M.K. Bharti, D. Rani and P. Kumar *et al*., 2014. Effect of Thermal Stress on Milk Production in Livestock. In: CAFT in Veterinary Physiology Short Course on Physiological Capacity Building for Enhancing Reproductive Efficiency Through Nutritional Interventions, Maurya, V.P., G. Singh, M. Sarkar, V. Chandra and G.T. Sharma (Eds.). Indian Veterinary Research Institute, Izatnagar, pp: 46-49.
113. Amaral-Phillips, D.M., 2016. Dairy feeding and management considerations during heat stress. http://articles.extension.org/pages/67811/dairy-feeding-and-management-considerations-during-heat-stress
114. Sejian, V., L. Samal, N. Haque, M. Bagath and I. Hyder *et al*., 2015. Overview on Adaptation, Mitigation and Amelioration Strategies to Improve Livestock Production under the Changing Climatic Scenario. In: Climate Change Impact on Livestock: Adaptation and Mitigation, Sejian, V., J. Gaughan, L. Baumgard and C.S. Prasad (Eds.). Springer Publisher, New Delhi, India, pp: 359-398.
115. Chandra, V., V. Sejian and G.T. Sharma, 2015. Strategies to Improve Livestock Reproduction Under the Changing Climate Scenario. In: Climate Change Impact on Livestock: Adaptation and Mitigation, Sejian, V., J. Gaughan, L. Baumgard and C.S. Prasad (Eds.). Springer Publisher, New Delhi, India, pp: 425-440.
116. Shaji, S., P.A. Abdul Niyas, K. Chaidanya, V. Sejian and R. Bhatta *et al*., 2015. Ameliorative strategies to sustain livestock production during heat stress. J. Vet. Sci. Med. Diagn., Vol. 4. 10.4172/2325-9590.1000161.