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Review Article

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

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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

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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 factors 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 efficiency³. 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 address 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 etc⁸. 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 increase⁹ 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 another study it was established that severe heat stress caused a loss of \$800 million dollars to the US dairy industry¹³. Further, it was also reported that the Californian dairy farmers lost more than 1 billion dollar of milk and animals during 2006 heat wave¹⁴. 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 sector¹⁵.

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 lactose¹⁵. 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 mastitis²². Further, heat stress also can cause immunosuppression by inhibiting rumination thereby leading to more chances of disease occurrence in dairy cattle²³. 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 heat²⁶. 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 ovulation²³. 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 date²⁸. The decreased milk production during heat stress can be due to dwindled nutrient uptake by portal drained viscera of the cattle and decreased nutrient uptake²⁰.

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 intake²⁹⁻³¹. 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 lactation⁴. 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 temperature⁴. 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 stress²¹. Decreased nutrient absorption, alteration in rumen function and hormonal imbalance are other factors which contributes to reduced

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

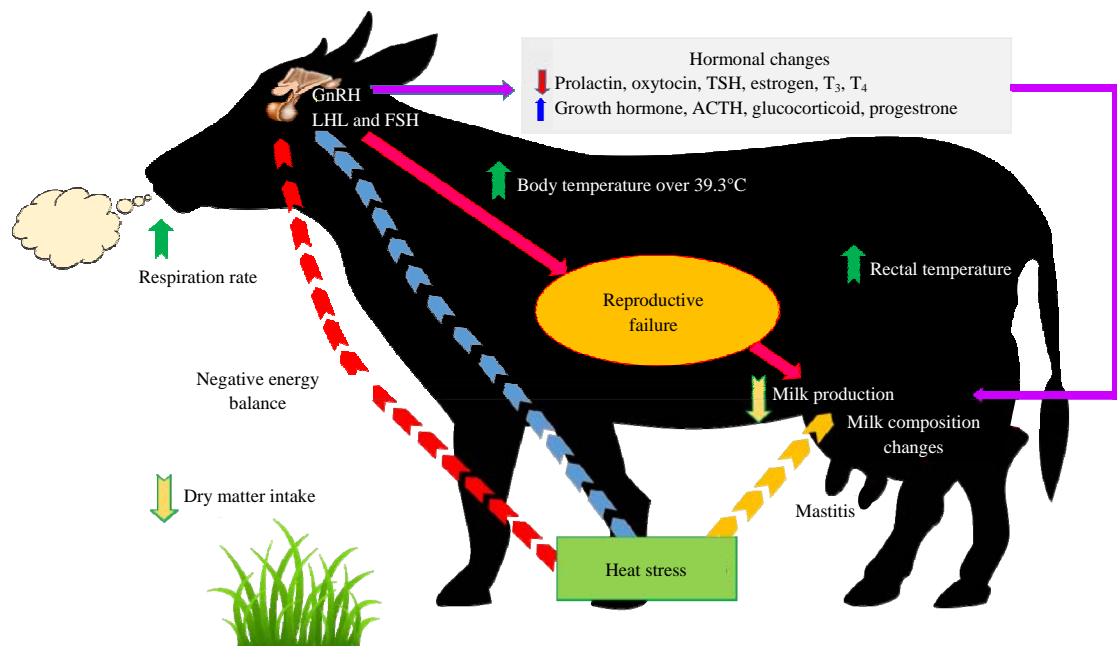


Fig. 1: Pictorial representation of heat stress impacting milk production in dairy cattle

milk production during heat stress⁴¹. The above consequences of heat stress are harmful to high yielding cows that are already under huge metabolic strain³⁷. 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 kg⁴⁴. Further, heat stressed Holstein cows with high rectal temperature showed reduction in milk yield and reduced reproductive efficiency⁴⁷. 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 66⁴⁸. 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°C⁵⁰. 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 recorded¹⁹. 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 milkyield gets further intensified, due to reduced feed intake by the cattle to counter the heat stress⁴⁵. 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 cows³². 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 stress⁵⁶. 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 lactation⁵⁷. 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 year⁵³. 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 cows²⁶. 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 synthesis⁵⁸. 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 milk⁶⁶. 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 protein⁶⁷. 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, respectively⁶⁸. Heat stress can increase body temperature which may affect the fat synthesis of mammary gland⁶⁹. From an experiment Goniak *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 yield⁷⁴. 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 <i>et al.</i> ²⁶ |
| Holstein-Friesian | Milk yield decreased | Reduction in protein concentration casein number and casein concentration | Cowley <i>et al.</i> ⁵⁸ |
| Zebu cattle (<i>Bos indicus</i>) | 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 <i>et al.</i> ⁷² |
| Tharparkar | No significant yield reduction | No significant change in SNF and fat | Alhussien <i>et al.</i> 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 yield⁷⁵. Heat stress can weaken immune system of the cattle which will eventually facilitate mastitogenic udder infection⁷⁶. Mastitis can spread from cow to cow via milking equipment and milker's hands⁷⁷. The regenerative mammary gland involution which is vital for optimal cell proliferation will be compromised by alterations in autophagic activity induced by heat stress⁷⁵. Cows dried off in summer months are more prone to mastitis than cows dried off in cool months⁷⁴. Further, heat stress can inhibit the flow of glucose to mammary glands³². 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 attack⁷⁸. 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 diseases⁸⁰. Further it was also established in dairy cattle that udder are very much sensitive to the variations in the THI⁶⁹. In addition, it was also established that heat stressed dairy cows shows impaired mammary gland development during late gestation⁸¹. It has also been observed that even in adapted breeds like Tharparkar cows showed mastitis during high temperature and humidity condition⁷³. Also in another study, it was established that heat stress increased the frequency of mastitis in Karan Fries, Karan Swiss, Sahiwal and Tharparkar cows⁸². The incidence of mastitis in cows increases significantly with raise THI in comparison to Murrah buffaloes⁸². 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 conditions³³.

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 Abdellatif⁸³ 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 observed⁸⁴. 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 cattle⁸⁵. 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 observed⁸⁴. 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 leucocytes⁸⁸. 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 mastitis may lead to broadening of inter alveolar stroma. Infiltration of plasma cells, eosinophils and mononuclear cells are generally visible in the infected quarters⁸⁹. Mammary tissue of mastitis affected cattle showed a low protein staining and increased alkaline phosphate activity than healthy cattle⁸⁵. Further, vacuolar degeneration of mammary epithelial cells was observed in cattle affected with coagulase negative *Staphylococcus* mastitis, depletion of sub capsular edema

and destruction of lymphoid center⁸⁴. 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 udders⁹⁰.

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, adrenocorticotrophic hormone (ACTH), oxytocin, estrogen and progesterone^{92,93}.

Prolactin is an essential hormone for lactogenesis and mammatogenesis in cattle⁹⁴. 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 concentration⁹⁶. 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 17 α -hydroxylase during heat stress¹⁰⁵. The reduced estradiol concentration may lead to reduction in milk production through by 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 cattle¹⁰⁵⁻¹⁰⁸.

Plasma thyroxine and triiodothyronine level is found to be decreasing during heat stress than in normal thermoneutral conditions¹⁰⁹. During heat stress concentrations of plasma T₃ and T₄ 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 supplementation¹¹². 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 conditions¹¹³. 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 temperature¹¹⁴. 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 production¹¹⁶. 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 production¹¹⁵. Efforts need to be made to increase the energy content of the diet by

adding fat and high quality forages. Further, yeast supplementation also was found to reduce the negative effect of heat stress on dairy cows¹¹³. 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 cows³³.

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.

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