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# Impact of thermal stress on milk production, composition and fatty acid profile in dairy cows: A review

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**Abstract**
Thermal stress is one of the major issues affecting the production capacity of dairy cows almost in every area of the globe. Thermal stress lowers feed intake, milk yield, compromised rumination and nutrient absorption and increased respiratory rate and sweating. Thermal stress adversely affects milk production and its composition in dairy animals, especially in animals of high genetic merit. Elevated temperature and humidity affect various components of milk such as fat (%), SNF, protein and fatty acid profile also. Thermal stress was associated with a decline in total protein and fat content. Cow milk has potential benefit to human health as it contains a large number of fatty acids (FA), including polyunsaturated fatty acids (PUFA) and conjugated linoleic acid (CLA). Milk fat in summer consists of more linoleic acid, linolenic acid, oleic acid and CLA than in winter. Total saturated fatty acids (SFA) content was higher in summer, where as total monounsaturated fatty acid (MUFA), polyunsaturated fatty acid (PUFA) and conjugated linoleic acid (CLA) concentration were lower in summer as compared to winter season. It may be concluded from this review that thermal stress adversely affects both quantity as well as quality of milk in high yielding dairy cows and therefore effective mitigation strategies should be implemented to minimize the negative effects of high ambient temperature and to boost the production performance of high yielding dairy cows.

**Keywords:** Thermal stress, dairy cows, milk production, composition, fatty acid

## Introduction

India ranks first in milk production. India's milk production increased from 176.3 million tones in 2017-18 to 187.7 million tones in 2018-19, accounting a growth rate of 6.46 per cent according to ESI [1]. The per capita availability of milk in India has increased from 375 gm/day in 2017-18 to 394 gm/day during 2018-19 and it is estimated to increase up to 592 gm/day by 2023-24 [2]. India is a tropical country whose major part is characterized as humid tropic and is subjected to extended periods of high ambient temperature and humidity. All livestock species maintain their body temperature within a close defined thermoregulatory limit regardless of the external environmental variations. The endeavor by thermoregulatory processes to stabilize body core temperature within a set narrow limit is essential to control biochemical reactions and physiological processes associated with normal metabolism [3]. Dairy animals are homeotherms (maintain constant body temperature) and therefore, when the environmental temperature rises or falls abnormally, the animals are subjected to stress. This thermal stress lowers feed intake, milk yield [4], compromised rumination and nutrient absorption [5] and increased respiratory rate and sweating [6]. Thermal-stressed lactating cows presented a negative energy balance due to these collective changes.

Thermal stress adversely affects milk production and its composition in dairy animals, especially in animals of high genetic merit [7, 8]. Most studies have found that thermal stress was associated with a decline in total protein content and fat content [9, 10]. Milk lipid composition showed significant changes in triacylglycerol (TAG) and polar lipid profiles. Thermal stress (Temperature-Humidity Index up to 84) was associated with a reduction in TAG groups containing short- and medium-chain fatty acids and a concomitant increase in long-chain fatty acids [11]. Thermal stress may induce an increase in the formation of endogenous free radicals causing oxidative stress in animals. During thermal stress, the decrease in dry matter intake leads to increased energy demands due to the disruption of homeostasis, thermoregulation and for repairing of damaged tissues [12]. The crossbred cattle are more sensitive to temperature rise than Indigenous cattle, a rise of 2-6 °C due to global warming will have more impact on growth, puberty and production potential of crossbred cattle, and the negative effects of thermal stress will become even more apparent in the near future if climate change continues as predicted [13]. This review has made an attempt to collect and refine details pertaining to impact of thermal stress on milk production and composition in dairy cows. Attempts have been made to review the high-temperature impact on economic consequences; fatty acid profile of milk and also focuses on key mitigation measures to combat the adverse effects of thermal stress in dairy cows.

**Economic consequences of thermal stress in livestock production**

Livestock economy is one of the world's largest economies that fulfill the world's nutritional requirements though high quality milk and meat [14]. Growing population, urbanization and improving health may raise the need for milk and other livestock products. High temperature and humidity adversely affect feed intake, eventually contributing to reduced milk production. It has been noted that thermal stress can generate a major economic burden for the dairy sector of about $900 million per year. Effect of thermal stress in dairy cattle estimated the annual economic loss to be 897-1,500 million dollars to US dairy industry [15]. The annual total milk loss due to thermal stress at the all-India level was 1.8 million tones or approximately 2% of the total milk production of the country amounting to a whopping Rs. 2661.62 crores per year [16]. The negative impact of global warming on total milk production in India is also estimated to about 3.2 million tons by 2020 and more than 15 million tons by 2050.

**Impact of thermal stress on milk production and composition**

Thermal stress results in reduction in dry matter intake and feed conversion efficiency which directly affects the body condition of animals hence resulting in low milk yield [17]. Bouraoui *et al.* [7] investigated that an increase in THI value from 68 to 78 lead to decrease in milk production by 21% and dry matter intake by 9.6% in lactating Friesian-Holstein cows. As compared to spring season, the summer season showed a decrease in milk fat (3.24 vs. 3.58%) and milk protein (2.88 vs. 2.96%). During cold (average temperature 17.9 – 29.5ºC and THI 63.8 – 76.6) and a hot period (average temperature 22.5 – 34.4ºC and THI 72.1 – 83.6), lactating dairy cows showed a linear decline in DMI and milk yield with respective increases in air temperature or THI during the hot rather than cold period [17]. Bernabucci *et al.* [9] studied the effect of hot season on milk protein fractions in 40 mid-lactating Holstein cows and found reduction of milk protein content in the summer due to the reduction in α-casein and b-casein contents. Aggarwal and Singh [18] and Ozrenk and Inci [19] reported that milk fat, protein and total solids percentages in cow milk being highest during the winter and lowest during summer. According to Nardone *et al.* [20], dairy cows are very sensitive to climatic variations and heat greatly influences their welfare as well as their ability to produce milk. In order to avoid hyperthermia and maintenance of the vital functions of the animals, thermal stress conditions leads to the activation of thermoregulation mechanisms which further leads to the decline in production performance. The levels of milk protein have usually been shown to decrease under high temperature which strongly modified the milk gross composition [21, 7, 22, 23].

Gaafar *et al.* [24] reported that with increase in THI from 59.82 in the winter season to 78.53 in the summer season, thermal stress reduced total (305 days) and daily milk yield by 39.00%, 31.40% and 29.84%, respectively. Thermal stress significantly reduced milk fat, protein, lactose, SNF and ash contents from 3.79, 3.20, 4.78, 8.69, 12.48 and 0.71% during the winter season to 3.49, 3.07, 4.59, 8.34, 11.83 and 0.67% during summer season. Milk protein percentage decreases continuously with increasing THI. However, the impact of THI on milk protein content was very weak. Therefore, decrease in protein yield for THI over 60 can mainly be attributed to the decrease in milk yield [25]. Hamzaoui *et al.* [26] exposed eight Murciano-Granadina dairy goats to different ambient conditions: thermal neutral (TN; 15 to 20 °C day-night) and heat stress (HS; 12 h day at 37 °C and 12h night at 30.5 °C) in a climatic chamber. They investigated greater milk yield losses (9%) in early lactating dairy goats under HS as compared to late lactating animals (3%) and also greater reductions in milk fat at early lactation (12%) with lower protein (6-13%) and lactose (1-5%) contents compared to late lactation (1%). During their study Rejeb *et al.* [27] reported that in lactating Holstein Friesian cows thermal stress significantly reduced milk fat content from 3.79% during the spring (THI = 65.62) to 3.65% during the summer (THI = 83.91). Singh *et al.* [28] also reported negative impacts of thermal stress on lactation length, dry period, calving interval, milk constituents and milk yield in Murrah buffaloes. The shift in glucose utilization in non-mammary gland tissue affecting milk synthesis was explained by increase in basal insulin levels with improved insulin response in heat-stressed cows [29, 4]. In case of thermal stressed goats, Hamzaoui *et al.* [26] reported milk with lower protein (6-13%) and lactose (1-5%) contents. Kumar *et al.* [30] observed that high temperature with high humidity during calving had a detrimental effect on lactation yield and lactation length of Holdeo crossbred (Holstein Friesian × Deoni) cattle. Fat and protein percentages of milk samples were significantly lower in Dhofari cows during hot (3.56 and 3.43%) in comparison to cold season (4.89 and 3.71%), respectively [31].

Bernabucci *et al.* [9] collected data on milk, fat and protein yields and fat and protein percentages of first, second and third parity Holstein cows from 484 farms for a period of 2001- 2007. Data analysis revealed that daily THI at which milk production started to decline for the 3 parities and traits ranged from 65 to 76. The highest negative effect of THI was observed 4 day before test day over the 3 parities for all traits. The negative effect of THI on production traits indicates that first-parity cows are less sensitive to thermal stress than multiparous cows. Over the parities, the general additive genetic variance decreased for protein content and increased for milk yield and fat and protein yield. Gorniak *et al.* [32] evaluated the impact of increasing THI on dry matter intake, milk yield and milk composition during summer season on mid-lactation Holstein dairy cows. They observed that dry matter intake and milk yield decreased when THI rose above 60, whilst water intake increased in a linear manner beyond THI 30 and milk protein and milk fat content decreased continuously with increasing THI. Zhang *et al.* [33] supplemented betaine at different dose rates 10 g/day (group I), 15 g/day (group II) and 20 g/day (group III) for 8 weeks to lactating Holstein cows during summer thermal stress and indicated that supplementing betaine to the diet of dairy cows increased milk performance and improved antioxidant capacity. In conclusion, 15g/day betaine supplementation in dairy cows had the most positive influence on performance and productivity. Pagna *et al*. [34] also reviewed that themal 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.

**Impact of thermal stress on fatty acid profile in milk**

Bovine milk contains 3–6% of fat, of which the dominant portion (about 98%) is in the form of triacylglycerols (TAG) located inside fat globules [35]. As reported by Jensen [36], bovine milk have potential benefit to human health as it contains a large number of fatty acids (FA), including polyunsaturated fatty acids (PUFA) in the n-3 (omega-3) FA group and the conjugated linoleic acid (CLA) isomer *cis*-9 *trans*-11 C18:2. The fat globule membrane contains polar lipids including phospholipids and sphingolipids which represent 0.5–1% of total fat [37]. Researchers have already established that milk fat content and lipid composition vary with cow breed, animal diet, stage of lactation and season [36, 38, 39]. The content of unsaturated fatty acids decrease in winter and spring depends on animal feed which is quite poor and composed mainly of cellulose at that time [40, 41]. Salamon *et al.* [42] reported that the milk fat in summer consists of more linoleic acid, linolenic acid, oleic acid and CLA than in winter. The CLA content in cow milk varied in the range of 0.6–1.7% throughout the year. CLA synthesis in dairy cows is increased by fresh grass due to increased activity of 9-desaturase in the mammary gland and unknown factors [40]. Nudda *et al.* [43] observed a regular monotonic decrease of ewe milk CLA content during pasture feeding from 2.20% in March to 1.14% in summer.

Talpur *et al.* [44] studied the changes in fatty acid profile of ruminant's milk throughout the year and found highest concentration of short chain FAs (14:0) in milk during winter and lowest during summer months, while the content of C-16:0 was lower in summer as compared with all months which varied by 20–38% throughout the year in all ruminant species. Summer milk produce more elevated concentration of total polyunsaturated (4–35%), trans (16–35%) and conjugated linoleic acid contents (24–48%) in comparison to winter milk. Lipid catabolism was strengthened by thermal stress due to the increased plasma fatty acid, such as linoleic acid, oleic acid and arachidonic acid. Thermal stress decreased phosphatidylcholine PC (16:0/14:0), PC (14:1/18:3), PC (12:0/22:2), PC (15:1/18:2), PC (20:2/12:0) and PC (18:1/18:3), but increased choline, lysoPC (0:0/18:0), lysoPE (18:0), lysoPC (16:0) and lysoPC (18:0) [45]. Thermal stress was associated with a reduction in TAG groups containing short and medium chain fatty acids and a concomitant increase in long chain fatty acids. The abundance of five polar lipid classes including phosphatidyl ethanolamine, phosphatidyl serine, phosphatidyl choline, lyso phosphatidyl choline and glucosyl ceramide was found to be significantly reduced during thermal stress [11]. Hammami *et al.* [10] described a decrease in content of short and medium chain fatty acids and an increase in long chain fatty acids from thermal stressed cows, but the ratios of C14:1 to C14:0, C16:1 to C16:0 and C18:1 to C18:0 were very close between baseline and thermal stress samples. At the class level, a 4-day heat challenge had no significant influence on the abundance of phosphatidylinositol, sphingomyelin and lactosylceramide, but reduction of phosphatidylserine, phosphatidylethanolamine, phosphatidylcholine, lysophosphatidylcholine and glucosylceramide.

Saroj *et al.* [46] evaluated the variation in fatty acid profile in the milk of all ruminant species during summer and winter seasons and found that total saturated fatty acids (SFA) content (g/100g of fat) was 13–14% higher in summer than winter in all ruminants. Total monounsaturated fatty acid (MUFA), polyunsaturated fatty acid (PUFA) and conjugated linoleic acid (CLA) concentration (g/100g fat) were 10–12%, 3–4%, 30–40%, respectively and lower in summer as compared to winter season. They concluded that PUFA and CLA in milk of different species increased during winter season than summer because of seasonal availability of green fodder. Saroha *et al.* [47] analyzed goat milk samples for estimation of fatty acid profile by using gas chromatography and revealed the highest concentration of saturated fatty acids (69.55 g/100g of fatty acid). Within saturated fatty acid, the concentration of palmitic acid (C16:0) was 26.99% followed by myristic (C14:0) 11.77%, stearic (C18:0) 7.66% and capric (C10:0) 6.75%. The concentration of short chain fatty acids (SCFAs, C4 to C10), medium chain fatty acids (MCFAs, C12 to C15) and long chain FA (LFA, C16 to C24) was 13.51, 20.05 and 35.08%, respectively. The average concentration of unsaturated fatty acids (UFAs) was 28.50 g/100grm of FAME which includes monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) of 24.57 and 3.96 g/100g of FAME, respectively. Moringa oleifera (MO) foliage had increased milk yield and energy corrected milk, and milk total solids, fat and energy content, unsaturated fatty acids, conjugated fatty acids, UFA/SFA ratio and lowered milk total saturated fatty acids and athrogenicity index in lactating Nubian goats [48].

**Mitigation strategies to minimize adverse effect of thermal stress on milk production**

Mitigation strategies have been used to maximize milk yield during the summer months. The effect of Thermal stress on milk production can be minimized by providing proper shelter, shifting micro-environments and dietary supplementation [49]. Proper nutritional management can also be adopted by offering high-energy feeds along with bypass protein, which will enable animals to retain their production performance under high temperature condition [50] and supplementing with feed additives [51] or pharmaceutical additives [52]. There is a recent interest in herbal feed additives for abating negative effects of high ambient temperature and improving production in chickens [53] and pigs [54]. These additives have nutritional and medicinal values and no toxic side effects. Few of these herbal feed additives were effective at improving lactation production. Dairy cows under thermal stress condition must be cooled to allow heat exchange between the animals and environment and to minimize increase in a cow's core body temperature [55]. By providing shade, improved ventilation and cooling of the ambient air by fans alone or in addition with sprinklers, milk cows are better able to reduce the adverse effects of thermal stress on milk yield, reproduction and immune system [56]. Dietary manipulation to modify micronutrients may also have a significant effect on mitigating the negative effect of thermal stress on milk yield [57]. Appropriate concentrate and roughage ration should be maintained. The essential micronutrient consisting of mineral mixtures and antioxidants enrichment could have a better impact on improving the thermal discomfort induced a decline in production of milk [56]. Initiatives ought to be taken to increase the energy content of the diet by including fat and top quality grasses. Optimization of ruminally undegraded proteins enhances milk yield in warm climates. Dry matter Intake and milk yield rises for cows fed diets containing 14 per cent of acid detergent fiber. In addition, the rise in dietary fat content also improves the capacity of milk production in milk cows during thermal stress [58].

**Conclusion**

Thermal stress is one of the major issues affecting the production capacity of dairy cows which ultimately results in severe economic loss to livestock farmers almost in every area of the globe. This review offers a strong overview into how heat stress impacts milk production and its composition and also illustrates the mechanisms by which milk production is adversely affected when the animal is subjected to thermal stress problem. Thermal stress adversely affects both quantity as well as quality of milk especially in high yielding dairy cows. Therefore effective mitigation strategies should be implemented to minimize the negative effects of high ambient temperature and to boost the production performance of high yielding dairy cows.

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