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RESEARCH ARTICLE

Global Climate Change Effects on Milk Yield and Composition of Dairy Cattle

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ABSTRACT

Solar radiation, air movement, relative humidity, and temperature are environmental variables that affect the well-being of dairy cows. However, the two primary factors influencing animal production are relative air humidity and temperature. When the temperature increases outside, cows must sweat and pant more to maintain their coolness, as their main non-evaporative cooling mechanisms (convection, conduction, and radiation) become less effective. During humid and warm conditions, heat stress can occur when the body's ability to dissipate heat into the environment is insufficient compared to the amount of heat produced by metabolism. Dairy cows under heat stress can experience a range of costly and dangerous side effects. Elevated ambient temperatures and increased temperature-humidity index above acute thresholds are associated with reduced feed intake, as well as milk production and milk efficiency.

Key words: Climate change, dairy cattle, heat stress, milk composition, milk yield

INTRODUCTION

Climate change is expected to impact future livestock considerably, farmer incomes, maintenance practices, and global food safety due to the rising frequency and severity of extreme weather events.[1] Changes in the weather are expected to happen rapidly. By 2040, global warming is expected to raise temperatures by 1.5°C, and by 2050, environmental temperatures could rise by as much as 2°C.[2] By the year 2100, the average surface temperature is expected to increase by 1.88°C.[3] Over the next century, temperatures are predicted to rise by 0.3–4.8°C, which is expected to have a significant impact on agricultural and food production.[4] Heat stress is the outcome of an animal's inability to maintain a balance between heat retention and dissipation. When the body temperature of a dairy cow rises due to insufficient evaporative heat loss, the animal begins to generate additional heat, which is known as the upper critical air temperature. This temperature falls between 25°C and 26°C.[5] Producers in tropical regions who rely on subsistence farming would be most affected by the global increase in greenhouse gases, which is already causing climate change.[6] Due to the increasing global temperature and the lengthening of hot seasons, farm animals are experiencing more extreme heat stress, which poses a serious risk to milk production and composition.[6] The heat stress forces the animal to adjust on several levels to prevent physiological dysfunction and improve environmental adaptation. The homeotherms work very hard to save their stable body temperature in very narrow ranges by maintaining appropriate biological responses and physiological functions related to metabolic rate. To preserve homeothermy, an animal has to remain in thermal stability with all of its environmental factors.[7] The thermo-neutral zone, which is kept between 5°C and 25°C, is a pleasant temperature range for nursing dairy cows.[8] When the outdoor temperature rises above 26°C, and a cow is unable to cool down enough, it

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is said to be under heat stress.[9] The animal body's thermoregulatory mechanisms normally maintain temperatures within 1°C of normal when there is not severe heat stress.[10] An imbalance between the body's heat production and its heat loss through metabolism leads to hyperthermia.[11,12] A decrease in milk production, decreased rates of reproduction, elevated metabolic processes, and compromised immune systems are all contributing to financial losses for the dairy business.[13] This drop in milk production was also noted in research, which found that summer milk productivity was 10% lower than that of spring.[14]

For instance, heat stress costs cattle producers billions of dollars annually in lost productivity. Economic losses yearly attributed to lactating cows in Florida and Texas have been assessed at $337 and $383/cow, respectively.[15] Based on present milk prices, losses were estimated to reach US$670 million annually in 2014; by the end of the century, this amount is likely to increase to US$2.2 billion yearly.[16] According to recent economic research, the US dairy sector may suffer financial losses of up to $810 million yearly if cows are not chilled during the dry season.[17] Heat stress severely impacts the financial success of dairy farms in the US. Heat stress causes the cattle business in the United States to lose between $1.69 and $2.36 billion annually in revenue. Between $897 and $1500 million of these losses are attributed to the dairy sector each year.[18] Research by meteorologists and climatologists has revealed a specific hazard to all of Europe. In comparison to previous years, the European Union's dairy production is predicted to drop by 70 to 550 kg of milk/day for a herd of 100 cows in 2015. The maximum harmful consequence of heat stress on cows is reduced milk output, as the economic effects generally become apparent within a few days.[19] This review aimed to provide an overview of the impacts of global warming-induced heat stress on the milk output of dairy animals.

Global Climate Change Effects on Milk Yield

The ideal temperature for breastfeeding relies on the breed, species, and heat-tolerance level. For Holstein cattle, the temperature must be over 21°C to cause a drop in milk output; for Brown Swiss and Jersey cattle, the temperature must be between 24°C and 27°C.[20] The ideal temperature range for nursing cows is between 5°C and 25°C simply because this is when milk production peaks.[21] High-producing dairy cows suffer when the temperature-humidity index (THI) rises over 72, since this is a frequent indicator of stress levels.[22,23] Climate change, particularly global warming, will have both direct and indirect effects on the welfare and health of farm animals.[24] Farmers and livestock producers are extremely concerned about heat stress since it results in significant financial losses for animals' reproductive and production characteristics. Dairy farmers lose a portion of their money because heat stress lowers feed intake, milk output, growth rate, and reproductive function, particularly in tropical nations.[25] A reduction in milk production is the first obvious consequence of heat stress. Milk output in Friesian cows dropped by 30% in the hotter climate as opposed to the milder one.[26] The yield of milk from Holstein cows was decreased by 10–40% when THI levels exceeded 72.[27] Research reported a 16.6% decrease in the overall mean milk output during six lactation numbers, indicating that buffalo produced higher-quality milk in the winter than in the summer.[28] The average milk yield on test day was around 26.3 kg for a THI <72; for a THI ≥ 72, the output decreased by about 0.2 kg for each unit increase in the THI.[29] In the Mediterranean climate, milk production decreased by 21%, and dry matter intake decreased by 9.6% when the THI value rose from 68 to 78. The scientists came to the conclusion that for every increase in THI unit, the milk supply decreased by 0.13 kg/milking in each cow.[30] Dairy cows produced 0.2 kg less milk for every unit increase in THI over 72, and a 1°C increase in the ambient temperature over the thermoneutral zone causes a roughly 36% reduction in milk output.[31] The latter author found that at temperatures outside of 35°C and 40°C, respectively, the quantity of milk was reduced by 33% and 50% and decided that dairy cows with higher yields are more susceptible to heat stress than animals with lower milk production potential genetically. The cattle industry experiences significant financial losses when milk output diminishes by 10–35% during the sweltering summer months and 2 days following heat stress.[32] The latter authors reported that for every THI unit rise over 69, milk production in dairy cows under heat stress falls by 0.41 kg/cow/day, with medium-lactation cows seeing a 35% decline and early-lactation cows only experiencing a 14% decrease. There was also a 2.2 kg daily drop in milk production following exposure to an average THI score of 68. Milk yield decreased by 33% at 35°C and by 50% at 40°C.[33] Holstein cows under cooling management produced considerably more milk and milk energy output (21.12 kg of milk and 13.6 Mcal/day) than cows under summer heat (19.1 kg of milk and 12.6 Mcal/day).[34] Milk yield decreased by 27.6% (equating to 9.6 kg) during periods of heat stress and by 13.9% (equating to 4.8 kg) during pair-feeding.[35] The same authors indicate that a reduction in feed intake accounted for only a portion (50%) of the decline in milk yield. High temperatures and humidity over extended periods of time damage cattle's ability to dissipate body heat, which lowers lactating cows' milk yields and milk production efficiency.[36] Compared to the summer (39.60 L), the springtime season saw a considerable increase in the average milk output per Holstein–Friesian cow (42.74 L), and it was concluded that the high-yielding dairy cows are more vulnerable to the effects of heat during the beginning of lactation.[37] Dairy cows experiencing heat stress produce 25–40% less milk due to reduced feed intake.[20] The heat stress caused the THI values to rise from 59.82 in the winter to 78.53 in the hot summer, which was interpreted as a 39.0% and 31.4% decrease in the total (305 days) and daily milk yield, respectively.[38] In Germany, depending on the region, milk yield decreased by 0.08 kg to 0.26 kg for each increase in THI units.[39] The daily milk output in the Polish cows dropped from 0.18 to 0.36 kg per THI unit as the THI value increased.[40] As the THI values increased from 64.21 in the spring, 66.36 in the fall, and 42.34 in the winter to 79.31 in the summer, the heat stress of the hot summer decreased the daily milk production of Holstein–Frisian cows in Serbia by 1.32, 0.92, and 1.27 kg.[41] Heat stress was responsible for 3–10% of the difference in lactation milk output.[7] The Iranian Holstein dairy cows in THI groups 81–90 produced less milk and fat than those in other THI groups, whereas cows in THI groups 30–40 and 41–50 made the most milk and fat. The linear regressions of milk yield and milk fat yield on THI were highly significant; $R^2 = 0.88$ and $R^2 = 0.83$, respectively. The findings showed that the milk output and composition of dairy cows were adversely impacted by summer heat stress.[42] Murrah buffaloes calving in the winter had the greatest peak milk output when compared to buffalo calving in the rainy and summer seasons. Buffaloes calving in the winter had the maximum milk output (1257.15 L/month), whereas those calving in the rainy and summer seasons had lactation yields of 1088.00 and 982.42 L/month, respectively.[43] Compare the effect of the THI on milk production traits of lactating Holstein–Friesian cows reared in four different housing systems. The authors found a negative impact of THI on milk production as well as fat and protein percentages, although the housing system was superior in altering heat stress effects.[44] The average daily milk yield per cow and total milk yield per group under THI >78 were 9.83 and 380.80 kg, respectively, whereas the corresponding values for cows exposed to THI <72 were 11.12 and 422.43 kg, and those exposed to THI = 72–78 were 10.77 and 409.13 kg.[45] Cows indoors decreased milk yield as THI increased, and when the THI value was 55, the highest milk yields were obtained, and cows' outdoor milk yields were lower at the THI extremes than at normal values.[46] The main source of loss was the high THI levels, as milk output decreased by 0.32 kg for every unit increase in THI.[47] When THI levels rise from 65.6 to 83.2, there is a 2.31 kg decrease in DMI and a 5.59 kg decrease in milk production.[10] The warmer season of the year considerably affects the daily milk output per cow. The ambient temperature significantly reduces dairy cows' ability to produce milk.[48] Holstein Friesian crossbred cows in Bangladesh had the greatest milk output and milk content values on average in October and the lowest values in July because of the high THI value. The authors also noted a negative correlation between milk output and the THI.[49] Heat stress reduces milk output by 25 to 40%, with the decreased feed intake accounting for half of the decline in milk synthesis.[50] Holstein-Frisian cows in Serbia, when subjected to heat stress, produced less milk (23.2 L/day compared to 27.6 L/day).[51] Cows exposed to a 4-day short-term temperature and humidity challenge decreased their milk output by 53%.[52] The higher milk-producing cows will be more susceptible to heat stress than lower- or dry-producing cows, and heat stress also lowers milk yield in the successive lactation in dairy cattle during the dry season, when animals are not lactating.[53] The average milk output of Holstein-Friesian crossbred cows was much greater during the winter season than during the warmer one, and a dairy cow is deemed to be experiencing heat stress when the THI surpasses 68 during the dry season, which leads to a decrease in milk production during the following lactation.[54] For every unit increase in the THI over the specified limits of 75, 75, and 72, respectively, the average daily milk production of heat-stressed Holstein cows decreased by 1.3%, 1.9%, and 0.9%.[55] When the THI value is 68°F or above, the heat stress begins to manifest and becomes dangerous when the THI reaches 79/80°F. The authors concluded that dairy cows with high productivity lose more milk than cows with medium or low production when heat stress occurs.[56] The milk production of Holstein–Friesian cows reared in the Marmara zone of Turkey was revealed to be significantly impacted by the THI.[57] The author noted that August had the lowest adjusted average daily milk production, recorded at 24.0 kg, while April displayed the highest production value, reaching 31.5 kg. The same author concluded that the THI threshold value that permanently affects milk output is 70, while a starting THI value of 65 negatively impacts milk yield, and the association between THI and daily milk output was found to be −0.771. The daily milk production decreases (from 15 kg/day to 40 kg/day) in the more productive cows as the THI increases from 72 to 80.[58] In Tunisia, the milk yield per milking of Holstein cows was 24% lower during the hot summer months compared to thermoneutral conditions. Every unit increase in THI resulted in a 0.13 kg decrease in milk yields per milking. The scientists observed that at THI levels between 68 and 78, milk production is reduced by 21%. A drop of 0.41 kg in daily milk output per cow also occurs for every unit rise in the THI above 69. The yield loss was largest below the threshold THI value of 72, while the milk yield decreased linearly between the THI values of 60 and 80.[59] Moving a lactating Holstein cow from an ambient temperature of 18–30°C reduces milk output by around 15% in Bangladesh. This reduction is accompanied by a 35% decline in the efficiency of energy use for production purposes.[54] Reduced yields of milk, fat, and protein are linked to heat stress. Cows could produce up to 45.62 kg of milk/day at optimal temperatures, but when THI levels increase, this quantity drops to 33.26 kg/day.[60] The Holstein cows in the semiarid Mediterranean area of western Algeria reduced their daily milk output by 17.6% as the THI climbed from 71.7 in the spring to 83.6 in the summer. Daily milk production decreases by 0.36 kg/cow for every unit increase in THI value beyond 71.7, and a negative association was also found between THI score and daily milk production ($r^2 = 0.72$; $P < 0.01$).[61] A considerable drop in milk output was caused by an increase in THI levels, with an average regression rate of 15.51%.[62] The dairy cows exposed to ambient temperatures over their comfort zones may have a 10–40% decrease in milk production.[63] The annual loss in milk production for a single cow was calculated to be 98.25, 157.68, 207.36, 164.30, and 190.08 kg, respectively, and the THI's corresponding losses in milk output per unit increase were 0.07, 0.08, 0.09, 0.07, and 0.08 kg.[64]

Global Climate Change Effects on Milk Composition

Thermal stress had an impact on the milk components as well as milk production. The average yields of total solids, fat, protein, ash, and lactose in Friesian cows maintained at temperatures below 38°C were lower than those kept at thermo-neutral ambient temperatures (18°C). The observed decreases were 28.0%, 27.0%, 7.0%, 22.7%, and 30.0%, respectively.[65] The milk produced by buffaloes in the winter season was of higher quality than the milk produced in the hot summer. The total solids, butterfat, protein, and lactose levels of milk significantly decreased in the summer season due to the greater outside temperature.[28] Protein and fat yields were 0.92 and 0.85 kg, respectively, at a THI, and dropped by 0.012 and 0.009 kg for every degree of THI.[29] The summer-calving cows exhibited lower fat and protein content than winter-calving cows.[30] The concentration of milk protein similarly dropped under the heat stress.[66] The amount of milk fat in Holstein–Friesian cows was significantly greater in the spring (3.25%) compared to the summer (2.62%). The milk also had a higher protein content in the spring (3.15%) compared to the summer (2.75%).[37] In comparison to the winter season, the percentages of fat, protein, lactose, solids other than fat, total solids, and ash decreased by 7.92, 4.06, 3.97, 4.03, 5.21, and 5.63%, respectively.[38] In contrast to winter and spring levels (3.80 and 3.61 g/100 g, respectively), a notable drop in milk fat during the hot summer (3.20 g/100 g). In addition, both milk casein and protein levels of cows kept in heat-stressed environments tend to decline. In addition, the milk casein concentration was higher in the winter (2.75 g/100 g) and spring (2.48 g/100 g) than in the hot summer season (2.27 g/100 g).[67] The fat percentage was lower at greater THI than at moderate THI in both indoor- and outdoor-housed animals.[46] The milk produced by cows under heat stress had lower protein levels than milk from cows housed at normal temperatures. The yields of fat and protein decreased by 0.4 g and 0.3 g, respectively, per milking for every unit increase in THI.[68] A negative correlation between THI and the levels of protein, fat, and milk products, and the higher THI adversely affects these components in milk. Cows raised in pleasant settings had a higher quantity of casein in their milk than the group that experienced heat stress (28.1 vs. 26.8 g/L, respectively). The protein fraction analysis also revealed reduced amounts of immunoglobulin G, immunoglobulin A, casein, and lactalbumin.[59] Thermal stress occurring during the dry period negatively impacts the production of protein and lactose.[69] The high environmental temperature reduced the amount of milk protein (19.3%) but did not affect milk fat content, and confirmed that there is a significant relationship between the drops in milk protein and the rise in THI.[70]

Global Climate Change Effects on Milk Hormonal Levels

The primary source of hormones in milk is the continuous transfer of these hormones from the bloodstream to the mammary glands. Radioisotope techniques were used in radioimmunoassay procedures to assess the amounts of hormonal levels in the milk. Prolactin and progesterone levels in milk and blood dropped dramatically.[71] In reaction to heat stress, serum and milk prolactin and progesterone showed a similar pattern. When comparing cows exposed to summer heat with those in winter conditions, the levels of prolactin and progesterone decreased significantly, with reductions of 45.40% and 27.14% in the blood and 34.30% and 20.56% in the milk, respectively. Although blood and milk prolactin concentrations were comparable in the summer, serum prolactin in blood was greater than in milk during the winter season. In both winter and summer, the serum progesterone level in milk was 3 times greater than in blood.[71] Both high-yielding and low-yielding cows had much lower triiodothyronine (T_3) hormone levels in their milk in regions with higher temperatures than in milder ones, and the high-yielders appeared more susceptible to hot conditions. Animals subjected to elevated ambient temperatures of 37.1°C during the hot summer months experienced a significant reduction in milk T_3 levels when compared to the milder winter months, which averaged 17.5°C.[72] In contrast, cortisol levels demonstrated an opposing trend. The decrease in T_3 hormone concentration in plasma may be the cause of the drop in T_3 content in secretory milk brought on by rising ambient temperatures. T_3 in milk decreased less than that in plasma, and milk had a larger proportion of cortisol rise from heat exposure (64%) than plasma (38%).[28] The amount of milk progesterone on day 24 following service may be utilized as a measure of reproductive state to detect ovarian activity or diagnose pregnancy with an accuracy of 86.0% and it was concluded that milk progesterone was observed to increase the accuracy of pregnancy diagnosis.[73]

How Global Climate Change Effects on Milk Production and Composition

In heat-stressed lactating cows, a loss of energy, substrates, and hormones may be the reason for the drop in milk production and composition. In addition, compared to an environment at 18°C, cows consume digestible energy 35.4% less efficiently, and elevated maintenance costs, anticipated to be 20% higher at ambient temperatures of 35°C, result in decreased energy efficiency for milk production during hot weather.[74] In certain regions, the effects of climate change on livestock systems may be particularly severe due to reductions in feed quality and quantity, which would result in lower feed intake.[31] Several reasons for decreased milk production include altered hormone profiles, altered energy metabolism, and elevated body temperature that reduce feed intake.[75] Reduced food intake, abnormalities in mineral balance, enzymatic reactions, hormone and metabolite production in the blood, and metabolism of proteins and energy are all brought on by excessive heat.[76] Dairy cows under heat stress had worse feed efficiency, lower milk output, and lower dry matter intake.[77] Only 35–50% of the decrease in milk production may be attributed to a decrease in dry matter consumption.[20] Dairy cows may have a 50% decrease in milk production due to the heat stress response, which profoundly alters post-absorptive lipid, protein, and carbohydrate metabolism as part of decreased feed intake.[78] The high-temperature stress adversely influences the rate at which the cows' mammary cells regenerate throughout the dry season.[79,80] The physiological integration of several organs and systems, including the immunological, digestive, endocrine, and cardiorespiratory systems, is necessary for adaptation to heat stress, and the heat generated internally by the food metabolism and the ambient temperature affect milk production. When feed consumption and milk output rise, more heat is generated during nutritional metabolism, exacerbating any heat stress brought on by external factors.[81] The heat stress has a detrimental effect on milk supply, mostly as a result of decreased feed intake and changed hormone levels, and internal metabolic heat generation during lactation decreases milk supply and changes the content of milk.[7,82] A 50% decrease in milk production and reproduction is the outcome of the significant changes in biological processes caused by heat stress. Under some conditions, protein synthesis cannot counteract protein catabolism, resulting in a negative nitrogen balance. Increases in glucocorticoid hormones lead to protein catabolism, which breaks down protein tissues.[56] In lactating cows, food intake declines at ambient temperatures of 25–26°C, with a more rapid decrease observed at 30°C; at 40°C, intake can be reduced by as much as 40%.[66] Rather than a drop in feed consumption, the direct effects of heat stress are mostly responsible for the loss in milk protein content.[69] The heat stress exacerbates oxidative stress, which alters the molecular and metabolic activity of cells that make up the mammary secretory tissue and decreases their ability to produce milk components.[83] A substantial reduction in the digestibility coefficients of the nutrients, feeding values, and feeding intake in suckling Friesian calves in the summer ration. The effects of climate change on livestock systems would be particularly severe due to decreases in feed quality and quantity, resulting in lower feed intake.[84] Heat-stressed animals may have higher levels of glucocorticoid hormones like cortisol because of increased gluconeogenesis, the process that converts amino acids into their equivalent α-keto acids. Protein anabolism during milk biosynthesis is influenced by either a rise in catecholamines or a fall in insulin.[85] The heat stress during the dry phase inhibits the growth of glandular tissue in mammary cells, which lowers the amount of milk produced during the next lactation.[79] The loss of certain levels and consumption of glucose in tissues outside the mammary gland leads to lower milk synthesis in cows under heat stressors.[86] In addition to irregularities in water, protein, energy, and mineral balances, enzymatic activity, hormonal secretions, and blood metabolites, the animals' capacity to produce milk is hampered by reduced feed intake, feed efficiency, and feed utilization.[87] Eventually, a reduction in the quantity of mammary epithelial cells might lead to a drop in milk output. Furthermore, endocrine abnormalities brought on by heat stress might affect milk production by altering the levels of growth hormone, estrogen, progesterone, oxytocin, thyroid hormones, prolactin, and glucocorticoids. The heat-stressed animals may attempt to lower their body temperature through thermoregulatory processes, which might impact feed conversion efficiency and lower milk production.[88] Heat stress has a detrimental impact on the health and biological functions of dairy cows, resulting in decreased milk production.[88] The reduction in milk protein and casein content is attributed to insulin resistance and the apoptosis of mammary epithelial cells, which are triggered by oxidative stress resulting from heat stress conditions.[89] In addition, in heat-stressed animals, reactive oxygen species levels rise due to oxidative stress in animal cells and tissues, which has detrimental effects on regular bodily functions and metabolism.[90] In lactating cows, increased levels of oxidants and decreased antioxidant molecules in the blood have been recorded during the hot summer.[91] The consequences of elevated temperatures are associated with an increase in the generation of reactive oxygen species, which leads to cellular death and disrupts the development of fertilized eggs.[47]

We advise eating in the early morning and late evening, when digestion is at its best, 3–4 h after meal intake, to avoid the hottest part of the day. Cows must be shaded from the sun by fans and sprinkler systems; fed high-quality feed with sufficient amounts of proteins, fats, minerals, and vitamins; fed smaller rations multiple times a day during the colder months; have feeders cleaned to prevent ration spoilage; and have access to an endless supply of clean, cold water.

CONCLUSION

The milk production and welfare of dairy cattle are considerably impacted by heat stress as a result of climate change. Extreme heat stress and extended high relative humidity make animals more difficult for lactating cows to expel excess body heat. When dairy cows are under heat stress, their DMI and milk production efficiency drop, resulting in their producing less milk with worse quality features. Because cows are less tolerant of heat and because future global warming is unknown, heat stress is predicted to increase for dairy farms in the future.

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AUTHOR CONTRIBUTION

The authors participated in completing this manuscript, and they have directly participated in the planning, execution, and analysis of this study. The authors have also read and approved the final version submitted.

DATA AVAILABILITY

The authors confirmed that the availability of data and materials supports their published claims and complies with field standards. The authors affirmed that the information and resources available support their stated claims and adhere to industry standards. The authors attest that the bespoke or available software applications support their claims and adhere to industry standards.

DECLARATIONS AND ETHICS APPROVAL

Our study was approved by the appropriate ethics committee of the Egyptian Atomic Energy Authority Committee for research involving animals, and a statement on the welfare of animals. Our work submitted for publication does not have any implications for public health or general welfare.

CONSENT FOR PUBLICATION

The authors were accepted for publication of this manuscript, and the content of this manuscript will not be copyrighted, submitted, or published elsewhere while acceptance by the journal is under review.

CONFLICT OF INTEREST

The authors declare no competing interests.

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