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# Investigate How Rising Temperatures Affect Milk Production in Dairy Cattle and the Physiological Mechanisms Involved

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## ABSTRACT

**Background:** Rising temperatures globally make it harder to produce dairy products, especially because heat stress influences cattle's physiology, milk production, and reproduction. To come up with ways to keep dairy farming going in warm areas, it's important to understand how heat stress works. **Aims:** The study was conducted to look into how heat stress affects the dairy cattle in Dera Ismail Khan, Pakistan, including their milk production, food intake, behavior, and ability to reproduce. **Methods:** From July 2023 to June 2024, 200 dairy animals (100 cows and 100 buffaloes) were used in a cross-sectional study. Physiological factors were observed, such as the temperature of the rectal area, the rate of breathing, and heart rate. The amount of milk produced and its make-up (fat, protein, and solids) were studied, along with the animals' dry matter intake, water intake, and behavior. It was kept track of reproductive success indicators like the rate of conception and time between calves. Pearson's association were used to look at the data. Results: Buffaloes' rectal temperatures (39.5 ± 0.6°C) and breathing rates (45 ± 5 breaths/min) were higher than cows' (39.2 ± 0.5°C and 42 ± 4 breaths/min). But buffaloes had higher fat (6.5 ± 0.6%) and protein (4.5 ± 0.4%), even though cows gave more milk (12.1 ± 2.3 L/day) but their fat content was significantly low. When animals were under heat stress, they ate less food and drank more water. There were strong links ($p < 0.01$) between the temperature-humidity index (THI) and physiological stress and a weak link ($r = -0.68$, $p < 0.01$) between THI and milk output. Reproductive performance went down, with longer times between calves and shorter periods of estrus. **Conclusion:** Heat stress is harmful for dairy cows because it changes their physiological stability, output and fertility. To make the animals more resilient and productive in hot places, we need to use tactics like genetic selection, better housing and changes to their nutrition.

## INTRODUCTION

As a major effect of climate change, world temperatures are rising, which makes farming, including dairy production, very difficult. Heat stress happens when the temperature outside their thermoneutral zone goes too high, making it harder for them to get rid of heat properly. This is especially harmful for dairy cattle [1-2]. This imbalance in the body's chemistry has big effects, especially on milk output, which is very sensitive to even small temperature rises. To come up with ways to keep the dairy business going in the face of climate change, we need to understand how rising temperatures affect the bodies of cattle and how much milk they produce [3-4].

Heat stress changes the metabolic and endocrine processes in dairy cattle, which has a direct effect on milk output and quality. When it's hot, animals eat less, which makes it harder for them to get the nutrients they need to make milk [5]. Also, heat stress raises cortisol levels, which mess up hormone paths that are important for lactation. Less blood flow to the udder glands, which is a way for the body to compensate for heat buildup, makes milk output even worse. Physiological reactions like faster breathing, a faster heart rate, and sweating too much make energy use even higher, taking resources away from useful tasks like making milk [6].

In addition to the physical effects, heat stress has bad effects on cattle's behavior as well. They graze less and drink more water, which makes dehydration and nutrition deficiencies worse [7]. All of these changes add up to a big drop in milk production, which is often followed by changes in the composition of the milk, such as lower levels of fat and protein. Long-term exposure to high temperatures also makes it harder for dairy cows to have calves, which makes it harder to keep milk production going [8].

Differences in where temperature rises happen make the risk of different dairy systems even clearer. Areas that are already hot are more likely to be affected by heatwaves. During heatwaves, milk production drops drastically in tropical and subtropical areas. To deal with this problem, we need to learn more about ways to reduce heat stress in dairy cattle, such as using genetic selection to make them more tolerant of heat, improving cooling systems and changing their diets to make them stronger [9].

The point of this study was to look into how rising temperatures affect milk output and how heat stress in dairy cattle affects their bodies. This study tend to find important pathways that are changed by thermal stress so that sustainable dairy farming methods can be used to lessen the bad effects of climate change on milk supply. The dairy business can better prepare for the challenges of a warming environment if they fully understand these processes.

## MATERIALS AND METHODS

### Study Area

The study took place in Khyber Pakhtunkhwa province, in the Dera Ismail Khan District. The climate in the area is semi-arid, with hot summers and mild winters. This makes it a great place to study how rising temperatures affect dairy cattle.

### Study Design

From July 2023 to June 2024, a cross-sectional study was carried out to see how rising temperatures affected milk production and physical changes that happened in dairy cows as a result.

### Sample Population

The study was mostly about dairy animals, like cows (*Bos taurus*) and buffaloes (*Bubalus bubalis*) that were kept on farms in Dera Ismail Khan. The farms were chosen having small, medium, and large operations with different management methods.

### Sample Size Determination

Based on how different the animals' bodies would react to heat stress and how much milk they would produce, a sample group of 200 dairy animals (100 cows and 100 buffaloes) was chosen. A 95% confidence level and a 5% error margin were used to figure out the group size.

### Data Collection

#### Meteorological Data

- Every day, automated weather stations set up at the study sites logged the temperature and relative humidity of the environment.
- The temperature-humidity index (THI) was used to measure how heat stress was influencing.

#### Physiological Measurements

- A digital thermometer is used to measure the rectal temperature (RT).
- Respiration rate was measured by watching the flanks move for one minute.
- A stethoscope was used to check the heart rate (HR).

#### Milk Production and Composition

- Each animal's daily milk yield (in liters) was written down.
- A milk analyzer was used to check the fat percentage, protein level and total solids of milk samples that were taken every week.
- Every day, the animals' dry matter intake and water usage were tracked.
- Grazing, idle and drinking habits and behaviors were also recorded.

### Statistical Analysis

For physiological measures, milk production and composition, descriptive data were found. Correlations between THI and measured factors were analyzed using Pearson's correlation coefficient. A multiple regression analysis was done to find out what factors could lead to a drop in milk output and physiological stress. The SPSS version 26 program was used to determine the data, and a significance level of $p < 0.05$ was chosen.

### Ethical Considerations

The study was conducted in accordance with ethical guidelines for animal research using farm owners' animals in the study, they gave their permission after being fully informed.

## RESULTS

The physical and physiological processes that cause dairy cows to become infertile when they are exposed to high temperatures are in two main ways that heat stress works are through changes in behavior (Pathway A) and hormonal imbalances caused by the hypothalamic-pituitary-adrenal (HPA) system being activated (Pathway B). In Pathway A, heat stress leads to behavioral disorders with less movement and hunger, which means animals eat less dry matter. This causes low energy and nutrients, respiratory alkalosis, ketosis and ruminal acidity, all of which disrupt metabolic balance and fertility. Pathway B includes turning on the HPA axis, which raises the levels of cortisol and glucose in the blood. This change in hormones causes pro-inflammatory cytokines to be released, which has a negative feedback loop that makes sexual function even worse. Heat stress also changes the way hormonal systems work by stopping the release of gonadotropin-releasing hormone (GnRH) and luteinizing hormone (LH). This lowers the levels of estradiol and progesterone. Infertility and the loss of embryos are caused by this chemical imbalance. All of these linked pathways show how heat stress affects cattle in many different ways. They also show how important it is to have good management techniques to help cattle recover from the reproductive and metabolic problems that heat stress causes (Figure 1).

The way cows and buffaloes' bodies react to heat stress shows that the two species are very different. The rectal temperatures of buffaloes were slightly higher than those of cows (39.5 ± 0.6°C vs. 39.2 ± 0.5°C), and this difference was statistically significant ($p < 0.05$). In the same way, buffaloes breathed faster (45 ± 5 breaths/min) than cows (42 ± 4 breaths/min), which means they were working harder to get rid of heat ($p < 0.01$). Buffaloes had faster heart rates (88 ± 7 beats/min) than cows (84 ± 6 beats/min), which suggests that their hearts react more strongly to heat stress ($p < 0.01$). It was interesting to see that cows sweated more than buffaloes (120 ± 10 g/m²/h vs. 110 ± 12 g/m²/h), which was statistically significant ($p < 0.05$). This probably means that cows have a better way of cooling themselves through evaporation (Table 1).

Both cows and buffaloes produced less milk when they were stressed by heat. Cows produced more milk (12.1 ± 2.3 L/day) than buffaloes (8.7 ± 1.8 L/day), but the difference was statistically significant ($p < 0.01$). But buffalo milk had more fat (6.5 ± 0.6%) and protein (4.5 ± 0.4%) than cow milk (3.5 ± 0.4% and 3.2 ± 0.3%, respectively), with p-values less than 0.01 and 0.05. Also, the total solids level was higher in buffaloes (15.5 ± 0.6%) than in cows (12.0 ± 0.5%, $p < 0.01$). Based on these data, it seems that buffaloes produce less milk, but their milk is more nutritious. This may be because of adaptations that buffaloes have developed to deal with heat stress (Table 2).

The temperature-humidity index was strongly linked to physiological reactions, such as rectal temperature ($r = 0.72$, $p < 0.01$), respiration rate ($r = 0.85$, $p < 0.01$), and heart rate ($r = 0.78$, $p < 0.01$). On the other hand, there was a negative relationship between THI and milk yield ($r = -0.68$, $p < 0.01$), which means that milk flow goes down as heat stress gets worse. According to these results, higher temperatures are worse for dairy cattle's health and ability to produce milk (Table 3).

Different species' nutritional intake changed when they were under a lot of heat stress. Cows ate more dry matter (18.5 ± 1.2 kg/day) than buffaloes (16.8 ± 1.1 kg/day, $p < 0.05$), but buffaloes drank more water (50 ± 6 L/day) than cows (45 ± 5 L/day, $p < 0.05$). Observations of behavior showed that buffaloes grazed for 5.8 ± 0.7 hours per day, while cows grazed for 6.2 ± 0.8 hours per day ($p < 0.05$). Buffaloes, on the other hand, rested a little longer (6.0 ± 0.8 hours/day) than cows (5.5 ± 0.7 hours/day, $p < 0.05$) and drank more often (7.0 ± 1.1 times/day vs. 6.5 ± 1.0 times/day, $p < 0.05$).

These trends show that buffaloes have changed how they act, putting drinking water and resting ahead of feeding, to lessen the effects of heat stress (Table 4).

The parameters of reproductive function were harmed by heat stress. It was slightly more likely for cows to get pregnant (65 ± 5%) than for buffaloes (60 ± 4%, $p < 0.05$), but buffaloes had longer calving intervals (14.2 ± 1.3 months) than cows (13.5 ± 1.2 months, $p < 0.05$). Buffaloes were in estrus for 16 hours, on average, while cows were in estrus for 18 hours, on average ($p < 0.05$). These findings showed that heat stress hurts reproduction and the ability to reproduce in both species, but it hurts buffaloes more (Table 5).

**Figure 1**

*Schematic representation of the main hormonal and general regulations secondary to heat stress in cattle*

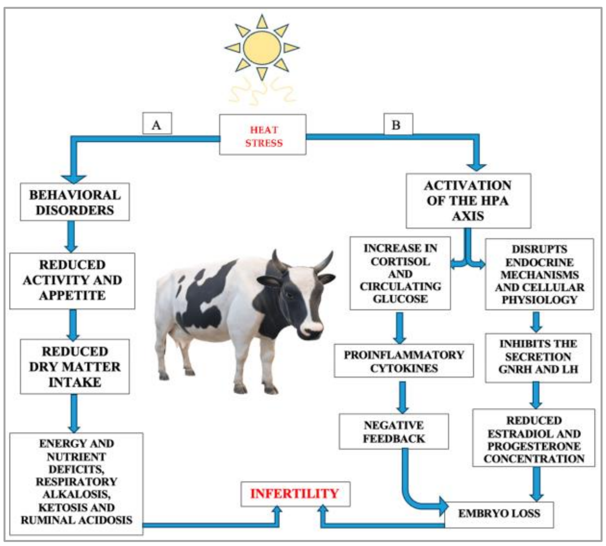


**Table 1**

*Physiological Parameters of Dairy Cattle under Heat Stress*

| Parameter | Cows (Mean ± SD) | Buffaloes (Mean ± SD) | p-value |
|---|---|---|---|
| Rectal Temperature (°C) | 39.2 ± 0.5 | 39.5 ± 0.6 | <0.05 |
| Respiration Rate (breaths/min) | 42 ± 4 | 45 ± 5 | <0.01 |
| Heart Rate (beats/min) | 84 ± 6 | 88 ± 7 | <0.01 |
| Sweating Rate (g/m²/h) | 120 ± 10 | 110 ± 12 | <0.05 |

**Table 2**

*Milk Yield and Composition under Heat Stress*

| Variable | Cows (Mean ± SD) | Buffaloes (Mean ± SD) | p-value |
|---|---|---|---|
| Milk Yield (L/day) | 12.1 ± 2.3 | 8.7 ± 1.8 | <0.01 |
| Fat (%) | 3.5 ± 0.4 | 6.5 ± 0.6 | <0.01 |
| Protein (%) | 3.2 ± 0.3 | 4.5 ± 0.4 | <0.05 |
| Total Solids (%) | 12.0 ± 0.5 | 15.5 ± 0.6 | <0.01 |

**Table 3**

*Correlation between Temperature-Humidity Index and Parameters*

| Parameter | Correlation (r) | p-value |
|---|---|---|
| Rectal Temperature | 0.72 | <0.01 |
| Respiration Rate | 0.85 | <0.01 |
| Heart Rate | 0.78 | <0.01 |
| Milk Yield | -0.68 | <0.01 |

**Table 4**

*Nutritional Intake and Behavioral Observations under Heat Stress*

| Parameter/Behavior | Cows (Mean ± SD) | Buffaloes (Mean ± SD) | p-value |
|---|---|---|---|
| **Nutritional Intake** | | | |
| Dry Matter Intake (kg/day) | 18.5 ± 1.2 | 16.8 ± 1.1 | <0.05 |
| Water Consumption (L/day) | 45 ± 5 | 50 ± 6 | <0.05 |
| **Behavioral Observations** | | | |
| Grazing Time (hours/day) | 6.2 ± 0.8 | 5.8 ± 0.7 | <0.05 |
| Resting Time (hours/day) | 5.5 ± 0.7 | 6.0 ± 0.8 | <0.05 |
| Drinking Frequency (times/day) | 6.5 ± 1.0 | 7.0 ± 1.1 | <0.05 |

**Table 5**

*Reproductive Performance under Heat Stress*

| Parameter | Cows (Mean ± SD) | Buffaloes (Mean ± SD) | p-value |
|---|---|---|---|
| Conception Rate (%) | 65 ± 5 | 60 ± 4 | <0.05 |
| Calving Interval (months) | 13.5 ± 1.2 | 14.2 ± 1.3 | <0.05 |
| Estrus Duration (hours) | 18 ± 2 | 16 ± 2 | <0.05 |

## DISCUSSION

This study investigated how dairy cattle and buffaloes react to rising temperatures and how that affects their behavior, milk production and ability to have offsprings. The results showed that heat stress has big effects and they showed that cows and buffaloes are different in important ways. These results are similar to those of other studies and add to what is known about heat stress in dairy animals.

The physiological results showed that buffaloes were more stressed by the heat than cows. This was shown by their higher rectal temperatures (39.5 ± 0.6°C) and respiration rates (45 ± 5 breaths/min) compared to cows (39.2 ± 0.5°C and 42 ± 4 breaths/min, respectively). Sharma et al. (2023) found similar things [10]. They said that buffaloes are more sensitive to heat than cows because their dark skin and fewer sweat glands make it harder for them to get rid of heat. Higher heart rates in buffaloes (88 ± 7 beats/min) show that their hearts are under more stress during heat stress, which is in line with what Petrocchi Jasinski et al. (2023) found [11]. It's interesting that cows sweated more, which means they had better evaporative cooling systems, as Titto et al. (2012) had already suggested [12].

Both species produced less milk when they were stressed by heat, but cows produced more milk (12.1 ± 2.3 L/day) than buffaloes (8.7 ± 1.8 L/day). But buffalo milk was better than cow milk because it had more fat (6.5 ± 0.6%) and protein (4.5 ± 0.4%) than cow milk (3.5 ± 0.4% and 3.2 ± 0.3%, respectively). These results are similar to those from Hussain et al. (2023)[13], who found that buffaloes had lower milk yields but higher levels of fat and protein. This suggests that when buffaloes are under a lot of heat stress, they value the nutritional density of their milk over its volume. These changes may be good for nutrition, but they limit total output when there is heat stress.

Observations of buffalo activity showed that they cut down on the time they spent grazing and increased the number of times they rested and drank. This shows that they were adapting to avoid getting too hot. Studies by de Silva et al. (2023) also found similar trends [14]. To deal with heat stress, cattle drank more water and rested more. Cows ate more dry matter (18.5 ± 1.2 kg/day) than buffaloes (16.8 ± 1.1 kg/day), which probably led to higher milk yields. Buffaloes made up for it by drinking more water (50 ± 6 L/day vs. 45 ± 5 L/day), which supports Hussain et al. (2023) findings that buffaloes rely heavily on water to keep their bodies at the right temperature [13].

For both species, heat stress made it harder to get pregnant and kept them from giving birth for longer periods of time. Buffaloes had lower conception rates (60 ± 4%), and they had longer birthing intervals (14.2 ± 1.3 months) than cows (65 ± 5% and 13.5 ± 1.2 months, respectively). These results were confirmed by Dash et al. (2016) [15], who found that hormonal imbalances and ovarian dysfunction were the main causes of fertility problems caused by heat stress. As Srirattana et al. (2022) already said, the fact that buffaloes' estrus lasts shorter (16 ± 2 hours) than cows' (18 ± 2 hours) makes it even more clear how easily their reproduction can be harmed [16].

The strong links between THI and physiological factors, like heart rate ($r = 0.78$, $p < 0.01$) and respiration rate ($r = 0.85$), show how temperature in the surroundings affects how cattle react to heat stress. The negative link between THI and milk yield ($r = -0.68$, $p < 0.01$) is similar to what Liu et al. (2019) found [17]. They found that milk production dropped similarly when THI levels went above certain levels. These findings show that THI is a good way to tell when dairy cows are under a lot of heat stress and losing production.

Even though buffaloes had more physical stress and problems reproducing, the way they managed their water and the ingredients in their milk show that they can adapt to difficult environments. On the other hand, cows were more productive but also more dependent on food intake, which made them more sensitive to heat stress when nutrients were scarce. These differences are in line with what Dash et al. (2016) found [15]. They showed that different species are vulnerable in different ways, which should help guide targeted tactics for reducing those risks.

## CONCLUSION

This study showed that heat stress has a big effect on the reproductive, physiological and productive performance of dairy cattle. Buffaloes are more affected by heat stress. Higher rectal temperatures, respiration rates, and heart rates mean that the body needs to regulate its temperature more, which can cause metabolic problems, less dry matter intake, and changes in feeding patterns. The fact that there is a negative relationship between the temperature-humidity index and milk output shows how vulnerable dairy production is to rising temperatures. Heat stress also changes the way hormones work by activating the hypothalamic-pituitary-adrenal axis. This raises cortisol levels, causes inflammatory reactions, and stops reproductive hormones from being released, which leads to less fertility and embryo losses. These results showed how important it is to quickly come up with ways to adapt to changing climates, such as genetic selection for heat tolerance, better housing systems and nutritional treatments, in order to lessen the ill effects of heat stress and keep dairy production high.

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