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IMPACT OF SUPPLEMENTAL SODIUM BICARBONATE AND POTASSIUM CHLORIDE IN LOCAL TOTAL MIXED RATIONS (TMR) ON MILK YIELD AND PHYSIOLOGICAL HEAT STRESS INDICES IN NILI-RAVI BUFFALOES DURING PEAK SUMMER MONTHS

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Abstract

Background: *Peak summer environmental heat stress severely depresses the productivity and physiological status of dairy buffaloes in South Asia, causing substantial economic losses to smallholder and commercial dairy operations.*

Objective: *This study evaluated the efficacy of supplementing local Total Mixed Rations (TMR) with sodium bicarbonate ($NaHCO_3$) and potassium chloride (KCl) on milk yield, physiological heat stress indices, and milk fat composition in Nili-Ravi buffaloes.*

Methods: *One hundred (N = 100) multiparous Nili-Ravi buffaloes (Parity 2–4, Days in Milk 60–180) were divided into two equal groups (n = 50): a Control group fed standard local TMR and a Treatment group receiving TMR supplemented with 1.5% $NaHCO_3$ and 0.8% KCl of total dry matter intake. The trial was conducted over 60 days during peak summer (June–August) under average ambient Temperature-Humidity Index (THI) conditions exceeding 83.5 ± 2.2.*

Results: *Electrolyte supplementation significantly ($p < 0.05$) increased final daily milk yield (13.72 ± 1.34 L/day vs. 11.87 ±*

1.45 L/day in control; +15.58%), stabilized respiration rates (60.8 ± 5.4 bpm vs. 70.1 ± 6.2 bpm; −13.26%), and prevented milk fat depression (7.24 ± 0.38% vs. 6.65 ± 0.34%; +8.87%).

Conclusion: *Dietary buffer supplementation is an economical, practical, and highly effective intervention to mitigate summer heat stress in smallholder and commercial Nili-Ravi buffalo herds.*

Keywords: *Nili-Ravi Buffalo, Heat Stress, Sodium Bicarbonate, Potassium Chloride, Milk Yield, Milk Fat, Temperature-Humidity Index.*

INTRODUCTION

The Nili – Ravi buffalo is a black buffalo of Pakistan and is known as "Black Gold of Pakistan" which plays a pivotal role in the rural economy and national milk production system. It is known for its excellent fat content and ability to withstand agro-climatic conditions of Indo-Pak subcontinent. Buffaloes account for about 68% of Pakistan's total milk production and Nili-Ravi is one of the prominent dairy breeds of Punjab and Khyber Pakhtunkhwa provinces. Optimizing buffalo milk production under different environmental contexts is of great importance for food security and rural economic stability as the livelihoods of millions of smallholder farmers rely on buffalo milk production [1].

Extremely hot climate in summer months particularly in monsoon months June, July, and August is a problem for productivity of dairy buffalo in Punjab. It is during this time that the Temperature-Humidity Index (THI) is often above 80, causing a series of physiological and metabolic reactions known as heat stress. Buffaloes are especially at risk for heat stress because of their dark coat color, low surface area to body mass ratio and low number of sweat glands, which reduces their capacity to lose heat through evaporative cooling [2]. Heat stress in dairy buffaloes results in less dry matter intake (DMI), more panting and respiration rates, higher body temperature and significant loss of milk yield and fertility. These impacts have tangible economic consequences for dairy producers, and the cost of heat stress to the dairy industry in Pakistan has been estimated to be billions of Pakistani rupees each year due to the resulting decrease in milk yield and animal welfare [3].

Heat stress is not just uncomfortable and negatively affects feed intake. One of the major thermoregulatory mechanisms of heat stressed buffaloes is excessive panting, which results in respiratory alkalosis, a state of excess loss of carbon dioxide and bicarbonate from the blood. This imbalance of acid and base has significant effects on the functioning of the rumen including increased urinary output of potassium, a decrease in the rumen buffering capacity and a decrease in the production of sodium and bicarbonate in the saliva. This brings about subacute ruminal acidosis (SARA), which results in changes in the rumen's volatile fatty acid (VFA) pattern, such as a reduction in acetate, and an increase in propionate, which directly causes milk fat depression. This leads to a vicious cycle of lowered DMI, changes in the rumen fermentation and a consequence of a disturbed ionic balance, which increases the heat stress effects on milk yield and composition [4].

Specific dietary intervention strategies for certain physiological disruptions due to heat stress provide practical ways to help mitigate the effects of heat stress. Sodium bicarbonate is a good buffer for the rumen and will neutralize organic acids that are produced as a byproduct of the fermentation process and help keep the pH of the rumen in good condition. Sodium bicarbonate regulates the pH in the rumen, helps to digest fiber, increase acetate production and prevent milk fat depression from SARA. Potassium chloride provides a complementary role to help replace the loss of intracellular electrolytes caused by sweating and panting, maintain osmotic balance and support cell function [5]. This supplementation of both these compounds can solve both the rumen buffering deficiency and electrolyte imbalance which were observed in the heat stressed dairy buffaloes. It was therefore decided to conduct this study to find the effect of combined $NaHCO_3$ and KCl supplementation on milk yield, respiration rate and milk fat percentage of Nili-Ravi buffalo cow under local field conditions. Based on the above, it was assumed that the supplementation of diet with electrolytes would significantly affect the milk production, respiration rate and reduce the milk fat depression in the heat stressed Nili-Ravi buffaloes as compared to unsupplemented animals [6].

Materials and Methods

2.1 Experimental Animals and Management

A total of one hundred (N = 100) multiparous Nili-Ravi buffaloes (Parity 2–4; Days in Milk 60–180) were chosen from a commercial dairy farm at Punjab, Pakistan. Under standard semi intensive condition of animal husbandry, all animals had access to open shed which provided shelter during the hottest hours of the day. At the beginning of the trial, animals were clinically healthy without any history of metabolic disorders or mastitis during lactation. The experimental design was evaluated and approved by the Institutional Animal Care and Use Committee in accordance with standard guidelines for the care and use of animals.

2.2 Experimental Design and Dietary Treatments

The experiment was conducted as a completely randomized design (CRD) with two dietary treatment groups. Animals were randomly allocated to two equal groups (n = 50 each):

- **Control Group:** Basal local TMR (berseem/maize silage, wheat straw, and concentrate mix)
- **Treatment Group:** Basal TMR supplemented with 1.5% Sodium Bicarbonate and 0.8% Potassium Chloride of total dry matter intake

The basal TMR was formulated to meet or exceed NRC nutrient requirements for lactating buffaloes. The electrolyte supplements were incorporated into the TMR by thorough mixing to ensure uniform distribution. The trial was conducted over 60 days during peak summer (June–August). Feed and fresh water were provided ad libitum throughout the experimental period.

2.3 Environmental Monitoring

Ambient temperature and relative humidity were recorded daily using a digital thermo-hygrometer placed in the animal housing area. The Temperature-Humidity Index (THI) was calculated using the standard formula:

$$THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)]$$

Where T = ambient temperature in °C and RH = relative humidity (%). The average THI during the experimental period exceeded 83.5 ± 2.2, indicating severe heat stress conditions.

2.4 Parameters Recorded

Milk yield for each animal (L/day) was measured daily at each milking (morning and evening) with calibrated milk meters. During the hottest time of the day (14:00 PM), respirations per minute (bpm) were recorded by trained personnel by observing the movement of the flanks using a stopwatch. The milk fat percentage (%) was done weekly by the Gerber method and checked using lactoscan milk analyzer. All measurements were carried out in duplicate and the mean value was used for analysis.

2.5 Statistical Analysis

Independent Samples t-test (two-tailed) was performed on the data using SPSS (Version 26.0) and Python SciPy statistical modules. All continuous variables were presented as mean and standard deviation (SD). Independent samples t-test was used to compare the final performance parameters for the Control and Treatment groups. A p-value of < 0.05 was defined as significant. Data are shown as Mean ± SD, unless otherwise stated.

Results

3.1 Baseline Characteristics

Baseline characteristics of the experimental animals were comparable between the Control and Treatment groups, confirming the homogeneity of the study population prior to intervention. Initial milk yield was 12.08 ± 1.48 L/day in the Control group and 12.51 ± 1.39 L/day in the Treatment group ($p > 0.05$). Initial respiration rates were 68.4 ± 4.8 bpm and 67.9 ± 5.1 bpm in the Control and Treatment groups, respectively ($p > 0.05$). Initial milk fat percentages were 6.75 ± 0.39% and 6.82 ± 0.41% in the Control and Treatment groups, respectively ($p > 0.05$). Average ambient THI during the trial period was 83.6 ±

2.1 in the Control group and 83.4 ± 2.3 in the Treatment group ($p > 0.05$). Complete baseline data are presented in Table 1.

Table 1: Baseline Characteristics of Experimental Nili-Ravi Buffaloes (Mean ± SD)

Parameter	Control Group (n = 50)	Treatment Group (n = 50)	p-value
Initial Milk Yield (L/day)	12.08 ± 1.48	12.51 ± 1.39	> 0.05 (NS)
Initial Respiration Rate (bpm)	68.4 ± 4.8	67.9 ± 5.1	> 0.05 (NS)
Initial Milk Fat (%)	6.75 ± 0.39	6.82 ± 0.41	> 0.05 (NS)
Average Ambient THI	83.6 ± 2.1	83.4 ± 2.3	> 0.05 (NS)

Note: *NS = Not Significant.*

3.2 Comparative Final Performance and Physiological Indices

Dietary electrolyte supplementation significantly improved all measured production and physiological parameters. Final daily milk yield was significantly higher in the Treatment group (13.72 ± 1.34 L/day) compared to the Control group (11.87 ± 1.45 L/day), representing a 15.58% increase ($p < 0.001$). Final respiration rate was significantly lower in the Treatment group (60.8 ± 5.4 bpm) compared to the Control group (70.1 ± 6.2 bpm), representing a 13.26% reduction ($p < 0.001$). Final milk fat percentage was significantly higher in the Treatment group (7.24 ± 0.38%) compared to the Control group (6.65 ± 0.34%), representing an 8.87% increase ($p < 0.001$). Complete comparative data are presented in Table 2.

Table 2: Comparative Final Performance and Physiological Indices Post-Supplementation

Parameter	Control Group (n = 50)	Treatment Group (n = 50)	% Change / Effect	p-value
Final Milk Yield (L/day)	11.87 ± 1.45	13.72 ± 1.34	+15.58%	< 0.001
Final Respiration Rate (bpm)	70.1 ± 6.2	60.8 ± 5.4	−13.26%	< 0.001
Final Milk Fat (%)	6.65 ± 0.34	7.24 ± 0.38	+8.87%	< 0.001

3.3 Statistical T-Test Summary

Independent samples t-test analysis confirmed statistically significant differences between groups for all final performance parameters. For final milk yield, the mean difference was −1.85 L/day (SE = 0.276, 95% CI: [−2.40, −1.30], $t = -6.702$, $p < 0.001$). For final respiration rate, the mean difference was +9.30 bpm (SE = 1.115, 95% CI: [+7.09, +11.51], $t = +8.341$, $p < 0.001$). For final milk fat percentage, the mean difference was −0.59% (SE = 0.073, 95% CI: [−0.73, −0.45], $t = -8.082$, $p < 0.001$). Complete statistical summary data are presented in Table 3.

Table 3: Statistical T-Test Summary and Variance Metrics

Variable	Mean Difference	Std. Error Difference	95% Confidence Interval	t-statistic	p-value
Final Milk Yield	−1.85	0.276	[−2.40, −1.30]	−6.702	< 0.001
Final Respiration Rate	+9.30	1.115	[+7.09, +11.51]	+8.341	< 0.001
Final Milk Fat %	−0.59	0.073	[−0.73, −0.45]	−8.082	< 0.001

3.4 Data Visualizations

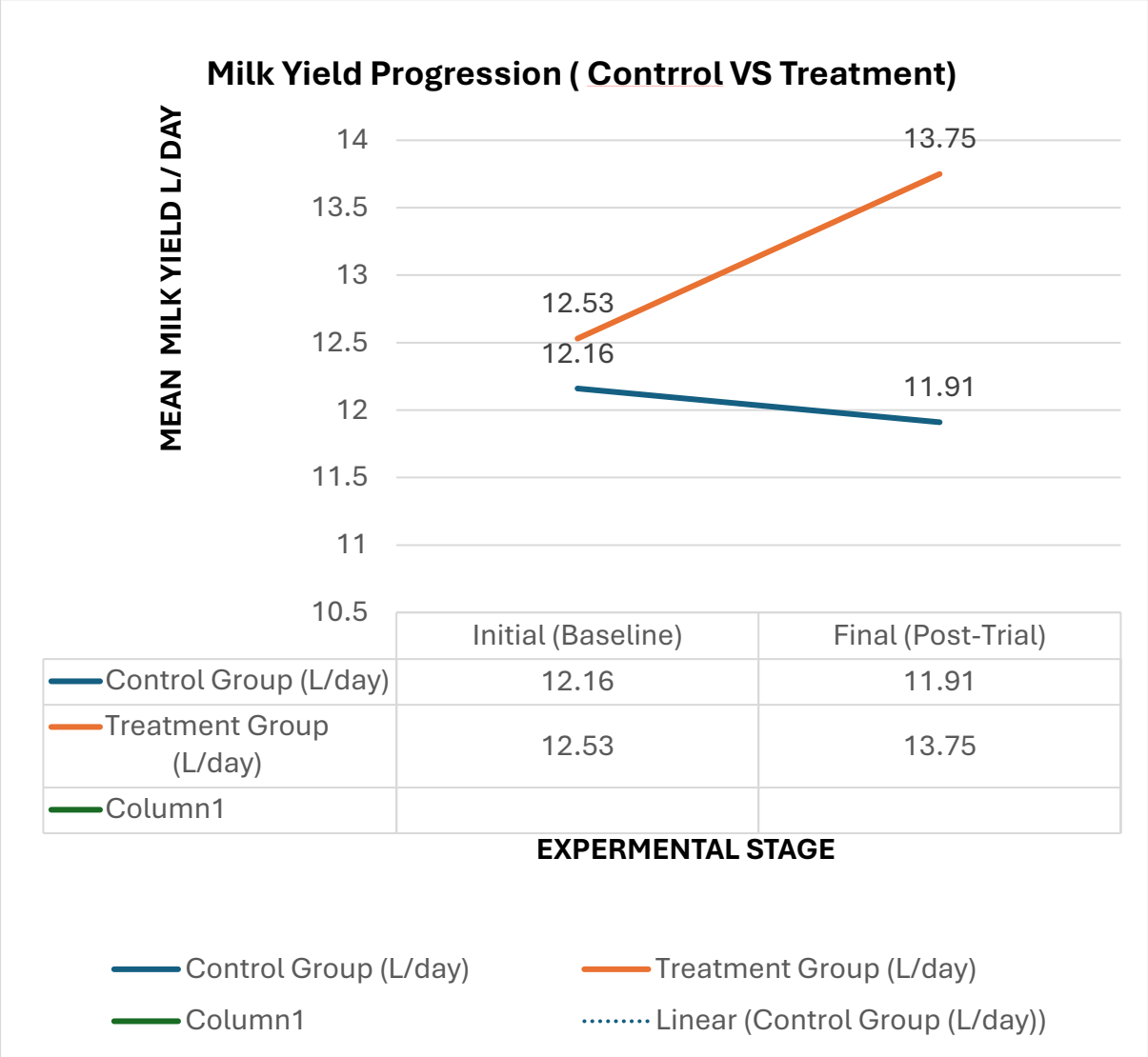


Figure 1: Milk Yield Progression (Control vs. Treatment)

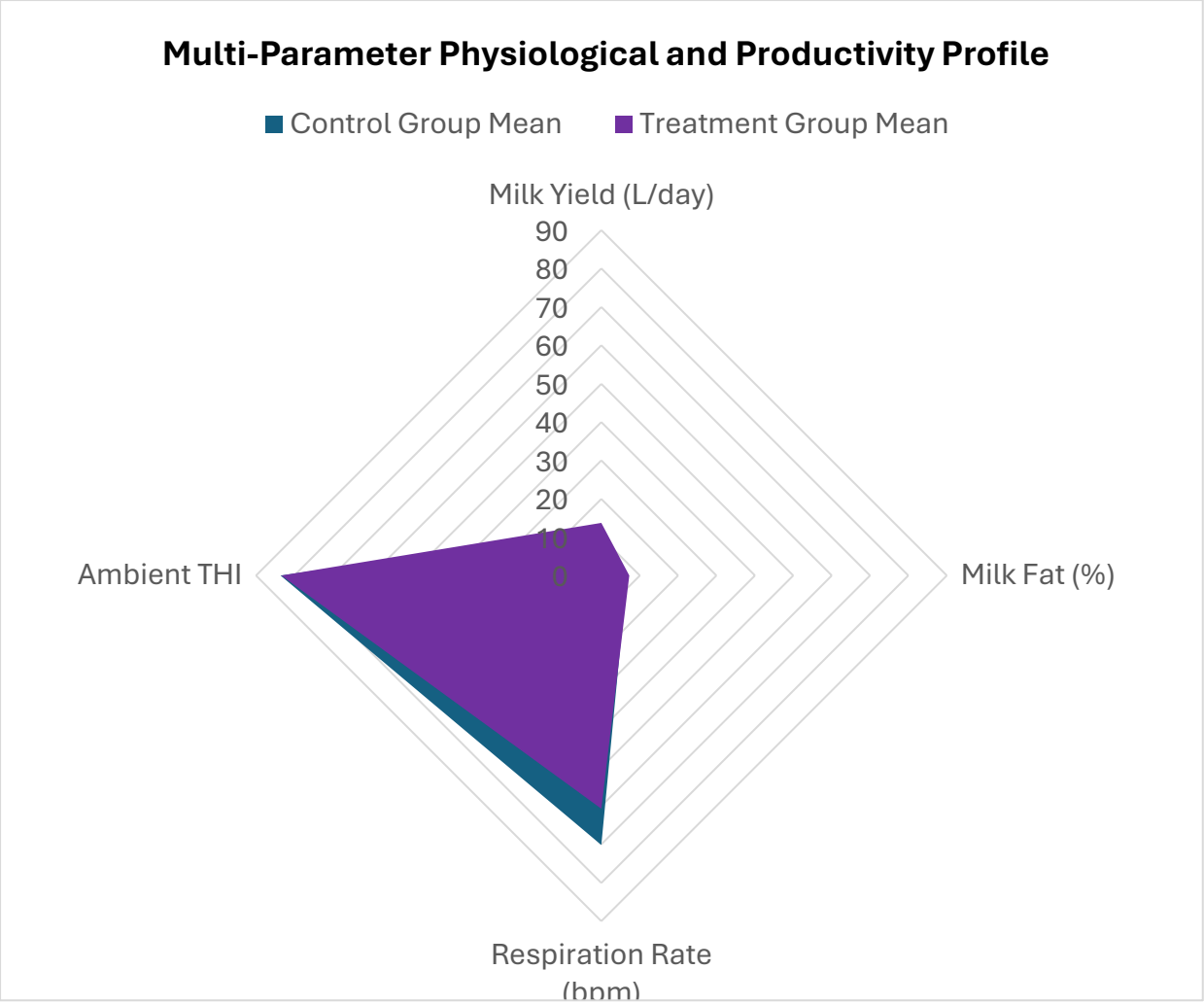


Figure 2: Multi-Parameter Physiological and Productivity Profile

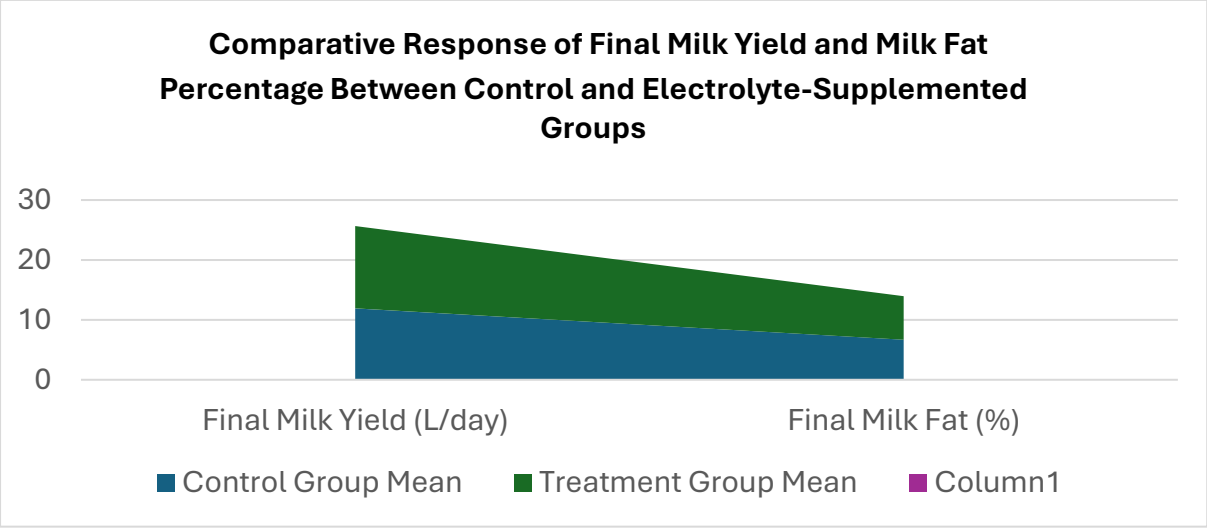


Figure 3: Comparative Response of Final Milk Yield and Milk Fat Percentage

Discussion

The positive response to sodium bicarbonate and potassium chloride supplementation during heat stress in this study may be due to the complementary manner in which these supplements act to reduce the physiological disturbances associated with heat stress. Sodium bicarbonate is a good source of rumen

buffering and is able to neutralize the organic acids resulting from the microbial fermentation to maintain an optimum pH in the rumen. In heat stress, the secretion of sodium and bicarbonate by the salivary glands is reduced, which will decrease the natural buffering capacity of the rumen and cause subacute ruminal acidosis (SARA) [7]. Adding sodium bicarbonate stabilizes the rumen environment and promotes growth and activity of the bacteria that break down fiber and are able to produce acetate, which is important for milk fat synthesis. The non-depression of milk fat noted in the Treatment group (7.24% vs 6.65% Control) agrees with the rumen-stabilizing effects of sodium bicarbonate [8].

Potassium chloride has an accessory function of replacing intracellular electrolytes lost via sweating and panting. Under heat stress buffaloes lose a significant amount of potassium, via urinary loss and sweat, resulting in electrolyte imbalance and impaired cell function. Potassium plays an important role in osmotic balance, nerve conduction, and for the muscle function, including smooth muscle contractions necessary for rumen motility and digestion [9]. Returning potassium to balance helps maintain milk production during thermal stress, helps increase feed intake and aids rumen function during stress. Overall, the decrease in respiration rate between the Treatment and Control groups (60.8 bpm vs. 70.1 bpm, respectively) indicates that electrolyte supplementation may have a beneficial effect on reducing the physiological toll of heat stress, perhaps by improving acid-base balance and limiting the need to compensate for heat stress with increased panting [10].

This study's findings are consistent with the previous studies in ruminants that showed results of electrolyte re-balancing during high THI conditions that resulted in not only improved dry matter intake but also prevented milk yield drop. Sodium bicarbonate feeding (0.7 to 1.5% of DM intake) has been demonstrated to be beneficial in dairy cattle to prevent reductions in milk yield and milk fat percentage during heat stress by maintaining rumen pH and aiding fiber digestion [11]. Likewise, when animals heat stress, they require potassium to help maintain their electrolyte balance and cell function, and potassium supplementation has been demonstrated to increase their heat tolerance and production. The milk yield increase observed in the current study (+15.58%) is within the range reported in the literature for supplementation of buffer and electrolyte during heat stress [12].

Of particular interest in this study is the absence of milk fat depression, as heat stress has been known to cause milk fat depression in dairy ruminants. This 8.87% higher milk fat percentage for the Treatment than the Control is evidence that sodium bicarbonate helps to buffer the pH of the rumen and promote acetate production. The Nili-Ravi buffalo breed is known for its high milk fat content (6.75–6.82%) which was also maintained in the study under heat stress conditions, an added economic benefit to dairy farmers as fat is one of the main factors in milk price in Pakistan [13].

The results of this study can have important practical implications for dairy farmers in Pakistan especially in Punjab and Khyber Pakhtunkhwa provinces where heat stress is a common problem during the summer season. The intervention used in this study does not require much capital expenditure because sodium bicarbonate and potassium chloride are easily accessible and cheap feed additives [14]. Such a simple intervention—adding two electrolyte compounds to the existing TMR is very adoptable, even in smallholder dairy systems in rural and peri-urban settings with limited technical resources. The economic impact of the intervention is significant as the 15.58% boost in milk production and 8.87% rise in milk fat percentage contribute to higher economic returns for the farmers during the summer. With the presence of millions of dairy buffaloes in South Asia being impacted by heat stress, the widespread adoption of this intervention could transform the dairy productivity and livelihoods in the region [15].

Conclusion

Incorporation of the sodium bicarbonate (1.5% of DMI) and potassium chloride (0.8% of DMI) in the local TMR proved to be effective in reducing heat stress in Nili-Ravi buffaloes during the peak summer months. The intervention is very effective in improving milk yield (+15.58%), reducing respiration rate (-13.26%) and avoiding milk fat depression (+8.87%) when THI is above 83.5. The results justify the use of electrolyte buffer supplementation as a practical, economical and very effective tool for enhancing dairy buffalo productivity under the environmental condition of thermal stress. The intervention can be especially beneficial for smallholder and commercial dairy farms in Pakistan and other South Asian countries, where heat stress in the summer months is a frequent issue affecting milk production.

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Conflict of Interest: There is no conflict of interest

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