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Examine the Effects of Climate Change on Forage Quality and its Subsequent Impact on Milk Yield and Composition

Mukhtar Ahmad[1], Muhammad Jamil[2], Saeed Ullah[1], Shakirullah[3], Mubarik Ali[4]

[1]Livestock and Dairy Development Extension, KP, Pakistan.
[2]Arid Zone Research Center, PARC, Dera Ismail Khan, KP, Pakistan.
[3]Faculty of Veterinary and Animal Sciences, Gomal University, Dera Ismail Khan, KP, Pakistan.
[4]Animal Science Institute, National Agricultural Research Center, Islamabad, Pakistan.

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Corresponding Author: Mukhtar Ahmad, Livestock and Dairy Development Extension, KP, Pakistan.
Email: mukhtarahmad2010@gmail.com

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ABSTRACT

Background: Climate change is a major threat to animal productivity because it lowers the quality of fodder, which in turn lowers milk yield and changes its composition. The connection between cow and buffalo dairy output, environmental variables, and pasture quality is explored in this research. **Methods:** From July 2023 through June 2024, a cross-sectional study was conducted carrying 400 animals, including 200 cows and 200 buffaloes. The mineral composition, digestibility, crude protein and fiber content of the forage were evaluated to determine its quality. The analysis focused on milk production and its constituent parts, such as fat, protein, lactose, and solids-not-fat (SNF). There was a log of feed consumption habits and environmental data (rainfall, humidity, and temperature). **Findings:** We found a lot of variation in the nutritional composition of the forages we looked at. Berseem had the highest levels of crude protein (17.5%) and digestibility (80.2%), whereas wheat straw had the lowest. Even while buffaloes had a higher protein and fat content (6.8% and 3.4%, respectively), cows produced more milk (12.1 ± 1.8 L/day) than buffaloes (9.8 ± 1.6 L/day). There was a positive correlation between crude protein and milk protein ($r = 0.72$, $p < 0.001$), although digestibility and yield were significantly impacted by lignin and neutral detergent fiber (NDF) ($p < 0.05$). Dairy output was affected by changes in fodder quality and consumption habits brought about by environmental variables. **Conclusion:** Climate change and forage quality have a major impact on milk production and composition. Low-quality diets restricted the performance, whereas forages like berseem and maize silage, which are high in protein and easy to digest, increase output. Sustainability of dairy output in the face of changing environmental circumstances requires adaptive measures such as climate-resilient pasture systems and precision feeding.

INTRODUCTION

The rise of climate change has become an enormous problem for the world's farmers, endangering both food production and productivity of livestock [1]. Dairy cattle rely on pasture and fodder crop output for their nutrition, but this is being negatively impacted by changing precipitation patterns, more frequent extreme weather events and generally warmer temperatures. Livestock health, milk production, and composition are all impacted by changes in the environment, and forage quality which is determined by the nutrients, digestibility, and energy content of the feed is especially vulnerable to these changes [2-3].

Drought stress and temperature swings diminish forage biomass and change its chemical makeup, resulting in higher lignification, lower crude protein content and mineral profile imbalances. Increasing the concentration of carbon dioxide (CO_2) can improve plant development, but it also dilutes important nutrients, which means plants have less protein and more fiber [4-6]. The metabolic performance and lactation efficiency of dairy cattle are affected by these changes, which lead to decreased digestibility and energy availability. Heat stress worsens productivity losses in cattle already caused by poor forage quality because it reduces feed intake, rumen function, and nutrient absorption [7].

As a result of changes in fat, protein, and lactose concentrations, low-quality forage has an impact on milk composition in addition to milk output [8]. Milk protein content drops when forage quality drops, and changes in carbohydrate availability impact lactose production [9]. The processing characteristics and nutritional value of milk can be compromised due to insufficient amounts of certain minerals, vitamins, and important fatty acids, which affect the milk's fat composition and overall quality [8-10].

In addition to driving up production costs and posing challenges to sustainable dairy farming techniques, climate-induced fluctuation in fodder supply pushes farmers to rely on supplemental feeds. To combat the negative impacts of climate change on dairy production systems, adaptive measures are needed, such as forage crops that can withstand extreme weather, better management of pastures, and nutritional supplements for cows [11].

In order to create sustainable methods of livestock management, it is crucial to comprehend the intricate relationship between climate change, feed quality, and milk production. Improvements in resource efficiency and losses can be achieved by the use of precision agriculture technologies, the development of more climate-resilient forage species, and the optimization of feeding practices. The purpose of this research was thus to determine how climate change is influencing pasture quality, which in turn affects milk yield and composition, and how we can adapt to keep producing dairy products even when the weather gets worse.

MATERIALS AND METHODS

Study Design and Site

The Dera Ismail Khan district in Khyber Pakhtunkhwa, Pakistan, was the site of this cross-sectional study that spanned from July 2023 to June 2024. The area was chosen because of its large animal population and the fact that dairy farming is a main source of revenue and food for the local community.

Selection Criteria and Sample Size

The research used a random sampling technique to choose 400 animals, including 200 cows and 200 buffaloes. The animals were selected from households and dairy farms in the area. Prerequisites for inclusion were that the animals in the lactation period and kept under comparable dietary and management conditions. To minimize potential confounding factors, we did not include animals that were pregnant or receiving veterinary treatment for metabolic problems.

Data Collection

Sampling and Analysis of Forage

The farmers of the farms included in the study provided us with fresh samples of the forage that the animals consumed. Using conventional proximate analysis methods, these samples were examined for nutrient composition, which included crude protein, fiber content, dry matter and mineral profiles. To evaluate the quality of the fodder, we assessed its lignin content and digestibility.

Milk Sampling and Analysis

Each animal had its milk collected in a sterile environment, and then the yield and content of the milk were examined. Included parameters:

- A calibrated weighing scale was used to measure the yield.
- We used a milk analyzer to find out how much fat, protein, lactose, and solid-not-fat (SNF) there was.

Environmental Monitoring

Throughout the study period, on-site meteorological stations and historical weather reports were used to capture environmental data, which included temperature, humidity and rainfall. Because of this information, we can better understand how climate change affects forage quality and milk yield patterns.

Animal Health Monitoring

We evaluated the animals' health and physical condition. In addition to that, we kept track of things like feed consumption, water consumption and signs of heat stress (like breathing rate).

Statistical Analysis

We used software SPSS version 25.0 to examine the data. Forage quality and milk characteristics were subjected to descriptive statistical calculations. Means were compared between groups using independent t-tests and analysis of variance (ANOVA). In order to determine the connections between environmental factors, forage quality, and milk production and composition, Pearson's correlation analysis was used. A significance level of $p < 0.05$ was used.

Ethical Approval

All farm owners gave their informed consent before data was collected, and the study was authorized by the Institutional Animal Ethics Committee. The welfare and comfort of the animals were prioritized by adhering to established standards when handling them during the collection process.

RESULTS

Different types of feed show a lot of variation in the forage quality analysis. Wheat straw, despite having a high dry matter content (91.5 ± 1.2%), was found to have the lowest crude protein (3.5 ± 0.6%) and digestibility (45.3 ± 2.5%), rendering it an inadequate food source. The protein levels and digestibility were improved in maize silage (75.1 ± 2.9% and 78.6 ± 3.1%, respectively) and sugar beet pulp (10.2 ± 1.0%). Because of its exceptionally high levels of crude protein (17.5 ± 1.5%) and digestibility (80.2 ± 3.4%), Berseem was distinguished as the forage that contained the most nutrients. All metrics showed moderate values when maize was fresh (Table 1).

Cows and buffaloes produced milk with very different compositions and yields. The milk yields of cows were 12.1 ± 1.8 L/day, while those of buffaloes were 9.8 ± 1.6 L/day. However, the fat content of buffaloes was 6.8 ± 0.7% and the protein content was 3.4 ± 0.5 %, which were greater than those of cows. Cows had somewhat greater lactose and SNF percentages, while buffaloes had somewhat higher ash content. Cows are more adapted to larger yields, while buffaloes produce milk with richer components, according to the p-values for all parameters, which show that the two groups are statistically different (Table 2).

Important connections between feed quality and milk composition are shown by correlation analysis. The significance of protein-rich feeds in enhancing milk quality was highlighted by a robust positive correlation ($r = 0.72$, $p < 0.001$) between the levels of crude protein in forage and the protein content of milk. A negative connection between milk yield and neutral detergent fiber (NDF) was observed ($r = -0.58$, $p = 0.003$), suggesting that an increase in fiber content decreases the efficiency of milk production. The deleterious effects of high lignin levels on nutrient availability and utilization were further highlighted by the negative correlation between lignin concentration and digestibility ($r = -0.65$, $p = 0.002$) (Table 3).

The environmental data analysis showed that the research region was quite warm, with an average temperature of 28.5 ± 3.2°C and a temperature range of 23.1-35.7°C. Rainfall varied from 85 to 125 mm, with an average of 102.4 ± 15.6 mm, while humidity averaged 64.8 ± 5.1%. The forage growth patterns, nutritional profiles and total feed availability could be impacted by these climate circumstances, which in turn could affect the milk yield and composition (Table 4).

Analysis of feed consumption revealed notable differences among different types of pasture. The average daily intake of Berseem was 15.4 ± 1.4 kg, followed by maize silage at 12.8 ± 1.1 kg, and fresh corn at 10.2 ± 1.0 kg. Lower amounts of sugar beet pulp (8.6 ± 0.9 kg/day) and wheat straw (4.5 ± 0.3 kg/day) were consumed. Animals favored protein-rich, easily digestible forages like berseem and maize silage over less healthy alternatives like wheat straw, according to the p-values, which show that there were statistically significant differences in intake among feed types (Table 5).Cows had body condition scores of 3.2 ± 0.4 and buffaloes had 3.6 ± 0.5, which were significantly different from each other ($p = 0.021$ for buffaloes and $p = 0.015$ for cows). Buffaloes had improved body condition and fat reserves due to their greater fat diet and increased feed conversion efficiency, which shows in their milk composition (Table 6).

Various kinds of fodder were compared in terms of crude protein and digestibility percentages. The little nutritional value of wheat straw is indicated by its low crude protein content (around 3.5%) and digestibility (about 45 percent). Sugar beet pulp and maize silage are superior feed alternatives due to their high digestibility (75–78%) and moderate crude protein contents (8–10%). The exceptional quality of Berseem is demonstrated by its high crude protein content (about 17.5%) and digestion rate (80%). A balanced alternative, fresh maize has reasonable levels in both dimensions. These findings highlighted the significance of choosing protein-rich and easily digestible forages, like berseem and maize silage, for the best nutrition and performance of cattle (Figure 1).

Cows and buffaloes were compared in terms of milk yield and composition factors. The milk yield of cows was roughly 12 L/day, which is higher than that of buffaloes, which is around 8-10 L/day. Both the fat content (around 6.8% vs. 4.2%) and protein levels (about 3.4% vs. 3.1% compared. cows) were areas where buffaloes excel. Buffaloes have a little greater SNF percentage (9.0% vs. 8.5%) and little higher lactose content (4.8% vs. 4.5%) than cows. According to these tendencies, cows are better suited to produce large quantities of milk, whereas buffaloes yield milk that is nutritionally superior, especially in terms of fat and protein content (Figure 2).

Climate data, including temperature, humidity and precipitation, were also recorded. Conditions were moderately warm, with an average temperature of 28.5°C. The air was relatively moist, with an average humidity of 64.8%. The most variable factor was rainfall, which varied by an average of 102.4 mm, drawing attention to the effects of seasonality and other factors that may affect the availability and growth of fodder. The importance of these environmental elements in influencing fodder quality and, by extension, milk production, highlighted the necessity to adjust feeding methods according to weather patterns (Figure 3).

Table 1

Forage Quality Analysis

Forage Type	Crude Protein (%)	NDF (%)	ADF (%)	Dry Matter (%)	Lignin (%)	Digestibility (%)	Ash (%)	p-value
Wheat Straw	3.5 ± 0.6	76.2 ± 2.1	48.7 ± 1.9	91.5 ± 1.2	7.8 ± 0.5	45.3 ± 2.5	9.5 ± 0.8	<0.001
Maize Silage	8.1 ± 1.2	48.3 ± 3.0	28.5 ± 1.8	35.8 ± 2.5	3.6 ± 0.4	75.1 ± 2.9	6.8 ± 0.7	0.003
Sugar Beet Pulp	10.2 ± 1.0	42.5 ± 2.5	24.7 ± 1.5	89.4 ± 1.4	2.8 ± 0.3	78.6 ± 3.1	7.2 ± 0.6	0.005
Berseem	17.5 ± 1.5	35.8 ± 2.0	22.4 ± 1.6	18.5 ± 1.0	2.5 ± 0.4	80.2 ± 3.4	8.1 ± 0.7	<0.001
Maize (Fresh)	9.6 ± 1.3	52.3 ± 2.8	30.8 ± 2.0	27.6 ± 1.8	4.2 ± 0.5	72.8 ± 2.7	6.5 ± 0.5	0.002

Table 2

Milk Yield and Composition Analysis

Parameter	Cows (Mean ± SD)	Buffaloes (Mean ± SD)	p-value
Milk Yield (L/day)	12.1 ± 1.8	9.8 ± 1.6	0.004
Fat (%)	4.2 ± 0.5	6.8 ± 0.7	<0.001
Protein (%)	3.1 ± 0.4	3.4 ± 0.5	0.038
Lactose (%)	4.8 ± 0.3	4.5 ± 0.4	0.027
Solids-Not-Fat (SNF) (%)	8.5 ± 0.7	9.0 ± 0.6	0.015
Ash (%)	0.7 ± 0.1	0.8 ± 0.1	0.021

Table 3

Correlation Analysis

Parameter Comparison	r	p-value
Crude Protein vs Milk Protein	0.72	<0.001
Neutral Detergent Fiber (NDF) vs Milk Yield	-0.58	0.003
Lignin vs Digestibility	-0.65	0.002

Table 4

Environmental Data Analysis

Parameter	Mean ± SD	Range
Temperature (°C)	28.5 ± 3.2	23.1 - 35.7
Humidity (%)	64.8 ± 5.1	55 - 72
Rainfall (mm)	102.4 ± 15.6	85 - 125

Table 5

Feed Intake Analysis

Feed Type	Mean Intake (kg/day)	p-value
Wheat Straw	4.5 ± 0.3	<0.001
Maize Silage	12.8 ± 1.1	0.002
Sugar Beet Pulp	8.6 ± 0.9	0.003
Berseem	15.4 ± 1.4	<0.001
Maize (Fresh)	10.2 ± 1.0	0.004

Table 6

Body Condition Scores

Parameter	Mean ± SD	p-value
BCS (Cows)	3.2 ± 0.4	0.015
BCS (Buffaloes)	3.6 ± 0.5	0.021

Figure 1

Crude Protein and Digestibility in Forages

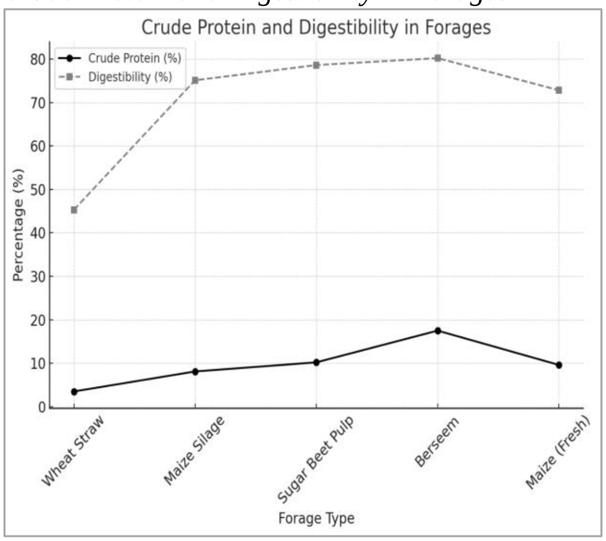


Figure 2

Milk Yield and Composition Comparison (Cows vs. Buffaloes)

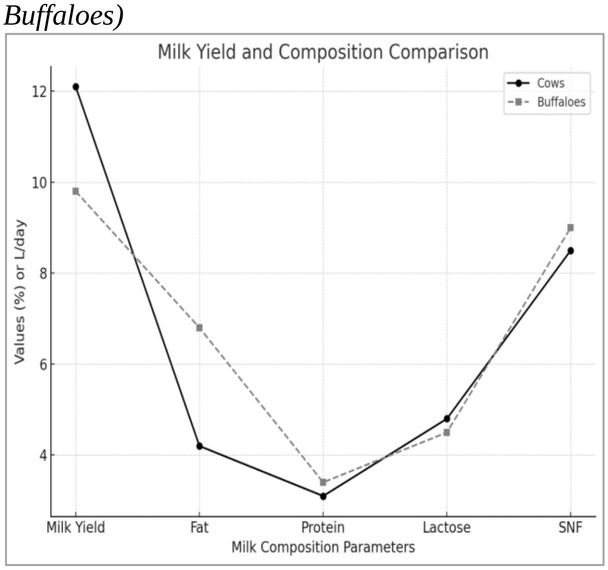
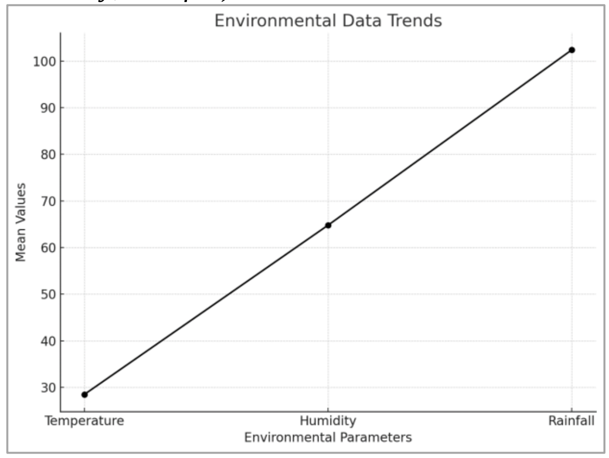


Figure 3

Environmental Data Trends (Temperature, Humidity, Rainfall)



DISCUSSION

The purpose of this research was to determine how dairy cows and buffaloes' milk production and composition are affected by changes in fodder quality brought on by climate change. Sustainable dairy production in the face of changing climate is better understood in light of the results, which show that environmental factors significantly affect feed quality, milk composition, and animal performance.

The study of different kinds of forage brought attention to the fact that they have different nutritional profiles, which in turn affect the performance of the cattle. This study confirms previous research that wheat straw is a low-quality fodder mainly employed for its high fiber content; it found that the feed's digestibility was 45.3% and crude protein was 3.5% [12-13]. Berseem, on the other hand, is an excellent feed for increasing milk production and quality since it has the most crude protein (17.5%) and digestibility (80.2%). Consistent with previous research, these results highlight the significance of forages high in protein for increasing milk protein content and total output [14].

Maize silage (8.1% crude protein, 75.1% digestibility) and sugar beet pulp (10.2% crude protein, 78.6% digestibility) are both moderately performing feeds, which means they can be used together. The digestibility of wheat straw and maize silage is negatively affected by their lignin levels (7.8% and 3.6%, respectively) [15]. Smart feed selection is crucial for maximizing dairy output, as there are notable variations among different types of forage ($p < 0.05$).

There are significant differences between buffalo and cows, according to research comparing their milk yield and composition. In comparison to buffaloes, which produced 9.8 L/day of milk with 6.8% fat and 3.4% protein, cows produced 12.1 L/day of milk with lower fat (4.2%) and protein levels (3.1%). As a result of variations in feed metabolism and digestive efficiency, these findings are consistent with earlier research showing that milk from buffaloes is higher in fat and protein [16].

The fact that there is a positive relationship between the amount of crude protein in forage and the protein content of milk ($r = 0.72$, $p < 0.001$) provides more evidence that diets rich in protein can improve the quality of milk. It was found that feed efficiency is reduced by increased fiber content; this is supported by the negative association between NDF and milk yield ($r = -0.58$, $p = 0.003$). These results stress the need of dietary protein and fiber balance for optimal milk production and composition [17].

Forage quality and, by extension, dairy output are highly susceptible to weather conditions like heat, humidity, and precipitation. Conditions that are good for forage growth with a mean temperature of 28.5°C and humidity of 64.8% raise worries about heat stress in cattle. Reduced feed intake, nutritional absorption, and milk output have all been linked to heat stress [18]. Forages' nutritional value and availability are both impacted by rainfall fluctuation; for example, water stress typically lowers protein content while increasing fiber levels [19].

If we want to lessen the impact of climate change, we need to use adaptation measures like better pasture management and drought-resistant fodder varieties. Another way to make dairy systems more resilient is to use precision feeding techniques. One of them is to augment feeds with protein when the forage quality is low.

The analysis of feed intake showed a preference for forages that are easy to digest and provide a lot of protein. Berseem had the greatest intake (15.4 kg/day), followed by maize silage (12.8 kg/day). This confirms what Rafiuddin et al. (2018) found: that these feeds are very nutritious and have a high palatability. On the other hand, wheat straw has low digestion and nutritional content, which is why its minimal consumption of 4.5 kg/day is significant [20].

It appears that buffaloes have stronger fat reserves and general health, as their body condition score of 3.6 is higher than that of cows, which is 3.2. This variation is because their milk has a larger fat content and they are better able to use fibrous foods [21]. Extreme scores (too low or too high) might cause metabolic issues and decreased fertility, so it's crucial to maintain appropriate BCS to sustain milk production and reproductive success.

The study highlighted the significance of coordinating feeding methods with the quality of forage and environmental factors in order to improve milk production. Adding high-protein forages to feeding regimens, such as berseem and maize silage, can greatly enhance milk yield and composition, according to the results. Crop rotation, irrigation management, and supplementation during low forage availability seasons are adaptive methods that are necessary because to the variable in forage quality caused by environmental conditions. The study also showed that buffaloes may provide high-fat milk, which is desirable in some areas, and that their milk has a lot of nutritional value. However, additional study into breeding and feeding methods is needed to maximize the milk production potential of buffaloes because their yields are lower than those of cows.

Research in the future should focus on different agro-ecological zones to determine how climate change may affect pasture quality and dairy farming in the long run. Another way to learn about sustainable dairy production is to look into the heritability of different cattle breeds and how well they can adjust to new environments. Additionally, additional investigation into the function of cutting-edge technology, like precision feeding systems and remote sensing for forage monitoring, is necessary to improve resource utilization and lessen the impact of climate-related hazards.

CONCLUSION

This study shows that the quality of the forage and environmental factors have a big impact on the milk production and composition in dairy cows and buffaloes. Forages with a lot of protein and easy digestion, like berseem and maize silage, improve milk production and quality. On the other hand, low-quality feeds, like wheat straw, limit performance. Buffaloes make milk with more fat and protein, while cows make more milk overall. Correlation analysis shows that crude protein has a positive effect on milk protein, while fiber and lignin have negative effects on digestibility and yield. Lastly, environmental factors like temperature, humidity, and rainfall further affect the quality and intake of forage, so it's important to use adaptive feeding strategies to keep dairy productivity up when the weather is unpredictable.

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