International Journal of Natural and Social Sciences
ISSN: 2313-4461

Nutritional challenges and prospects of buffalo production and development strategies in Bangladesh

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ARTICLE INFO

Article history

Received: 19 July 2026
Accepted: 29 July 2026
Published: 15 September

Keyword

Feeding practices, breeds, artificial insemination, milk yield, constraints, contribution in economy

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ABSTRACT

Buffaloes play a vital role in the rural economy of Bangladesh, contributing to milk, meat, and draught power production. This study investigated buffalo nutritional challenges, prospects and development strategies across four districts- Patuakhali, Barguna, Dinajpur and Panchagarh through a survey of 87 buffalo-rearing households. Statistical analyses, including descriptive statistics, chi-square tests, and ordinal logistic regression, were used to assess farm practices and productivity outcomes. Results showed that 63.0% of total breed responses belonged to domestic buffalo breeds, with 81.6% practicing extensive grazing and 92.0% not providing balanced rations. Straw (48.6%) and grass (42.5%) were the main feed sources, while farmer-prepared concentrate feed use was only 8.9%. Most buffaloes (79.3%) produced 1–3 liters of milk per day. Only 9.2% of farmers had received training, yet training was significantly associated with improved practices: 85.7% of trained farmers used balanced rations compared to just 2.5% of untrained ones. Artificial insemination and urea-molasses straw were adopted by only 11.5% and 17.2% of farmers, respectively. Seasonal feed scarcity was significantly related to reduce feeding frequency, system changes, and lower meat prices. Ordinal logistic regression revealed that balanced ration feeding ($p = 0.001$) and combined stall-grazing systems ($p < 0.001$) significantly increased milk production. The study underscores the importance of farmer training, nutritional interventions, and access to reproductive technologies to enhance productivity and promote sustainable buffalo farming in Bangladesh.

1. Introduction

Buffaloes (Bubalus bubalis) play a pivotal role in the livestock sector of Bangladesh, especially in rural areas, where they contribute significantly to milk, meat, and draught power. Despite their multipurpose utility and adaptability to local conditions, buffalo production has historically remained underdeveloped in comparison to cattle. However, in recent years, the potential of buffalo farming has gained increasing attention due to its economic value, particularly in the realms of milk and meat production. This surge in interest is not only due to the growing demand for buffalo milk and meat but also due to the economic advantages buffalo farming offers in terms of feed conversion efficiency, disease resistance, and suitability for the country's diverse agro-climatic conditions. Buffaloes are regarded as one of the most important livestock species in tropical and sub-tropical regions. Their resilience and adaptability to Bangladesh's climate, particularly in coastal areas and floodplains, have made them integral to the agricultural and rural economies (Das & Khan, 2010). According to Saadullah (2012), buffaloes are the second most significant livestock species in Bangladesh, primarily serving three key functions: milk production, meat production, and draught power. Although buffalo farming has largely remained subsistence-based, traditional farming

How to cite this article: Awal R, Kabir F, Rashid MA, Tuhin MKH, Sultana J and Rana HMA (2026). Nutritional challenges and prospects of buffalo production and development strategies in Bangladesh. International Journal of Natural and Social Sciences, 13(1): 19-30. DOI: 10.5281/zenodo.22228316

systems such as extensive (bathan), semi-extensive (semi-bathan), and household systems are gradually being supplemented by intensive commercial farming models (Habib et al., 2017; Rahman et al., 2018; Rahman et al.,2019). Bangladesh accounts for approximately 0.8% of the global buffalo population, with around 1.5 million buffaloes. These animals are primarily concentrated in the country's coastal regions, the Meghna- Ganga and Brahmaputra-Jamuna floodplains (Faruque et al., 1990; Sohel & Amin, 2015), as well as specialized areas like the Sylhet haor, Jamalpur's sugarcane belt, and parts of northern Bangladesh (Huque & Khan, 2017). Despite the growing popularity of buffalo farming, most of the buffalo population in Bangladesh consists of indigenous, non-descriptive riverine types, with some swamp buffaloes found in the eastern regions. Efforts to improve buffalo breed quality, including the introduction of higher-yielding breeds like Nili-Ravi and Murrah, have encountered significant implementation challenges (Hamid et al., 2016). The productivity of indigenous buffaloes in terms of milk production remains low, with lactation yields ranging from 620–1161 liters, far below regional standards set by Murrah (2335L) and Nili-Ravi (2345L) breeds (Singh, 2013; Anwar, 2013). This is further compounded by the fact that buffalo milk contributes only 3–4% of the total national milk production, while neighboring countries like India, Pakistan, and Nepal derive a far larger proportion of their milk supply from buffaloes 48%, 67%, and 71%, respectively (DLS, 2021).Similarly, buffalo meat, despite being valued for its lower cholesterol content, is often sourced from aged or emaciated animals, which affects its marketability and quality. In Bangladesh, buffalo meat contributes only 0.9% of the annual national meat production, while countries such as India and Pakistan derive a larger share (17% and 27.9%, respectively) from buffaloes (FAO, 2012; Pasha, 2013).

Despite these challenges, buffalo farming has gained traction due to its numerous advantages, such as high feed conversion efficiency, disease resistance, and ability to thrive in adverse climatic conditions (Hamid et al., 2016; Thomas, 2008). However, several systemic constraints continue to limit the growth of buffalo farming. These include a lack of knowledge about balanced nutrition, insufficient access to high-quality fodder, and limited veterinary care (Uddin et al., 2016; Pata et al., 2018; Rajkumar et al., 2017). Housing conditions for buffaloes are inadequate, with 99% of buffaloes lacking dedicated shelters (Hamid et al., 2016). Additionally, financial constraints, poor market systems, and exploitation by middlemen hinder the commercial development of buffalo farming (Pasha & Hayat, 2012; Sarita and Ahuja, 2017; Patel et al., 2013).

The current study aims to address these issues by systematically analyzing the current status, constraints, and future prospects of buffalo farming in Bangladesh. There is a clear research gap regarding the development potential of buffalo production in the country, particularly in terms of breed improvement, management practices, and commercialization. This study intends to fill that gap by providing an in-depth analysis of the buffalo farming landscape, identifying challenges and opportunities for growth, and proposing recommendations for sustainable development. The objectives are:

1. To assess the current status of buffalo population and production in Bangladesh.
2. To know the practices of present buffalo development strategies in Bangladesh (especially farming system, feeding, breeding, and house management).
3. To identify nutritional challenges especially feed scarcity and overcoming strategies in coastal region of Bangladesh.
4. To explore the future prospects of buffalo farming in Bangladesh; on aspect of economic and commercial viability.

2. Materials and methods

2.1. Study area and target population

The study was conducted in the southern and northern parts of Bangladesh (Figure 1), where buffalo farming has been practiced both commercially and domestically for a long time. A total of four districts: Patuakhali, Barguna, Dinajpur and Panchagarh were selected to assess buffalo rearing and regional feeding practices. The North Bengal (Dinajpur, Panchagarh) region generally experiences moderately cool to dry conditions, while the Southern region (Patuakhali,

Barguna) lies in a coastal saline zone with better market access.

2.2. Study design, sample size and study period

Buffalo data were collected from local hat, Kali Mela (Dinajpur), and from farm owner house (Panchagarh) and in the grazing land of Patuakhali and Barguna districts. A total of 87 farmers (n=87) were selected randomly from four districts based on easy accessibility, cost-effectiveness, and farmer's willingness (Table 1). The data were collected from January, 2024 to October, 2024 for a period of 10 months.

Table 1: Characteristics of respondents

Area		Frequency (n)	Percentage (%)
District	Barguna	5	5.7%
	Dinajpur	11	12.6%
	Panchagar	5	5.7%
	Patuakhali	66	75.9%
Education level	Below primary	70	80.5%
	Primary	12	13.8%
	SSC	5	5.7%
	HSC	0	0.0%
	Higher	0	0.0%
Age group	<30	18	20.7%
	31-45	51	58.6%
	46-60	17	19.5%
	>60	1	1.1%

2.3. Preparation of the questionnaire

The questionnaire was prepared by focusing on some basic aspects, such as the farmers demographic status, the buffaloes feeding process, farmers reliance on grass or concentrate feed, seasonal variations in feed availability or scarcity across two different regions, the purpose of buffalo farming, data recording and other relevant factors like housing, rearing method, health and dieses issue, breeding management, adaptation to modern technology (Questionnaire is attached in Appendix 1).

2.4. Methods of data collection

At first, Farmers are informed about the purpose of the study, and data were collected from them through face-to-face interviews using a questionnaire. Sometimes, if the farmers are unable to provide immediate responses or answers, data is collected later through phone communication.

2.5. Data entry and evaluation

Data gathered from the field survey were entered into Microsoft Excel 2019 for checking, cleaning, and coding, and then stored for further processing. IBM SPSS Statistics (Version 26.0, IBM Corp., Armonk, NY, USA) was used to conduct the statistical analysis.

2.6. Statistical analysis

2.6.1. Descriptive analysis

Descriptive statistics were used to summarize farm characteristics and practices. Frequencies and percentages were calculated for all categorical variables to identify patterns and the extent of adoption of best practices. Tables 2 and 3 present the detailed distributions. The analysis focused on highlighting prevalent trends in breed composition, feed sources, grazing duration, production purpose, feeding methods, animal health practices, and technology adoption. These descriptive insights serve as the foundation for subsequent inferential analyses that explore relationships between farm practices and production outcomes. All analyses were performed using IBM SPSS Statistics (Version 26.0, IBM Corp., Armonk, NY, USA), and results were interpreted in the context of existing literature and best practices in livestock management.

2.6.2. Statistical analysis for testing associations

To examine the associations between categorical variables such as training status, livestock management practices, seasonal feed availability, feeding systems, and market outcomes, chi-square (χ^2) tests of independence were employed. This non-parametric test is suitable for identifying whether a statistically significant relationship exists between two categorical variables.

2.6.3. Chi-Square test of independence

The chi-square test was applied to assess the strength and significance of associations between: Training received by farmers and livestock management practices, including balanced ration feeding, record keeping, use of artificial insemination (AI), urea molasses straw (UMS), deworming, and regular vaccination. Seasonal feed availability and key outcomes such as feeding frequency, feeding system (stall feeding, grazing, or both), and meat price received by farmers. The chi-square statistic (χ^2) was computed along with the corresponding p-value to determine statistical significance. A p-value of less than 0.05 was considered indicative of a significant association.

2.6.4. Contingency Coefficient (C)

To evaluate the strength of the association between the variables, the Contingency Coefficient (C) was calculated. The value of C ranges between 0 (no association) and 1 (perfect association), providing an estimate of the degree of relationship between the variables.

2.6.5. Ordinal logistic regression analysis

To examine the factors influencing daily milk production levels among buffaloes, an ordinal logistic regression analysis was conducted using a cumulative logit model with proportional odds. This method is appropriate when the dependent variable is ordinal and categorized in a meaningful order. The outcome variable, daily milk production, was categorized into three ordered levels:
1 = Low (1-3 kg), 2 = Medium (4-5kg), 3 = High milk (6-10 kg) production.

The independent variables included: Balanced ration (Yes = 1, No = 2)

Feeding system: this was categorized into three groups:
1 = Stall feeding only; 2 = Grazing only; 3 = Both stall and grazing (reference category)

Before running the model, the assumptions of ordinal logistic regression were assessed. The proportional odds assumption was checked and deemed appropriate for the data. The model was fitted using the logit link function. The analysis was conducted using SPSS, and results were interpreted at a significance level of $p < 0.05$. The model fitting information, goodness-of-fit statistics, and pseudo-R-square values (Cox & Snell, Nagelkerke, and McFadden) were used to assess the overall performance of the model. Parameter estimates were evaluated to determine the direction and strength of the predictors' effects on milk production.

This analytical approach enabled the identification of feeding practices that significantly contribute to improved milk yield, offering practical insights into optimal buffalo husbandry practices.

2.7. Ethical considerations and informed consent

This study was conducted in accordance with the ethical guidelines for human subject research. Prior to the commencement of the face-to-face interviews, the objectives and purpose of the study were clearly explained to each participant in their native language (Bengali). Participation was entirely voluntary, and explicit verbal informed consent was obtained from all farmer-respondents before any data collection began. Participants were assured of the strict confidentiality and anonymity of their personal information, and they retained the right to withdraw from the interview at any stage without any negative consequences.

3. Results and discussion

3.1. Farm characteristics and practices

Table 2 presents the descriptive statistics on various characteristics of buffalo rearing among the surveyed respondents. The analysis of farm characteristics revealed that the majority of buffalo owners maintained mid-sized herds, with 6–19 buffaloes being most common. This suggests a semi-commercial orientation among many farmers. The predominance of domestic buffalo breeds (63% of total reported breeds) over high-yielding breeds such as Murrah and Niliravi may reflect limited access to improved genetics, as well as farmer preferences for low-input, locally adapted animals. Indigenous buffalo populations

are generally valued by smallholder farmers for their adaptability to local environmental conditions and their ability to perform under relatively low-input production systems (FAO, 2017; Khan et al., 2007).

Table 2: Farm characteristics (n= 87)

Characteristics		Frequency (n)	Percent (%)
No of Buffaloes	1-5	18	20.7
	6-10	26	29.9
	11-19	26	29.9
	>20	17	19.5
Buffalo breed	Murrah	28	23.5
	Niliravi	15	12.6
	Jafrabadi	1	0.8
	Domestic	75	63.0
Main feed	Grass	76	42.5
	Straw	87	48.6
	Concentrate (farmer-prepared)	16	8.9
	Ready feed	0	0.0
Grazing Time	No grazing	5	5.7
	<= 8 hrs	28	32.2
	> 8 hours	54	62.1
Rearing purpose	Meat	7	8.0
	Milk	20	23.0
	Both	58	66.7
	Ploughing	2	2.3
Feeding frequency	Once	0	0.0
	Twice	35	40.2
	Thrice	52	59.8
Feeding system	Stall	5	5.7
	Grazing	71	81.6
	Both	11	12.6
Water source	Pond/Canal	79	50.0
	Underground water	8	5.1
	River water	71	44.9
Buffalo weight (kg)	250-299	24	27.6
	300-499	38	43.7
	500-600	25	28.7
Daily Milk production (L)	1-3	69	79.3
	4-5	14	16.1
	6-10	4	4.6
	>10	0	0.0

Note: *For Buffalo breed, Main feed, and Water source, percentages are calculated based on the total number of responses rather than the individual sample size (n=87) due to multiple-response options.*

Feeding practices were largely traditional, with 91.1% of respondents relying primarily on straw and grass, and none reporting the use of ready-made commercial feed. This aligns with findings from other rural studies in South Asia where availability, cost, and farmer awareness constrain feed diversification. In smallholder livestock production systems, inadequate availability of quality feed and imbalanced nutrient supply are recognized as important constraints to improving animal productivity (FAO, 2017; Makkar, 2016). Similarly, extensive grazing was the dominant feeding system (81.6%), reflecting land-based practices with minimal reliance on stall feeding or formulated diets. The availability and quality of forage resources are important determinants of nutrient intake and productive performance in dairy animals, while supplementation with appropriate feed resources can help overcome nutritional limitations in pasture-based systems (Knaus, 2016; Makkar, 2016). Half (50.0%) of the respondents used ponds or canals as their main water source, followed by river water (44.9%). Underground water usage was minimal (5.1%). These findings demonstrate the predominant reliance of surveyed buffalo farmers on surface water resources for livestock watering. Adequate access to clean and sufficient water is essential for maintaining livestock health, feed intake, thermoregulation, and productive performance, particularly in buffaloes, which are highly dependent on water availability for thermoregulation under hot and humid environmental conditions (FAO, 2017; Thomas et al., 2004).

A majority (66.7%) reared buffaloes for both milk and meat purposes. Milk-only production was reported by 23.0%, while meat-only rearing accounted for 8.0%. A minority (2.3%) used buffaloes for ploughing, showing limited but ongoing integration in agricultural work. The multipurpose use of buffaloes for milk, meat, and agricultural activities is common in smallholder production systems, particularly in developing countries, where buffaloes contribute to household food security, income generation, and agricultural operations (FAO, 2017; Khan et al., 2007). Daily milk yield was generally low, with nearly 80% of buffaloes producing only 1–3 L of milk per day. This low productivity is likely linked to poor feeding practices, limited genetic potential, and

lack of health management (Khan et al., 2007; FAO, 2017).

3.2. Health and management practices

Farm management practices also showed notable gaps (Table 3). Less than half of the respondents practiced regular vaccination (51.7%), and only 11.5% dewormed their animals. Veterinary service access was limited for most respondents (73.6%), which may explain the high prevalence of digestive and infectious diseases like FMD.

Table 3. Farm practices of the respondents

Practices		Frequency (n)	Percentage (%)
Regular vaccination	Yes	45	51.7%
	No	42	48.3%
Health issues	Digestive	57	49.6%
	FMD	50	43.5%
	Reproductive disorders	8	7.0%
Availability of vet service	Yes	23	26.4%
	No	64	73.6%
Artificial insemination	Yes	10	11.5%
	No	77	88.5%
Urea molasses straw	Yes	15	17.2%
	No	72	82.8%
Training received	Yes	8	9.2%
	No	79	90.8%
Deworming	Yes	10	11.5%
	No	77	88.5%
Keeping records	Yes	13	14.9%
	No	74	85.1%
Balanced ration	Yes	7	8.0%
	No	80	92.0%
Seasonal feed availability	Rainy season	16	18.4%
	Summer	0	0.0%
	Winter	0	0.0%
	Both Rainy and Summer	71	81.6%

Note: *For 'Health issues', percentages are calculated based on the total number of responses (denominator = 115) instead of individual farmers (N=87) because multiple responses were allowed.*

Use of modern reproductive and nutritional techniques such as artificial insemination (11.5%), urea molasses straw (UMS) (17.2%), and balanced ration (8.0%) was also limited. Only 9.2% of farmers had received training in buffalo management, and this lack of capacity-building is likely a major constraint to improving farm performance. Similarly, the low rate of record-keeping (14.9%) suggests limited tracking of production and inputs, which can impede informed decision-making.

3.3. Impact of training on management practices

A key finding from the study was the significant association between farmer training and the adoption of improved practices (Table 4). Farmers who received training were significantly more likely to use balanced rations, maintain records, practice artificial insemination and urea-molasses-straw (UMS) feeding, and deworm their animals. For instance, 85.7% of trained respondents used balanced rations compared to only 2.5% of untrained respondents. This reinforces the critical role of education and extension services in disseminating best practices. Interestingly, no significant association was found between training and regular vaccination, which may suggest that vaccination is influenced more by external access and availability than by farmer knowledge alone. Studies have consistently shown that farmers who receive training are more likely to adopt improved livestock management practices. For instance, a study on the adoption of improved management practices (ILMPs) such as artificial insemination, concentrate feed, vaccination, and deworming found that farmers who had contact with livestock extension agents were 11% more likely to adopt these practices (Rahman et al., 2023). Similarly, another study found that training beneficiaries were more likely to adopt technologies related to housing, feeding, treatment, breeding, and marketing (Akteruzzaman et al., 2012).

Table 4: Association between training received and livestock management practices

Variables			Training received			$\chi 2$	r	p-value
Name	Categories		Yes	No	Total			
Balanced ration	Yes	n	6	1	7	53.381	0.617	<0.001
		%	85.70	14.30	100			
	No	n	2	78	80			
		%	2.50	97.50	100			
Keeping records	Yes	n	8	5	13	50.15	0.605	<0.001
		%	61.50	38.50	100			
	No	n	0	74	74			
		%	0	100	100			
Using AI	Yes	n	8	2	10	67.838	0.662	<0.001
		%	80	20	100			
	No	n	0	77	77			
		%	0	100	100			
Using UMS	Yes	n	6	9	15	20.598	0.438	<0.001
		%	40	60	100			
	No	n	2	70	72			
		%	2.80	97.20	100			
Regular vaccination	Yes	n	6	39	45	1.911	0.147	0.167
		%	13.30	86.70	100			
	No	n	2	40	42			
		%	4.80	95.20	100			
Deworming	Yes	n	8	2	10	67.838	0.662	<0.001
		%	80.00	20.00	100.00			
	No	n	0	77	77			
		%	0.00	100.00	100.00			

n=frequency; r = contingency co-efficient

Table 5: Association between seasonal feed availability and feeding practices and meat price

Variables			Seasonal feed availability		Total	χ2	r	p-value
Name	**Categories**		**Rainy season**	**Both Rainy and Summer**				
Feeding frequency	Twice	n	16	19	35	29.128	0.501	<0.001
		%	45.70	54.30	100			
	Thrice	n	0	52	52			
		%	0	100	100			
Feeding system	Stall	n	0	5	5	87	0.707	<0.001
		%	0	100	100			
	Grazing	n	0	71	71			
		%	0	100	100			
	Both	n	11	0	11			
		%	100	0	100			
Meat price (BDT)	650-699	n	13	13	26	24.686	0.47	<0.001
		%	50	50	100			
	700-750	n	3	58	61			
		%	4.90	95.10	100			

3.4. Role of seasonal feed availability on feeding practices and economic outcomes

Table 5 showed that a significant association was found between feeding frequency and seasonal feed availability. Notably, all farmers who fed their buffalo three times a day reported feed availability during both the rainy and summer seasons (100%), while those feeding twice a day were more distributed, with 45.7% having availability only in the rainy season and 54.3% in both seasons. The feeding system also demonstrated a strong and statistically significant association with seasonal feed availability. Farmers practicing stall feeding and combined systems (stall + grazing) exclusively reported feed availability during the rainy season, whereas those relying on grazing had availability in both the rainy and summer seasons (100%). A similar pattern was observed for meat price categories. The majority of farmers who could sell beef at higher prices (BDT 700–750/kg) had access to feed during both seasons (95.1%), whereas those selling at a lower price range (BDT 650–699/kg) were equally split between the two seasonal availability categories.

These findings suggest that broader seasonal feed availability is positively associated with increased feeding frequency, grazing-based systems, and the ability to sell meat at higher prices, highlighting the critical role of year-round feed access in improving buffalo productivity and profitability. These findings were supported by Rahman et al. (2020); Takele et al. (2014); Sihag et al. (2002), who stated that the availability and type of feed significantly affect lactating buffaloes' production performance, with areas having better feed supply showing higher economic return. On the other hand, Despal (2014) observed that seasonal feeding practices do not significantly impact dairy cow performance.

3.5. Role of balanced ration and feeding system on daily milk production

Based on the output from ordinal logistic regression analysis (with daily milk production as the dependent variable, balanced ration and feeding system as predictors). Balanced ration had a significant positive effect on milk production levels (Estimate = 3.492, p = 0.001), indicating that buffaloes fed a balanced ration were more likely to produce higher amounts of milk. The feeding system also showed a significant influence on milk yield. Specifically, the "Grazing" system exhibited a strong negative association with higher milk production levels (Estimate = -5.014, $p < 0.001$) when compared to the reference category "Both" (stall + grazing). In contrast, the "Stall" system did not show a statistically significant effect (p = 0.935).

These findings suggest that providing a balanced ration and combining stall and grazing feeding practices may be more effective in enhancing productivity and milk yield among buffaloes (Table 6). These findings were supported by Singh et al., 2024, who observed that implementing balanced rations has been shown to enhance milk yield by 2 to 14 percent. Similarly, a study on crossbred cows demonstrated that balanced rations not only increased milk production but also improved feed conversion efficiency and reduced methane emissions, highlighting environmental benefits alongside economic gains (Sherasia et al., 2016). In developing regions, imbalanced feeding remains a critical barrier to productivity, with balanced nutrition identified as a key strategy for enhancing milk production efficiency and supporting rural livelihoods (Deen et al., 2019). The inclusion of green fodder in feeding systems has been shown to significantly improve dry matter intake and nutrient digestibility (Lade et al., 2007). Internationally, the debate between pasture-based and indoor feeding systems reflects differing priorities; while pasture systems in regions like New Zealand and Ireland focus on maximizing milk yield per unit of pasture, indoor systems in North America and Europe prioritize high annual milk production per cow, often at the expense of animal welfare and global food security (Knaus, 2016). Overall, balanced rations and strategic feeding systems are crucial for optimizing milk production, improving economic outcomes, and addressing environmental and welfare concerns in diverse buffalo contexts.

Table 6: Parameter estimates from ordinal logistic regression predicting buffalo milk production

Parameter Estimates		Estimate	Std. Error	Wald	df	Sig.	95% CI	
							Lower Bound	Upper Bound
Threshold	[Milk production = 1]	-1.503	.715	4.425	1	.035	-2.904	-.103
	[Milk production = 2]	1.503	.715	4.425	1	.035	.103	2.904
Location	[Balanced ration=1]	3.492	1.039	11.289	1	.001	1.455	5.529
	[Balanced ration=2]	0[a]	.	.	0	.	.	.
	[Feeding system=1]	.093	1.147	.007	1	.935	-2.156	2.342
	[Feeding system=2]	-5.014	1.020	24.150	1	<0.001	-7.013	-3.014
	[Feeding system=3]	0[a]	.	.	0	.	.	.

Link function: Logit. a. This parameter is set to zero because it is redundant.

3.6. Implications for policy and practice

The results of this study underscore several critical intervention points:

- Training and Extension: To encourage the adoption of better feeding, health, and breeding methods, organized farmer training programs are essential.
- Feed Security: Seasonal fluctuations in feed supply can be lessened by investments in silage production, feed storage, and forage farming.
- Veterinary Infrastructure: It's critical to increase access to routine deworming and vaccination services as well as other animal healthcare services.
- Technology Promotion: To increase productivity, more people need to be aware of and have access to artificial insemination (AI) and nutritional technologies like Urea Molasses Straw (UMS).

4. Conclusion

Buffalo farming in Bangladesh holds promising potential, especially in contributing to national meat and milk supply. However, the sector remains underdeveloped due to prevailing challenges in nutrition, limited access to modern technologies, and inadequate veterinary and extension services.

The study underscores the critical need for strategic interventions focused on enhancing nutritional support, promoting knowledge dissemination, and establishing sustainable development models. Capacity-building through farmer training can significantly increase adoption of improved practices, leading to enhanced productivity and profitability.

For buffalo farming to evolve into a commercially viable enterprise, coordinated efforts in research, extension, and policy support must prioritize nutritional management and farmer education. These changes are vital for unlocking the full potential of the buffalo sector in Bangladesh.

Competing interest

The authors declare that they have no competing interests

Acknowledgement

We would like to acknowledge the Upazila Livestock Officer (ULO), Veterinary Surgeon (VS), and Veterinary Field Staff of the respective district. We also would like to show our heartfelt gratitude to the owners of the buffalo farms of the Patuakhali, Barguna, Dinajpur and Panchagarh district for their cooperation.

Limitations

Several limitations of this study should be acknowledged. First, there is a pronounced regional skew in the sample, with Patuakhali accounting for approximately 76% of the respondents, which may limit the generalizability

of the findings to other regions of Bangladesh. Second, the total sample size (N=87) is modest relative to the number of subgroups analyzed, particularly within specific cross-tabulations. Third, certain contingency tables (specifically Tables 4 and 5) contained small sample sizes or zero cell counts in some categories (e.g., record-keeping and AI usage among untrained farmers); consequently, the minimum expected frequency assumptions for the standard Chi-square test may not have been fully satisfied. Lastly, the cross-sectional, non-experimental design of the study captures data at a single point in time, which restricts the ability to establish definitive causal relationships between variables, such as whether training directly caused the adoption of balanced rations. Therefore, the statistical associations and Chi-square results reported for these specific sparse cells should be interpreted with appropriate caution. Future longitudinal studies with larger, more geographically balanced cohorts are highly recommended to further validate these associations using Fisher's Exact Test.

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