Water consumption in heifers fed rice DDGS and wheat-groundnut straw mixture

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Abstract

This study evaluated the water intake patterns in growing heifers fed varying dietary treatments, including concentrates with 0%, 20% and 40% rice distillers dried grains with solubles (DDGS) (T1, T2, T3) and roughage consisting of wheat straw alone (R1) or a mixture of wheat and groundnut straw (R2). The water intake, relationships between water intake and dry matter intake (DMI), body weight (BW), roughage-to-concentrate (R: C) ratio and environmental temperature-humidity index (THI) were analyzed. Results showed that DDGS fed groups exhibited stable water intake and moderate to strong positive correlations with DMI ($r = 0.17$; 0.29) and BW ($r = 0.19$; 0.33), while correlations with R: C ratios were weak and inconsistent. In contrast, heifers in the R2 group, which received a mixture of wheat straw and groundnut straw, demonstrated higher and more variable water intake, attributed to incomplete rumen fill despite meeting ICAR (2013) nutrient standards, leading to additional straw intake. Across all groups, water intake generally increased with rising THI, indicating physiological adaptation to thermal stress. The findings suggest that DMI and BW are better predictors of water intake than R: C ratio and that fiber quality plays a critical role in hydration response under heat stress.

Keywords: Water intake pattern, Heifers, Rice DDGS, Groundnut straw

Introduction

The freshwater requirement for agriculture including livestock production is emerging as a critical concern globally, attracting growing attention from both the scientific community and policymakers. This concern stems from increasing tension between the expansion of animal production and the need for improved water use efficiency (Godde et al., 2021). As the global demand for agri-livestock commodities continues to rise, the pressure on limited freshwater resources is expected to intensify further (Li et al., 2020). Water scarcity along with climate change is affecting global small and large ruminant production system (Daneshi et al., 2012) and is responsible for social conflict in countries where pastoral system is major way of animal husbandry (Djohy et al., 2013). Water is a critical nutrient for livestock, essential for supporting growth, reproductive performance and general physiological functions. It is the main component of body fluids including blood, chyme and urine. Being a universal solvent, it allows the circulation of numerous molecules, including nutrients, hormones, minerals and other substances, throughout the body and facilitates the elimination of metabolic waste (Wagner and Engle, 2021). Water intake in dairy animals depends on several factors including growth, body weight (BW), feed intake, stage of production, water quality and several other environmental factors. Understanding the factors affecting water intake in dairy cows could improve dairy husbandry practices and subsequently the health and welfare of dairy cattle, especially in tropical climates (Golher et al., 2021). Water consumption patterns in livestock have been studied previously; however, the effects of non-conventional feed ingredients and their combinations on water intake have received limited attention.

Dried Distillers Grains with Solubles (DDGS), a non-conventional feed ingredient, is now widely utilized in animal nutrition. It is a significant by-product of distilleries and is notable for its high protein content, reaching up to 40% in rice-based DDGS (Yogi et al*.,* 2017; Dey et al., 2019). The presence of dead yeast cells gives the protein better amino acid composition and very good nutritive value (Pecka-Kiełb et al., 2017). Studies have demonstrated that distillers dried grains with solubles (DDGS) can be incorporated into growing dairy heifer rations at levels up to 40% of dietary dry matter without adversely affecting growth performance, nutrient digestibility, or rumen fermentation (Manthey et al., 2016; Pecka-Kiełb et al., 2017).

The rising cost of conventional roughages, such as wheat and paddy straw, has sparked growing interest in alternative sources like non-conventional straws. India, the world's second-largest producer of groundnuts after China, produces approximately 10.24 million tonnes annually. In 2021, around 5.96 million hectares of land in India were under groundnut cultivation, highlighting the significant availability of groundnut crop residues (Suthar et al., 2024). Groundnut straw, a by-product of groundnut cultivation, has considerable potential as a nutritious fodder resource for ruminants because of its acceptable intake, digestibility, and nutrient value (Avornyo et al., 2020; Ansah et al., 2021). Feeding of concentrates could be saved by feeding legume straw in comparison to cereal straw feeding (Shelke et al., 2014).

The rising global concern over freshwater use in livestock production has garnered increasing attention from researchers and policymakers due to the growing tension between expanding animal production and the need for improved water use efficiency. In this context, understanding the water consumption dynamics associated with alternative and non-conventional feed resources is essential. Therefore, this study aims to evaluate the water intake patterns of growing dairy heifers fed with rice DDGS and mixture of wheat straw and groundnut straw, providing insights into sustainable feeding strategies under increasing resource constraints.

Material and Methods

Place of Study, Experimental Animals and Duration

The experiment was carried out at the Livestock Research Station, College of Veterinary Sc. & Animal Husbandry, Anand Agricultural University, Anand, Gujarat, India. Total twenty-four Holstein Friesian and Kankrej cross (75:25) heifers with mean BW of 116.13±4.74 kg and an average age of 281.92±13.26 days were selected for the study. A 168-day trial was conducted from 24th June 2020 until 9th December 2020. Prior approval was taken from CPCSEA/IAEC for carrying out the experiment (CPCSEA Reg. No: 486/GO/Re-S/ReBi-L/01/CPCSEA, dated 1/11/2021 and project No: 313/LPM/2019).

Experimental Treatments and Feeding Regime

There were three treatment groups T1, T2 and T3 groups based on concentrates type containing 0%, 20% and 40% RDDGS. Within each concentrate type, half of the heifers were provided with wheat straw (R1 group), while the other half received a mixture of groundnut straw and wheat straw as dry roughage (R2 group) (Table 1). The experiment followed a randomised block design (factorial). Ingredient (RDDGS) and Groundnut straw were procured from Daman, India based a rice grain distillery and Regional Research Station, Anand Agricultural University, Anand, Gujarat, India, respectively.

General Management

All experimental heifers were de-wormed with Fenbendazole drug @ 7.5mg/kg BW before the starting experimental trial. They were reared under iso-managerial conditions in ventilated, hygienic sheds, receiving calculated amounts of concentrate, roughage and green fodder as per the treatment schedule. Heifers were tethered with neck chains in front of partitioned mangers for individual feeding.

Feeding Management

In experimental heifers protein requirements were met as per standard feeding standards (ICAR, 2013). Concentrate and roughage were offered twice daily between 9:00 to 9:30 h and 16:00 to 16:30 h. Experimental heifers also received fixed amounts of green hybrid napier. Protein requirements were adjusted biweekly based on changes in BW. Additional, fixed amount of wheat straw during night time was provided to all heifers to meet rumen fill requirements and feed leftovers were weighed daily.

Analysis of Feeds and Fodder Sample

Feed ingredients and concentrate mixtures were analysed for proximate composition according to the official methods of AOAC INTERNATIONAL (2019) at the Centre of Excellence for Animal Nutrition, Anand Agricultural University, Anand, Gujarat, India. (Table 2 and 3).

Water Intake (L/ day)

Water intake was measured fortnightly by recording the volume of water offered and refused using graduated plastic buckets, following standard procedures for measuring drinking water intake in dairy cattle (Singh et al., 2022). A pre-measured volume of clean water was offered to each animal three times daily morning (08:00 h), afternoon (14:00 h), and evening (18:00 h). The leftover (refused) water was measured to calculate actual water consumption per day.

Table 1: Type of concentrate and straw mixture offered to experimental heifers

(Groups)		Number of heifers	Ingredients in Ration		
			Concentrate	Dry Roughage	
				Wheat Straw	Groundnut straw
T1	R1	4	Concentrate-I 50%	50%	0%
	R2	4		25%	25%
T2	R1	4	Concentrate-II 50%	50%	0%
	R2	4		25%	25%
T3	R1	4	Concentrate-III 50%	50%	0%
	R2	4		25%	25%

* Concentrates (Types I, II, III) contain varying proportions of rice dried distillers grains with solubles (RDDGS): T1 (0%), T2 (20%), T3 (40%). Dry roughage includes wheat straw (R1) and a mixture of groundnut straw and wheat straw 1:1 (R2). Heifers were also offered with preset 35 gm/head/d mineral mixture throughout the experiment.

Table 2: Proximate composition of various feed ingredients (% DM basis)

Particulars	Rice DDGS	Soya DOC	Amul Dan	Groundnut Straw	Wheat Straw	Hybrid Napier
OM	95.18	87.60	86.27	90.79	87.54	80.14
CP	44.67	43.15	18.8	10.67	2.63	10.60
EE	7.27	0.15	2.79	2.24	3.33	2.32
CF	2.04	8.93	16.26	30.37	39.26	28.18
Ash	4.82	12.45	13.73	9.21	12.46	19.87
NFE	41.2	35.32	48.42	47.51	42.32	39.03

*OM -organic matter, CP-Crude protein, EE –Ether extract, CF- Crude fiber, NFE- Nitrogen Free Extract. Analysis was performed at Centre of Excellence for Animal Nutrition, AAU, Anand

Table 3: Proximate composition of experimental concentrate mixtures, % DM basis

Particulars	Conc –I (0% RDDGS)	Conc-II (20% RDDGS)	Conc -III (40% RDDGS)
OM	86.58	88.18	89.77
CP	28.33	28.91	29.17
EE	1.70	3.05	4.42
CF	12.66	11.36	10.48
Ash	13.42	11.82	10.23
NFE	43.89	44.86	45.70

*OM -organic matter, CP-Crude protein, EE –Ether extract, CF- Crude fiber, NFE- Nitrogen Free Extract. Analysis was performed at Centre of Excellence for Animal Nutrition, AAU, Anand

Water Intake (L/100 kg BW)

Water intake per 100 kg BW was calculated fortnightly by dividing the average daily water intake (L/day) by the corresponding BW (kg) and multiplying by 100. BW data used for this calculation were obtained from the same experimental trial reported earlier (Pandey et al., 2025).

Water Intake (L/kg MW)

Water intake (L/kg MW) was calculated fortnightly using the standard formula:

$$\text{Water Intake (L/kg MW)} = \frac{\text{Water Intake (L/day)}}{\text{BW}^{.75}}$$

*MW: Metabolic weight

Water Intake per unit DMI (L/kg)

Water intake per unit of dry matter intake (DMI) was calculated on a fortnightly basis by dividing the total water consumed (L) by the corresponding DMI (kg). The DMI data utilized in this study were derived from the same experimental trial (Pandey et al., 2025).

Temperature-Humidity Index (THI)

The Temperature–Humidity Index (THI) was determined on each day of water intake measurement at 2:00 pm using the temperature–humidity index equation originally proposed by the National Research Council and currently recommended for dairy cattle heat stress assessment (NASEM, 2021).

THI = $0.72 \times (T_{db} + T_{wb}) + 40.6$, where T_{db} and T_{wb} represent the dry bulb and wet bulb temperatures, respectively.

Roughage to concentrate ratio

The Roughage (R) to Concentrate (C) ratio was calculated fortnightly by the formula given below.

$$\text{R:C} = \frac{\text{Average daily DMI from roughage (kg/day)}}{\text{Average daily DMI from concentrate (kg/day)}}$$

Statistical Analysis

The experiment followed a factorial arrangement within a Randomized Block Design (RBD). Data were analyzed using two-way ANOVA in R software (R Core Team, 2024). Graphical figures were generated using the ggplot2 package in R. Pearson's correlation coefficients were calculated to assess relationships between variables.

Results

Effect of Rice DDGS and Mixture of wheat straw and groundnut straw on Water Intake

The water intake in T1, T2 and T3 group heifers and in R1 and R2 group recorded during the experimental period is depicted in Figure 1 and Table 4. The water intake (L/day), water intake (L/100 kg BW), water intake (L/kg MW) and water intake (L/kg DM) did not change due to DDGS inclusion. However, the water intake (L/day), water intake (L/100 kg BW) and water intake (L/kg MW) changed significantly ($P < 0.05$) in group R1 and R2 that were offered only wheat straw and mixture of wheat straw and groundnut straw, respectively. Water intake (L/kg DM) between R1 and R2 heifers did not change.

Correlation Coefficient (r)

The correlation coefficient (r) of water intake (L/day) with DMI (kg/day), BW (kg) and roughage to concentrate ratio is depicted in Table 5.

Correlation between water intake (L/day) and DMI (kg/day): Across the treatment groups, DMI showed a moderate to strong positive correlation with water intake. The strongest association was seen in the T1 group (r = 0.57), indicating that under conventional concentrate-based diets, water intake closely followed dry matter consumption. In other groups, the correlation was weaker (r = 0.17 to 0.45), suggesting that DDGS inclusion or higher-fiber diets may affect this relationship.

Correlation between water intake (L/day) and BW (kg): BW also showed a consistent positive correlation with water intake, with the highest in T1 (r = 0.66) Table 5. This supports the general trend that heavier animals consume more water. The other groups showed moderate correlations (ranging from 0.19 to 0.49), highlighting BW as a dependable factor influencing water needs.

Correlation between water intake (L/day) and R: C ratio: The R: C ratio observed during the experimental period is depicted in figure 2. The relationship between R: C ratio and water intake was weak and varied across treatments. Correlation values ranged from r = -0.23 to 0.23, with T3 showing the highest (r = 0.23). Some groups like T2 and R1 showed weak negative correlations. These inconsistent patterns suggest that R: C ratio had no clear or predictable impact on water intake

Table 4: Effect of rice DDGS and straw mixture on Water Intake of experimental heifers

Particulars	Group				
	T1	T2	T3	R1	R2
Water Intake (L/day)	20.63±0.64	19.98±0.58	21.55±0.62	19.78ª±0.43	21.65ᵇ±0.53
CD value	NS			1.151	
Water Intake (L/100 kg BW)	11.41±0.26	11.22±0.33	12.03±0.45	11.13ª ±0.24	11.98ᵇ ±0.33
CD value	NS			0.702	
Water Intake (L/100 kg MW)	415.81ᴬ±9.39	407.67ᴬ±10.9	437.43ᴬ±14.54	403.98ª±7.92	436.62ᵇ±11.0
	NS			24.595	
Water Intake (L/kg DM)	4.42±0.13	4.32±0.11	4.63±0.14	4.35±0.09	4.57±0.12
CD value	NS			NS	

Table 5: Correlation of Body Weight, Dry Matter Intake, and R:C Ratio with Water Intake in Growing Heifers

Particulars	Group				
	T1	T2	T3	R1	R2
	Correlation coefficient (r) between Water Intake (L/day)				
DMI (kg/day)	0.57	0.29	0.17	0.45	0.25
BW (kg)	0.66	0.33	0.19	0.49	0.34
R:C ratio	0.09	-0.02	0.23	-0.23	0.01

*r is correlation coefficient; DMI: Dry matter intake; BW- Body weight; R: C ratio- Roughage to concentrate

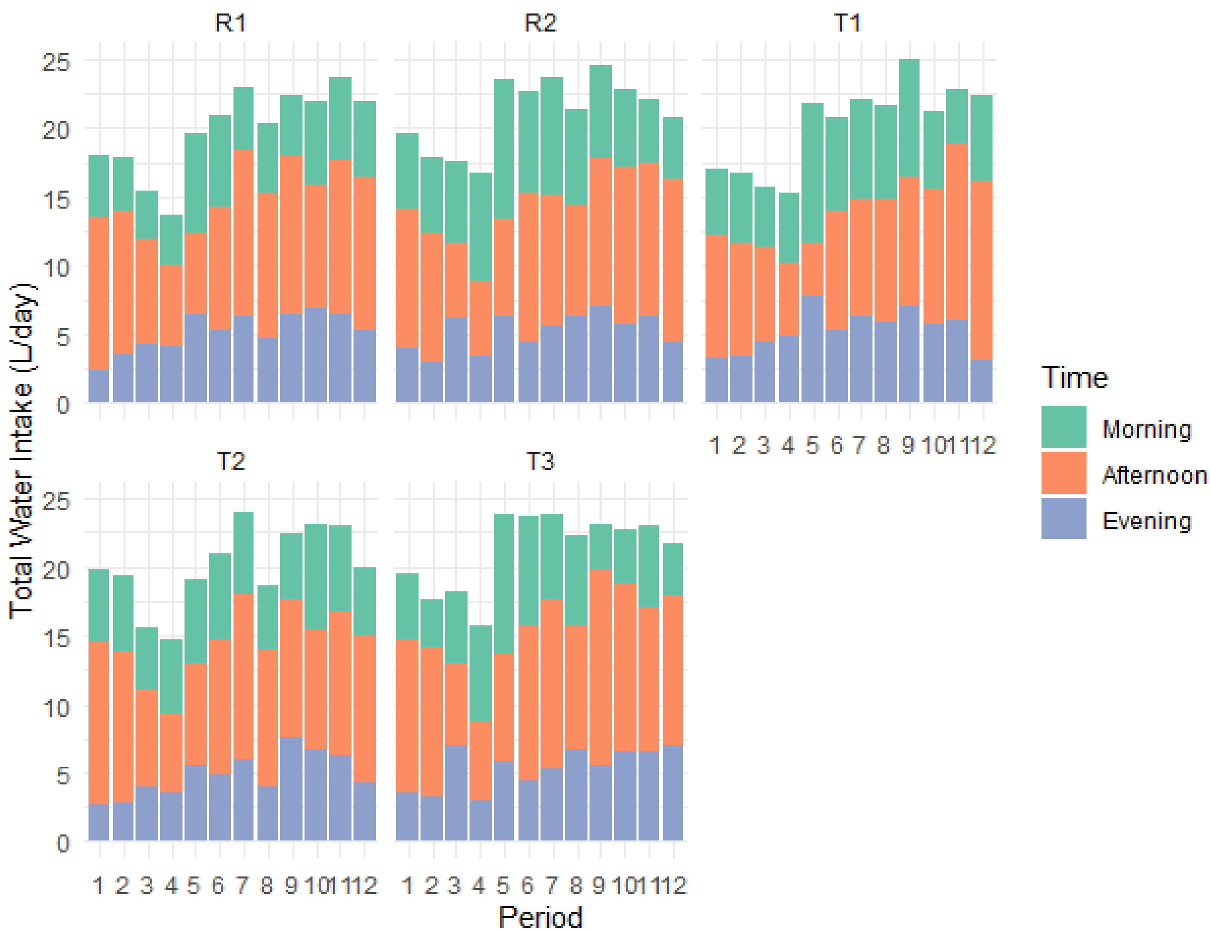

Figure 1. Stacked Bar Plot for fortnightly water intake in experimental Heifers

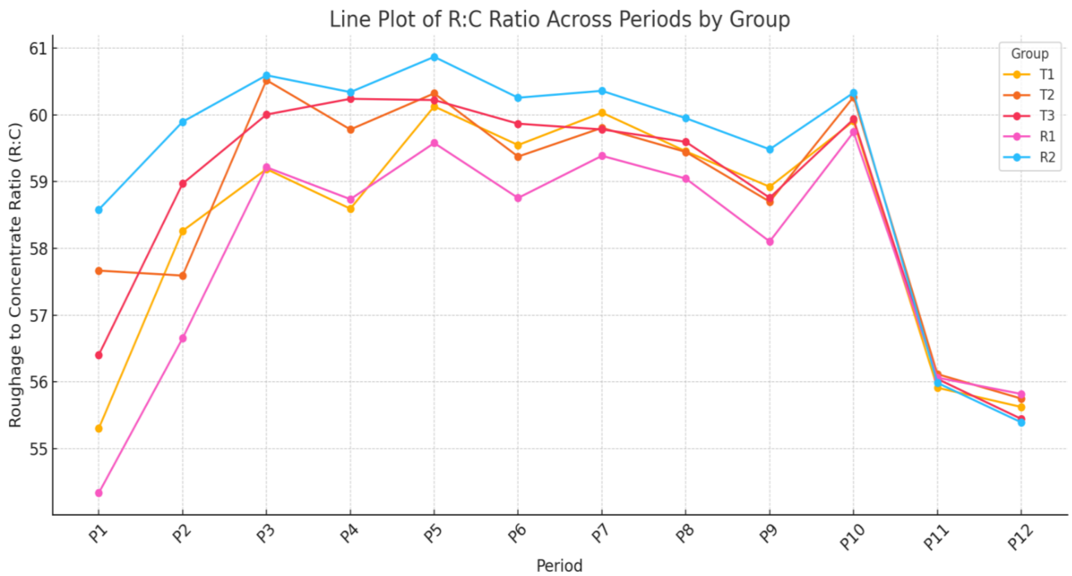

Figure 2. Roughage: Concentrate ratio of treatment groups

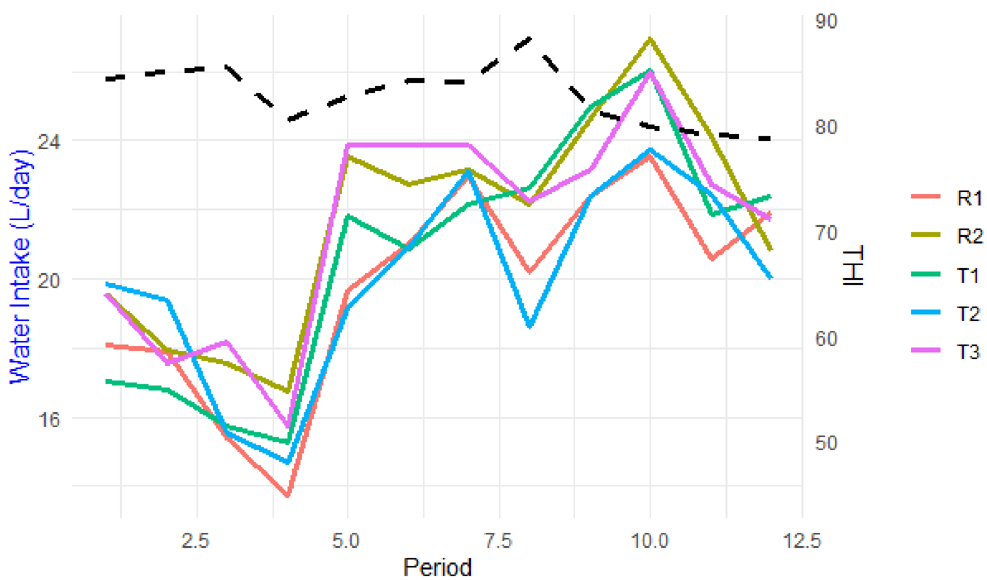

Figure 3. Plot of water intake and Temperature–Humidity Index (THI)

Water Intake Pattern in Relation to Temperature Humidity Index across Experimental Groups

Figure 3 illustrates the water intake trends in growing heifers from different dietary groups in relation to the corresponding Temperature Humidity Index (THI) over the study period. T1, T2, and T3 groups fed concentrates containing 0%, 20%, and 40% rice DDGS, respectively demonstrated relatively stable water intake patterns, with slightly elevated values during periods of higher THI, indicating a possible heat stress response. In contrast, R1 (fed only wheat straw) and R2 (fed a mixture of wheat and groundnut straw) exhibited more variable water intake, suggesting that fibrous diets may lead to inconsistent hydration responses under thermal stress. Overall, water intake across all groups showed a general increasing trend with rising THI, aligning with known physiological adaptations to maintain thermoregulation in heifers.

Discussion

In the present study, water intake did not differ significantly among T1, T2, and T3, which corresponded to stable dry matter intake levels. In Holstein heifers and lactating cows when the dietary physical characteristics (e.g., bulk density, moisture) are consistent, altering concentrate formulation (DDGS inclusion) does not significantly affect water intake, provided that DMI remains similar across groups (Manthey et al., 2016; Cervantes et al., 2024). Heifers in the R2 group, despite receiving a balanced ration comprising a mixture of wheat straw and groundnut straw that met their nutrient requirements as per ICAR (2013) standards, exhibited significantly ($P < 0.05$) higher water intake compared to other groups. This elevated water consumption appears to be associated with incomplete rumen fill, prompting the animals to consume additional wheat straw beyond their planned intake, particularly during nighttime feeding. Notably, this intake was even greater than that observed in the R1 group, which received only wheat straw. Such behavior can be attributed to the lower bulk density and physical characteristics of fibrous feedstuffs, which reduce the effectiveness of ruminal fill as a satiety signal, allowing greater voluntary intake before physical distension limits feed consumption (Grant, 2023). Recent findings also indicate that cattle offered high-fiber; low-density diets tend to increase their voluntary feed and water intake in an effort to achieve rumen distension and maintain digestive function (Grant, 2023; Heering et al., 2024). Furthermore, ruminants consuming straw-rich diets generally require greater amounts of drinking water to support ruminal fermentation, fiber digestion and the passage of fibrous digesta through the gastrointestinal tract (Heering et al., 2024; Wang et al., 2022).

The comparatively lower water intake observed in heifers fed wheat straw alone (R1) may be attributed to the physical and nutritional characteristics of cereal straw. Wheat straw generally contains higher cell-wall fractions and lower digestibility than legume crop residues such as groundnut straw, which increases the physical limitation imposed by rumen fill and restricts voluntary dry matter intake. Consequently, the lower feed intake is associated with a reduced requirement for drinking water to support feed hydration, ruminal fermentation, microbial activity, and digesta passage. Similar responses have been reported in tropical crop-residue-based feeding systems, where supplementation or partial replacement of cereal straws with legume residues improved voluntary feed intake, nutrient utilization, and animal performance (Wang et al., 2022; Antwi et al., 2020; Finangwai et al., 2020).

The strongest positive correlation between DMI (kg/day) and water intake (L/day) was observed in the T1 group ($r = 0.57$), indicating that under traditional concentrate diets, water consumption closely followed dry matter intake. This relationship weakened with the inclusion of DDGS in T2 and T3 (ranging from 0.17 to 0.29), possibly due to alterations in fermentation dynamics or reduced palatability of the DDGS-containing diets (Manthey et al., 2016; Bai et al., 2024). BW also showed a consistent positive correlation with water intake (L/day) across all groups, with the highest correlation in T1 ($r = 0.66$), supporting previous reports that larger animals generally consume more water (Cervantes et al., 2024). In contrast, the correlation between the roughage-to-concentrate (R: C) ratio and water intake was weak and inconsistent (r ranging from –0.02 to 0.23 in T1–T3). This trend agrees with observations of a researcher who found that R: C ratio had limited predictive value for water intake unless significant changes in fiber type or moisture content occurred (Bai et al., 2024).

Among groups (R1 and R2), the R2 heifers fed a mixture of wheat and groundnut straw showed significantly ($P < 0.05$) higher water intake than the R1 group. This is likely due to incomplete rumen fill despite diets meeting feeding standards, leading to additional voluntary straw intake during nighttime. The higher water intake observed in the R2 group is consistent with recent findings that the physical characteristics and digestibility of dietary fibre, rather than fibre quantity alone, influence rumen fill, voluntary feed intake, and consequently drinking water consumption in ruminants (Grant, 2023; Wang et al., 2022). Furthermore, while DMI and BW showed moderate correlations with water intake in both R1 and R2 groups, the relationship between water intake and R: C ratio was weak ($r = –0.23$ in R1, 0.01 in R2). This indicates that even within roughage-dominant diets, the structural composition of fiber may be more critical than numerical R: C ratio alone (Wang et al., 2022). The variation in water intake is thus more reflective of physical fill and rumen motility patterns than just concentrate proportion.

In the T1, T2 and T3 groups, water intake remained relatively stable with only slight upticks during periods of elevated THI, indicating that the addition of rice DDGS did not alter the normal hydration response to heat stress (Cervantes et al., 2024). In contrast, R1 and R2 group refers exhibited more variable and often higher water intake, especially under higher THI conditions. This variability suggests that fiber-rich diets may exacerbate hydration demands during heat stress. This aligns with field observations where dairy cows increase drinking frequency and compete more intensively at waterers as THI approaches ~65–68 (McDonald et al., 2020). In another trial higher THI increased both water intake and drinking events in cows, particularly under diets low in water content but high in fiber (Ammer et al., 2018). Mechanistically, heat stress triggers increased panting and skin surface blood flow, which both increase water loss and demand, especially when combined with high-fiber rations that require additional fluid for rumen processing (Tian et al., 2021). The threshold around THI (68–72) is recognized as critical for these physiological responses (Chang-Fung-Martel et al., 2021). Although the observed differences in water intake were statistically significant, their direct economic impact may be limited under production systems where drinking water is readily available at low cost. However, in many parts of India and other semi-arid regions, livestock producers increasingly face seasonal water shortages, rising energy costs for groundwater extraction and greater competition for freshwater resources. Under such conditions, even modest reductions in daily water consumption can improve water-use efficiency, reduce pumping and labour costs associated with water supply, and contribute to the sustainability of livestock production. Therefore, evaluation of feeding strategies should consider not only statistical differences in water intake but also their practical significance under water-limited production systems and changing climatic conditions (FAO, 2023; Singh et al., 2022).

Conclusion

The present study showed that water intake is influenced more by roughage composition and environmental conditions than by concentrate type offered. Water requirements were closely associated with dietary fibre characteristics and increasing temperature–humidity index (THI), whereas the roughage-to-concentrate ratio showed only a weak relationship with water consumption. Improving roughage quality can enhance water-use efficiency and should be considered while formulating sustainable feeding strategies under heat stress and water-limited conditions.

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Ethics declarations

All experiments were performed in accordance with required guidelines and regulations. Prior approval was taken from CPCSEA/IAEC to perform the experiment (CPCSEA Reg. No: 486/GO/Re-S/ReBi-L/01/CPCSEA, dated 1/11/2021 and project No: 313/LPM/2019).

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