Effects of sugarcane bagasse inclusion on rumen fermentability and feeding behavior in large ruminants: A meta-analysis

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Abstract. Sugarcane bagasse (SCB) is the main by-product of the sugar industry and represents a potential fiber source for ruminant feeding. Due to inconsistent findings across studies, this study aimed to synthesize the available evidence through meta-analysis to derive more robust and reliable conclusions on the effects of sugarcane bagasse inclusion in ruminant diets. The study was initiated by constructing a database in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol. Literature searches were performed in two databases, Google Scholar and ScienceDirect. Relevant data were extracted and analyzed using PROC MIXED in SAS On Demand for Academics. This meta-analysis revealed that SCB had no significant effect ($P>0.05$) on rumen fermentability (pH, $N\text{-}NH_3$, total and partial volatile fatty acids (VFA)), but significantly reduced feeding time ($P<0.05$), while rumination, idling, and total chewing time were unaffected. Therefore, SCB can be used as a fiber source in large ruminant diets, with a moderate inclusion level to prevent reduced feed intake and productivity.

1 Introduction

Sugarcane (*Saccharum officinarum*) is one of the most widely cultivated crops in the world, with a global production of 2,026 million tons per year (FAOSTAT). The sugar industry not only produces sugar as its main product but also generates by-products such as bagasse, press mud, and molasses [1] Processing one ton of sugarcane yields approximately 150 kg of sugar, 280–300 kg of bagasse, 30 kg of press mud, and 41 kg of molasses [2].

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Sugarcane bagasse (SCB), the largest by-product of the sugar industry, is a solid residue obtained after sugarcane crushing [2]. It contains a high proportion of crude fiber, consisting of 81.83% neutral detergent fiber (NDF), 54.77% acid detergent fiber (ADF), and 13.50% lignin, while its crude protein content is relatively low at 2.41% [3]. Although bagasse is a potential fiber source for ruminants, the high lignin fraction reduces microbial degradation in the rumen, potentially influencing fermentation and feeding behavior.

However, the effects of SCB supplementation on rumen fermentability and feeding behavior remain inconsistent. Jin et al. [3] reported that SCB inclusion influenced ruminal N-NH_3, total VFA, acetate, propionate, and butyrate, whereas Sirisan et al. [4] found no effects on the same parameters. In terms of feeding behavior, Medeiros et al. [5] observed a reduction in feeding and rumination times, while Molavian et al. [6] reported that feeding time was not affected, but rumination time increased. These conflicting findings complicate the interpretation of SCB utilization in large ruminant diets.

Given these discrepancies, synthesizing evidence from multiple studies is essential to derive more reliable and generalized conclusions. Meta-analysis offers a robust approach to quantitatively combine results across studies, thereby increasing statistical power and reducing uncertainty. Previous meta-analyses have successfully evaluated agro-industrial by-products such as coffee pulp [7], distiller's dried grains with solubles (DDGS) [8], and oil palm fronds [9].

Based on the above, the present study aims to evaluate the effects of SCB as a feed ingredient for ruminants through a meta-analysis approach. The findings provide clearer insights into the role of sugarcane bagasse in rumen fermentability and the feeding behavior of large ruminants.

2 Material and Method

The database for this meta-analysis was constructed by collecting published articles from Google Scholar and ScienceDirect. The literature search was conducted using the keywords ("sugarcane bagasse") AND ("ruminant" OR "cattle" OR "buffalo"). Article selection followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (Fig. 1).

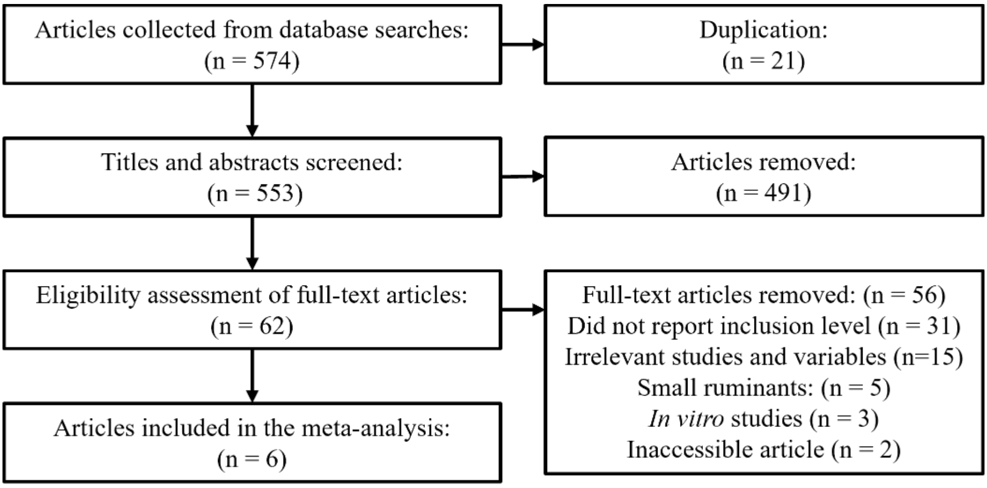

Fig.1. PRISMA flow chart.

Eligible studies were restricted to English-language articles with no limitation on the year of publication. This restriction was applied to ensure consistent interpretation of experimental methods and results and to minimize potential inaccuracies arising from the translation of non-English publications. The articles were required to provide information on the inclusion level of SCB in large ruminant diets. Data extracted from the included studies were compiled into a database. The dataset was then analyzed with SAS On Demand for Academics, following the meta-analysis approaches described by St-Pierre [10] using the mixed model procedure. A total of six articles were included in the meta-analysis [3–6,11,12]. The descriptive statistics of the database are summarized in Table 1.

Table 1. Descriptive statistics of the database regarding the effects of sugarcane bagasse on rumen fermentability and feeding behavior of large ruminants.

Response Variables	**n**	**Mean**	**SD**	**Min**	**Max**
Rumen fermentability					
pH	5	6.42	0.21	6.10	6.68
$N\text{-}NH_3$ (mg/dL)	8	12.72	2.87	9.70	18.56
Total Volatile Fatty Acid (mmol/L)	8	95.70	20.24	67.84	127.00
Acetate (mmol/L)	8	62.21	11.71	49.89	80.52
Propionate (mmol/L)	8	19.84	6.07	11.53	27.40
Isobutyrate (mmol/L)	5	0.74	0.35	0.33	1.09
Butyrate (mmol/L)	8	10.72	3.23	5.18	13.97
Isovalerate (mmol/L)	5	1.82	1.25	0.46	3.04
Valerate (mmol/L)	5	1.02	0.54	0.43	1.64
Acetate/Propionate	5	4.03	0.25	3.75	4.32
Feeding behavior					
Feeding (min/d)	18	315.44	23.15	283.00	358.00
Rumination (min/d)	18	497.56	90.81	376.00	667.00
Idle (min/d)	15	607.73	88.40	467.00	764.00

Total chewing time (min/d)	8	781.25	79.01	659.00	906.00

3 Results and Discussion

The results of the meta-analysis indicated that the average inclusion level of SCB in the analyzed studies was 24.13%, with a maximum inclusion of up to 60% of the total diet. Within this range of SCB inclusion, no significant effects were observed on rumen fermentability variables. Rumen pH, N-NH_3 concentration, and total VFA remained stable ($P>0.05$). Similarly, the concentrations of acetate, propionate, butyrate, isobutyrate, isovalerate, and valerate, as well as the acetate/propionate ratio, did not differ significantly ($P>0.05$). Regarding feeding behavior, a linear reduction in feeding time was observed with increasing SCB supplementation ($P<0.05$). Meanwhile, rumination time, idle time, and total chewing time did not show significant changes ($P>0.05$) (Table 2).

The acid-base balance of the rumen was not disrupted by SCB inclusion, as evidenced by the stable rumen pH values ranging from 6.10 to 6.68. This range represents the optimal rumen pH that supports microbial activity. Additionally, saliva produced during mastication plays an active buffering role in maintaining the optimal pH value. It was observed that large ruminants consuming SCB maintained stable chewing and rumination times. Nellore cattle supplemented with SCB exhibited increased rumination and chewing activity, which is associated with saliva production [13].

The stability of rumen fermentation is attributed to the adaptive capacity of rumen microbes to high-fiber diets. Fiber fractions, particularly lignin in SCB, may slow down degradation rates but still provide substrates for fiber fermentation, thereby preventing drastic declines in total and partial VFAs. Stable total VFA also indicates that energy production from fermentation was maintained. Likewise, stable N-NH_3 concentrations reflect that protein degradation rates were unaffected. The average N-NH_3 concentration (12.72 mg/dL) in this study remained within the optimal range for supporting rumen microbial growth. Rumen N-NH_3 concentration is strongly influenced by dietary protein content [4]. However, the high fiber content of SCB may slow protein degradation [3], leading to lower N-NH_3 production.

Table 2. Regression equations of the effects of sugarcane bagasse on rumen fermentability and feeding behavior of large ruminants.

Variables	n	Parameter estimates				Model estimates	
		Int	SE Int	Slope	SE slope	P-value	AIC
Rumen fermentability							
pH	5	6.68	0.3099	-0.02	0.06777	0.8173	1.8×10^{308}
N-NH_3 (mg/dL)	8	12.4421	1.8596	-0.02877	0.2532	0.9167	48.9
Total VFA (mmol/L)	8	95.5184	14.2991	-0.396	0.9356	0.7006	65.5
Acetate (mmol/L)	8	62.8835	7.6042	-0.4428	0.4612	0.4078	59
Propionate (mmol/L)	8	18.8353	4.7685	0.09527	0.6031	0.8845	57.6
Isobutyrate (mmol/L)	5	0.6595	0.3135	0.00935	0.04144	0.8587	20.8
Butyrate (mmol/L)	8	10.4566	2.4987	0.04134	0.1392	0.7859	47
Isovalerate (mmol/L)	5	1.5448	1.1706	-0.01294	0.0908	0.9099	25
Valerate (mmol/L)	5	0.8933	0.4996	0.002726	0.07743	0.9776	23
Acetate/Propionate	5	4.1192	0.1519	-0.05556	0.0267	0.2852	18.5

Feeding behavior							
Feeding (min/d)	18	326.93	11.2975	-1.4282	0.6111	0.0376	158.9
Rumination (min/d)	18	488.45	52.3628	0.3773	2.3602	0.8757	199.1
Idle (min/d)	15	591.91	58.9608	1.9599	2.942	0.5204	166.1
Total chewing time (min/d)	8	800.4	71.5935	0.6847	6.8199	0.9249	80.3

Note: n = number of studies, VFA = volatile fatty acid, Int = intercept, AIC = Akaike information criterion.

These meta-analysis results are consistent with Sirisan et al. [4], who reported no significant effect of SCB supplementation on rumen fermentability. Conversely, Jin et al. [3] found reduced $N\text{-}NH_3$ and total VFA concentrations due to the high lignin fraction in SCB. Similarly, Molavian et al. [6] reported decreased rumen pH in dairy cattle fed SCB. Nonetheless, in the present study, although the changes were not statistically significant, there was a tendency toward reduced rumen pH, total VFA production, and $N\text{-}NH_3$ concentration. Therefore, SCB supplementation in large ruminants should be limited to moderate levels to prevent disturbances in rumen fermentation.

The above findings indicate that SCB has low digestibility, limiting its contribution to VFA production. This also explains the reduction in feeding time with increasing SCB levels, reflecting lower palatability due to the high NDF and lignin content of SCB. Moreover, high-fiber intake may trigger the rumen-filling mechanism, causing early satiety and reduced feed intake [12]. The reduction in feeding time warrants attention, as excessive SCB supplementation may reduce nutrient intake and negatively affect animal productivity. On the other hand, rumination, idle, and total chewing time remained stable, indicating that rumination activity continued normally, thereby ensuring sufficient time for remastication and particle degradation. This behavior helps maintain rumen balance and supports fiber fermentation while preserving animal physiological stability. These results align with Medeiros et al. [5], who reported reduced feeding time, while Freitas et al. [11] observed a linear increase in feeding time with higher SCB levels, and De Almeida et al. [12] found no significant changes. Furthermore, rumination and total chewing time were reported to increase in dairy cattle consuming SCB [6].

Improving rumen fermentability and the palatability of SCB can be achieved through feed processing strategies. Physical, chemical, and biological processing methods have been suggested to enhance SCB digestibility [14,15], thereby maximizing its potential benefits within sustainable feeding systems. The present meta-analysis further indicates that although SCB maintains stable rumen fermentation across a wide inclusion range, its low digestibility and reduced palatability remain key constraints, as reflected by the decrease in feeding time. These limitations highlight the need for processing interventions that specifically target the lignified fiber structure of SCB. Techniques such as particle size reduction, alkaline treatment, and biological delignification can improve fiber accessibility, enhance fermentation efficiency, and potentially allow higher inclusion rates while maintaining rumen stability.

4 Conclusion

SCB can be utilized as an alternative fiber source for ruminant feed while maintaining rumen fermentation stability. Although a tendency for reduced pH, VFA, and N-NH_3 concentrations was observed, these values remain within the optimal range and do not impair rumen microbial activity. However, the reduction in feeding time may negatively affect animal productivity; thus, SCB supplementation should be limited to moderate levels. Therefore, SCB is considered a feasible alternative fiber source in ruminant diet formulation.

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Data availability statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author contribution statement
Samadi Samadi: Conceptualization, Methodology, Investigation, Writing- Original draft preparation. Said Mirza Pratama: Data curation, Writing- Original draft preparation. Sugito Sugito: Validation, Writing- Reviewing and Editing. Fenda Alvionita Fhonna: Validation, Writing- Reviewing and Editing.

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