Research Advances in Regulating Saliva Secretion in Dairy Cows through Dietary Approaches: Postprint

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Abstract

Subacute ruminal acidosis (SARA) is a common nutritional metabolic disease in dairy cows. The neutralizing effect of saliva secretion on acids produced during ruminal fermentation represents a crucial factor for maintaining rumen homeostasis, and the organism effectively prevents SARA through the regulation of saliva secretion. Currently, most studies primarily utilize chewing activity as an indicator to reflect saliva secretion, whereas research directly evaluating saliva secretion remains scarce. This article provides a relatively comprehensive review of studies investigating the regulation of saliva secretion in dairy cows via dietary approaches, with the aim of providing a reference basis for the effective prevention of SARA.

Full Text

Recent Advances in Regulating Saliva Secretion Through Dietary Approaches in Dairy Cows

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Abstract: Subacute ruminal acidosis (SARA) is a common nutritional metabolic disease in dairy cows. Salivary secretion plays a crucial role in neutralizing acids produced during ruminal fermentation, representing a key mechanism for maintaining rumen homeostasis and preventing SARA. While most studies have used chewing activity as an indirect indicator of saliva secretion, direct measurements of salivary output remain scarce. This paper provides a comprehensive review of research on dietary regulation of saliva secretion in dairy cows, offering new insights and reference points for effective SARA prevention strategies.

Keywords: saliva secretion; dairy cow; subacute ruminal acidosis

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Subacute ruminal acidosis (SARA) frequently affects dairy cows during early and mid-lactation [1-2], causing substantial economic losses and triggering conditions such as intermittent anorexia, diarrhea, liver abscesses, and laminitis [1,3-5]. Additionally, SARA disrupts fiber digestion by rumen microorganisms, thereby reducing feed conversion efficiency [6]. Saliva accounts for 70-90% of the liquid and buffering capacity entering the rumen [7], neutralizing approximately 30-40% of acids produced during fermentation [8]. Consequently, regulating saliva secretion represents an important nutritional strategy for preventing SARA.

Increasing dietary fiber proportion is a common practice for SARA prevention, based on the principle that fiber enhances chewing activity, which in turn stimulates saliva secretion to neutralize ruminal acids [9]. Most studies have employed chewing activity as an indirect proxy for salivary output, and chewing has been considered the optimal indicator for assessing rumen health and dietary fiber adequacy. Physically effective neutral detergent fiber (peNDF) refers to the ability of fiber' s physical characteristics to stimulate chewing activity and establish a two-phase stratification of rumen contents [10-11]. The concept has gained attention because it incorporates both the chemical NDF content and physical particle size information of feed [12]. The effects of dietary peNDF on chewing activity and ruminal pH have been extensively investigated in recent years, yet inconsistent findings have prevented peNDF from becoming a routine nutritional index for dairy ration formulation [13]. The exclusive reliance on chewing activity as an indicator of salivary changes remains questionable. Moreover, the lack of direct salivary data hinders interpretation of discrepancies in current research and limits the development of ruminal pH prediction models [14].

This review synthesizes literature on dietary regulation of saliva secretion in dairy cows, examining measurement methodologies, dietary effects on salivary output, and the relationship between chewing activity and saliva secretion, with the aim of providing novel perspectives for SARA prevention.

1. Measurement Methods for Saliva Secretion Rates in Dairy Cows

Saliva secretion rate is determined by three distinct phases: eating, ruminating, and resting (when neither eating nor ruminating occurs). Existing studies have primarily measured secretion rates during eating and resting, while assuming equivalent rates between eating and ruminating phases.

1.1 Eating Saliva Secretion Rate

During feeding, saliva secretion rate is measured by collecting swallowed boluses through a rumen fistula [15]. Prior to measurement, all rumen contents are removed to expose the cardia. The evacuated contents are placed in black plastic bags, immediately sealed, and kept warm with water to maintain microbial activity and minimize thermal stress when returned to the animal [16]. The collection apparatus consists of a flexible metal rod approximately 50 cm long, with a 9-cm diameter metal ring attached at the collection end, which holds a plastic collection bag [17]. After the cow remains calm without ruminating for at least 5 minutes, feeding begins. The collection device is inserted through the fistula to capture boluses at the cardia, carefully avoiding contact with the cardia or adjacent rumen wall to prevent external stimuli from affecting measurement accuracy [7]. All boluses swallowed within a 2-minute period are collected, with the procedure repeated six times at 5-minute intervals. Feed intake and bolus weight are recorded during collection. Saliva secretion volume during eating is calculated using the method of Maekawa et al. [16]:

Saliva collection volume (mL) = collected bolus weight (g) - feed intake (g).

Since saliva dry matter (DM) content is only 1%, its contribution to bolus weight is negligible [18]. Eating saliva secretion rate is calculated as:

Eating saliva secretion rate (mL/min) = saliva secretion volume during collection (mL) / collection time (min).

1.2 Ruminating Saliva Secretion Rate

Direct measurement of ruminating saliva secretion rate is not feasible, leading most studies to assume it equals the eating saliva secretion rate [16,19-21].

1.3 Resting Saliva Secretion Rate

The same collection device used for eating measurements is employed for resting saliva secretion. After complete removal of rumen contents and exposure of the cardia, saliva is observed to flow in streams into the rumen approximately every 30 seconds. Once the cow remains calm for at least 5 minutes, all saliva produced during a 5-minute period is collected and weighed, with four repetitions at 2-minute intervals [16]. Resting saliva secretion rate is calculated as:

Resting saliva secretion rate (mL/min) = total saliva secretion volume during collection (mL) / collection time (min).

Given the difficulty of collecting all saliva continuously for 5 minutes due to rumen motility and the high risk of rumen fluid contamination, Jiang et al. [21] optimized the methodology based on Cassida et al. [17] and Maekawa et al. [16]. First, 2-3 consecutive saliva streams are collected and weighed, with five repetitions at 5-minute intervals to calculate average volume per stream (mL/stream). Then, the number of streams swallowed per minute is recorded during five 5-minute observation periods (with 2-minute intervals between recordings) to determine streams per minute (streams/min). Resting saliva secretion rate is then calculated as:

Resting saliva secretion rate (mL/min) = weight per saliva stream (mL/stream) × number of streams swallowed per minute (streams/min).

2.1 Saliva Secretion Rates

Reported eating and resting saliva secretion rates in dairy cows range from 166-246 mL/min and 91-152.1 mL/min, respectively (Table 1). The ratio of eating to resting saliva secretion rates varies between 1.1 and 2.7. Although substantial variation exists across studies, within individual studies, both eating and resting rates remain unaffected by dietary composition or feeding management. Eating saliva secretion rate is influenced by two factors: eating rate and saliva content per unit of DM. Within a given study, increasing eating rate simultaneously decreases saliva content per unit DM, and vice versa, creating a counterbalancing effect that explains why eating saliva secretion rate is not affected by dietary composition (forage source, proportion, or particle size) [21-22]. This compensatory mechanism also applies when feeding concentrate or forage separately [16,22-23]. For example, Maekawa et al. [16] reported that cows consumed concentrate three times faster than barley silage, but the saliva content per unit DM was only 26.9% of that for barley silage, resulting in no significant difference in eating saliva secretion rate. Similarly, resting saliva secretion rate within individual studies is not influenced by dietary composition.

Cassida et al. [17] reported higher resting saliva secretion rates than Maekawa et al. [16] and Jiang et al. [21], possibly because their diets contained higher concentrate proportions (60% and 70%), prompting cows to increase resting saliva output to maintain rumen stability. These studies primarily investigated effects of varying forage-to-concentrate ratios, forage sources, forage particle sizes, or separate feeding of concentrate and forage, yet demonstrated minimal impact of dietary composition or feeding method on saliva secretion rates.

The reasons for large variations in eating and resting saliva secretion rates across different studies remain unclear but may relate to animal factors such as breed, parity, or lactation stage beyond dietary differences. Cassida et al. [17] found that resting saliva secretion rate increased by 48.7% from week 4 to week 8 postpartum (129.8 mL/min vs. 173.0 mL/min), which may partially explain why early-lactation cows are more susceptible to SARA. Maekawa et al. [24] and Bowman et al. [25] reported that multiparous cows had 29.5% and 17.6% higher resting saliva secretion rates than primiparous cows, respectively. Additionally, Bowman et al. [25] found multiparous cows had 15% higher eating saliva secretion rates than primiparous cows.

Currently, no direct method exists for measuring ruminating saliva secretion rate. Previous methodologies are based on the theoretical assumption that the ratio of parotid saliva secretion rate to total saliva secretion rate remains constant between resting and ruminating states. Using this assumption, parotid saliva secretion rates during rest and rumination (measured via parotid cannulation) have been used to estimate ruminating saliva secretion rate. Bailey et al. [19] and Seth et al. [20] found ruminating saliva secretion rates were 2-3 times higher than resting rates in dairy cows. Steers fed hay showed ruminating rates 2.5 times higher than resting rates [15]. Cassida et al. [17] summarized published data, calculating an arithmetic mean ratio of 1.8 between ruminating and resting saliva secretion rates. Collectively, these findings indicate that ruminating saliva secretion rate is significantly higher than resting rate and similar to eating rate, leading subsequent studies to assume equivalence between ruminating and eating saliva secretion rates [16,21]. Further research is needed to elucidate the patterns and measurement methods for ruminating saliva secretion in dairy cows.

Table 1 Effects of different diets on saliva secretion during eating and resting in dairy cows

2.2 Saliva Secretion Quantity

Total daily saliva production in dairy cows ranges from 180-284 L/d, with secretions during eating, ruminating, and resting accounting for approximately 24.6%, 41.9%, and 33.4%, respectively (Table 2). Maekawa et al. [16] found that increasing dietary forage proportion significantly increased saliva secretion during eating and rumination but simultaneously decreased resting secretion, resulting in no significant change in total daily production. Similarly, Jiang et al. [21] observed that while eating saliva secretion increased significantly, resting secretion tended to decrease, yielding no change in total secretion. These findings are puzzling given that higher forage proportions markedly increase chewing time and eating saliva secretion rate exceeds resting rate. The explanation may be that the incremental increase in saliva from higher forage represents a small proportion of total daily secretion and can be masked by measurement errors or animal variation. Beauchemin [22] estimated saliva production using literature values: eating and ruminating times from Beauchemin et al. [26] for two diets (30% alfalfa hay:70% concentrate; 81% alfalfa hay:29% concentrate), eating and resting secretion rates from Maekawa et al. [16] and Cassida et al. [17], and ruminating rate estimated at 1.8 times resting rate. Results showed that increasing dietary forage proportion increased eating and ruminating times by 2.2 and 1.2 h/d, respectively, and eating saliva secretion by approximately 41.0%, yet total secretion increased by only 8-12 L/d, with eating saliva representing about 4% of total production. Jiang et al. [21] confirmed this, showing that increasing forage proportion from 40% to 70% increased total saliva production by only 16.6 L/d, with eating saliva comprising approximately 7% of total secretion. In summary, daily saliva production is minimally affected by dietary forage proportion and particle size, suggesting that increasing saliva volume to enhance rumen buffering may not be the primary mechanism for SARA prevention through dietary intervention.

Table 2 Effects of different diets on daily saliva production in dairy cows

3.1 Limitations of the peNDF Index

The effects of dietary peNDF on chewing activity and ruminal pH have been research hotspots. Some studies found that increasing peNDF content significantly enhanced chewing activity and elevated ruminal pH [27-28], while others reported no significant effects [29-30]. These discrepancies have prevented peNDF from becoming a routine nutritional index for dairy ration formulation [13], possibly due to inherent limitations: (1) Variations in peNDF measurement methods across studies, including sieve types, sieve apertures, stack thickness, and calculation methods. Murphy et al. [31] compared nine methods for assessing feed particle size and found inconsistent results. (2) Differences between formulated and actual dietary peNDF content. Heinrichs et al. [32] confirmed that actual peNDF content is affected by TMR processing and mixing procedures.

3.2 The Relationship Between Saliva Secretion and Chewing Activity Requires Further Quantification

Whether chewing activity accurately reflects changes in saliva secretion remains questionable. Maekawa et al. [16] and Jiang et al. [21] found that increasing dietary forage proportion significantly increased total daily chewing time (eating + ruminating) without affecting total saliva production. Furthermore, Maekawa et al. [24] reported that although multiparous cows had significantly higher total daily chewing time than primiparous cows (821 min/d vs. 720 min/d), total daily saliva production increased only numerically (252 L/d vs. 227 L/d). Bowman et al. [25] investigated dietary cellulase supplementation and parity effects on chewing activity and saliva secretion, finding that total daily chewing time was unaffected by diet, yet cows receiving fibrolytic enzymes had significantly higher total saliva production than controls. Additionally, no significant difference in total chewing time existed between multiparous and primiparous cows, but multiparous cows produced significantly more saliva. Future research must further explore the relationship between chewing activity and saliva secretion.

3.3 Evaluation Methods for Saliva Secretion Need Improvement

Methodological limitations have restricted research on direct measurement of dietary fiber effects on saliva secretion. The few available studies are based on theoretical assumptions of constant daily saliva secretion rates and equivalent rates between ruminating and eating phases. Developing reliable methods or indicators to evaluate saliva secretion is crucial for advancing understanding of dietary fiber' s role in regulating rumen environment. Saliva measurement methodologies require further optimization and development in future research.

3.4 Intrinsic Salivary Buffering Capacity Requires In-Depth Investigation

No reports have examined dietary fiber effects on saliva' s intrinsic buffering capacity. Whether changes in salivary buffering power constitute a key mechanism for regulating rumen environment remains unclear. Future studies should investigate dietary fiber impacts on saliva' s buffering capacity in conjunction with saliva secretion volume.

4 Conclusion

Dietary forage proportion and particle size have minimal effects on saliva secretion rates and daily production in dairy cows, possibly due to limitations in current measurement methodologies. Future research should further quantify the relationship between chewing activity and saliva secretion and develop more reliable indicators or methods for evaluating salivary output.

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Note: Figure translations are in progress. See original paper for figures.