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Sub-acute ruminal acidosis: Understanding the pathophysiology and management with exogenous buffers

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Abstract
Sub-acute ruminal acidosis (SARA) is an economically important clinical condition and contributes to loss of farm returns, second only to mastitis. It is more prominent in cows in their early and mid-lactation, having peak milk yield and considerably high dry matter intake. SARA detection in a dairy farm is difficult as it does not present any pathognomonic symptoms, and the manifestation of clinical signs is delayed. SARA's characteristic feature is the occurrence of daily fluctuations of pH when the pH drops to the range of 5.2 to 6 for a considerable period due to the accumulation of volatile fatty acids in the rumen. Grain-based diets, which have higher proportions of non-structural carbohydrates, high-quality fermentable forages like legumes, and lack of physically adequate dietary fibre (peNDF), are the significant causes of SARA. SARA consequences include the inflammation of rumen mucosa and several other organs and long-term health and economic losses like reduced feed intake reduced fibre degradability, drop in milk yield and milk fat, damage to the gastrointestinal tract, laminitis, liver dysfunctions, and lameness. SARA can be prevented and treated by the right combination and judicious use of exogenous dietary buffers like sodium bicarbonate, magnesium oxide, and direct-fed microbial like yeast. This review aims to provide a gist of the recent literature available on the pathophysiological aspects, indicators, detection techniques, prevalence, and preventive measures for SARA, including the mechanism of action and utility of the commonly used dietary buffers and direct-fed microbials.

Keywords: sub-acute ruminal acidosis, diagnosis, dairy cattle, rumen pH, buffers

Introduction
India ranks first in the world in terms of milk production. The annual milk production was 176.3 million tonnes for the year 2017-18 [1]. Nonetheless, the per capita production of milk is still far below the world average. Having the world's largest herd, the country has enormous prospects of transforming the dairy sector into a humongous enterprise, provided the livestock is fed with nutritionally adequate diets. Current practices at intensive dairy systems advocate concentrate feeding in order to elevate the plane of nutrition. Thus, cattle are fed high starch and low fibre [2] to increase milk production [3, 4]. Ruminants are adapted to digest mainly forage diets [5]. Any alteration in the physical form or effectiveness of the diet, e.g. smaller forage particle size or fine grinding of grain, decreases ruminal pH, giving rise to sub-acute ruminal acidosis (SARA) [6]. Thus, concentrate feeding affects rumen health. The more serious concern about the decline in ruminal pH is its sub-clinical nature, making it more difficult to detect and cure, thus causing considerable losses to the animal and the farm productivity. SARA has been a significant menace to Indian dairy farms over the years, second only to mastitis regarding the monetary losses caused [7]. It alters fermentation patterns, reduces dry matter intake, milk yield, fat content, and consequently, farm profitability [8]. Garret *et al.* [9] Reported that approximately 19% of cows in their early-lactation period and 26% of cows in their mid-lactation period are affected with metabolic acidosis in the United States. The figures remain similar even after 23 years [10], as SARA's diagnosis is quite challenging due to its sub-clinical nature. Early lactation cattle are prone to acidosis due to their energy-dense diet and unstable microflora [11], and mid-lactation cows suffer as they have a higher dry matter intake [12].

Acute and sub-acute ruminal acidosis

The significant difference between acute and sub-acute ruminal acidosis lies in their duration of onset of symptoms. While acute acidosis is a grave condition with a poor prognosis, the number of incidences in dairy cattle is relatively minor. It is not a significant concern in feedlot cattle [13].

Table 1: Differences between acute and sub-acute ruminal acidosis (Plaizier *et al.*, 2008 [14]; Calsamiglia *et al.*, 2008 [7])

Parameters	Acute acidosis	Subacute acidosis
Clinical signs	Present	Absent
Mortality	Yes	No
Rumen pH	<5	5-5.5
Lactic acid	50-120 mM	0-5 mm
Volatile fatty acids	<100 mm	150-225 mm
Lactic acid producing bacteria	Increase	Increase
Lactic acid utilizers	Decrease	Increase
Ciliate protozoa	Decrease	Decrease
Incidence	14% incidences Generally goes unnoticed	44% incidences Reduced dry matter intake and fiber digestion milk fat depression, laminitis, liver abscesses, or death
Duration	<90 minutes in a day	111-180 minutes in a day

pH and buffering of rumen

The ruminal pH is about 6.2-6.8, which fluctuates by ±2.5 points depending on the type and frequency of feeding [15]. The major contributors to the buffering action of rumen liquor are phosphate-bicarbonate buffer with urea and mucous secreted in the saliva. Cattle produce about 200-300 L of saliva daily, which has about 100-140 mEq of bicarbonates. It constitutes about 30-40% of the buffering capacity of the rumen.

$$HPO_4^{2-} + H_30^+ \leftrightarrow H_2PO_4^- + H_20 \quad .... (1)$$
$$HCO_3^- + H_3O^+ \leftrightarrow H_2CO_3 + H_2O \leftrightarrow CO_2 + 2H_2O \quad ....(2)$$

Equations (1) and (2) [16] summarize the buffering mechanism of saliva and rumen.

Another source of buffering action is feed, majorly by legumes. If the diet is predominantly rich in grains, over forages, the feed's buffering action is significantly reduced and affects the rumen's pH. Diets rich in concentrate favor the synthesis of propionate by the acrylate pathway, leading to the formation and accumulation of lactic acid in the rumen, causing a decline in pH. In severe cases, the organ's muscular activity can also be hampered, and atony may occur [17]. The rumen papillae, mainly adopted to absorb and transport VFA from the rumen to the bloodstream, may erode. Thus, gram-negative bacteria may leak into the systemic circulation, causing septicemia and giving rise to various disorders like ruminitis, rumen parakeratosis, metabolic acidosis, lameness, hepatic abscessation, pneumonia, and death [18].

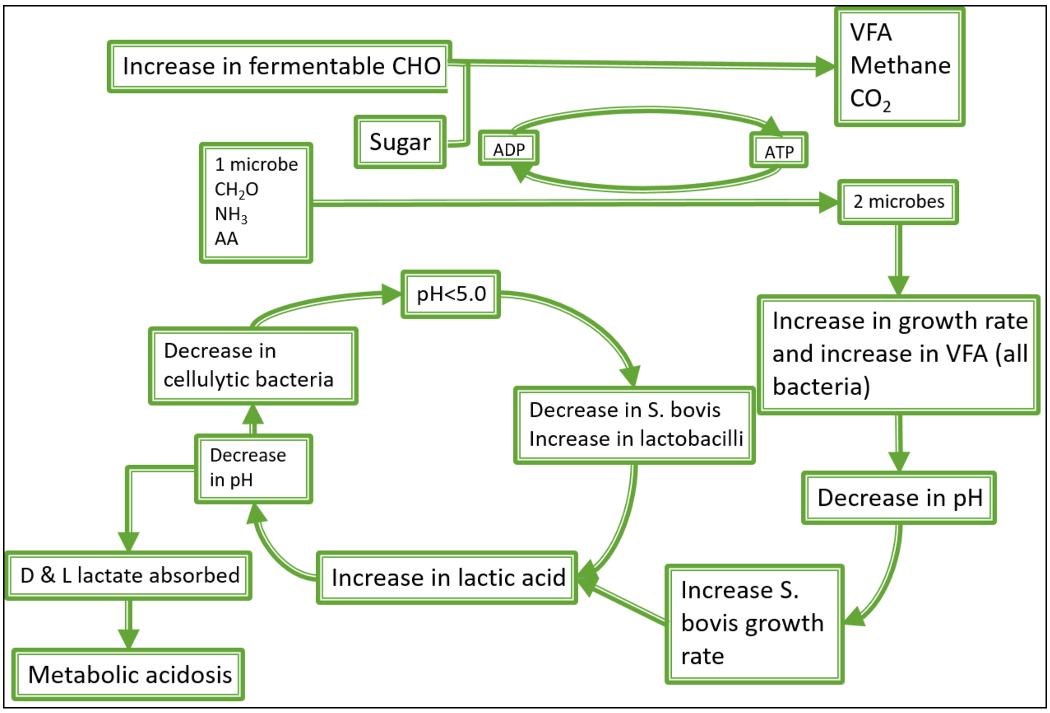

Fig 1: Etiopathology of acidosis

By increasing the amount of fermentable carbohydrates by grain feeding, pH drops below the expected levels by accumulating lactate. The ruminal pH pattern displays a biphasic curve with a decline in pH immediately after feeding.

The pH achieves a minimum value 2 to 3 h after feeding and increases continuously until the next feeding [19]. However, the pattern of pH is much more stable and higher (≈6.5) when the animal is maintained on *ad-libitum* hay, as opposed to concentrating feeding [15]

Rumen microflora: The rumen milieu is a complex ecosystem. Protozoa engulf bacteria to satiate their nitrogenous needs [20]. This bacterial uptake drops to nil if the pH falls to 5. The protozoal population is completely demolished at this pH [21]. A decline in ruminal pH also drastically reduces the population of cellulolytic bacteria, as they are adapted to grow in near-neutral pH [22, 23]. The accumulation of lactic acid favors lactobacilli's growth, which carries out fermentation and further worsens the rumen milieu [24].

Clinical signs of SARA
Although there are no confirmatory signs for SARA, and it is called 'silent sickness' of the herd [25], some symptoms can be considered indicative of the condition.
- Decreased voluntary DMI
- Losing of body condition and emaciation
- Reduction in milk yield and fat
- Rumenitis–caudal vena cava syndrome complex,
- Liver abscesses
- Lameness [26].

Diagnosis of SARA
The easiest reliable technique to detect sub-acute ruminal acidosis is to monitor reticulo-ruminal pH [27] continuously. The ruminal pH is lowest till 5-8 h after feeding TMR. More accurate estimation of pH can be done by collecting ruminal samples by various methods viz., oral intubation using a probe and ruminal pump, rumenocentesis, intraluminal sensors, evaluation of dung for the presence of bubbles and lipopolysaccharides, measurement of ruminal thickness, and blood acid-base analysis [10].

Clinical Sequelae of SARA
1. **Metabolic acidosis:** It is unclear that lactate accumulates in the rumen and has a metabolic acidosis role [28]. However, it induces inappetence in early lactation periods due to high dry matter intake [29]. Due to ruminal acidosis, cellular functions are impaired, and VFA concentration rises in the peripheral circulation, which affects insulin secretion [30], reduced phagocytic activity [31], reduced neutrophil migration [32], increased cortisol secretion [33]. Long-term acidosis may lead to immunosuppression and a decrease in milk production [34].
2. **Rumenitis:** Accumulation of VFA's like butyrate, propionate and lactate may be involved in the pathogenesis of rumenitis. Parakeratosis results from acute acidic conditions, which also affect the long-term absorption capacity of the ruminal mucosa, making it susceptible to the entry of gram-negative bacteria like *Fusobacterium necrophorum.* The bacteria might also migrate to the liver as emboli, leading to the rumenitis liver abscess complex [35].
3. **Abomasal displacement:** Increased flux of ruminal gases and VFA between abomasum and rumen may lead to abomasal displacement, which is complemented by the fact that low functional fiber in the ration also causes the same [35].
4. **Laminitis:** Endotoxins produced by gram-negative bacteria in the rumen migrate to various organs of the body by embolism. If they reach the hoof, induce a vascular reaction leading to vasoconstriction. Inflammation and pododermatitis follow the course [36].
5. **Bloat:** The release of macromolecules like mucopolysaccharides and endotoxins unknown macromolecules from gram-negative bacteria leads to the formation of a static foam, leading to a drop in pH and accumulation of gas [37].
6. **The decrease in milk fat:** An increase in the concentration of protons and a decline in the proportion of acetate in the rumen leads to the incomplete biohydrogenation of unsaturated fats to various intermediates. Hence the final fat yield is decreased [38].

Prevention and treatment
SARA being a silent condition, displays delayed symptoms and hence makes the prevention difficult. Nevertheless, adequate nutrition and adaptation of microflora to the feed are crucial to preventing SARA incidences in the herd [39]. Physically effective fibre (peNDF>1.18) in the diet stimulates saliva production, and hence ruminal buffering, assisting in maintaining rumen pH [40]. Exogenous preventive measures like buffers and direct-fed microbials also provide an effective tool for monitoring and preventing SARA. The mode of action and effects of specific dietary buffers and DFMs are described below:

Effects of exogenous buffers on rumen health
- The decline in ruminal urea concentration
- The increased flow of undegraded starch from the rumen
- Greater microbial utilization of ammonia N with an increased level of energy supplied
- Increase water intake, stabilize rumen pH
- Buffers enhance cellulose digestion and increase rumen turnover
- Buffers improve protein solubility; hence microbial protein synthesis is better [41]
- Buffers increase the completeness of biohydrogenation & decrease the formation of intermediates. They also increase acetate and decrease propionate [42].
- Buffers increase milk protein content due to better utilization by microbes. Cationic salts improve lactation performance by improving ruminal buffering ability, blood pH, rumen microbial synthesis, and biohydrogenation in the rumen [43].

The mode of action and effects of specific dietary buffers is described below.

Bicarbonates
The dissociation constant of sodium bicarbonate is 6.25, and they have a short half-life [44]. Bicarbonates have a significant buffering action, which compensates for saliva and increases the DMI [45]. Buffers increase the HCO_3^- concentration in ruminal fluid and shift the equilibrium towards CO_2, decreasing the free H^+ ion concentration and increasing the pH. By adding dietary buffers, there is an increase in the proportion of acetate, while the molar proportions of propionate and butyrate remain the same. For every mole of VFA that leaves the rumen, one proton is added (Fig. 2). Bicarbonates neutralize protons & increase the dilution rate of

rumen [46]. Bicarbonates increase the voluntary water intake by the animals, decreasing the rumen osmolality. Hence the flow of starch increases, preventing its accumulation. This assists in hindering the growth of lactobacilli in the rumen [47]. Increased bacterial nitrogen flow increases bacterial protein synthesis [48], while the rise in pH improves protein utilization by increasing its solubility [49]. Buffers also improve nitrogen retention by increased nitrogen retention [50].

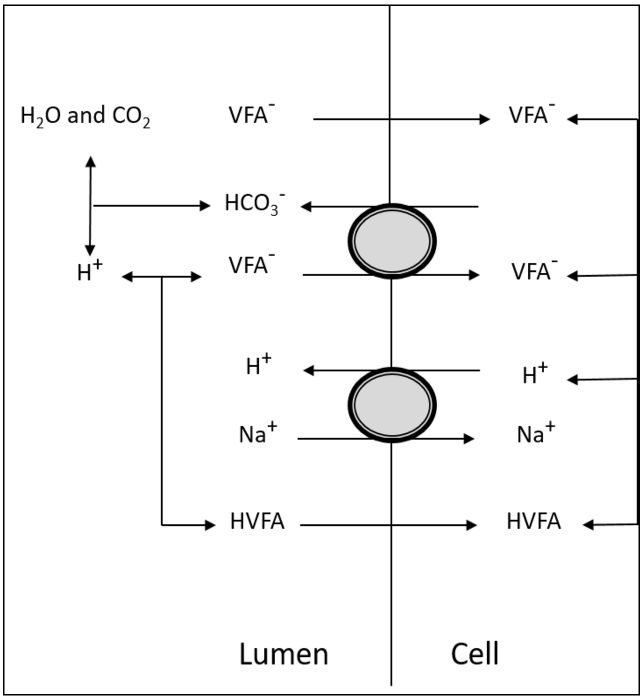

Fig 2: Exchange of protons and VFA from the ruminal wall (*Adapted from Bannick et al.,* 2012)

Potassium carbonate: It has a similar action mechanism as sodium bicarbonate. Nonetheless it is a more potent neutralizing agent [51]. It is generally preferred to alleviate incidences of fat milk depression, as it favors the predominant pathway of milk fat dehydrogenation. Milk fat increases by 24% on a matter basis in cows fed with potassium carbonate, while the milk yield declines [52]. Cows with their potassium carbonate as top dressing have more forage intake than cows fed with sodium bicarbonate. In a study by Zali *et al*. 2019 [53], two new buffers called HBNa and HBK containing sodium and potassium carbonates respectively, were developed and evaluated for milk yield in Holstein Friesian cows. It was observed that there was no difference in milk yield and 3.5% FCM between the groups fed with two different buffers. Milk fat and protein%, calcium levels in cows fed with potassium carbonate buffer were higher than the sodium-based buffer. The new commercial buffer HBK proved to give the best results in milk composition at the level of 6% of DMI.

Magnesium oxide: MgO is yet another effective and commonly used buffer in ruminants. It is generally the preferred top dressing overfeed, in combination with sodium bicarbonate. It increases the uptake of blood metabolites like plasma acetate and triglycerides by the mammary gland, hence raising the fat content. Its efficacy depends on its particle size. The dose rate is 45-90 g/d. The preferred ratio is 2-3:1 with $NaHCO_3$ [54]. In a comparative evaluation of MgO and soda bicarb by Bach *et al*. (2018) [55], it was found that 0.4% MgO can sustain pH fluctuations in rumen more than 0.8% soda bicarb when the animal is subjected to a high concentrate challenge.

Sodium sesquicarbonate: It is a double salt of sodium bicarbonate and sodium carbonate, having a pH of 9.9, as opposed to bicarbonates, which have a pH of 8.4. Hence the acid-neutralizing capability is higher than bicarbonate, with the added advantage of being cost-effective. Dietary supplementation of sesquicarboante decreases the molar proportions of butyrate and valerate. It improves milk fat and 4% FCM yield. Although in an *in-vitro* study by Sharma *et al*., [56], it was found that there was no change in *in vitro* DM digestibility, ammonia nitrogen, and molar proportions of VFAs. In-vivo studies suggest differently [45].

Zeolite: It has a high attraction for water & cations like K^+, NH_4^+, Ca^{2+}, and Mg^{2+}, which are reversibly bound. When these ions are released, fermentation is facilitated. Osmotic activity regulates pH by buffering against hydrogen ions of organic acids. It also improves nitrogen utilization.
A comprehensive summary of the effect of different buffers by various researchers over the years is presented in table 2.

Table 2: Effect of different buffers on different diet patterns by various researchers

Diet	Buffer and dose rate	Effect on milk fat%	Effect on milk yield	Effect on milk protein%	References
Corn silage	180g $NaHCO_3$	0.25% Increase	0.12% increased	No change	(Fishert and Mackay, 1983) [57]
68% concentrate	1.5% $NaHCO_3$	0.45% increase	3.5% FCM was higher	No effect	(Xu *et al*., 1994) [58]
Rotational grazing	1.25% $NaHCO_3$	No change	No change	No change	(Rearte *et al*., 1984) [59]
Hay crop silage 70% roughage + 30% concentrate	0.7% $NaHCO_3$	0.09% increase	FCM decreased by 0.3 kg	0.04% rise	(Stokes *et al*.,1985) [60]
Corn silage 40% +60% concentrate	1% Bicarbonate 1% sesquicarbonate	0.15% increase	4% FCM higher for sequicarbonate	No effect	(Ghorbani *et al*., 1989) [61]
23.1% starch	1% $NaHC0_3$	No change in Milk fat or milk yield	--	from 5.9-6.2	(Bougouin *et al*.,2018) [62]
Concentrate challenge	90 g/d Acid buff + 180 g /d $NaHC0_3$		5.42 vs control (5.19) vs (5.26)		(Beya *et al*., 2007) [45]

Direct fed microbials and yeast

DFMs and yeast prevent lactate accumulation and allow better fiber digestion by improving the reducing conditions of rumen and fibrinolytic bacteria's stimulation. Conversion of lactate to propionate is enhanced, and ruminal pH is stabilized [63] Nocek, and Kautz (2006) [64] showed in a study that three different organisms (*Enterococcus faecium, Lactobacillus plantarum, Saccharomyces cerevisiae*) administered at 10^5 cfu/mL stabilized rumen acidity and improved digestion.

Conclusions

SARA's economic losses are relatively high (approximately Rs.20,000 per cow per lactation). So, it poses a significant threat to the dairy industry if not appropriately treated. Exogenous dietary buffers have been proven to help overcome acidosis, though the results are not consistent. The type of buffer, its dose, and the type of diet are the major factors affecting the buffers' efficiency. Yeast may be an effective alternative for bicarbonate buffers. The success of an effort in preventing SARA depends on the coordinated efforts between nutritionists and clinicians.

References

1. DAHD, Department of Animal Husbandry & Dairying (DAHD), India 2018. http://dahd.nic.in/
2. Oetzel GR. Subacute ruminal acidosis in dairy herds: physiology, pathophysiology, milk fat responses, and nutritional management. In 40th Annual Conference, American Association of Bovine Practitioners 2007;17:89-119.
3. Kmicikewycz AD. Effects of Diet Particle Size and Supplemental Hay on Mitigating Subacute Ruminal Acidosis in High-Producing Dairy Cattle. Doctoral thesis, 2014.
4. Abdela N. Sub-acute ruminal acidosis (SARA) and its consequence in dairy cattle: A review of past and recent research at global prospective. Achievements in the life sciences 2016;10(2):187-196.
5. Dryden GM. Animal nutrition science. Cabi 2008.
6. Krause KM, Combs DK, Beauchemin KA. Effects of forage particle size and grain fermentability in midlactation cows. II. Ruminal pH and chewing activity. Journal of dairy science 2002;*85*(8):1947-1957.
7. Calsamiglia S, Blanch M, Ferret A, Moya D. Is subacute ruminal acidosis a pH related problem? Causes and tools for its control. Animal Feed Science and Technology 2012;172(1, 2):42-50.
8. Wang Y, Liu J, Yin Y, Zhu W, Mao S. Rumen microbial and fermentation characteristics are affected differently by acarbose addition during two nutritional types of simulated severe subacute ruminal acidosis in vitro. Anaerobe 2017;47:39-46.
9. Garrett EF, Nordlund KV, Goodger WJ, Oetzel GR. A cross-sectional field study investigating the effect of periparturient dietary management on ruminal pH in early lactation dairy cows. Journal of Dairy Sciences 1997; 80(1):169.
10. Kovács L, Rózsa L, Pálffy M, Hejel P, Baumgartner W, Szenci O. Subacute ruminal acidosis in dairy cows-physiological background, risk factors and diagnostic methods. Veterinarska stanica 2020;51(1):5-17.
11. Devries TJ, Beauchemin KA, Dohme F, Schwartzkopf-genswein KS. Repeated ruminal acidosis challenges in lactating dairy cows at high and low risk for developing acidosis: feeding, ruminating, and lying behavior. Journal of Dairy Sciences 2009;92:5067-5078
12. Nordlund KV, Garrett ET, Oetzel GR. Herd-based rumenocentesis-a clinical approach to the diagnosis of subacute rumen acidosis. Compendium on Continuing Education for the Practicing Veterinarian 1995;17:S48-S56.
13. Krause KM, Oetzel GR. Understanding and preventing subacute ruminal acidosis in dairy herds: A review. Animal feed science and technology 2006;126(3-4):215-236.
14. Plaizier JC, Krause DO, Gozho GN, Mcbride BW. Subacute ruminal acidosis in dairy cows: the physiological causes, incidence and consequences. The Veterinary Journal 2008;176:21-31.
15. Gasteiner J, Fallast M, Rosenkranz S, Häusler J, Schneider K, Guggenberger T. Measuring rumen pH and temperature by an indwelling and wireless data transmitting unit and application under different feeding conditions. Vet Med Austria 2009;96:188-94.
16. Hu W, Kung Jr L, Murphy MR. Relationships between dry matter intake and acid–base status of lactating dairy cows as manipulated by dietary cation–anion difference. Animal feed science and technology 2007;136(3, 4):216-225.
17. Russell JB, Rychlik JL. Factors that alter rumen microbial ecology. Science 2001;292:1119-1122.
18. Lean IJ, Golder HM, Hall MB. Feeding, evaluating, and controlling rumen function. Veterinary Clinics: Food Animal Practice 2014;30(3):539-575.
19. Gasteiner J, Guggenberger T, Häusler J, Steinwidder A. Continuous and long-term measurement of reticuloruminal pH in grazing dairy cows by an indwelling and wireless data transmitting unit. Veterinary medicine international 2012.
20. Hobson PNN, Stewart CSS. The rumen microbial ecosystem. Blackie Academic & Professional - An imprint of Chapman & Hall 1988, 719.
21. Lettat A, Noziere P, Silberberg M, Morgavi DP, Berger C, Martin C. Experimental feed induction of ruminal lactic, propionic, or butyric acidosis in sheep. Journal of Animal Sciences. 2010;88:3041-3046.
22. Ogunade IM, Lay J, Andries K, McManus CJ, Bebe F. Effects of live yeast on differential genetic and functional attributes of rumen microbiota in beef cattle. Journal of animal science and biotechnology 2019;10(1):1-7.
23. Mulligan FJ, Doherty ML. Production diseases of the transition cow. The Veterinary Journal 2008;*176*(1):3-9.
24. Mackie RI, Gilchrist FM. Changes in lactate-producing and lactate-utilizing bacteria in relation to pH in the rumen of sheep during stepwise adaptation to a high-concentrate diet. Applied and environmental microbiology 1979;38(3):422-430.
25. Minami NS, Sousa RS, Oliveira FLC, Dias MRB, Cassiano DA, Mori CS *et al*. Subacute Ruminal Acidosis in Zebu Cattle: Clinical and Behavioral Aspects. Animals 2021;11(1):21.
26. Eun JS, Kelley AW, Neal K, Young AJ, Hall JO. Effects of altering alfalfa hay quality when feeding steam-flaked versus high-moisture corn grain on ruminal fermentation and lactational performance of dairy cows. Journal of dairy science 2014;97(12):7833-7843.
27. Humer E, Aschenbach JR, Neubauer V, Kröger I, Khiaosa-Ard R, Baumgartner W *et al*. Signals for identifying cows at risk of subacute ruminal acidosis in dairy veterinary practice. Journal of animal physiology and animal nutrition 2018;102(2):380-392.
28. Höltershinken M, Kress V, Rathjens U, Rehage J, Scholz

H. Auswirkungen oral zu verabreichender Therapeutika auf Fermentationsvorgänge im Pansensaft ruminierender Rinder (in vitro). 7. Deutsche Tierärztliche Wochenschrift 1997;104:317-320.
29. Ho¨hling A, Ho¨ltershinken M, Holsten NB, Scholz H, Influence of starvation on fermentation in bovine rumen fluid (*in vivo*). In: Proceedings of the XXIII World Buiatrics Congress, 11–16 July, Quebec, Canada, 2004, 183
30. Bigner DR, Goff JP, Faust MA, Burton JL, Tyler HD, Horst RL Acidosis effects on insulin response during glucose tolerance tests in jersey cows. Journal of Dairy Science 1996;79:2182-2188.
31. Rossow N, Horvath Z In: Rossow, N., Horvath, Z. (Eds.), Innere Krankheiten der Haustiere, Band II, Funktionelle Sto¨rungen. Jena: Fischer 1988, 246
32. Hofirek B, Slosarkova S, Ondrova J. Effect of chronic metabolic acidosis on migration activity of polymorphonuclear leukocytes in sheep. Veterinarni Medicina 1995;40:171-175.
33. Ras A, Janowski T, Zdunczyk S. Einfluss subklinischer und akuter Azidose ante partum bei Ku¨hen auf den Gravidita¨tsverlauf unter Beru¨cksichtigung der Steroidhormonprofile. Tiera¨rztliche Praxis 1996;24:347-352.
34. Mwansa P, Makarechian M, Berg RT. The effect of level of concentrate in feedlot diets on the health status of beef calves. Canadian Veterinary Journal 1992;33:665-668.
35. Enemark JM. The monitoring, prevention and treatment of sub-acute ruminal acidosis (SARA): A review. The Veterinary Journal 2008;176(1):32-43.
36. Andersen PH, Jarløv N. Investigation of the possible role of endotoxin, TXA2, PGI2 and PGE2 in experimentally induced rumen acidosis in cattle. Acta Veterinaria Scandinavica 1990;31:27-38.
37. Cheng KJ, McAllister TA, Popp JD, Hristov AN, Mir Z, Shin HT A review of bloat in feedlot cattle. Journal of Animal Science 1998;76:299-308.
38. Kolver ES, De Veth MJ. Prediction of ruminal pH from pasture-based diets. Journal of dairy science 2002;85(5):1255-1266.
39. Kleen JL, Hooijer GA, Rehage J, Noordhuizen JPTM. Subacute ruminal acidosis (SARA): a review. Journal of Veterinary Medicine Series A 2003;50(8):406-414.
40. Banakar PS, Anand Kumar N, Shashank CG. Physically effective fibre in ruminant nutrition: A. Journal of Pharmacognosy and Phytochemistry 2018;7(4):303-308.
41. Miller-Webster T, Hoover WH, Holt M, Nocek JE. Influence of yeast culture on ruminal microbial metabolism in continuous culture. Journal of Dairy Science 2002;85(8):2009-2014.
42. Cabrita ARJ, Vale JMP, Bessa RJB, Dewhurst RJ, Fonseca AJM. Effects of dietary starch source and buffers on milk responses and rumen fatty acid biohydrogenation in dairy cows fed maize silage-based diets. Animal feed science and technology 2009;152(3-4):267-277.
43. Shire JA, Beede DK. DCAD revisited: Prepartum use to optimize health and lactational performance. Proceedings of the 28th annual Southwest Nutrition and Management 2013;86:1-11.
44. Van Soest PJ. Nutritional ecology of the ruminant. Cornell university press 1994.
45. Cruywagen CW, Taylor S, Beya MM, Calitz T. The effect of buffering dairy cow diets with limestone, calcareous marine algae, or sodium bicarbonate on ruminal pH profiles, production responses, and rumen fermentation. Journal of dairy Science, 2015;98(8):5506-5514.
46. Tucker WB, Aslam M, Lema M, Shin IS, Le Ruyet P, Hogue JF *et al*. Sodium bicarbonate or multielement buffer via diet or rumen: Effects on performance and acid-base status of lactating cows. Journal of dairy science 1992;75(9):2409-2420.
47. Bannink A, Gerrits WJJ, France J, Dijkstra J. Variation in rumen fermentation and the rumen wall during the transition period in dairy cows. Animal Feed Science and Technology 2012;172(1, 2):80-94.
48. Mees DC, Merchen NR, Mitchel CJ. Effects of sodium bicarbonate on nitrogen balance, bacterial protein synthesis and sites of nutrient digestion in sheep. Journal of animal science 1985;61(4):985-994.
49. Sharif M, Mahr-un-Nisa MS, Shahzad MA. Influence of varying levels of dietary cation anion difference on ruminal characteristics, acid base status and milk yield of early lactating animals (a review). Pakistan Journal of Agricultural Sciences 2008;45(2).
50. Westendorf ML, Wohlt JE. Brewing by-products: Their use as animal feeds. The Veterinary clinics of North America. Food animal practice 2002;18(2):233-252.
51. Lee SH, Moon JJ, West JL. Three-dimensional micropatterning of bioactive hydrogels via two-photon laser scanning photolithography for guided 3D cell migration. Biomaterials 2008;29(20):2962-2968.
52. West JW, Coppock CE, Nave DH, Schelling GT. Effects of potassium buffers on feed intake in lactating dairy cows and on rumen fermentation *in vivo* and in vitro. Journal of dairy science 1986;69(1):124-134.
53. Zali A, Nasrollahi SM, Khodabandelo S. Effects of two new formulas of dietary buffers with a high buffering capacity containing Na or K on performance and metabolism of mid-lactation dairy cows. Preventive veterinary medicine 2019;163:87-92.
54. Neville EW, Fahey AG, Gath VP, Molloy BP, Taylor SJ, Mulligan FJ. The effect of calcareous marine algae, with or without marine magnesium oxide, and sodium bicarbonate on rumen pH and milk production in mid-lactation dairy cows. Journal of dairy science 2019;102(9):8027-8039.
55. Bach A, Guasch I, Elcoso G, Duclos J, Khelil-Arfa H. Modulation of rumen pH by sodium bicarbonate and a blend of different sources of magnesium oxide in lactating dairy cows submitted to a concentrate challenge. Journal of dairy science 2018;101(11):9777-9788.
56. Sharma H, Mani V, Kumar S, Mondal G. Effect of sodium sesquicarbonate supplementation on blood biochemical parameters and antioxidant activity in lactating Karan Fries Cattle. Indian Journal of Animal Nutrition 2020;37(3):284-287.
57. Fisher LJ, MacKay VG. The effect of sodium bicarbonate, sodium bicarbonate plus magnesium oxide or bentonite on the intake of corn silage by lactating cows. Canadian Journal of Animal Science 1983;63(1):141-148.
58. Xu S, Harrison JH, Riley RE, Loney KA. Effect of buffer addition to high grain total mixed rations on rumen pH, feed intake, milk production, and milk

composition. Journal of dairy science 1994;77(3):782-788.
59. Rearte DH, Kesler EM, Stringer WC. Forage growth and performance of grazing dairy cows fed concentrates with or without sodium bicarbonate. Journal of Dairy Science 1984;67(12):2914-2921.
60. Stokes MR, Bull LS, Halteman WA. Rumen liquid dilution rate in dairy cows fed once daily: effects of diet and sodium bicarbonate supplementation. Journal of dairy science 1985;68(5):1171-1180.
61. Ghorbani GR, Jackson JA, Hemken RW. Effects of sodium bicarbonate and sodium sesquicarbonate on animal performance, ruminal metabolism, and systemic acid-base status. Journal of dairy science 1989;72(8):2039-2045.
62. Bougouin A, Ferlay A, Doreau M, Martin C. Effects of carbohydrate type or bicarbonate addition to grass silage-based diets on enteric methane emissions and milk fatty acid composition in dairy cows. Journal of dairy science 2018;101(7):6085-6097.
63. Marden JP, Julien C, Monteils V, Auclair E, Moncoulon R, Bayourthe C. How does live yeast differ from sodium bicarbonate to stabilize ruminal pH in high-yielding dairy cows?. Journal of Dairy Science 2008;91(9):3528-3535.
64. Nocek JE, Kautz WP. Direct-fed microbial supplementation on ruminal digestion, health and performance of pre-and postpartum dairy cattle. Journal of Dairy Science 2006;89:260-266.