Dairy Australia

Australian Guidelines for the Integrated Management of Ruminal Acidosis

A resource for nutritional professionals and veterinarians

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Conflict of interest statement

These Guidelines have been developed with the objective of providing evidence-based and practical guidance for the Australian dairy industry.

The authors and contributors involved in preparing these Guidelines have collectively brought expertise from the dairy, animal health, feed, nutrition, veterinary and advisory sectors. Some authors and contributors have current or past commercial affiliations, consulting roles, research funding arrangements or other professional relationships relevant to the subject matter of these Guidelines.

Dairy Australia acknowledges that such relationships may give rise to actual or perceived conflicts of interest. To promote transparency and confidence in the development process, these draft Guidelines have been released for public consultation. Feedback received during the consultation process, together with any proposed amendments arising from that feedback, will be reviewed by independent experts appointed by Dairy Australia who have no financial or commercial interest in the outcomes addressed in these Guidelines.

The final content of the Guidelines will be determined by Dairy Australia having regard to the available evidence, feedback received during consultation and the outcomes of the independent review process.

The content and recommendations contained in these Guidelines are intended to provide practical guidance and are not intended to endorse, prefer or promote any particular product, supplier or commercial service.

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Foreword

Acknowledgements

Abbreviations

Table 1 Abbreviations used throughout these Guidelines

Abbreviation	Full Term
APP	Acute-phase proteins
AMR	Antimicrobial resistance
AMS	Antimicrobial stewardship
ARA	Acute ruminal acidosis
ASTAG	Australian Strategic and Technical Advisory Group on Antimicrobial Resistance
AVA	Australian Veterinary Association
BC	Buffer capacity
CLA	Conjugated linoleic acid
CP	Crude protein
DAFF	Australian Government Department of Agriculture, Fisheries and Forestry
DIM	Days in milk
DM	Dry matter
DMI	Dry matter intake
GHG	Greenhouse gas
iNDF	Indigestible NDF
kg	Kilogram
LPS	Lipopolysaccharide
ME	Metabolisable energy
MFD	Milk fat depression
MJ	Megajoule
mmol	Millimole
mOsm	Milliosmole
mM	Millimolar or millimole/L
NCAS	National Centre for Antimicrobial Stewardship
NDF	Neutral detergent fibre
OMD	Organic matter digestibility
peNDF	Physically effective neutral detergent fibre
pKa	Acid dissociation constant
PMR	Partial mixed ration
PSPS	Penn. State Particle Separator
S4	Schedule 4
S6	Schedule 6
SARA	Sub-acute ruminal acidosis
SCFA	Short-chain fatty acids
SFMCA	Stock Feed Manufacturers' Council of Australia
TGA	Therapeutic Goods Administration
TMR	Total mixed ration

Abbreviation	Full Term
VFA	Volatile fatty acids (acetate, propionate, butyrate)
WSC	Water soluble carbohydrates

Chapter 1: Introduction

Summary of key points:

- Ruminal acidosis is common and costly, with up to 37% of Australian cows at high risk. It reduces productivity, animal welfare and profitability, and increases greenhouse gas (GHG) emissions intensity.
- Ruminal acidosis encompasses a continuum of disorders that vary in severity, duration and clinical signs.
- Risk occurs across all production systems and is influenced by cow-related factors, diet composition, feeding management, environmental conditions, rapid dietary change and poor transition management.
- Diagnosing ruminal acidosis requires the assessment of multiple herd- and cow-level parameters.
- In-feed antimicrobials may be used to support the control of ruminal acidosis but should be used judiciously and only after nutrition, environmental conditions and management have been optimised.

Ruminal acidosis, its impacts and costs

Ruminal acidosis involves disruption of the rumen microbial ecosystem and ruminal epithelial structure and function. It encompasses a continuum of disorders that vary in severity, duration and clinical signs. It is a significant disorder of dairy cattle managed in grazing and contained housing systems in Australia and worldwide, with important implications for cow health, welfare and productivity. Many cows experience rumen dysfunction during lactation, with Golder et al. (2023) suggesting that up to 37% of Australian cows are at high risk. Ruminal acidosis can reduce animal welfare, farm productivity, profitability and sustainability, and increase GHG emissions per cow and per unit of milk produced.

Ruminal acidosis causes economic losses through:

- reduced milk solids yield and milk quality
- lower dry matter intake, digestibility and feed efficiency, making it a “silent thief” of feed conversion
- impaired reproduction due to altered energy balance
- increased health problems, including lameness, liver abscesses, gastrointestinal damage, metabolic disease, poorer body condition and reduced animal value
- premature culling and higher mortality, which increase herd replacement costs
- higher herd management, animal health and feed costs

Stone (1999) estimated that on a 500-cow dairy farm in New York, subacute ruminal acidosis (SARA) resulted in lost income of US$1.12 per cow per day, or US$400-475 per cow per year. This estimate was based on an increase in milk yield of 2.7 kg per day, milk fat concentration of 0.3 percentage points and milk protein concentration of 0.12 percentage points, when rumen pH was increased from acidotic conditions through changes in diet starch source. It did not include the costs of veterinary treatment or increased culling. Estimates of the current cost of subacute ruminal acidosis in Australian herds have not been published. However, assuming a similar difference in milk production due to SARA as the one reported by Stone (1999) on a typical Australian dairy farm, equivalent to approximately 200 g of milk solids per cow per day,

the resulting loss in income would be approximately A$1.80–2.00 per cow per day, based on a milk solids price of A$9-10/kg. The costs of veterinary treatment and increased culling would be additional.

Ruminal acidosis in diverse Australian dairying systems

When addressing ruminal acidosis on Australian dairy farms, it is important to recognise the diversity of dairy production across Australia's eight dairy regions (Figure 1). These regions vary markedly in climate, natural resources, feedbase, milk-processing capacity and markets. Ongoing intensification, defined as increasing milk output per unit of feed, labour, land or herd size, has driven the continued evolution and diversification of production systems. Within regions, farms vary widely in herd size, infrastructure and feeding practices, yet all systems can remain profitable when well managed.

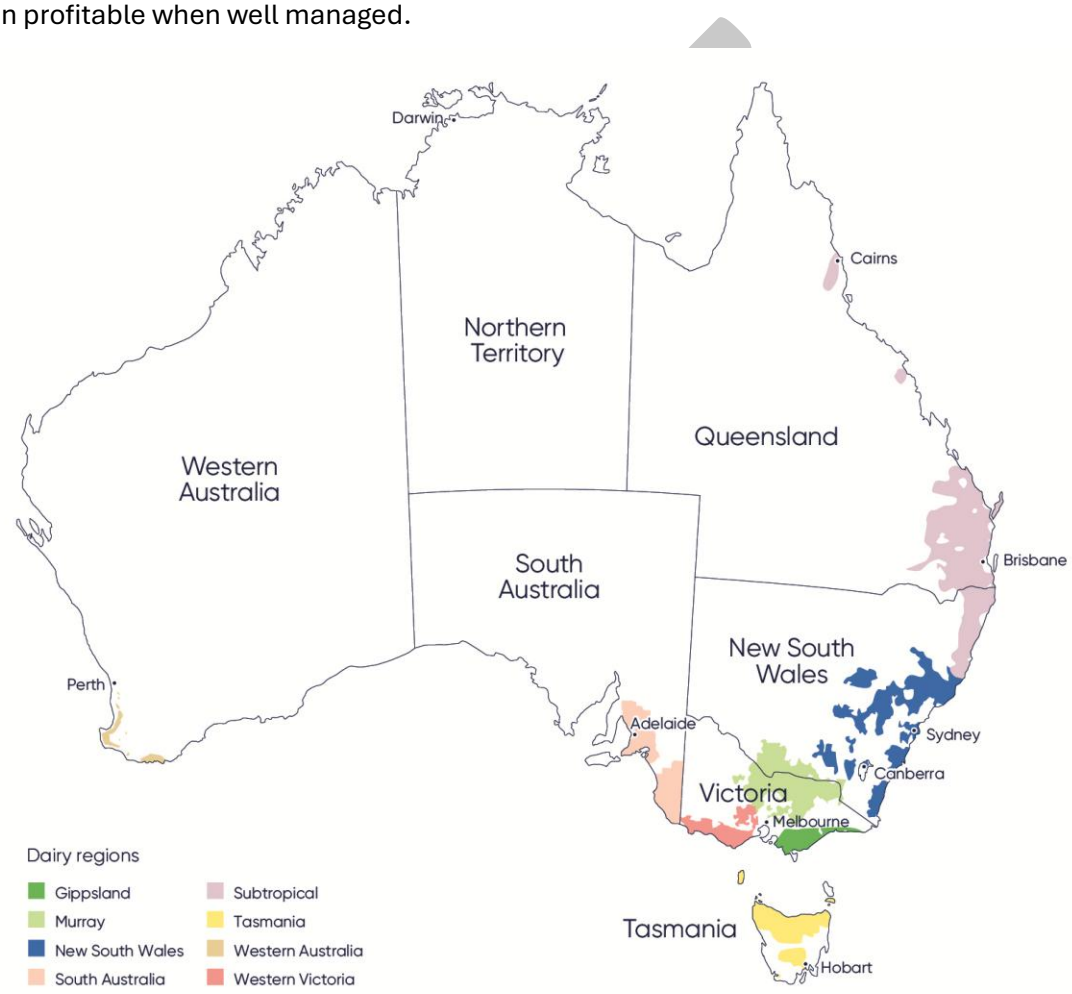


Figure 1 Australia's eight dairy regions. Source: Dairy Australia (2025).

For the purposes of these guidelines, the two main production systems operating in Australia are:

- **Grazing systems** (97.7% of farms and 88.9% of annual milk volume): Cows obtain a substantial proportion of their diet from grazed pasture. Supplementary feeds or a partially mixed ration (PMR) may be provided separately, or a total mixed ration (TMR) may be fed for part of the year (Figure 2 and Figure 4) (Dairy Moving Forward, 2025).

- **Intensive systems** (2.3% of farms and 11.1% of annual milk volume): Cows are zero-grazed and fed conserved forages, concentrates and by-products as a total mixed ration (TMR). They may be housed in freestall, loose-housing or dairy dry-lot facilities, or managed in another TMR-based system (Figure 3 and Figure 4) (Dairy Moving Forward, 2025).

Figure 2 Dairy farm using a grazing system with a roofed concrete feedpad for supplementary feeding of a partially mixed ration (PMR). Source: Dairy Australia (2024).

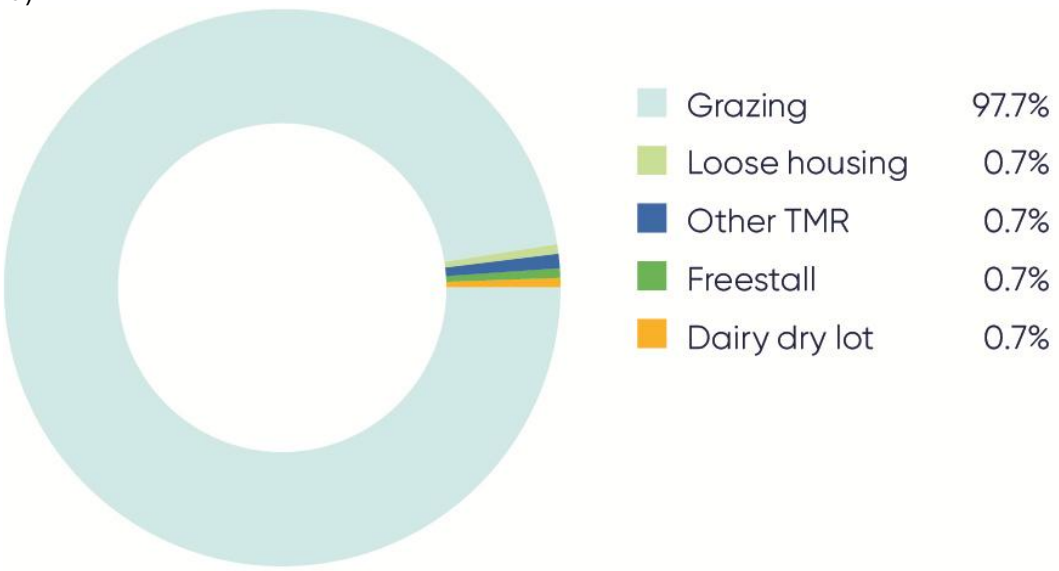
a)

b)

c)

Figure 3 Farms using intensive systems, with: a) a dairy dry lot, b) loose housing, and c) a freestall shed. Source: Dairy Australia (2024).

a)



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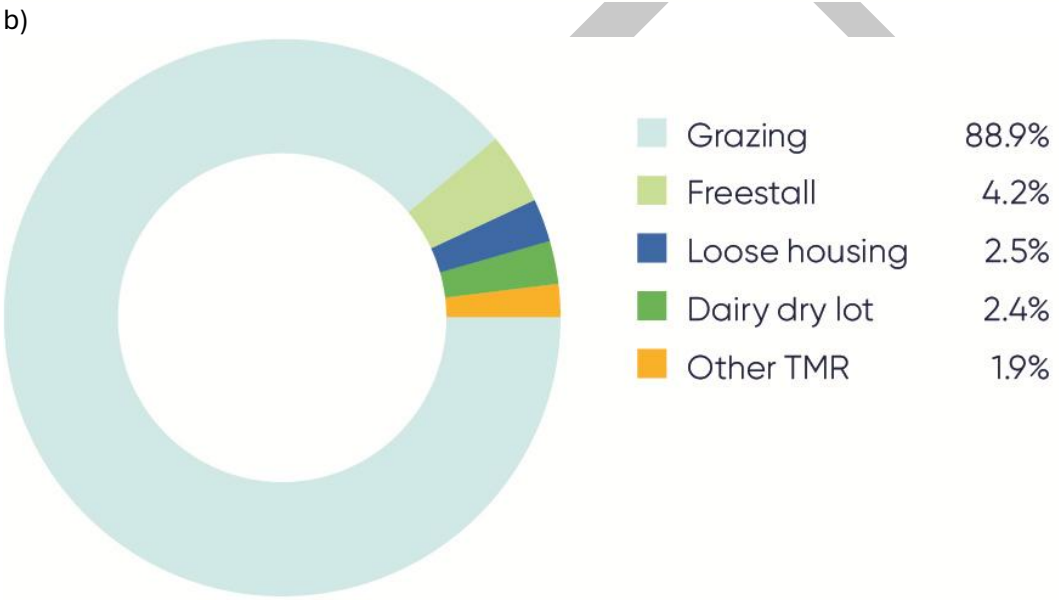

Figure 4 Percentage of a) Australian dairy farm businesses by production system, and b) annual milk volume by production system. Source: Dairy Moving Forward (2025).

On Australian grazing farms, the quality and quantity of fermentable feed consumed are highly variable. The type, quality and quantity of pasture, forage and supplementary feeds consumed by cows over each 24-hour period vary seasonally and, to a lesser extent, from day to day as cows are rotated through day and night paddocks. Supplementary feeds may include concentrates, such as grain, mixes and pellets, as well as hay, silage and by-products.

Consumption of highly digestible forages, such as annual ryegrass pasture, and/or by-products that provide insufficient physically effective fibre can disrupt rumen function. The consumption of substantial quantities of rapidly fermentable concentrates at each milking, such as more than 3 kg DM/cow, is also a major risk factor for the development of ruminal acidosis.

Over the past two decades, Dairy Australia surveys have reported increases in supplementary feeding, stocking rates and per-cow production, as well as changes in seasonal milk supply patterns (Dairy Australia, 2023 & 2025). These changes have likely been driven by increasingly variable environmental and market conditions. Many grazing farms now feed more than 2

tonnes of concentrate per cow annually (Figure 5), with some cows receiving 4-5 kg or more per milking during peak feeding periods.

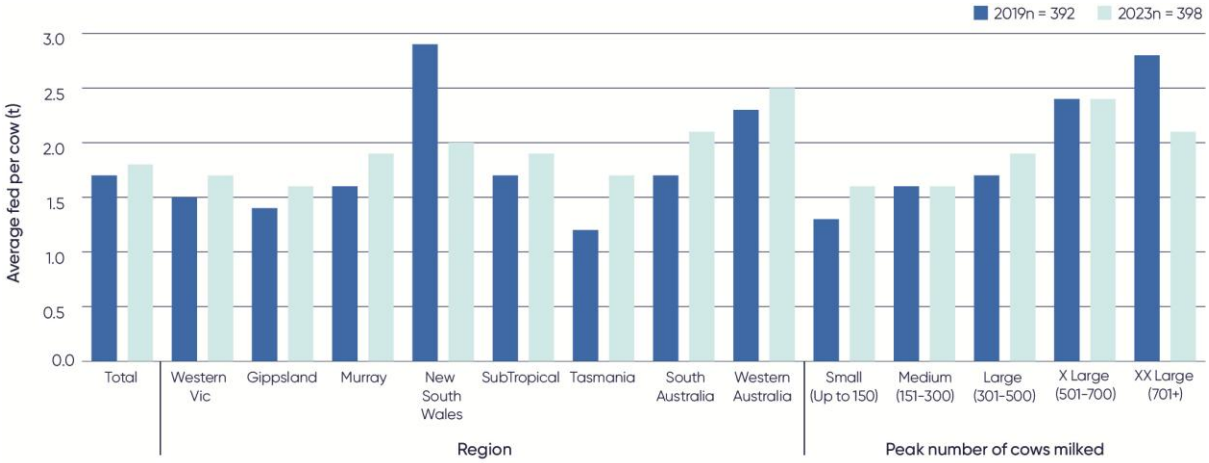

Figure 5 Average tonnes of grain, pellets or concentrates fed per cow per year, by region and herd size, in 2019 (red) and 2023 (green). Source: Dairy Australia (2023).

Increasingly, Australian grazing dairy farms are investing in feeding and housing facilities, such as feedpads and cattle shelters, to provide greater flexibility in feeding and herd management (Dairy Moving Forward, 2025). Although these facilities are generally not intended for full-time feeding or housing, they allow cows to be fed and/or sheltered during seasonal feed gaps, extreme heat, wet weather, drought, floods, bushfires and other emergencies. They may also be used when pasture or fodder is limited or unavailable, or when there is a high risk of pasture damage.

Over the past five years, some Australian dairy farms have transitioned from grazing to contained-housing, zero-grazing systems by investing in feeding and housing infrastructure to maintain performance, profitability and sustainability (Dairy Moving Forward, 2025). Key drivers of this change include drought, limited or costly irrigation water, prolonged wet conditions, extreme weather, high land prices, the need to modernise infrastructure, challenges associated with PMR or hybrid feeding systems, and farm succession. Climate-related factors are expected to have an increasing influence on production-system decisions over the next decade.

On Australian intensive farms, TMR feeding in loose-housing or freestall systems allows cows to consume larger quantities of feed and provides greater ration uniformity, while reducing the energy expended by cows on grazing and thermoregulation. This can support more stable rumen function and higher milk yields. However, poor feed quality, inappropriate ration formulation, feed processing, TMR mixing, facility design and/or inconsistent feed delivery can disrupt rumen function and contribute to ruminal acidosis.

In both grazing and intensive systems, rapid dietary changes and poor transition-cow management increase the risk and severity of ruminal acidosis.

Importance of maintaining optimal rumen health and function

The ruminant digestive system uses the rumen, a pre-gastric fermentation chamber, to break down plant material that is indigestible to monogastric species. Its dense and diverse microbiome produces short-chain fatty acids (SCFA), including the volatile fatty acids (VFA)

acetate, propionate and butyrate, which supply up to 70% of a cow's energy requirements. The SCFA profile is influenced by genetics, age, diet and environment.

Acetate, propionate and butyrate can supply up to 70% of a cow's energy requirements.

The ruminal epithelium absorbs SCFA, helping to maintain osmolarity, acid–base balance and barrier function. Excessive SCFA production can overwhelm this absorptive capacity, predisposing animals to SARA. SARA is characterised by high SCFA concentrations without lactic acid accumulation, together with low ammonia concentrations and a moderately low ruminal pH. Acute ruminal acidosis (ARA) is characterised by severe lactic acid accumulation, which may result in damage to the ruminal epithelium (Figure 6). In lactating dairy cows, ruminal acidosis has both local effects within the rumen and systemic effects on health, milk production, feed intake, feed conversion efficiency and GHG emissions.

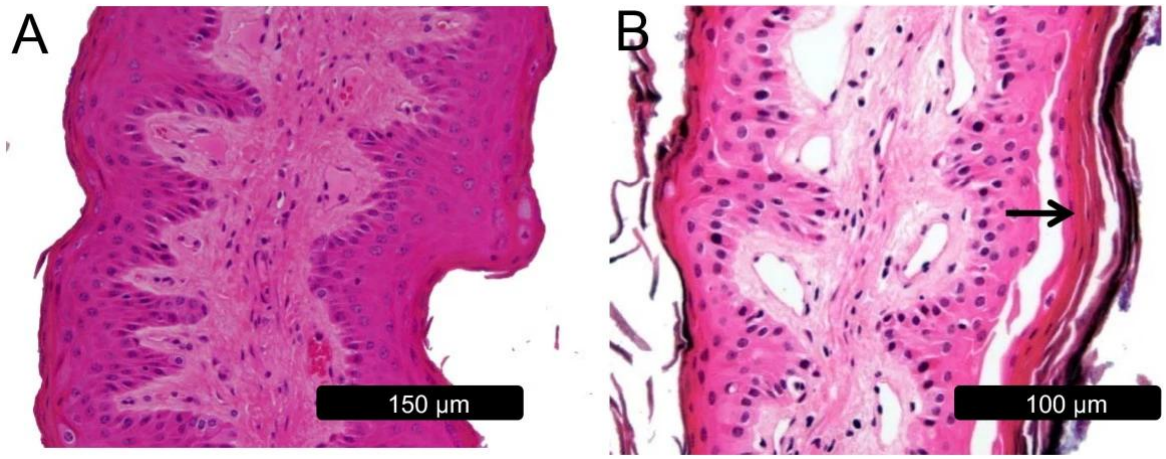

Figure 6 Micrographs of cross-sections of ruminal papillae from: a) a healthy cow, showing an intact stratum corneum and stratum granulosum, and b) a cow with acute ruminal acidosis, showing sloughing of the stratum corneum and demarcation of cells throughout the epithelial layers. Source: Steele et al. (2009).

Strategies for prevention and control of ruminal acidosis

Effective prevention and control of subacute ruminal acidosis (SARA) require a systems-based approach that considers interactions among dietary, animal, environmental and management risk factors. Key nutritional strategies include balancing the amount and fermentability of carbohydrates, providing adequate physically effective fibre (peNDF) to stimulate rumination and saliva production, maintaining consistent feeding practices and introducing dietary changes gradually. Together, these measures help maintain rumen stability and reduce fluctuations in ruminal pH that can predispose cattle to SARA.

Non-antibiotic rumen modifiers, including buffers, alkalinisers, prebiotics, probiotics, postbiotics and phytogenic additives, may further support rumen function and help reduce the risk of SARA. In some situations, combining additive classes may provide complementary modes of action. However, feed additives should be considered supportive tools rather than substitutes for sound nutritional and management practices.

In-feed antimicrobials may have a role in managing the risk of ruminal acidosis. Disease prevention is a core principle of antimicrobial stewardship (AMS) and therefore their use should always follow a thorough review of nutritional and management practices, including the provision of adequate physically effective fibre, gradual adaptation to sugar- or starch-rich feeds, appropriate timing and distribution of concentrate feeding, and the use of rumen buffers or alkalinising agents where appropriate (House et al., 2024). Where in-feed antimicrobials are used, they should be selected, prescribed and administered in accordance with recognised best practice, approved label directions and relevant regulatory requirements (AVA, n.d.). Given the complexity of the Australian feed supply chain, including the manufacture and distribution of stockfeeds and premixes, responsible antimicrobial use requires collaboration among farm managers, veterinarians, nutritionists and feed manufacturers to support compliance, traceability and best-practice management.

How to use these guidelines

Given the impacts of ruminal acidosis on the productivity, health and welfare of cows in Australian dairy herds, there is a need for:

- greater understanding of rumen function and the pathophysiology of ruminal acidosis (Chapter 2: Ruminal function, acidosis and associated disorders)
- greater understanding of the risk factors that predispose dairy cows to ruminal acidosis (Chapter 3: Risk factors for ruminal acidosis)
- effective prevention and control strategies (Chapter 4: Prevention and control of ruminal acidosis)
- improved diagnosis and monitoring (Chapter 5: Diagnosis and monitoring of ruminal acidosis)
- a collaborative, team-based management approach involving farm managers and key staff, nutrition advisers, veterinarians, and stockfeed and premix suppliers (Chapter 6: Supporting better farm management of ruminal acidosis)

The *Australian Guidelines for the Integrated Management of Ruminal Acidosis* address these needs by drawing on national and international expertise and scientific literature. They provide a knowledge base for practical decision-support tools and learning programs for nutrition professionals, veterinarians, farm managers and key farm staff.

Importantly, the information and tools in these guidelines support best-practice nutrition, feeding and animal welfare. Their implementation can enhance on-farm productivity, cow health and reproductive performance well beyond the management of ruminal acidosis. The guidelines also support responsible antimicrobial use by emphasising the prevention and management of underlying dietary, animal, environmental and management risk factors.

The guidelines are intended specifically for nutrition professionals and veterinarians supporting dairy farm businesses across Australia. A moderate to high level of competency in ruminant nutrition and/or health management is assumed.

The guidelines are not intended to be read from cover to cover in one sitting and then filed away on a bookshelf. They are designed to be used regularly to locate specific information and to stimulate thought, discussion and greater teamwork. If they become worn and tattered through regular use, that is a sign they are serving their purpose, and they can be readily replaced.

To help readers locate and interpret specific information quickly, the guidelines include a detailed table of contents, a clear hierarchy of headings and shaded boxes containing

additional technical detail. A complete reference list is provided at the end of each chapter to support further reading.

Conclusion

Ruminal acidosis is an important nutritional challenge for the Australian dairy industry. It is common, costly and often under-recognised, affecting cow health, welfare, productivity, reproductive performance and farm profitability, while also increasing the environmental footprint of milk production. Because ruminal acidosis occurs along a continuum and arises from interactions among animal, dietary, management and environmental factors, its successful prevention and control require a whole-system approach rather than reliance on any single intervention.

Maintaining optimal rumen function should be a core objective on every dairy farm, regardless of production system. Effective management depends on understanding risk factors, implementing sound nutritional and feeding practices, monitoring herd performance, making an accurate diagnosis and fostering collaboration among farm managers, nutrition advisers, veterinarians and feed suppliers. In-feed antimicrobials may have a role in the management of ruminal acidosis in some circumstances and should be used judiciously within a strong antimicrobial stewardship framework.

These guidelines provide a framework for understanding, diagnosing, preventing and managing ruminal acidosis. They enable nutrition professionals and veterinarians to make informed decisions that support herd health and performance while strengthening antimicrobial stewardship.

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Chapter 2: Ruminal function, acidosis and associated disorders

Summary of key points:

- Consumption of relatively large quantities of highly fermentable carbohydrate can result in microbial short-chain fatty acid (SCFA) production exceeding the combined capacity of ruminal buffering mechanisms and the ruminal epithelium to absorb these acids.
- Increased SCFA concentrations and low ruminal pH can disrupt epithelial function and compromise ruminal barrier integrity, allowing lipopolysaccharides (LPS), other toxins and pathogens to enter the bloodstream and directly trigger systemic inflammation.
- Ruminal acidosis occurs along a continuum, with differing microbial, epithelial and systemic responses.
- An extremely high rate of SCFA production and accumulation in the rumen can lead to acute ruminal acidosis (ARA), characterised by increased production and accumulation of lactic acid, systemic acidosis, dehydration and inflammation, and potentially resulting in death.
- In subacute ruminal acidosis (SARA), the ruminal microbial ecosystem and ruminal epithelium are not completely disrupted. However, local and systemic changes occur that may affect the animal in numerous ways.
- Ruminal acidosis can have many potential sequelae in dairy cows, including reduced milk production, altered milk composition, reduced feed intake, liver abscessation, laminitis and reduced fertility.

Advances in understanding of ruminal acidosis

In recent years, increasing evidence has supported the use of a combination of biomarkers and changes in microbial populations to characterise the severity of ruminal acidosis along a continuum.

Rather than viewing individual microbial taxa in isolation, the rumen is now better understood as an integrated host–microbiome system in which microbial populations and activity, and host responses to diet, interact dynamically to maintain or disrupt normal ruminal function. Shifts in microbial populations are therefore not only a consequence of changes in ruminal pH and inherent host–microbiome characteristics but also reflect broader changes in fermentation substrate supply and fermentation patterns. The type, amount and rate of carbohydrate fermentation strongly influence microbial populations and the profile of fermentation end products. Highly fermentable substrates promote rapid microbial growth and acid production, increasing the risk of imbalance when this is not matched by adequate buffering and absorptive capacity.

Although this body of research has significantly improved our understanding of ruminal function and acidosis, translating these complex interactions into clear, practical diagnostic tools and feeding recommendations remains challenging. The consistent and actionable application of these insights on farm is still evolving. Traditional biomarkers, such as ruminal pH, together with indicators of animal production, behaviour and health, and sound nutritional management, therefore, remain central to monitoring and preventing ruminal acidosis.

The balance between ruminal acid production and removal, and the consequent production and removal of hydrogen ions (H^+), provides a useful framework for understanding ruminal stability. The rate of fermentation acid production varies considerably among diets and increases markedly with highly fermentable starch sources, sugars and highly digestible grasses. Hydrogen ions in the rumen may be neutralised by buffers, while acids may be

removed through absorption across the ruminal epithelium or passage from the rumen. The concentration gradient across the ruminal epithelium is likely to be a major factor influencing acid absorption. Ruminal pH is therefore affected by the balance between microbial production of fermentation acids and their absorption, passage, neutralisation and buffering. When this balance is disrupted, acids accumulate, contributing to declining ruminal pH and an increased risk of acidosis.

Ruminants rely on pre-gastric fermentation, during which symbiotic microbes convert plant material primarily into the volatile fatty acids (VFA) acetate, propionate and butyrate, as well as other short-chain fatty acids (SCFA). These microbes also convert non-protein nitrogen (NPN), such as ammonia, and other sources of crude protein into microbial protein. Other fermentation acids, including lactic acid, may also be produced by ruminal microbes, although lactic acid accumulation is generally transient during SARA.

The six most abundant short-chain fatty acids (SCFAs) in the rumen:

- Acetate
- Propionate

} Volatile fatty acids (VFA) = >90% of total SCFA concentration

- Butyrate
- Valerate
- Isobutyrate
- Isovalerate

Adapted from Hackmann (2024).

Anatomy and physiology of the rumen

Consumed feed enters the reticulorumen, comprising the rumen and reticulum, and passes through the omasum before entering the abomasum, where true gastric digestion occurs through the action of hydrochloric acid and pepsin.

The rumen is the primary fermentation chamber and the main site of short-chain fatty acid (SCFA) absorption. It is the largest forestomach compartment, accounting for approximately 85% of forestomach volume and exceeding 100 L in adult dairy cows. The rumen is divided into sacs by muscular pillars, including the dorsal sac, ventral sac, cranial sac and caudal blind sacs, which assist with mixing ruminal contents (Figure 7).

Ruminal papillae are finger-like projections that increase the absorptive surface area of the ruminal epithelium. Their length and density respond to SCFA concentrations, particularly butyrate. Cows consuming high-forage diets generally have shorter papillae, whereas cows consuming highly fermentable carbohydrates develop longer and denser papillae. Accordingly, low intake of fermentable carbohydrate reduces the absorptive surface area of the ruminal papillae (Pederzolli et al., 2018). Reductions in absorptive surface area occur much more rapidly than increases.

Ruminal contents are stratified into a floating fibrous raft containing long particles; a liquid phase in the ventral rumen containing SCFA, microbes and fine particles; and a gaseous phase in the dorsal rumen containing primarily carbon dioxide (CO_2) and methane (CH_4). The dry matter content of ruminal digesta in lactating cows ranges from 8–14% in pasture-fed cows to approximately 12–14% in cows fed a total mixed ration (TMR) (Bargo et al., 2002).

The long fibrous particles in the raft stimulate rumination. Rumination reduces particle size, allowing particles to be digested and pass from the rumen, and promotes the retention of finer particles for slower and more complete ruminal digestion (Zebeli et al., 2006). It also stimulates the secretion of saliva containing bicarbonate and phosphate buffers, which are important for maintaining ruminal pH.

The ruminal epithelium is the multilayered cellular lining of the rumen. Its absorptive function is highly selective, allowing the absorption of SCFA and other nutrients while providing a barrier that limits the passage of microbes and toxins from the rumen into the bloodstream. It is a stratified squamous epithelium comprising several distinct layers: the innermost stratum basale, where active cell division occurs; the stratum spinosum, which provides structural integrity and contains cells undergoing early differentiation; the stratum granulosum, in which cells begin to keratinise; and the outermost stratum corneum, which is keratinised and protects against the ruminal environment. This stratified structure provides mechanical protection while supporting absorptive and metabolic activity.

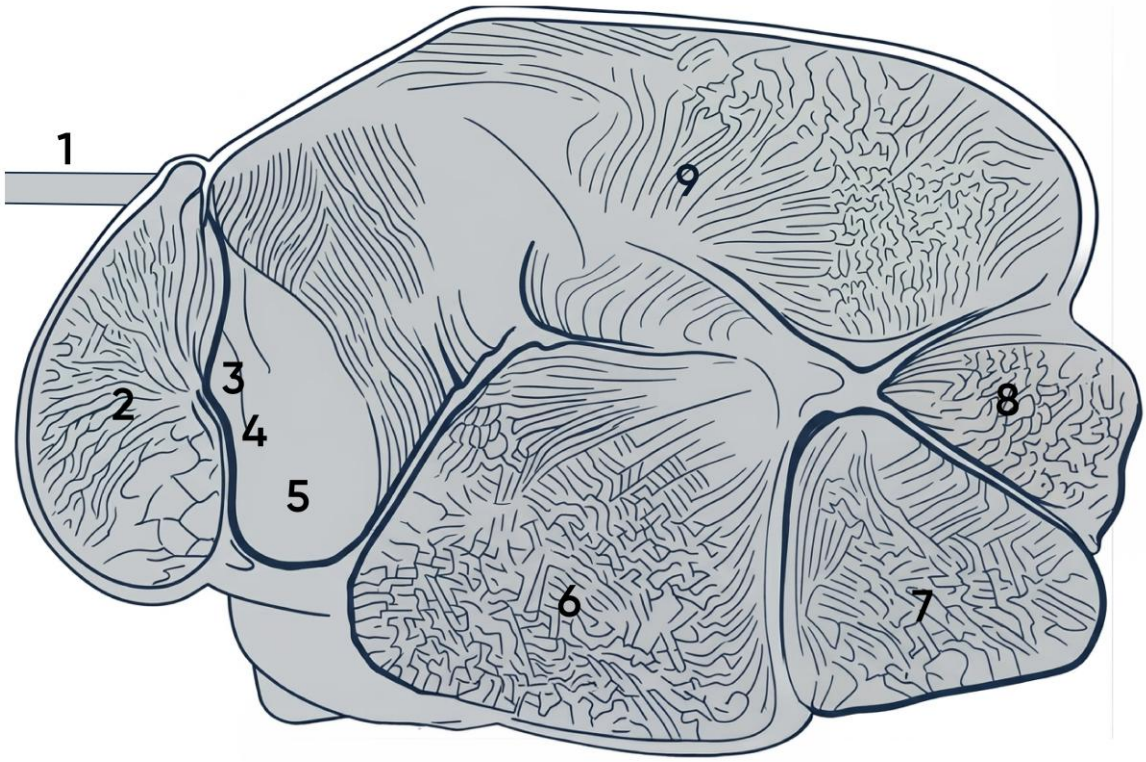

Figure 7 The right half of the rumen viewed from the inside. Key: 1) oesophagus; 2) reticulum; 3) reticulo-omasal opening; 4) rumino-reticular fold; 5) cranial sac; 6) ventral sac; 7) ventral blind sac; 8) dorsal blind sac; and 9) dorsal sac. Source: Adapted from Hungate (1966).

Fermentation acids

Fermentation acids produced by ruminal microbes include SCFA and lactic acid. The principal SCFA are the volatile fatty acids (VFA) acetate, propionate and butyrate. Acetate contains two carbon atoms (C2) and is used in milk fat synthesis and as an energy source for tissues. Propionate contains three carbon atoms (C3) and is converted to glucose in the liver, providing approximately 90% of the total glucose supply. Butyrate contains four carbon atoms (C4) and provides energy for the ruminal epithelium and supports its development. VFA provide approximately 70% of the energy required by cattle (Bergman, 1990).

The rumen is the primary site of VFA absorption. Absorption rates are influenced by carbon chain length, with C4 absorbed more rapidly than C3 and C3 more rapidly than C2, as well as by ruminal motility and mixing and the consistency of the digesta (Allen, 1997).

The total concentration of SCFA in the rumen can range from less than 100 mM in lactating cows consuming less fermentable diets to more than 200 mM in cows consuming diets containing highly fermentable starch or ryegrass. The composition of ruminal SCFA varies with diet. Acetate generally accounts for approximately 50–67%, propionate for 19–37% and butyrate for 9–12% of the total SCFA concentration (Sutton et al., 2003).

Sutton et al. (2003) also reported that net ruminal VFA production rates for acetate, propionate and butyrate in mid-lactation cows increased from 79.8 to 90.0 mol/day when a more fermentable diet was fed. Propionate production increased significantly from 16.8 to 36.2 mol/day, whereas acetate production decreased from 56.5 to 49.0 mol/day and butyrate production decreased from 6.5 to 4.8 mol/day.

Absorption of SCFA

Short-chain fatty acids (SCFA) exist in protonated, or undissociated, and deprotonated, or dissociated, forms. The acid dissociation constant (pKa) is a measure of an acid's tendency to dissociate. When the pH of a solution equals the pKa of an acid, approximately 50% of the acid is protonated and 50% is deprotonated.

Individual SCFA differ in their pKa, rates of absorption and effects on ruminal motility and blood flow to the epithelium. The pKa values of the principal SCFA are approximately 4.8, whereas lactic acid has a lower pKa of approximately 3.8. At a given pH, lactic acid therefore has a greater tendency to dissociate than the principal SCFA. However, its effect on ruminal pH also depends on its concentration and the buffering capacity of the rumen.

Although lactic acid production can contribute to ruminal acidosis in some circumstances, lactic acid rarely accumulates during SARA because it is rapidly metabolised to SCFA. The rate of conversion is likely influenced by substrate characteristics and adaptation of the ruminal microbiome.

Clearance of SCFA from the rumen through absorption across the ruminal wall is an important mechanism for removing hydrogen ions (H^+) from the rumen (Allen, 1997). Absorption of SCFA across the apical membrane of the ruminal epithelium occurs through:

1. passive diffusion of protonated SCFA
2. electroneutral exchange of deprotonated SCFA for bicarbonate
3. facilitated proton-coupled transport through a nitrate-sensitive pathway
4. sodium-coupled transport

(Aschenbach et al., 2011; Figure 8)

Of these pathways, SCFA–bicarbonate exchange is considered the predominant mechanism at normal ruminal pH. However, passive diffusion of protonated SCFA and proton-coupled transport become increasingly important as the concentration of H^+ increases and ruminal pH decreases.

Passive diffusion removes H^+ from the rumen through the absorption of protonated SCFA. The exchange of deprotonated SCFA for bicarbonate supplied to the epithelium from the blood also contributes to H^+ removal. The bicarbonate enters the ruminal contents, where it can neutralise H^+ through the carbonic anhydrase reaction (Aschenbach et al., 2011).

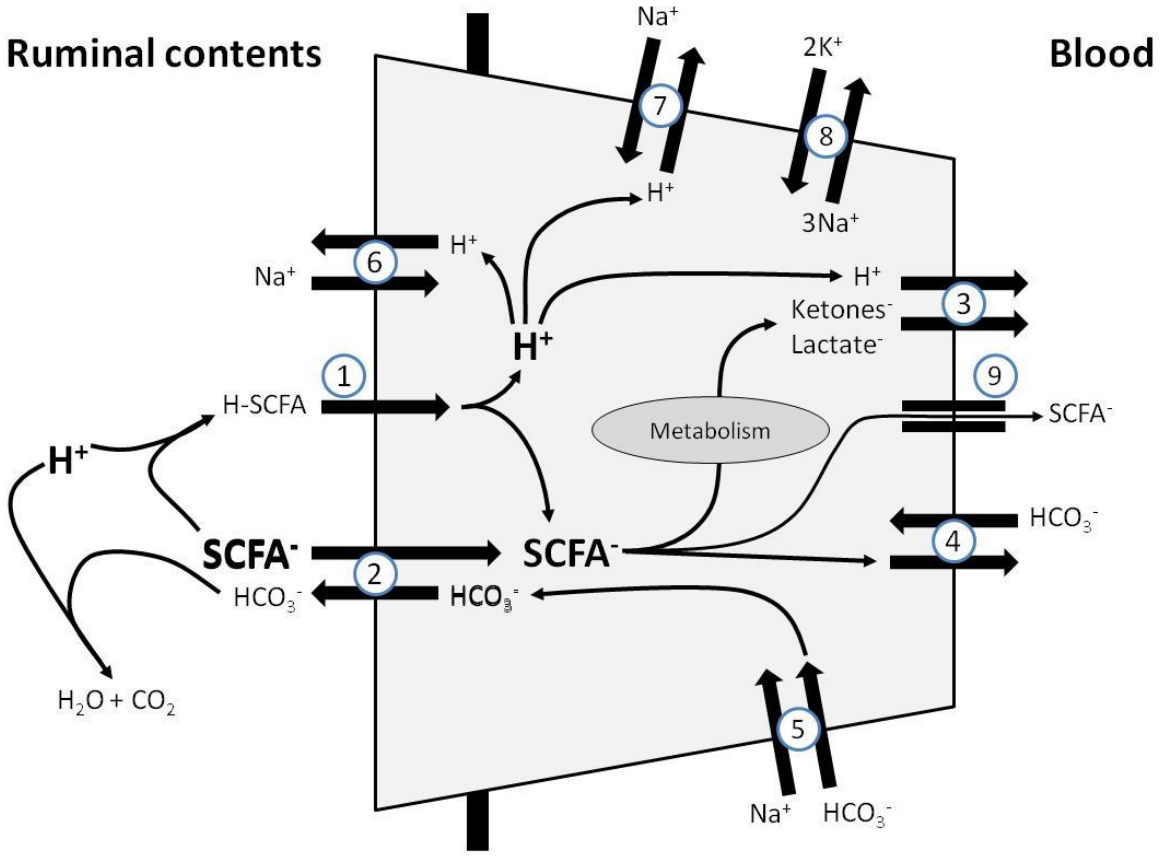

Figure 8 Partial model depicting the current understanding for SCFA absorption in relation to the stabilisation of ruminal pH. Key: 1) Diffusional absorption of SCFA facilitates the removal of a proton associated with the SCFA. This proton will rapidly dissociate in the cytosol where it can be exported by sodium/hydrogen exchanges (6, 7) or coupled with metabolites of SCFA (e.g. ketone bodies and lactate) via the monocarboxylate transporter (3) or a basolateral ion channel (9). Dissociated SCFA can be absorbed in an anion exchange mechanism thereby providing a source of bicarbonate to the ruminal contents (2). This bicarbonate can then neutralise a proton through the carbonic anhydrase reaction. The bicarbonate supply to the epithelia is derived from blood (4, 5). Note, the model does not show the structural complexity of the ruminal epithelia including the number of strata and cells within strata. Source: Adapted from Aschenbach et al. (2011) as reproduced in Penner and Aschenbach (2011).

Dijkstra et al. (1993) examined the effects of pH on the fractional absorption rates of acetic, propionic and butyric acids using evacuated and washed rumens. Absorption rates were similar among the three SCFA at pH 7.2. However, when pH was reduced to 4.5, the absorption rate nearly tripled for butyrate and nearly doubled for propionate, whereas the absorption rate of acetate was unaffected.

Because these SCFA have similar pKa values and therefore similar proportions in the protonated form, differences in their absorption rates were probably caused by differences in the concentration gradients generated by their metabolism within the ruminal epithelium (Dijkstra et al., 1993).

Rates of SCFA absorption decrease during feed restriction in sheep (Doreau et al., 1997) and cattle (Albornoz et al., 2013). This reduction in ruminal absorptive capacity may result from reductions in papilla size and surface area, epithelial blood flow, ruminal motility and the functional capacity of the ruminal epithelium. Maintaining dry matter intake (DMI), rumen fill, a

stable intake of fermentable carbohydrate and sufficient SCFA production help preserve ruminal absorptive capacity and may reduce the risk of acidosis.

Buffering by saliva and digesta

Saliva flow into the rumen of lactating dairy cows can exceed 300 L/day and is strongly influenced by chewing activity (Cassida and Stokes, 1986). Across 19 published values reviewed by Cassida and Stokes (1986), salivary flow was reported to be slightly greater during eating than during resting, at 177 and 151 mL/min, respectively, and approximately 1.8 times greater during rumination than during resting.

Mechanical stimulation of the ruminal wall activates tension and epithelial receptors, thereby stimulating rumination (Baumont et al., 1990; Leek, 2004). Rumination is promoted by increased dietary fibre, larger forage particle size, lower forage quality and high feed intake (Welch and Smith, 1969; Sudweeks et al., 1980; Welch and Hooper, 1988; Beauchemin, 1991). Conversely, rumination is inhibited by low ruminal pH, high ruminal osmolality, high SCFA concentrations and low feed intake (Welch, 1982; Welch and Hooper, 1988; Leek, 2004). High ruminal osmolality, for example 350 mOsm/kg, can completely inhibit rumination (Welch, 1982).

Saliva contains bicarbonate and hydrogen phosphate ions, which remove hydrogen ions from solution through alkalisation and buffering. Bailey and Balch (1961) reported mean bicarbonate and phosphate concentrations of 126 and 26 mEq/L, respectively. Although chewing activity and salivary flow vary with diet, the concentrations of buffers in saliva are relatively constant and are not greatly affected by diet or feed intake (Erdman, 1988).

Hydrogen ions combine with hydrogen phosphate to form dihydrogen phosphate, which passes from the rumen. Hydrogen ions also combine with bicarbonate to form carbonic acid, which decomposes into water (H_2O) and carbon dioxide (CO_2). The removal of CO_2 from the rumen by eructation drives the reaction towards completion, making this buffering process effectively irreversible (Allen, 1997).

Consumed feeds also contribute to the buffering of fermentation acids. The buffering capacity (BC) of a feedstuff is the quantity of acid or base, expressed in milliequivalents, required to change the pH of a feed suspension by one unit. It is measured by acid–base titration over a defined pH range, commonly pH 4–9, under controlled in vitro conditions.

The BC of feedstuffs varies considerably (Jasaitis et al., 1987; Erdman, 1988). Cereal grains generally have a low BC, forages have an intermediate BC, and protein supplements have a high BC. Among forages, legumes and high-protein forages generally have a greater BC than other forage types (Jasaitis et al., 1987).

However, feedstuffs have relatively little buffering effect within the usual ruminal pH range of healthy lactating cows, approximately pH 5.5–6.8. Most buffering by feeds occurs below pH 5 (Wohlt et al., 1987), meaning that their total measured BC is not normally realised in the rumen. Nevertheless, buffering by ruminal digesta, together with SCFA absorption, is important in resisting severe declines in ruminal pH below 5, even though these mechanisms have less influence within the normal ruminal pH range (Allen, 1997).

Coarse forage fibre can influence ruminal pH through several mechanisms. It retains digesta within the rumen, contributing to buffering through cation exchange; increases salivary buffering by stimulating rumination and salivation; and promotes ruminal motility, which may support the concentration gradients that drive SCFA absorption. Selecting an appropriate level of dietary fermentability and maintaining an adequate digesta pool to support buffering, ruminal motility and rumination are therefore important components of SARA prevention.

Rumen motility

The muscular activity of the reticulorumen comprises primary (mixing cycle) and secondary (eructative) contractions (Ruckebusch, 1988). Ruminal motility propels digesta from the reticulum over the reticulorumen fold into the rumen, mixes digesta, allows eructation of gases, and aids bolus formation during rumination. Mixing enhances the inoculation of recently consumed feed with microbes, replenishes the supply of SCFA at the rumen epithelium, and incorporates saliva into the ruminal digesta. It also enables gas eructation, moves particles from the inescapable to the escapable pool, and helps propel fluid, soluble compounds, microbial cells, and undigested feed residues into the omasum (Figure 9).

Ruminal motility increases with greater ruminal fill (Dado and Allen, 1995) and decreases with reduced ruminal pH (Shinozaki, 1959; Plaizier et al., 2008), increased concentrations of fermentation acids, especially butyrate (Ash, 1959), increased osmolality (Phillipson and Ash, 1965), and stimulation of cholecystokinin by unsaturated fatty acids (Nicholson and Omar, 1983). Decreased motility can reduce SCFA absorption through reduced mixing of digesta (Voelker and Allen, 2003). It is likely that increased rumen fluid osmolality, together with decreased absorption and outflow of water from the rumen, increases rumen water volume and decreases water intake, leading to systemic dehydration.

Gases produced during ruminal fermentation include CO_2 and CH_4. In lactating cows, production rates have been reported to range from 210 to 309 L/h for CO_2 and from 18 to 30 L/h for CH_4 (Kinsman et al., 1995). Nitrogen, derived primarily from swallowed air, and trace amounts of O_2 and H_2 are also present in the rumen. Eructation allows CO_2 to escape, which drives the alkalising effect of bicarbonate, makes the reaction irreversible, and traps the hydrogen ion in H_2O (Allen, 1997):

$$H^+ + HCO_3^- \leftrightarrow H_2CO_3 \leftrightarrow H_2O + CO_2 \leftrightarrow CO_2 \text{ (gas)}$$

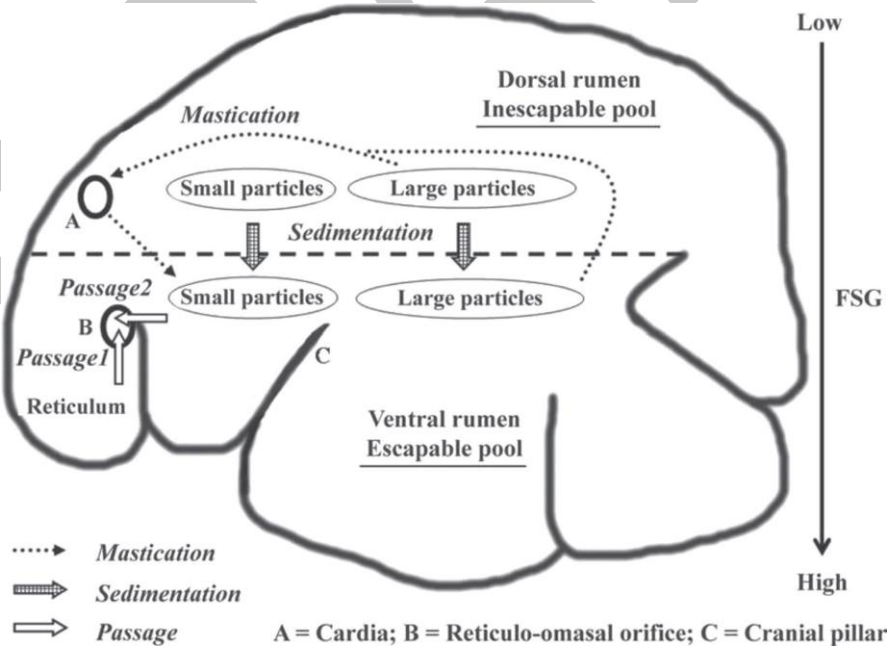

Figure 9 Conceptual diagram of feed particles in the rumen. Long, buoyant, newly ingested particles form a raft in the dorsal sac, which constitutes the inescapable pool. As particles are digested and ruminated, particle size decreases and particles become less buoyant, allowing them to sink ventrally into the escapable pool. Muscular contractions of the rumen move the sedimented digesta towards the reticulum and eventually through the omasal orifice. FSG = functional specific gravity. Source: Adapted from Seo et al. (2009), as reproduced in Beauchemin (2018).

Rumen fluid

The volume of ruminal liquid is determined by water entry into the rumen through drinking, feed consumption, and saliva, as well as water flux across the rumen wall and out through the omasal orifice. The total volume of water dilutes the concentration of hydrogen ions but has little effect on ruminal pH. A rapid increase or decrease in ruminal volume of 20% changes ruminal pH by less than 0.1 unit at pH 6.0 (Allen, 1997). However, greater water flux through the omasal orifice affects ruminal pH. Water passage through the omasal orifice removes an estimated 16% of hydrogen ions produced, primarily as dihydrogen phosphate and ammonium ions and in association with SCFA (Allen, 1997).

Saliva is the primary source of water flow into the rumen and, as previously mentioned, can exceed 300 L/d in dairy cows (Cassida and Stokes, 1986). Water intake in early-lactation cows can range from 90 to 150 L/d and depends on DMI, total dietary dry matter, crude protein, sodium and potassium concentrations, milk production, and environmental temperature (Appuhamy et al., 2016). Water influx from drinking and saliva may have a diminished effect on ruminal liquid volume because of incomplete mixing within the rumen (Woodford et al., 1984), as entry from the oesophagus is near the exit through the reticulo-omasal orifice. Water influx from the diet is much lower than that from saliva and drinking, ranging from 2 to 47 L/d in cows consuming 20 kg of DM/d when dietary moisture content ranges from 10 to 70%.

Water is transported across the rumen wall according to osmotic pressure. When the tonicity of rumen fluid, or its osmolality relative to blood, is lower than that of blood, water is absorbed from the rumen into the blood. However, when rumen fluid is hypertonic, such as after consumption of a highly fermentable diet, water enters the rumen from the blood (Engelhardt, 1970).

Rumen microbes

The rumen is now better understood as a complex and integrated host–microbiome system. Microbial populations and activity, and host responses to diet, interact dynamically to maintain or disrupt normal rumen function. Shifts in microbial populations are therefore not only a consequence of changes in pH and inherent host–microbiome characteristics but also reflect broader changes in fermentation substrate supply and fermentation patterns. The type, amount, and rate of carbohydrate fermentation strongly influence microbial populations and the profile of fermentation end-products. Highly fermentable substrates promote rapid microbial growth and acid production, increasing the risk of imbalance when this is not matched by adequate buffering and absorption capacity.

The rumen microbial population is a complex ecosystem whose outputs, including SCFA and microbial protein, determine animal performance. The total density of ruminal microbes is approximately 10^{10} microbes per mL of rumen fluid (Hungate, 1966), with a biomass of approximately 2 kg in an adult dairy cow. The rumen has a highly reduced environment, with almost no oxygen, and is dominated by obligate anaerobes. Bacteria have a rapid turnover, with generation times ranging from minutes to hours (Hungate, 1966). Microbial groups include bacteria, which are dominant and account for approximately 95% of cells; protozoa, which account for approximately 1 to 5% of cells; archaea, including methanogens; anaerobic fungi (Russell and Hespell, 1981); and viruses.

Bacteria are generally classified according to substrate use. They include fibre degraders (fibrolytic bacteria), which produce mainly acetate and some H_2 and are highly sensitive to pH, such as *Ruminococcus albus*, *Ruminococcus flavefaciens*, and *Fibrobacter succinogenes*; starch degraders (amylolytic bacteria), which produce propionate and lactate and can multiply rapidly in the presence of highly fermentable starch, such as *Streptococcus bovis*, *Ruminobacter amylophilus*, and *Selenomonas ruminantium*; sugar degraders (saccharolytic

bacteria), which produce butyrate and mixed SCFA, such as *Butyrivibrio fibrisolvens*; protein degraders (proteolytic bacteria), which deaminate amino acids to NH_3, such as *Prevotella* spp.; lactate utilisers, such as *Megasphaera elsdenii*; and biohydrogenating species, such as *Butyrivibrio* spp., which hydrogenate unsaturated FA (Russell and Hespell, 1981).

Protozoa are large and slow-growing but account for up to 50% of microbial biomass and are metabolically important (Newbold et al., 2015). The two main groups are ciliates: entodiniomorphs and holotrichs (Hungate, 1966). Protozoa may:

1. digest fibre and starch;
2. prey on bacteria, reducing microbial protein flow from the rumen;
3. engulf starch granules, thereby stabilising fermentation; and
4. have a symbiotic relationship with methanogens.

They produce acetate, butyrate, lactate, and H_2 (Russell and Hespell, 1981). Defaunation, or elimination of protozoa from the rumen, increases microbial protein supply, often reduces methane production by reducing H_2 supply, and may increase the risk of acidosis (Newbold et al., 2015).

Anaerobic fungi account for less than 1% of rumen microbes and include *Neocallimastix* and *Piromyces*. They have an important role, particularly in the digestion of low-quality forages, by physically penetrating plant cell walls and opening the fibre structure to fibrolytic microbes (Van Soest, 1994).

Some rumen archaea, including members of the Methanobacteriales, are anaerobic methane-producing microbes that convert H_2 and CO_2 into methane (CH_4) through different metabolic pathways (Khairunisa et al., 2023). Methanogens are found in the liquid phase, attached to feed particles, attached to or within protozoa, and on the rumen epithelium. They facilitate digestion by consuming H_2 produced by bacteria and protozoa, thereby preventing inhibition of some metabolic pathways. Although important for fermentation, they contribute to dietary energy loss through methane production, and methane is also a greenhouse gas.

Diets containing highly fermentable starch result in greater propionate and lower acetate production, whereas diets containing sugars result in greater butyrate production. As ruminal pH decreases with increasing diet fermentability, the fibrolytic bacterial population declines, reducing the rate and extent of fibre digestion and decreasing acetate production (Russell and Wilson, 1996). With greater amounts of fermentable starch, propionate and lactate production by amylolytic bacteria increases. Lactate concentrations are generally lower than SCFA concentrations (Figure 10) because lactate is rapidly metabolised by lactate utilisers (Gill et al., 1986). However, when ruminal pH remains below 5, the population of lactate utilisers decreases, allowing lactate concentrations to increase (Russell and Allen, 1984).

A decrease in the protozoal population reduces starch sequestration, H_2 production, and methanogenesis, shifting SCFA production towards propionate. Altered microbial biohydrogenation results in the accumulation of trans fatty acids, such as trans-10, cis-12 CLA, which reduce milk fat production. As ruminal pH decreases, ruminal propionate concentration typically increases, whereas acetate and butyrate concentrations decrease, without a corresponding increase in lactate concentration (Figure 11).

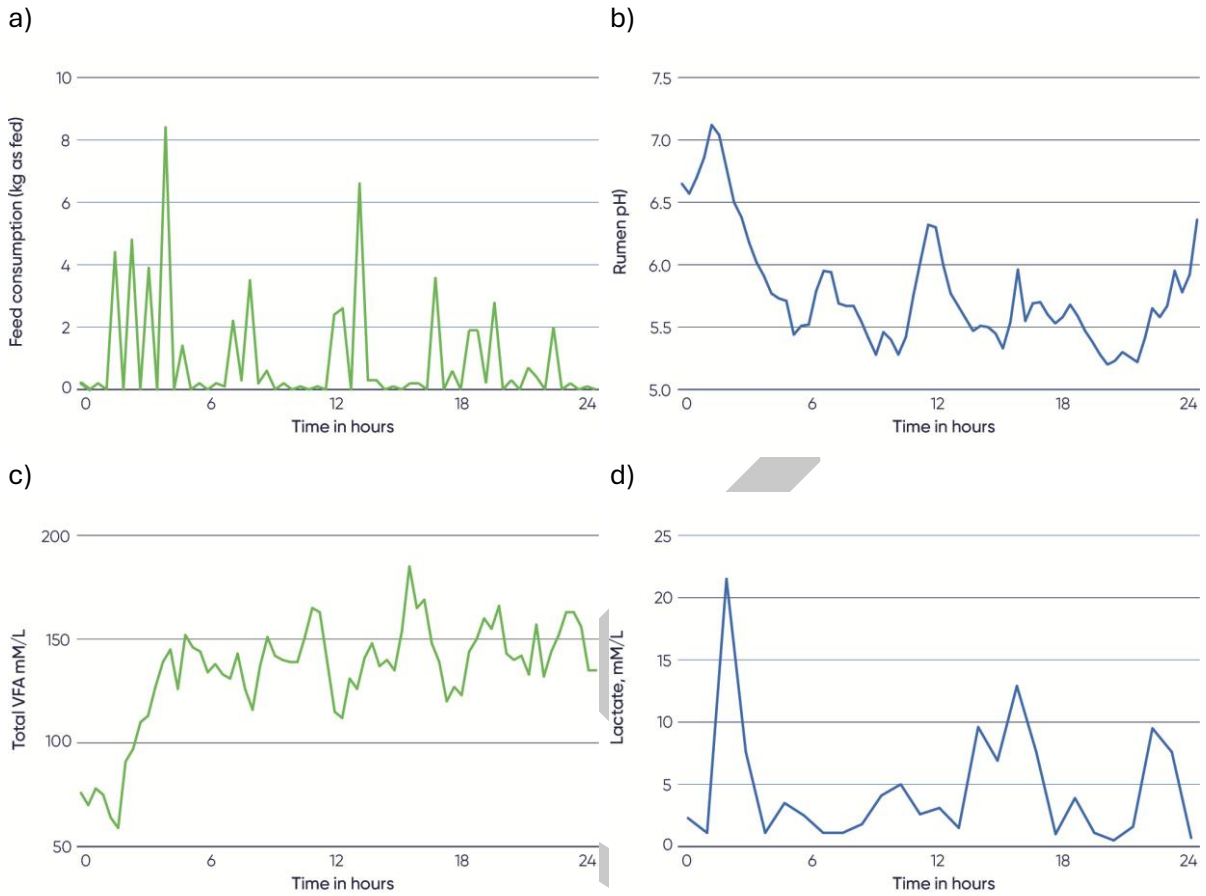

Figure 10 Transient increases in lactate following feeding and consumption of multiple meals of a TMR throughout the day. Lactate is rapidly metabolised by lactate utilisers at approximately pH 5.2 and above. Feed consumption (panel A), ruminal pH (panel B), total ruminal VFA concentration (panel C), and ruminal lactate concentration (panel D) were measured every 20 min for 24 h. Data are from a single cow and are representative of the eight cow-periods for cows consuming a highly fermentable TMR containing 32% starch and 23% NDF, with high-moisture corn, corn silage, and alfalfa silage. Source: Oba and Allen (unpublished data, 2003).

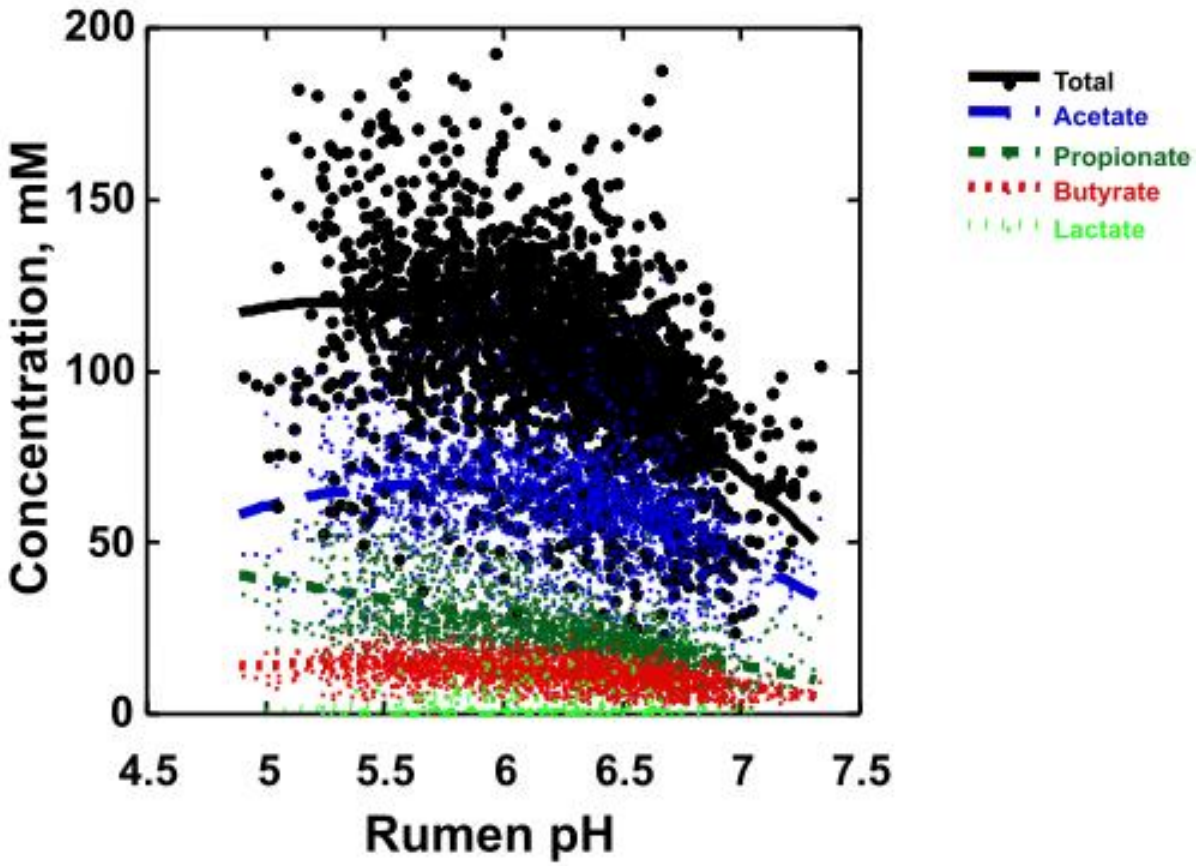

Figure 11 Relationship between ruminal pH and concentrations of total SCFA (black), acetate (blue), propionate (dark green), butyrate (red), and lactate (light green). Samples were collected every 20min for 24h from eight lactating cows consuming four diets that varied in starch concentration and fermentability (32 cow-periods, 72 samples per day, n = 2 304 samples). Source: Oba and Allen (unpublished data, 2003).

Microbial protein comprises 50 to 70% of metabolisable protein supply, and microbial protein yield depends on the rates of synthesis, cell death through protozoal predation and autolysis, and ruminal outflow. Microbial protein synthesis depends on the supply of fermentable organic matter and ammonia, as well as peptides and amino acids for some species, and possibly on the synchrony of these supplies. As much as 50% of the microbial mass in the rumen turns over before nitrogen passes from the rumen (Wells and Russell, 1996). Increased ruminal outflow of microbes increases microbial protein yield by reducing the time available for protozoal predation and autolysis.

Carbohydrate fermentation

Ruminal fermentability varies greatly among feeds. In general, sugars and starch ferment faster than fibre, but there is also considerable variation within feed types. Free sugar sources, such as molasses and whey, generally ferment very quickly, whereas limited microbial access to sugars within plant tissues slows their fermentation. Starch sources vary greatly in fermentability depending on the type of cereal grain, endosperm hardness, as determined by the protein–starch matrix, and processing methods, including grinding, steam flaking, and high-moisture fermentation and storage. Wheat generally ferments faster than barley, which ferments faster than corn. Maize and sorghum generally provide more slowly degradable starch, shifting a portion of digestion postruminally and reducing acid accumulation within the rumen (Owens et al., 1998; Oba and Allen, 2003). Insoluble zein protein in the vitreous

endosperm of corn is digested slowly, limiting microbial access to starch granules, whereas endosperm protein in floury corn is soluble, allowing faster access. Vitreousness is influenced by genetics and increases with harvest maturity. Wheat and barley, which are commonly used in Australian dairy systems, ferment rapidly in the rumen and therefore carry a greater risk of acidosis when fed in large, discrete meals. Soft wheat with a floury endosperm has a lower protein content, contains puroindolins A and B, and is fermented faster than hard wheat with a vitreous endosperm and a deletion of puroindolin A, puroindolin B, or both (Swan et al., 2006).

Grain processing, including grinding, rolling, steam flaking, and high-moisture storage, increases starch accessibility and fermentability (Huntington, 1997; Table 1). Although improved digestibility may enhance production efficiency, excessive ruminal starch digestion without adequate fibre increases susceptibility to SARA. Grinding increases the surface area available to microbes, moisture and heat gelatinise starch and disrupt the protein matrix, and high-moisture fermentation solubilises endosperm proteins. Particle size uniformity and starch availability may differ substantially among commonly used grain-processing methods. For example, particle size uniformity is greatest with disc mills, followed by roller mills, and lowest with hammer mills (Lyu et al., 2020). Optimal processing depends on the feeding system and therefore requires a balance between starch utilisation and rumen stability, rather than simply maximising degradability. Ruminal digestibility is a function of the rates of digestion and passage from the rumen. Factors affecting passage rate include conservation method, particle size, DM intake, ruminal digesta consistency, and ruminal motility.

Acid production from fermentation in the rumen is a function not only of ruminal fermentability, but also of feeding frequency and the degree to which highly fermentable carbohydrates and peNDF sources are integrated throughout the day. In general, the daily pattern of starch intake in a TMR system supports greater ruminal stability over a 24-h period than that in a grazing system (Figure 12). TMR systems therefore provide greater scope for grain processing to safely increase ruminal starch availability, provided the starch and peNDF specifications of the ration remain within acceptable ranges. In a contained-housing system, feeding a TMR twice daily rather than eight times daily results in a lower pH nadir (Figure 13). In a grazing system, incorporating a proportion of the daily grain allocation into a PMR, rather than feeding it all at milking, reduces the risk of ruminal acidosis (Figure 14).

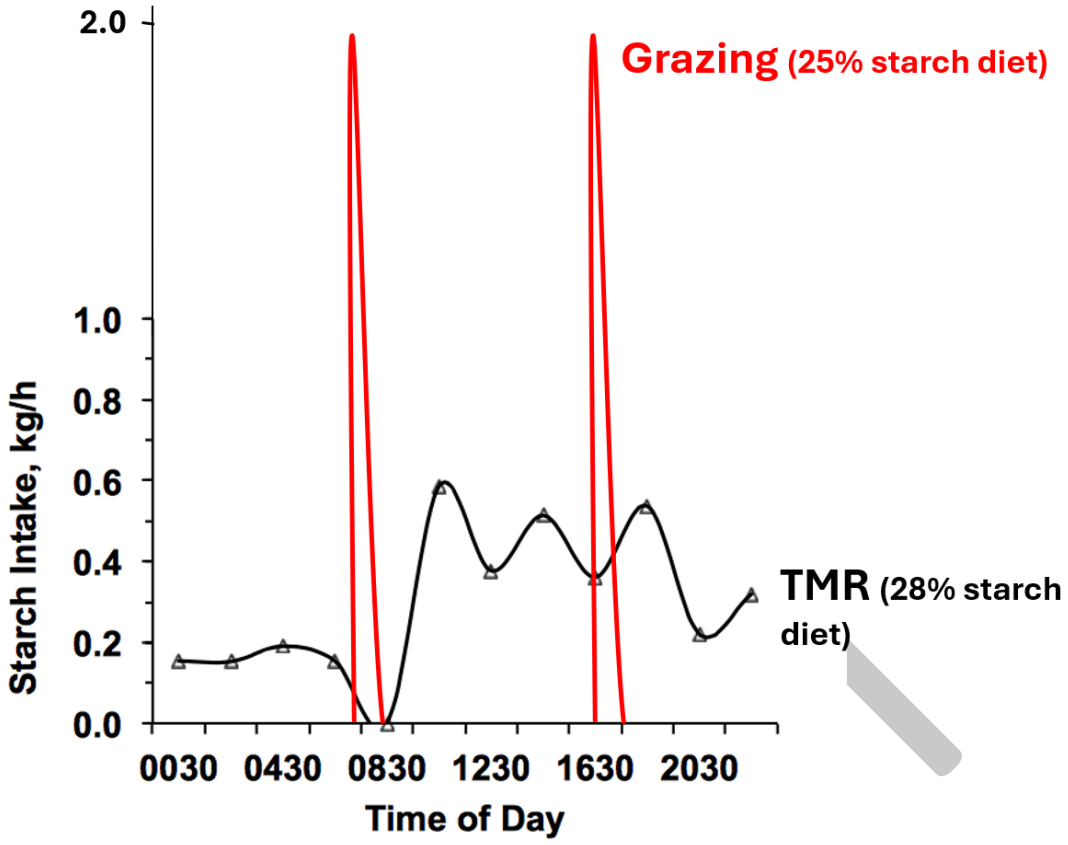

Figure 12 Starch intake from cows at grazing receiving moderate-high amount of cereal grain twice a day at each milking or cows on TMR ration. Source: Adapted from Ying et al. (2015).

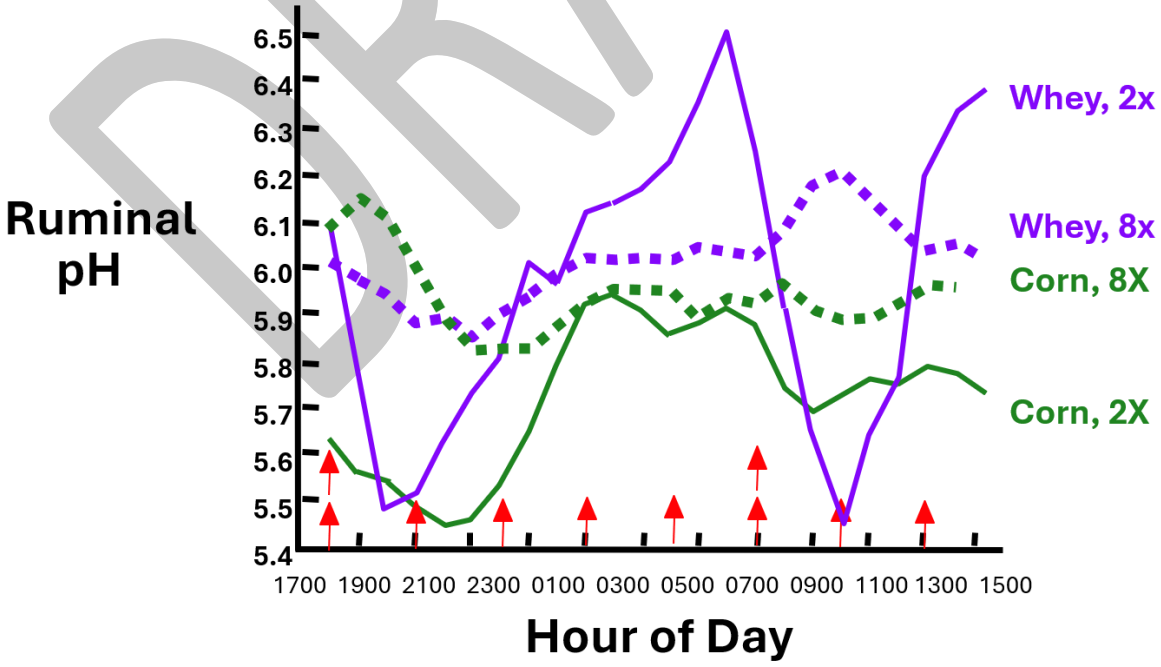

Figure 13 Effect of feeding frequency and rate of fermentation on ruminal pH over a day. Dry ground corn or dried whole whey were fed twice or eight times per day and pH of rumen fluid was measured hourly. Source: Bragg et al. (1986).

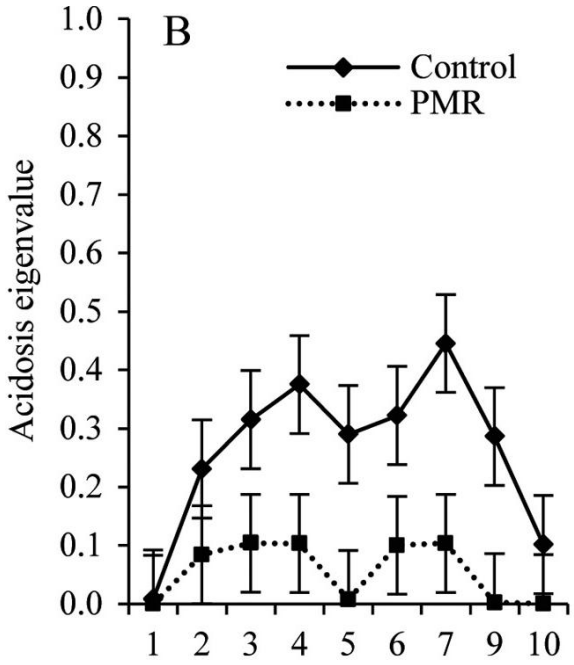

Figure 14 Effect of incorporating a portion of the daily grain allocation in a PMR in a grazing system compared with in-bail feeding twice a day. Mean (±SEM) acidosis eigenvalues, a ruminal acidosis risk value based on ruminal fermentation biomarkers (Bramley et al., 2008), at different rumen fluid sampling times over a 24h period for grazing dairy cows fed crushed wheat in the dairy twice daily at milking (Control) or fed part of their daily allocation of crushed wheat in the dairy (45%) at milking and the remainder fed in a PMR (55%) after each milking. Source: Adapted from Golder et al. (2014).

Table 2 *In vivo* ruminal starch and protein degradation (% of intake) of differently processed barley compared with wheat, corn and sorghum. Source: Adapted from Nikkhah (2012).

Processed grain	Rumen degradation (%)	Post-rumen digestion (%)	Total tract digestion (%)
Steam-rolled barley	84.6	13.6	98.2
Dry-rolled barley	80.7	13.7	94.3
Ground barley	88.0	10.5	98.5
Steam-rolled wheat	88.1	10.0	98.6
Dry-rolled wheat	88.3	9.9	98.2
Ground wheat	90.0	8.9	99.9
Steam-flaked corn	84.8	14.1	98.9
Dry-rolled corn[1]	76.2 (35)	16.2	92.4
Ground corn	49.5	44.0	93.5
Steam-flaked sorghum	78.4	19.6	98.0
Dry-rolled sorghum	59.8	26.1	87.2
Ground sorghum	70	15.4	91.0

[1]The value within parenthesis shows dramatic variation.

Insoluble fibre is measured as neutral detergent fibre (NDF) and comprises cellulose, hemicellulose, and lignin. Lignification of NDF is negatively associated with digestibility (Van Soest, 1994). The undigestible NDF (uNDF) fraction is positively associated with lignin content, while potentially digestible NDF (pdNDF) comprises the remaining fraction (NDF – uNDF). Oba and Allen (2003b) reported a positive linear relationship between mean ruminal pH and the degradation rate of pdNDF. In lactating cows, the degradation rate increased from approximately 1%/h at pH 5.7 to approximately 4%/h at pH 6.5. The rate of fibre digestion decreases through the combined or independent effects of low ruminal pH and starch fermentation (Grant and Mertens, 1992). Perennial C3 grasses generally have a greater NDF content than legumes, as well as lower concentrations of lignin and uNDF (NASEM, 2021). The fermentation rate of pdNDF is generally slower for grasses than for legumes (Smith et al., 1972), but ruminal digestibility is usually greater because grasses have a higher pdNDF content and longer retention time in the rumen (Voelker Linton and Allen, 2008; Kammes and Allen, 2012).

Feeding behaviour

Optimal ruminal pH depends on within-day variation determined by diet composition, production level, and feeding system. Ruminal pH measured at a single time point or averaged across the day has little biological significance without consideration of its within-day pattern. Even minimum ruminal pH has limited meaning if the duration at that pH is very short. Both the time spent at low pH and the extent of pH depression should therefore be considered (Mackie and Gilchrist, 1979).

SCFA concentrations increase during and after meals as fermentation of newly consumed feed adds to that of existing digesta, resulting in a decrease in ruminal pH. Rumination bouts occur between meals, stimulating the flow of salivary buffers into the rumen and increasing pH (Allen, 1997; Figure 15). The extent of the decrease in ruminal pH following meals depends on meal size and fermentability, while rumination activity depends largely on the effective fibre content of the diet, but may also be affected by other factors, such as osmolality.

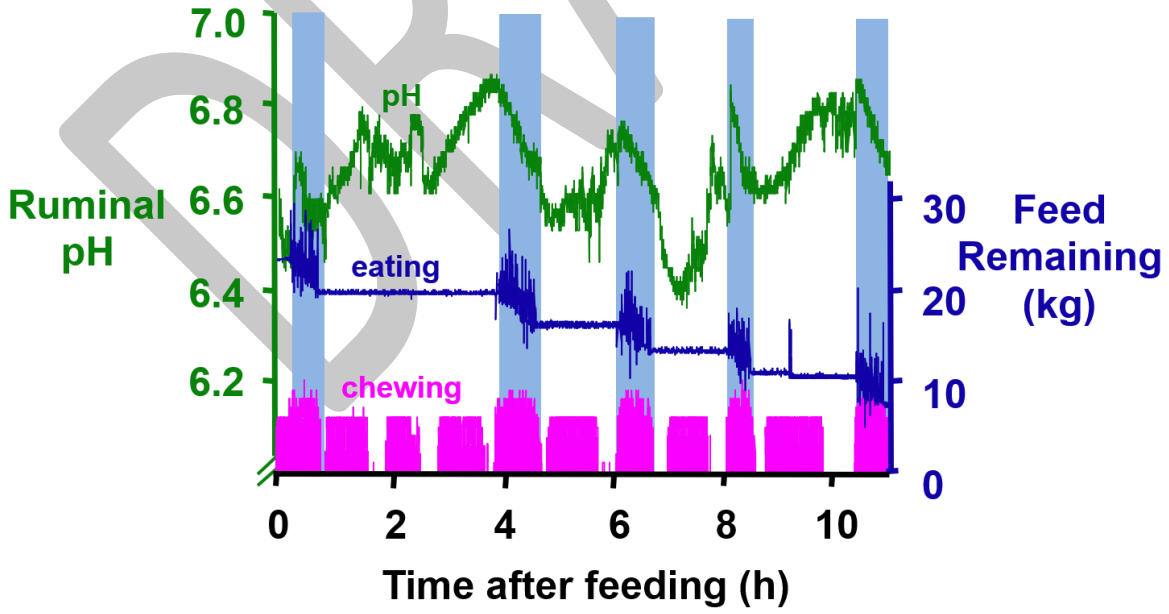

Figure 15 Relationship among ruminal pH, meals, and chewing activity in one cow fed a diet containing 35% NDF twice daily. Ruminal pH is represented by the top line. The weight of feed remaining, measured using a manger suspended from a load cell, is represented by the middle line. Meals are shown as vertical bars. Increases in feed remaining recorded during eating bouts were caused by downward pressure applied by the cow to the manger. Chewing activity is

represented by the bottom line. Because of the large number of observations, chewing activity appears as blocks of eating and rumination. Ruminal pH decreased rapidly following meals and increased rapidly during rumination.
Source: Adapted from Figure 2 in *Relationship Between Fermentation Acid Production in the Rumen and the Requirement for Physically Effective Fiber*, by M. S. Allen, 1997, Journal of Dairy Science, 80(7), pp. 1447–1462. Reproduced with permission.

Highly fermentable diets enhance propionate production, which affects feeding behaviour and dry matter intake (DMI) by stimulating hepatic oxidation and generating a satiety signal to the brain (Allen et al., 2009). The effects of propionate on meal size and the interval between meals depend on its rate of production in the rumen, its utilisation by the liver, and the availability of acetyl-CoA for oxidation (Allen, 2020). This mechanism likely contributes to the reduction in DMI associated with ruminal acidosis.

Pathophysiology of ruminal acidosis

The complex ruminal microbial ecosystem and host epithelium generally operate in a state of relative homeostasis. Under optimal conditions, microbial metabolism produces SCFA at a rate balanced by buffer intake and secretion and SCFA absorption across the ruminal epithelium. This relative homeostasis can be disrupted by disturbances on either side of the production–absorption equilibrium.

Excessive SCFA production

Consumption of relatively large quantities of highly fermentable carbohydrate can result in microbial SCFA production that exceeds the primary H^+ removal mechanisms, namely the net capacity of the rumen to buffer and absorb these acids. A common strategy for inducing acidosis in research studies has been to rapidly increase the supply of fermentable starch without allowing time for adaptation. For example, increasing dietary starch from 26 to 33% of dry matter using wheat and barley pellets more than doubled the time per day that ruminal pH remained below 5.6 and led to transient declines in DMI and milk yield (Khafipour et al., 2009a). In a study of nonlactating heifers, supplying approximately 1.5 kg of fructose to heifers weighing 359 kg resulted in a marked increase in ruminal lactate concentration and a decrease in ruminal pH compared with supplying the same quantity of crushed triticale grain (Golder et al., 2012). The acceleration of SCFA production in response to loads of fermentable carbohydrate is likely driven by both increased microbial metabolism and shifts in the microbial ecosystem towards species that rapidly metabolise readily available carbohydrate sources rather than fibre (Khafipour et al., 2009b).

Disruption of absorption or buffering

The rate of SCFA absorption across the ruminal epithelium is likely to be a critical determinant of acidosis risk. Indeed, the capacity for ruminal epithelial uptake of SCFA predicted the ability of sheep to resist ruminal pH depression when challenged with oral glucose (Penner et al., 2009). Beyond inherent differences among animals, gradual adaptation to grain, rather than sudden increases in grain feeding, clearly enhances the capacity of the rumen to absorb SCFA, helping to limit the decline in ruminal pH when cattle are given time to adapt to a more fermentable diet (Humer et al., 2018).

Ruminal adaptation of transition cow

Gradual increases in dietary fermentable carbohydrate over 2 to 4 weeks enable microbial and epithelial adaptation, reducing rapid SCFA accumulation and epithelial damage (Penner et al., 2007; Figure 16). Cows in the fresh period experience a large increase in metabolic demand and variable feed intake, making them particularly susceptible to SARA. A sound

transition cow management program supports cows through this period by minimising health disorders and the hypophagic effects of hepatic oxidation after calving, thereby promoting greater dry matter intake and improved energy balance. Key information and practical steps for implementing an effective transition cow management program are provided in Dairy Australia's transition cow management resource (Lean and DeGaris, 2021).

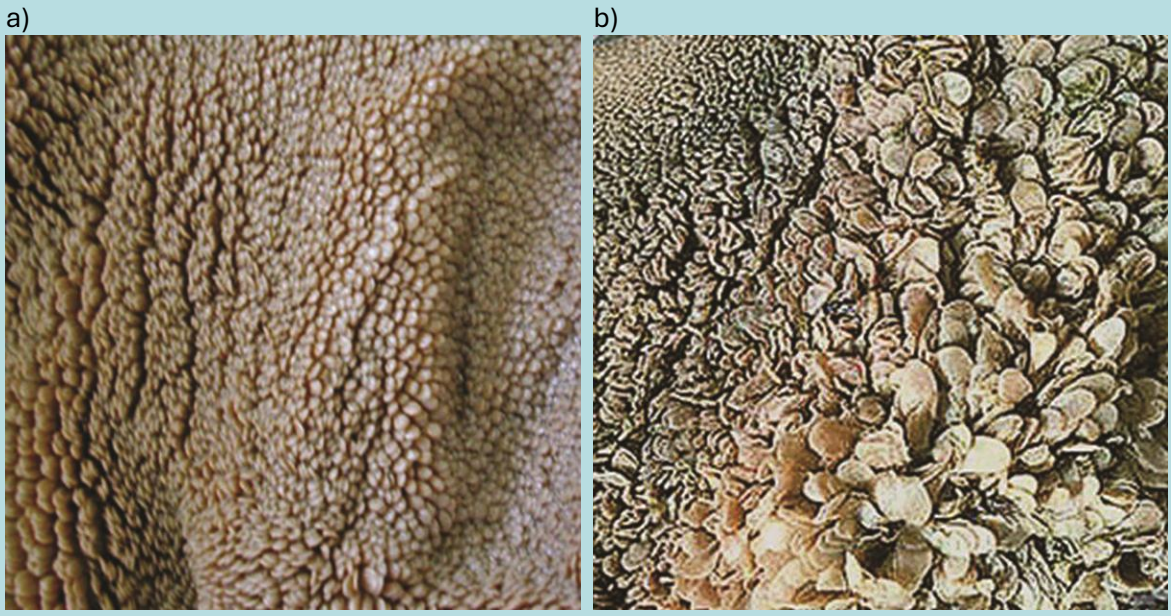

Figure 16 Ruminal papillae, a) before adaptation, and b) showing hypertrophy, after adaptation. Source: Lean and DeGaris (2021).

As noted earlier, SCFA absorption is disrupted when ruminal motility slows. This can occur in response to reduced feed intake, high osmolality, and physiological disturbances such as hypocalcaemia. Conditions that divert blood flow away from the gastrointestinal tract, such as heat stress, are also likely to reduce the rate of SCFA absorption (Storm et al., 2011).

Saliva secretion provides substantial buffering capacity in the rumen. Secretion is greatest during meals, remains relatively high during rumination, and is lower when the cow is neither eating nor ruminating. As noted earlier, the large mass of digesta in the rumen also contributes to buffering and becomes particularly important when ruminal homeostasis is disrupted and pH falls below 5. Reduced feed intake decreases both saliva secretion and ruminal digesta mass, thereby impairing buffering capacity. This may contribute to inconsistent intake patterns and further ruminal dysfunction.

Definitions of ruminal acidosis

The term 'ruminal acidosis' was first proposed in 1970 (Dirksen, 1970). In reviews and studies published in the scientific literature over the past 50 years, numerous terms have been proposed and used to describe ruminal acidosis (Kleen et al., 2003). Although ruminal acidosis occurs along a continuum, two terms are commonly used: 'acute ruminal acidosis' (ARA), which is more common in finishing beef cattle, and 'subacute ruminal acidosis' (SARA), which typically occurs in dairy cattle and describes the milder, more prevalent form of ruminal acidosis. The length of time that pH remains below a specified threshold within a 24-h period has been used as an indicator of the severity of ruminal acidosis. An episode of ARA has been defined as a ruminal pH below 5.5 for 3 h/d (Castillo-Lopez et al., 2014), whereas an episode of SARA has been defined as ruminal pH below 5.8 for 5 to 6 h/d (Zebeli

et al., 2008). However, as noted earlier, multiple biomarkers have since been proposed as a more accurate means of diagnosing ruminal acidosis (Bramley et al., 2008).

Australian researchers Golder and Lean (2024) recently proposed that the milder, more prevalent form of ruminal acidosis is better described using the term 'subclinical' rather than 'subacute'. Their recommendation was based on the premise that the terms 'acute' and 'subacute', as used in human and veterinary medicine, imply a specific temporal framework and the possible presence of pain. However, the time course of the disorder may vary due to many factors, and pain is not associated with a moderate decline in ruminal pH.

The terms 'subacute ruminal acidosis' and 'subclinical ruminal acidosis' are not readily interchangeable. Several studies have shown that many cows with ruminal pH values well below the threshold used to define 'subacute' ruminal acidosis are asymptomatic (Bramley et al., 2008; O'Grady et al., 2008; Denwood et al., 2018; Golder et al., 2023). However, although cows considered to have 'subclinical ruminal acidosis' or 'subacute ruminal acidosis' do not exhibit overt clinical signs, other indicators of ruminal dysfunction, often small in magnitude, may be observed. These include reduced or variable feed intake and decreases in bodyweight, milk yield, and milk fat concentration (Golder and Lean, 2024; Christodoulopoulos, 2025).

Neither the terms 'acute ruminal acidosis' and 'subacute ruminal acidosis' nor the terms 'clinical ruminal acidosis' and 'subclinical ruminal acidosis' provide ideal terminology. Given that the terms 'acute ruminal acidosis' and 'subacute ruminal acidosis' are widely used and accepted within the scientific community and among ruminant nutrition advisers and veterinarians, they will be used in these guidelines.

Acute ruminal acidosis

In situations where the above risk factors come together in a "perfect storm", acute clinical acidosis can occur, perhaps most commonly in feedlot cattle being transitioned to high-grain diets or dairy cattle that accidentally gain access to large quantities of grain. In subsets of cattle with transient poor intake, and therefore limited rumen digesta and buffer secretion, the return of appetite can lead to overconsumption of feed. When the diet is very high in fermentable carbohydrate, an extremely high rate of SCFA production can occur. Coupled with limited H+ removal mechanisms in an animal that is poorly adapted or has not been eating well, SCFAs can accumulate at a rate that drives rumen pH below 5.5. At this pH, particularly in a starch-rich rumen environment, species such as *Streptococcus bovis* can proliferate very rapidly. This has further consequences because *S. bovis* produces lactic acid as its primary metabolic end-product under these conditions. The low pKa of lactic acid drives rumen pH even lower. Lactate accumulates further as the population of lactate utilisers, such as *Megasphaera elsdenii*, decreases below pH 5.5 (Russell and Allen, 1984). As pH decreases below 5, Lactobacillus populations and lactate production increase. Once H^+ production overwhelms buffering by the ruminal digesta and SCFA, recovery becomes difficult, and acute acidosis occurs.

A combination of physiologically dangerous processes then occurs (Snyder and Credille, 2017). First, the high SCFA concentrations in the rumen, combined with the greater absorption rate of their protonated forms at low pH, result in rapid SCFA absorption, threatening the capacity of the blood to buffer this acid load. Animals that die from acute acidosis may have a blood pH of less than 7.2, compared with the normal range of 7.35 to 7.45. Second, the extremely high osmolality of the rumen contents during rapid fermentation causes water to be drawn from the bloodstream into the rumen, resulting in systemic dehydration. Third, disruption of ruminal tissue barrier function allows ruminal toxins to enter the circulation, causing an inflammatory response. The combination of systemic acidosis, dehydration, and inflammation can lead to

cardiovascular and renal collapse, resulting in death. The most extreme cases of acute acidosis can kill animals within hours.

Subacute acidosis

In the subacute acidosis scenario, changes in the ruminal microbiome and its metabolic end-products occur; however, lactic acid is rarely detected, and when present, it is generally transient. Whole-animal responses to subacute acidosis are variable; there are no consistent clinical signs associated with the condition. Rather, subacute acidosis is associated with both local and systemic shifts that may be considered adaptive, although some of these adaptations clearly come at a cost to the animal.

Local impacts

The physiological impacts of subacute acidosis have been studied more extensively than those of acute acidosis, although most have been studied in the context of grain challenges, which may or may not correspond with the local and systemic effects of chronic cases of subacute acidosis (Krogstad et al., 2023).

Steele et al. (2011) documented the stages of ruminal adaptation following a dramatic diet change from 100% chopped hay to 65% mixed grain over 4 days in mature dry Holstein cows. Predictably, rumen pH dropped dramatically, while rumen osmolality and SCFA concentration increased during the first week on the high-grain diet. More surprisingly, all three measures returned to approximately baseline values by week 3 on the high-grain diet.

A common local effect of acidosis is a change in the ruminal microbiome. Studies have shown that excessive grain feeding and the resulting ruminal acidosis reduce the richness, evenness and diversity of the ruminal microbiota, as well as the abundances of many beneficial microbial taxa in the reticulo-rumen (Plaizier et al., 2018). Some species, particularly the dominant fibrolytic species, lactate utilisers, protozoa and archaea, are more susceptible to inhibition at low pH, and decline as a proportion of the microbial population in response to acidosis. These changes consistently decrease fibre digestion and methane production, although these effects may be more closely correlated with starch intake than with rumen pH alone. Microbial species that specialise in starch degradation generally proliferate in grain-induced acidosis scenarios. This proliferation may be accompanied by the growth of *Escherichia coli* (Khafipour et al., 2009b). Although many of the beneficial commensal species in the rumen are Gram-negative bacteria that produce lipopolysaccharide (LPS; also known as endotoxin), LPS from *E. coli* is far more inflammatory and toxic to mammalian cells than LPS from most other common gut bacteria.

Higher acidosis risk has been associated with increased abundances of some bacterial families and decreased abundances of others. Intakes of highly fermentable carbohydrates and crude protein have been found to be most consistently associated with these changes in bacterial abundances and with acidosis risk, although these relationships are not yet well understood. In the future, it may be practical to define and predict ruminal acidosis risk based on these microbial changes (Golder et al., 2023). Additionally, greater feed intake of highly fermentable diets has been associated with an increased risk of SARA in cows due to the increased availability of starch, which promotes rumen fermentation and acid production (Hartinger et al., 2024).

There are also tissue responses to subacute acidosis. In Steele et al. (2011), rumen papillae sampled 7 days after the start of the transition to the high-grain diet showed clear disruption of the rumen epithelium, including sloughing of the keratinised outer epithelial layer (Figure 17). Although these lesions were more abundant after 1 week on the high-grain diet, they were no longer evident after 3 weeks on the diet, demonstrating tissue adaptation to the new diet.

Nonetheless, even transient disruption of the rumen epithelial barrier has potential systemic implications.

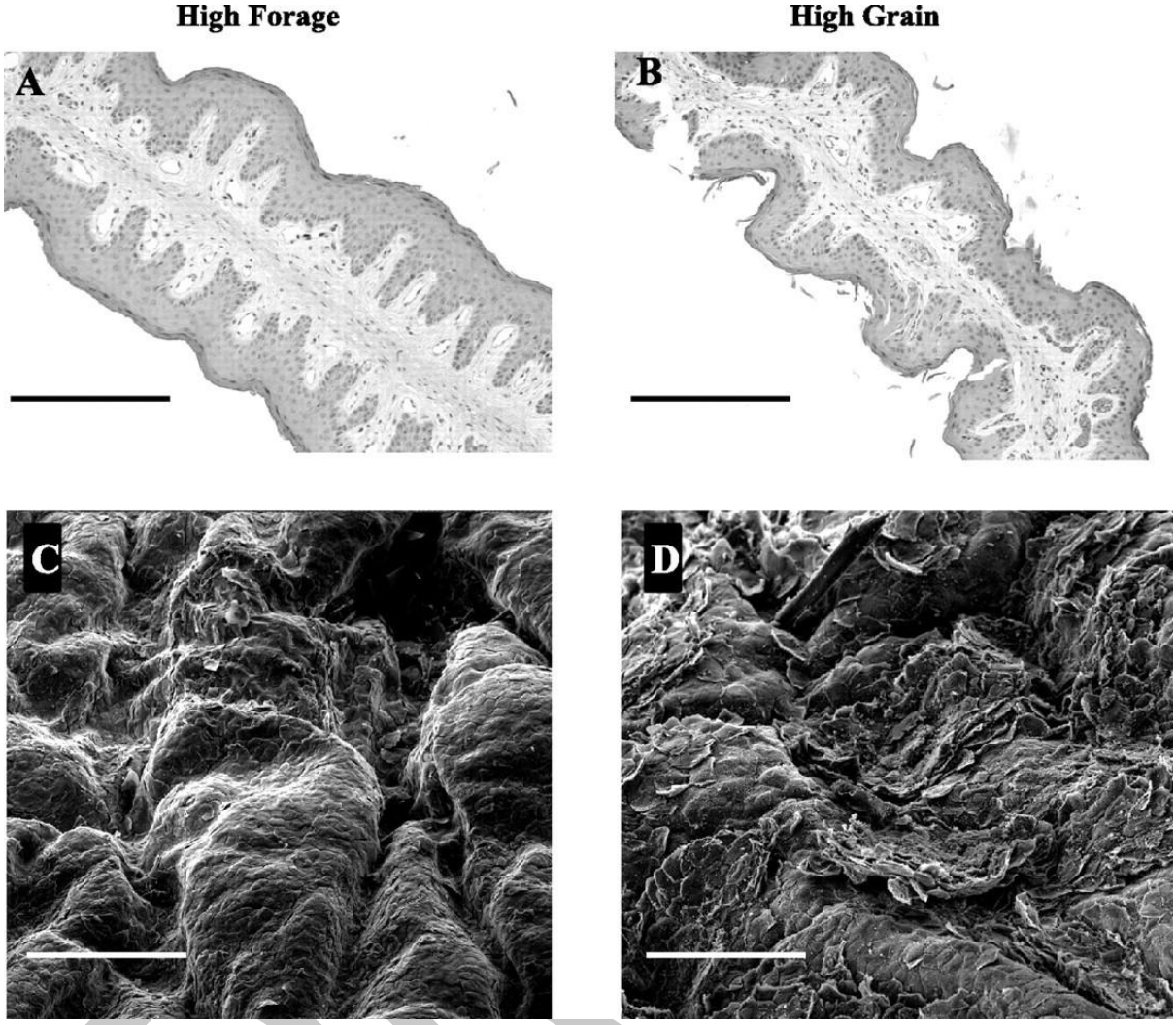

Figure 17 Light micrographs of papillae cross-sections (above) and scanning electron micrographs of the papillae surface (below) show the effects of a high-grain diet (right) compared with a high-forage diet (left) on the structure of ruminal papillae in non-lactating, non-pregnant cows.
Source: Reproduced from Figure 2 in *Bovine rumen epithelium undergoes rapid structural adaptations during grain-induced subacute ruminal acidosis*, by M. A. Steele, O. AlZahal, S. E. Hook, J. Croom, and B. W. McBride, 2011, American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 300(6), pp. R1515-R1523. Reproduced with permission.

It seems unlikely that disruption of the rumen epithelium is a consequence of excessive acid accumulation per se. Work by Meissner et al. (2017) showed that maintaining ruminal tissue at pH 5.1 rather than 6.1 had only minimal effects on tissue barrier function. However, when the ruminal tissue was maintained at pH 5.1 with an SCFA concentration consistent with subacute acidosis, which also increased osmolality, barrier function decreased dramatically, together with the decreased abundance of multiple epithelial barrier proteins. Despite the multilayered construction of the ruminal epithelium, it appears that chemical, such as osmotic, and/or physiological impacts of high SCFA concentrations can lead to a decline in the “mortar” that

holds cells tightly together. Concurrently, low ruminal pH results in the lysis of Gram-negative bacteria, releasing LPS into ruminal fluid, and shifts bacterial metabolism towards the production of histamine. Epithelial damage is likely aggravated by inflammation caused by LPS and histamine, combined with low rumen motility and hypoxia (Aschenbach et al., 2019).

Recent evidence suggests that approximately 60% of immune cells present in the rumen epithelium are gamma delta T lymphocytes (Vandevoorde and Krogstad, 2026). This unique cell population is thought to serve a regulatory, anti-inflammatory role and may contribute to the ability of at least some animals to tolerate acidosis and the associated tissue adaptations. However, it is too early to know whether this local immune population is partially responsible for differences in the severity of acidosis among animals within a population.

Systemic impacts

Many studies have reported that grain-induced SARA results in notable increases in acute-phase proteins in the bloodstream (Khafipour et al., 2009a; Steele et al., 2011). Because the production of acute-phase proteins is primarily induced by inflammatory pathways, these results have been used to describe the inflammatory effects of subacute acidosis. Damage to the ruminal epithelium could theoretically generate a direct inflammatory response, which could then affect whole-animal physiology. Alternatively, disruption of the epithelial barrier could allow ruminal LPS and other toxins to enter the bloodstream, directly triggering systemic inflammation. Although inflammation of ruminal tissue has been documented during induced subacute acidosis, it is difficult to determine whether this shift in tissue physiology is sufficient to affect systemic inflammatory tone. However, there is solid evidence that subacute acidosis in dairy cows results in increased blood LPS concentrations and allows intact pathogens such as *Fusobacterium necrophorum* to exit the rumen, which is thought to be a primary trigger of liver abscesses (Garcia et al., 2017). The relevance of these mechanisms is supported by the prevalence of rumen lesions found in slaughterhouse surveys of dairy cows across the Midwest region of the USA, as well as the high prevalence of liver abscesses (Amachawadi and Nagaraja, 2016).

The effects and signs of SARA have been assessed in many challenge studies using wheat- or barley grain-based SARA induction models in TMR-based intensive systems (Plaizier et al., 2022). In these studies, in addition to decreased ruminal pH and increased concentrations of short-chain fatty acids (SCFA) and possibly lactate in the ruminal digesta, SARA resulted in increased ruminal concentrations of bacterial endotoxins, especially LPS. These endotoxins can induce a localised immune response in the ruminal epithelium (Kent-Dennis et al., 2020) and may translocate across the gastrointestinal epithelium into the bloodstream, resulting in a systemic immune response (Zebeli and Ametaj, 2009; Plaizier et al., 2018).

Challenge studies using wheat- or barley grain-based SARA induction models in TMR-based intensive systems have found that the increase in LPS concentration in the ruminal digesta varies with feed type. SARA induced by feeding high quantities of grain resulted in an increased concentration of free LPS in the rumen digesta (Plaizier et al., 2022). It is important to note that LPS type and concentration can vary widely, likely due to differences in the severity and duration of the SARA challenge imposed on animals (Plaizier et al., 2018) and in the microbial community present. In contrast, feeding ground alfalfa pellets to induce SARA through reduced intake of physically effective neutral detergent fibre (peNDF) resulted in little or no increase in LPS concentration in the rumen digesta and no systemic inflammatory response (Khafipour et al., 2009; Li et al., 2012; Plaizier et al., 2014). SARA induced by feeding sugar has resulted in LPS concentrations intermediate between those observed when SARA was induced using grain or ground alfalfa pellets. In a challenge study in which treatment groups of heifers were fed additional grain, grain + fructose, grain + histidine, or grain + fructose + histidine, the

substitution of grain with fructose led to a marked increase in the ruminal concentrations of D- and L-lactate and a lower ruminal pH (Golder et al., 2012).

In cows suffering from ARA, rapid production and absorption of lactate into the bloodstream lead to reduced blood pH, or systemic acidosis, as the blood's buffering capacity is exceeded. The release of LPS from dead Gram-negative ruminal bacteria and its translocation across the damaged rumen epithelium may lead to endotoxaemia and a systemic inflammatory response. Dehydration and hypovolaemic shock may follow, leading to death, because high rumen osmolality draws fluid from the bloodstream into the rumen, while severe diarrhoea causes further fluid loss.

A model representing the triggers of ruminal epithelial barrier damage and the subsequent activation of systemic inflammation is shown in Figure 18.

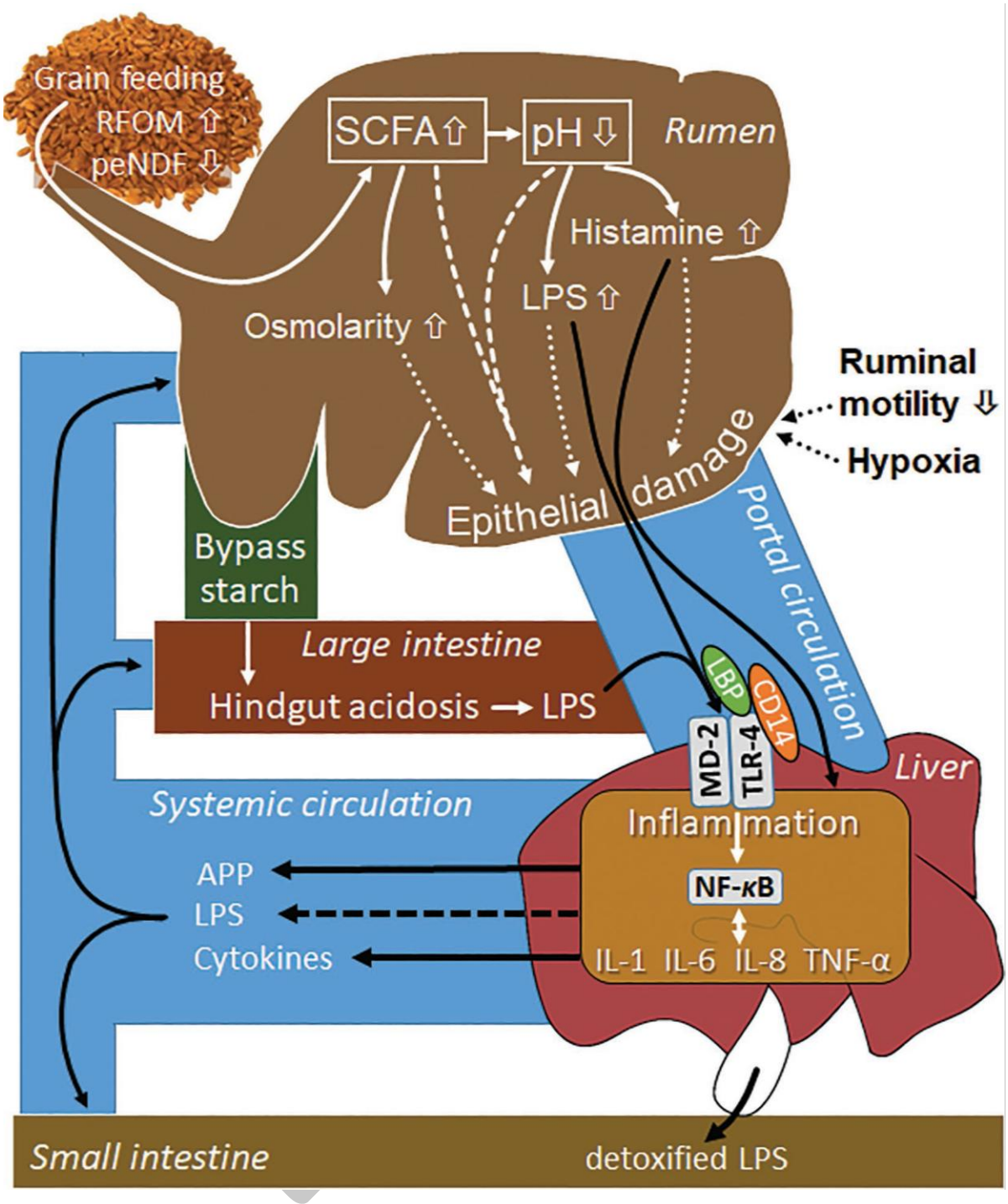

Figure 18 Model visualising the triggers of ruminal epithelial barrier damage and the subsequent activation of systemic inflammation. Grain-rich diets favour a high intake of rumen-fermentable OM (RFOM) that, if not properly balanced with physically effective NDF (peNDF), leads to excessive production of short-chain fatty acids (SCFA; possibly also lactic acid), a concurrent decrease in pH, and an increase in ruminal osmolality. These factors, especially the combination of low pH and SCFA, progressively damage the ruminal epithelium over time. Low pH also shifts bacterial metabolism towards the production of biogenic amines, including histamine, and provides unfavourable growth conditions for most Gram-negative bacteria, which then release large amounts of LPS into the ruminal fluid. Epithelial inflammation caused by histamine and LPS, low rumen motility, and hypoxia may aggravate epithelial damage. Histamine, LPS, and possibly live bacteria cross the damaged epithelial barrier and reach the

liver via the portal circulation, where they elicit inflammation, most prominently via the nuclear factor (NF)-κB pathway. Lipopolysaccharides play a dominant role in this inflammation. In addition to their local effects, proinflammatory cytokines such as IL-1, IL-6, IL-8, and tumour necrosis factor (TNF)-α spill over into the systemic circulation, where, together with released acute-phase proteins (APP), they induce systemic inflammation. The liver ultimately inactivates LPS and excretes it via the bile into the small intestine. However, if the detoxifying capacity of the liver is exceeded, LPS may also enter the systemic circulation, further promoting systemic inflammation. Systemic inflammation interferes with the barrier and transport functions of all gastrointestinal epithelia.
Source: Adapted from Figure 1 in *Symposium review: The importance of the ruminal epithelial barrier for a healthy and productive cow*, by J. R. Aschenbach, Q. Zebeli, A. K. Patra, G. Greco, S. Amasheh, and G. B. Penner, 2019, Journal of Dairy Science, 102(3), pp. 1866–1882. Reproduced with permission.

Potential sequelae to ruminal acidosis

There are many potential sequelae of ruminal acidosis in dairy cows reported in the literature (Figure 19). These include reduced milk production, altered milk composition, reduced feed intake, liver abscessation, laminitis and reduced fertility. There are also anecdotal reports of an increased risk of salmonellosis in cattle affected by SARA. Making sense of the sequelae of ruminal acidosis can be difficult. It should be borne in mind that not all states of acidosis are likely to result in the same level of LPS production in the rumen, the same sensitivity of the rumen epithelium to LPS and, consequently, the same inflammatory response in the animal (Plaizier et al., 2022). Therefore, “not all states of ruminal acidosis are the same”.

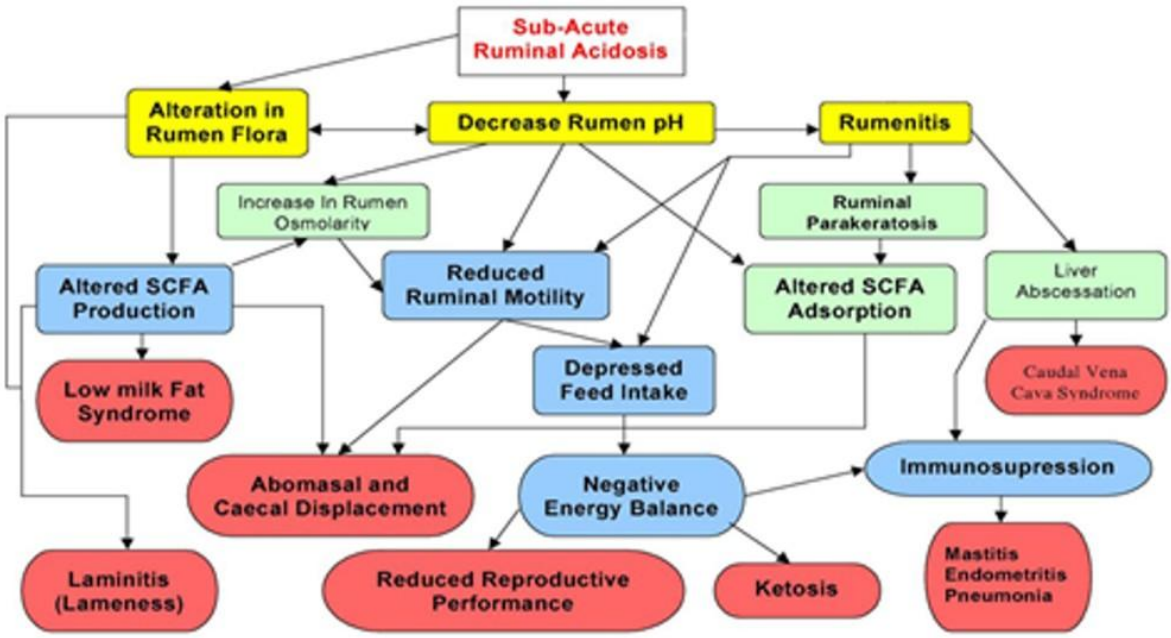

Figure 19 The many potential sequelae of subacute ruminal acidosis. Source: Adapted from Mulligan and Doherty (2008).

Changes in milk yield

Reports of the impact of acidosis on milk production are inconsistent. Krause and Oetzel (2005) described how milk yield was reduced during an episode of low rumen pH. Despite rumen pH recovering over time, cows did not return to basal milk yield. Stone (1999) also reported that

milk production was reduced in cows suffering from prolonged episodes of low rumen pH during a clinical study carried out on a large-scale dairy farm in the USA. However, other studies investigating low rumen pH across multiple grazing herds did not report any negative effects of SARA, defined using a pH threshold of 5.5 or less, on milk yield (O'Grady et al., 2008). Further, Kolver and de Veth (2002), who investigated the relationship between low rumen pH and productivity using 23 studies of pasture-fed cows, reported that lower ruminal pH was associated with higher microbial N flow from the rumen, total SCFA concentration, milk yield, milk component yield and dry matter intake. However, lower ruminal pH was associated with a lower milk fat percentage and a lower acetate ratio. Similarly, an Australian report of dairy herds fed predominantly pasture and concentrate found that herds classified as acidotic had higher milk yield and similar fat and protein yields compared with other herds (Bramley et al., 2008). Consistent with Kolver and de Veth (2002), the acidotic herds had higher milk yield and lower milk fat concentration. Therefore, some studies have reported better performance when ruminal pH is lower or when cows or herds are classified as acidotic (Bramley et al., 2008; Kolver and de Veth, 2002).

Possible explanations for these differing production responses to acidosis include: 1) not all states of low ruminal pH produce the same response (Plaizier et al., 2008; Plaizier et al., 2022); 2) ruminal pH alone does not fully quantify changes in rumen physiology that lead to production or clinical outcomes (Golder et al., 2014); and 3) multi-herd studies may not be suitable for evaluating the impact of low rumen pH on dairy herd performance.

Changes in milk fat synthesis

Reduced milk fat synthesis is one of the signs regularly associated with low rumen pH in dairy cows (Kolver and de Veth, 2002; Plaizier et al., 2014). Kleen et al. (2003) suggested that cows may experience episodes of low rumen pH under similar conditions to those in which milk fat depression (MFD) is likely to occur, rather than because of a direct causal relationship. Many other important factors can affect milk fat concentration in lactating dairy cows, including breed, season and stage of lactation (Oetzel, 2007; Carty et al., 2017). There have been numerous attempts to explain the link between rumen pH and milk fat synthesis and/or MFD. The importance of fibre, and particularly physically effective fibre, to rumen function in the dairy cow has been examined in relation to its role in MFD. Enjalbert et al. (2008) found that mean rumen pH was closely related to milk fat content. Allen (1997) also found that milk fat concentration and rumen pH were positively related.

Bauman and Griinari (2003) stated that changes in rumen biohydrogenation associated with low rumen pH are the most likely cause of MFD. This theory is based on the concept that certain dietary conditions alter the pathways of rumen biohydrogenation to produce unique fatty acid intermediates, some of which are effective inhibitors of milk fat synthesis. Baumgard et al. (2000) identified trans-10, cis-12 conjugated linoleic acid (CLA), produced through an altered rumen biohydrogenation process, as the main inhibitor of milk fat synthesis, affecting de novo milk fat synthesis, that is, the synthesis of new fatty acids. The same study showed that the CLA isomer trans-10, cis-12 caused reductions of 42% and 44% in milk fat concentration and overall milk fat yield, respectively. Other studies (Lock et al., 2007) have demonstrated similar reductions in milk fat percentage following supplementation with trans-10, cis-12 CLA. Colman et al. (2010) also stated that low rumen pH affects the rumen environment, changing both the nature of the rumen microbial population and the biohydrogenation process.

Changes in milk protein synthesis

O'Grady et al. (2008) reported no difference in milk protein percentage between dairy cows with low and normal rumen pH or between acidotic and normal herds. Similarly, Bramley et al. (2008) reported no difference in milk protein percentage or milk protein yield between acidotic

and normal herds. Interestingly, Kolver and de Veth (2002) reported a negative relationship between rumen pH and milk protein yield within herds. In another study, lower milk protein percentage and no effect on milk protein yield were reported in cows in which the number of hours at low rumen pH was reduced (Rafferty et al., 2019). Hence, low rumen pH or acidosis does not appear to be associated with reduced milk protein percentage or yield.

Feed intake

Reduced feed intake has been associated with low rumen pH (Kleen et al., 2003). Enemark (2008) suggested that an increase in rumen osmolality, associated with a disrupted feeding pattern during an episode of low rumen pH, may be linked to decreased DMI because of reduced bacterial fermentation of fibre and starch. Further, increased osmolality might increase water flow into the rumen from the blood and reduce water flow out of the rumen to the omasum by decreasing motility. In addition, increased propionate production associated with decreased rumen pH likely stimulates satiety via hepatic oxidation (Allen et al., 2009). Krajcarski-Hunt et al. (2002) induced an episode of low rumen pH by replacing 25% of the TMR with cereal-based pellets and found that the pH-reducing diet decreased DMI of the TMR. Similarly, Neville et al. (2019) demonstrated that reducing markers of low rumen pH may be associated with increased DMI. However, Krause and Oetzel (2005) induced low rumen pH by feeding 3.5 or 4.6 kg of a wheat-barley pellet to investigate its effect on production and found that DMI was not affected by the reduction in rumen pH. Similarly, Kolver and de Veth (2002) reported that, within studies, low rumen pH was positively correlated with feed intake in pasture-based systems. Thus, responses in DMI and ruminal pH are variable, consistent with ruminal acidosis being largely driven by substrate and changes in the ruminal microbiome, and ruminal pH being only one of many biomarkers of ruminal acidosis.

Laminitis

A direct causative relationship between low rumen pH or acidosis and laminitis in dairy cattle is not universally accepted. However, laminitis is often considered to be associated with both low ruminal pH and ruminal acidosis more generally (Elmhadi et al., 2022). Even though laminitis-related hoof problems such as sole ulcers and white line disease are common causes of lameness, particularly in freestall facilities, the relationship between laminitis and low ruminal pH is not fully understood. A recent systematic review highlighted the complexity of this area (Passos et al., 2023). It concluded that a relationship between diet, ruminal acidosis and laminitis can be demonstrated in induction studies, but that the mechanism of action remains unclear and that the different methods used to diagnose laminitis have hindered research in this area.

There are a number of theories that attempt to explain the link between rumen fermentation and laminitis. Damage to the rumen epithelium can lead to the translocation of LPS from the rumen into the bloodstream and may induce inflammation of the laminae (Plaizier et al., 2012). Nocek (1997) proposed that the development of laminitis may be initiated by the seepage of bacterial endotoxins and histamine into the bloodstream as a result of depressed rumen pH. This may lead to increased blood pressure, damage to blood vessel walls and internal haemorrhaging, causing expansion and severe pain in the hoof corium. A second phase of laminitis development may then be initiated by mechanical damage to the hoof, resulting in infection and damage to its digital tissues. Indeed, other authors have noted an increase in harmful bacterial metabolites, including LPS endotoxin, lactic acid and histamine, in dairy cows with SARA (Elmhadi et al., 2022). Interestingly, grain-induced SARA using barley and wheat has been reported to result in higher LPS endotoxin concentrations in rumen fluid than ryegrass-induced SARA (Plaizier et al., 2022). Thus, not all states of SARA will result in the same inflammatory response.

Despite the many unknowns surrounding causation, scientific reports linking acidosis with laminitis or lameness have been published. Danscher et al. (2010) demonstrated increased weight shifting and histological changes in sensitive claw horn tissue in heifers subjected to an oligofructose challenge. Donovan et al. (2004), using the hoof-scoring methodology of Greenough and Vermunt (1991), reported higher hoof scores at 50 to 70 DIM, indicative of poor hoof quality, in a group of cows that showed a higher prevalence of rumen acidosis following an abrupt postpartum dietary change from a low-energy to a high-energy diet. However, they failed to detect a significant relationship between low rumen pH postpartum and high hoof scores at the individual-cow level. Concurrent cases of lameness and acidosis have been reported in Australian dairy cows associated with transition failure in very fresh cows (Bramley et al., 2005). Pasture-based cows can also be susceptible to laminitis associated with low rumen pH. Bramley et al. (2013) demonstrated a greater proportion of cows with high locomotion scores in groups predicted to be acidotic in Australian dairy herds fed pasture and concentrates. Further, a report from New Zealand suggested that dairy cows in grazing herds are also susceptible to lameness associated with laminitis and acidosis (Westwood et al., 2003).

Liver abscesses

Low rumen pH has been linked to liver abscesses caused by the translocation of rumen bacteria, such as *Fusobacterium necrophorum* and *Arcanobacterium pyogenes*, into the bloodstream as a result of reduced barrier function of the rumen epithelial mucosa (Plaizier et al., 2008; Elmhadi et al., 2022). Rumen parakeratosis or rumenitis involves erosion and ulceration of the rumen epithelium, leading to inflammation and an increased risk of bacterial colonisation (Oetzel, 2007). According to Steele et al. (2011), rumen parakeratosis can result from feeding a high-grain diet that causes extended periods of low rumen pH, leading to increased permeability and reduced thickness of the rumen epithelium. Liver abscesses can be detrimental to animal health, possibly leading to peritonitis around the site of the abscess (Krause and Oetzel, 2006), and can also lead to the spread of bacteria from the liver to other organs, including the lungs, heart and kidneys (Kleen et al., 2003). The so-called 'acidosis-rumenitis-liver abscess complex', involving the translocation of anaerobic bacteria, is the main causal pathway (Amachawadi and Nagaraja, 2016; Elmhadi et al., 2022). Some authors have suggested that Holstein cattle, including dairy cows, may be more susceptible than other cattle types (Amachawadi and Nagaraja, 2016).

Reduced fertility and immunosuppression

Enemark (2008) suggested that SARA may indirectly reduce fertility through the exacerbation of negative energy balance in early lactation. This was supported by a study from Colombia, which found that the occurrence of SARA increased the odds of postpartum anoestrus 2 months after calving in grazing cows (Vallejo-Timarán et al., 2020). Furthermore, Enemark (2008) noted that metabolic acidosis in dairy cattle could result in reduced steroid hormone secretion around calving and reduced contractility of the uterine smooth muscle (Ras et al., 1996). When coupled with potential immunosuppressive effects (Hofírek et al., 1995), these mechanisms provide a plausible explanation for reduced fertility.

Conclusion

Ruminal acidosis is largely driven by fermentable substrate. The type, quantity and rate of fermentation of carbohydrates consumed strongly influence rumen microbial populations and the profile of fermentation end-products. Highly fermentable substrates promote rapid microbial growth and acid production, which may outstrip the rumen's buffering and H+ removal capacity, leading to ruminal epithelial barrier damage and activation of systemic inflammation.

Key principles for the prevention and control of ruminal acidosis are:

- Provide cows with sufficient physically effective fibre, i.e. peNDF, to maintain digesta pool size, provide adequate buffering by ruminal digesta, stimulate rumination and salivary buffer flow, and promote rumen motility to enhance SCFA absorption.
- Avoid the intake of large quantities of rapidly fermentable starch and sugar sources and highly digestible grasses. Where possible, integrate highly fermentable carbohydrates with physically effective fibre sources in the same feeding event, e.g. in a PMR or TMR. In grazing systems where there are no facilities to feed a PMR and a grain-based concentrate is fed in the dairy at milking, seek to minimise the number of hours between the intake of the grain-based concentrate and forage.
- Use a sound understanding of feed carbohydrate fractions and fermentation rates, together with appropriate ration formulation guidelines, to balance carbohydrate fermentability in the milker diet, reduce rapid ruminal acid production and lower the risk of acidosis.
- Support ruminal epithelial adaptation during the pre- and post-calving transition period through effective transition and fresh cow feeding management.
- Over each 24-hour period:
    - Shorten intervals between feed bouts to spread fermentation more evenly and minimise the associated declines in ruminal pH.
    - Maintain a consistent feeding regime, with minimal variation in the timing of feed bouts and the quantities fed.
    - Never allow cows to become hungry.
- Following the transition period, make substantial changes to the milker diet and introduce new feeds gradually and in steps to allow sufficient time for rumen adaptation.
- Ensure that all cows in the herd have equal and adequate access to all feeds offered, and that these feeds are palatable and unspoiled.

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Chapter 3: Risk factors for ruminal acidosis

Summary of key points:

- Ruminal acidosis in Australian production systems should be considered a multifactorial and system-dependent disorder resulting from interacting dietary, animal, environmental and management risk factors.
- Diet fermentability and physically effective fibre (peNDF) supply are the primary nutritional determinants of rumen stability.
- Rapid intake of highly fermentable carbohydrates, such as through slug feeding of concentrates or the consumption of highly digestible pasture, increases acidosis risk.
- Gradual dietary adaptation is essential to allow rumen microbes and the ruminal epithelium to adjust to more fermentable diets.
- On dairy farms using grazing systems, many scenarios occur each year in which SARA may be induced in some or all cows due to the rapid consumption of highly fermentable carbohydrates or low peNDF intake. SARA may manifest differently in each farm scenario.
- On dairy farms using total mixed rations (TMR) or partial mixed rations (PMR), the risk of SARA is increased when diet formulation, the physical characteristics of the ration, or inconsistency in feed access and delivery compromise effective fibre intake.

Risk factors in Australian dairy production systems

Risk factors predisposing dairy cows to ruminal acidosis can be broadly grouped into dietary, animal, environmental and management factors (Figure 20). These factors rarely act independently; instead, cumulative and interacting factors determine the likelihood, duration and severity of an imbalance between the production of fermentation acids by microbes in the rumen and the absorption, passage, neutralisation and buffering of those acids (Plaizier et al., 2008; Enemark, 2008).

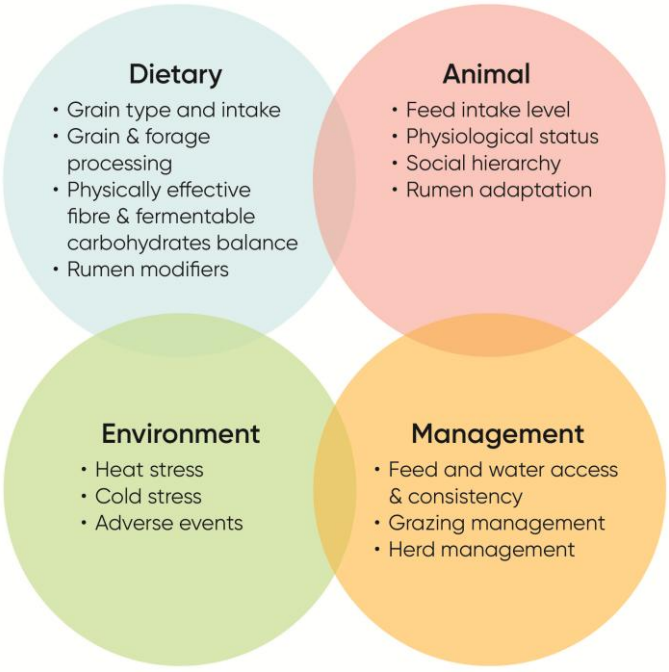

Figure 20 Risk factors predisposing cows to ruminal acidosis in Australian dairy production systems.

Dietary factors

Diet composition is the dominant driver of ruminal acidosis risk. Grain and plant carbohydrate fractions differ markedly in ruminal fermentability, typically ranking from rapidly degradable water-soluble carbohydrates (WSC), through starches, to structural carbohydrates within neutral detergent fibre (NDF). When rapidly fermentable carbohydrates are supplied in excess of the rumen's buffering and absorptive capacity, short-chain fatty acids (SCFA) and, occasionally, lactic acid accumulate, reducing rumen pH and predisposing animals to SARA or ARA (Allen, 1997; Owens et al., 1998).

Low dietary forage NDF or inadequate intake of physically effective NDF (peNDF) reduces rumination and saliva secretion, diminishing endogenous buffering of rumen contents (Mertens, 1997; Zebeli et al., 2012). The concept of physically effective NDF integrates both forage NDF concentration and particle size, and inadequate peNDF intake is consistently associated with an elevated risk of SARA. Decreased forage intake also reduces rumen digesta mass, which contributes to ruminal buffering through cation exchange (Erdman, 1988).

Sugars, starch and fibre

Sugars and starch are the two main forms of non-structural carbohydrates in feed. Water-soluble carbohydrates (WSC) include simple sugars (monosaccharides and disaccharides), fructans and other water-soluble oligosaccharides. They are generally fermented very rapidly by rumen microbes to SCFA. Starch comprises more complex carbohydrates (polysaccharides) that are fermented by rumen microbes more slowly than WSC, primarily to propionate. A proportion of dietary WSC and starch may bypass the rumen, undergo enzymatic digestion in the small intestine and be absorbed as glucose.

Neutral Detergent Fibre (NDF) measures the structural carbohydrates hemicellulose and cellulose, as well as lignin, in feed, but not the physical characteristics of the fibre.

Physically effective NDF (peNDF) reflects the physical properties of fibre that influence chewing activity, particularly particle size, and the stratified nature of ruminal contents, with a raft of large particles floating above a pool of liquid and small particles. Physical characteristics such as particle size and density are critical, as they can influence ruminal fermentation and feed utilisation, animal metabolism, animal health and milk fat production independently of the amount or composition of chemically measured NDF (Mertens, 1997).

Adapted from Mertens (1997).

Dietary protein helps the rumen maintain a balance between ruminal acid production and removal, primarily through indirect buffering mechanisms. Adequate crude protein, particularly rumen-degradable protein (RDP), supports efficient microbial growth and fibre digestion in the rumen, promoting DMI, which in turn promotes rumination and saliva secretion. During ruminal protein degradation, ammonia (NH_3) is produced and acts as a weak base, consuming hydrogen ions and contributing to rumen buffering, especially during periods of high acid production. In contrast, underfeeding protein can limit microbial activity, reduce fibre digestion, DMI and rumination time, and increase susceptibility to ruminal pH depression. Therefore, formulating diets to provide adequate protein, rather than a marginal supply, supports rumen stability and buffering capacity.

On Australian dairy farms using grazing systems, many scenarios occur each year in which SARA may be induced in cows due to the rapid consumption of highly fermentable carbohydrates or low peNDF intake. Depending on the carbohydrate source inducing SARA and the duration of exposure, whether short term or persistent, an inflammatory response may or may not be triggered. SARA may therefore manifest differently in each farm scenario in terms of severity and duration and may or may not escalate to acute ruminal acidosis.

Grazing scenarios

Herds in grazing systems are at elevated risk of ruminal acidosis during periods of lush pasture growth, typically between autumn and early spring in southern Australia. Lush ryegrass pastures may often contain low DM (<16%) and low NDF (<35%), but high CP (>23%), high WSC (>18%) and very high organic matter digestibility (OMD; 80 to 85%) (McKay et al., 2019; Leddin et al., 2022), creating a ruminal environment conducive to rapid carbohydrate fermentation and the accumulation of ruminal acids, even when grain supplementation is limited. This notion is supported by findings reported in pasture-based systems in Australia and Ireland, where highly digestible spring pastures were associated with reduced rumen pH (Williams et al., 2005a; Williams et al., 2005b) and milk fat depression consistent with SARA-type fermentation (O'Grady et al., 2008; Burke et al., 2010). One study reported a rumen pH as low as 5.2 and 289 minutes per day at a rumen pH below 5.6 when lactating grazing dairy cows were rapidly switched to a high-quality ryegrass diet (Plaizier et al., 2022). Low grazing intensity can also lead to selective grazing of the higher-quality parts of plants, such as leaves, or more palatable plant species within a sward, rather than more fibrous portions of plants, such as stems, or less palatable plant species, predisposing cows to SARA.

Herds in grazing systems are also at elevated risk of ruminal acidosis if they are 'slug-fed' moderate to high quantities of starch as grain-based concentrates in the feeding bail at each milking. This may occur, for example, during periods of low pasture availability or when seeking to increase milk production or body condition. This contrasts with herds in contained housing systems fed a TMR, which consume starch in smaller, more frequent meals over each 24-hour period. Australian dairy diets frequently rely on wheat and barley, both characterised by rapid ruminal starch fermentation relative to other grains such as oats, maize or sorghum. Some cows within the herd may have access to concentrate feed beyond their allocated amount if other cows do not consume their full grain allocation during milking and refusals are not removed from the bail. Higher concentrate refusals are typically observed among sick cows or recently calved animals, particularly heifers.

Herds in grazing systems may be at additional risk of ruminal acidosis when grazing fodder crops or when fed by-products with high sugar contents.

TMR and PMR scenarios

Situations of elevated ruminal acidosis risk commonly occur in herds fed total mixed rations (TMR) or partial mixed rations (PMR) when diet formulation, the physical characteristics of the ration, or inconsistency in feed access and delivery compromise effective fibre intake. Low dietary forage NDF or inadequate intake of physically effective NDF (peNDF) reduces rumination and saliva secretion, diminishing endogenous buffering of rumen contents and increasing susceptibility to disruption of the balance between ruminal acid production and removal (Mertens, 1997; Zebeli et al., 2012).

Elevated ruminal acidosis risk may also occur if herds are abruptly changed from one type of conserved forage to another (e.g. from sorghum silage to maize silage) or from one source of a particular conserved plant species to another with a higher starch concentration and lower NDF concentration or digestibility. On farms using a hybrid feeding system (grazing/lot feeding), herds are also at risk of ruminal acidosis if transitions are made abruptly, including the transition in early summer from grazed pasture and PMR to TMR and the transition in early autumn from TMR back to grazed pasture and PMR. When TMRs or PMRs are fed, suboptimal particle size distribution promotes feed sorting, typically against longer forage particles and toward smaller, rapidly fermentable fractions. Preferential consumption of fine particles reduces rumination time, disrupts rumen raft integrity and increases diurnal variation in ruminal pH, all of which increase the risk of SARA (Leonardi and Armentano, 2003; Zebeli et al., 2012). Overprocessing of forage fibre further exacerbates this risk by reducing chewing activity and saliva production while increasing fibre fermentability and passage rate. A dietary peNDF concentration of 19 to 23% has been proposed as a general target to minimise acidosis risk without impairing intake or production responses in high-yielding dairy cows (Zebeli et al., 2008).

Ration moisture management is also critical. While adding water to very dry, hay-rich rations may reduce sorting, excessive moisture in silage-based TMRs or PMRs can increase sorting, depress dry matter intake and destabilise fermentation. Monitoring and maintaining TMR dry matter at approximately 45 to 55% supports more consistent intake and rumen function (Leonardi et al., 2005; Miller-Cushon and DeVries, 2009). If the TMR or PMR is delivered once daily, especially in hot weather, rather than twice daily or more, it may dry out over time, thereby increasing the likelihood of cows sorting concentrate ingredients from the more fibrous components of the ration.

In TMR and PMR systems, the physical performance and maintenance of feed mixing equipment are critical determinants of ration consistency and, consequently, rumen stability, health and efficiency. Inadequate maintenance of mixing equipment and poor calibration of mixer scales can lead to inconsistent ingredient distribution, segregation of particles or variable nutrient delivery across the feed bunk, increasing within-herd variation in fermentable carbohydrate intake.

Worn knives, augers or mixing paddles can alter particle size distribution, often leading to overprocessing of forage fibre or incomplete incorporation of long particles, both of which reduce effective fibre intake and increase sorting risk (Leonardi and Armentano, 2003; Zebeli et al., 2012). Inadequate or excessive mixing time can similarly compromise ration structure, with undermixing or overmixing resulting in ingredient segregation and an uneven ration composition along the feed bunk or trough. Overmixing and overprocessing of fibre can also increase the proportion of fine, rapidly fermentable particles.

Dry matter and water intake are strongly correlated, and limited access to drinking water and poor water quality can impair dry matter and forage intake. Feed hygiene and selective intake behaviour also contribute to acidosis risk. Spoiled silage, poorly mixed rations or inadequate

forage particle size may encourage cows to preferentially consume concentrate fractions while rejecting forage, effectively increasing fermentable carbohydrate intake beyond formulated levels and increasing the risk of ruminal acidosis.

The following are therefore critical:

- Close attention to forage and grain processing to optimise ration particle size profiles;
- Regular inspection, maintenance and replacement of mixer components according to the manufacturer's recommendations;
- Use of written best-practice standard operating procedures (SOPs) by all staff mixing rations, with procedures that optimise ingredient loading order, mixing time and load size;
- Regular checks of the particle size distribution of rations using a four-sieve Penn State Particle Separator (PSPS);
- Regular calibration of scales and ingredient loading systems to ensure that systematic over delivery or under delivery of concentrates does not occur;
- Consistent feeding times from day to day, adequate feed-bunk space, access to fresh feed throughout the day and between milkings, and good feed-bunk hygiene to promote more frequent feeding events and reduce feed sorting, thereby improving rumen stability; and
- Free access to good-quality drinking water at all times of day.

a) b)

Figure 21 a), b) New and worn mixer wagon knives. Source: FeedWorks (2026).

The Penn State Particle Separator

The three-sieve Penn State Particle Separator (PSPS), commonly referred to as the Penn State Shaker Box, is regarded as the standard field method for assessing particle size distribution and the adequacy of physically effective fibre in TMR and PMR diets for dairy cattle. The device consists of a stack of three sieves and a bottom pan with decreasing screen sizes (>19mm, 8–19mm, 1.18–8mm and <1.18mm) that separates a representative feed sample based on particle size through a standardised shaking procedure. The proportion of feed retained on each sieve and in the bottom pan provides an objective measure of ration physical structure, which is closely linked to rumination activity, saliva production, rumen raft formation and ruminal pH stability.

Interpretation of PSPS results requires consideration of ration DM and ingredient composition. Higher-DM rations may result in a greater proportion of fine particles collecting in the bottom pan. Conversely, in lower-DM rations, including those containing high proportions of wet by-products such as wet distillers' grains, whey or citrus pulp, and in rations containing sticky ingredients that may prevent particle separation, such as molasses or bakery waste, fewer fine particles may settle into the bottom pan.

Figure 22 The three-sieve Penn State Particle Separator – regarded as the standard field method for assessing particle size distribution and the adequacy of physically effective fibre in TMR and PMR diets for dairy cattle. Source: Penn State University (2026). Reproduced with permission.

Humer et al. (2018) summarised recommended particle size distributions for TMR or PMR rations (Table 3), providing practical benchmarks for assessing whether a ration is likely to support adequate chewing activity and minimise the risk of subacute ruminal acidosis. For more information on how to use the PSPS, refer to www.extension.psu.edu.

Table 3 Recommendations for TMR or PMR particle size distribution when the TMR is composed of ground concentrates (TMR 1), with pelleted concentrates (TMR 2) or the diet is offered as a partial mixed ration (PMR). Source: Adapted from Humer et al. (2018).

Particle fraction	Screen size	TMR with ground concentrates (%)	TMR with pelleted concentrates (%)	PMR (%)
Large particles	>19 mm	3–8	3–8	15–25
Medium particles	8–19 mm	30–40	35–45	35–65
Fine particles	1.18–8 mm	30–40	40–50	15–25
Very fine particles	<1.18 mm	<20	<10	<8

Drought feeding scenario

Drought conditions commonly predispose dairy cows to ruminal acidosis by driving substantial changes in feed availability, particularly forage availability, diet composition and feeding management. Reduced pasture growth and shortages of conserved forage frequently increase reliance on diets containing higher proportions of concentrate to sustain feed intake and milk production. Diets with higher proportions of rapidly fermentable carbohydrates and reduced peNDF increase the risk of ruminal acidosis, particularly when dietary changes occur rapidly in response to feed shortages.

Economic pressures during drought often lead to the use of cheaper or opportunistic feeds, including variable-quality grains and high-risk by-products such as bakery waste or finely processed milling residues. Such feeds can vary widely in starch content, particle size and fermentability, increasing day-to-day fluctuations in ruminal acid load and pH.

Drought conditions are frequently compounded by summer heat stress and limited access to drinking water, both of which further increase susceptibility to ruminal acidosis. Heat stress alters feeding behaviour, reducing meal frequency and promoting slug feeding during cooler periods, resulting in large post-meal acid loads and lower ruminal pH. Concurrent dehydration or restricted water access can reduce saliva production and rumen liquid turnover, impairing buffering and acid clearance.

Table 4 Ruminal acidosis risk: Dietary factors (grazing and contained housing systems)

Factor	LOW Risk (Green Zone)	MODERATE Risk (Orange Zone)	HIGH Risk (Red Zone)
1. Grain type fed	Grain blends containing more than 50% maize or sorghum	Grain blends containing up to 50% wheat or barley	Wheat or barley
2. Grain processing	Coarsely ground (minimal powder seen when fed)	Moderately ground	Finely ground (powder seen when fed)
3. Kilograms of grain fed per cow per feed	Less than 3kg dry matter (grazing systems) OR less than 5kg dry matter (contained housing systems)	3–5kg dry matter (grazing systems) OR 5–8kg dry matter (contained housing systems)	More than 5kg DM (grazing systems) OR more than 8kg DM (contained housing systems)
4. Grain fed as % total DMI	Less than 25% (grazing systems) OR less than 40% (contained housing systems)	25–40% (grazing systems) OR 40–50% (contained housing systems)	More than 40% (grazing systems) OR more than 50% (contained housing systems)
5. Forage:concentrate ratio	More than 60:40	About 50:50	Less than 40:60
6. Low pH silages (pH less than 4) or acid dump feeds (e.g. corn gluten)	Not being fed	Fed up to 20% total DMI	Fed at more than 20% total DMI
7. High starch byproducts (e.g. bread, cereal meal, potatoes)	Not being fed	Fed up to 20% total DMI	Fed at more than 20% total DMI
8. High sugar byproducts (e.g. confectionary waste, molasses)	Not being fed	Fed at more than 10% total DMI	Fed at more than 20% total DMI
9. Turnover of wet feeds (e.g. grape marc, vegetable waste, brewers grains)	Fed within 7 days of delivery to the farm (N/A if not being fed)		Not fed within 7 days of delivery to the farm
10. % NDF in milker diet(s)	More than 36% DM (grazing systems) OR more than 34% (contained housing systems)	32–36% dry matter (grazing systems) OR 32–34% (contained housing systems)	Less than 32% DM
11. Proportion of large particles (greater than 19mm) and medium particles (8–19mm) in milker PMR/TMR	PMR; large particles 15–25%, medium particles 35–65% of DM TMR; large particles 3–8%, medium particles 30–45% of DM	PMR; large particles 10–14%, medium particles 40–70% of DM TMR; large particles 2–5%, medium particles 35–50% of DM	PMR; large particles 5–9%, medium particles 50–80% of DM TMR; large particles 1–3%, medium particles 35–50% of DM
12. % starch of fresh cow diet (up to 40 DIM)	Less than 22% DM	22–24% DM	More than 24% DM

Factor	LOW Risk (Green Zone)	MODERATE Risk (Orange Zone)	HIGH Risk (Red Zone)
13. % starch of early/peak lactation diet (40–100 DIM)	Less than 23% DM	23–27% DM	More than 27% DM
14. % NFC of milker diet(s)	Less than 40% DM	40–44% DM	More than 44% DM
15. Risk-level appropriate rumen modifiers in milker diet(s)	Included at recommended feeding rates/cow/day	Included but unsure if at recommended rates	Included at inadequate feeding rates/cow/day OR not included

Animal factors

Individual animal susceptibility varies according to DM and forage intake, feeding behaviour, physiological stage and rumen adaptation. High-producing cows in early lactation are generally at greatest risk of SARA within a herd because of their high DM intake and requirement for more energy-dense diets, which leads to greater consumption of rapidly fermentable carbohydrates.

During the transition period, the reduction in feed intake around parturition and the shift from dry cow diets (high-fibre, low-concentrate) to lactation diets (low-fibre, high-concentrate) place cows at particularly high risk of rumen dysfunction (Stone, 2004; Lean and DeGaris, 2021). Rapid increases in fermentable carbohydrate intake without sufficient microbial and epithelial adaptation reduce ruminal absorptive and buffering capacity. Cows during the fresh period are particularly vulnerable due to fluctuating intake and metabolic stress during early lactation (Penner et al., 2007; Steele et al., 2016). The risk is increased when the reduction in intake before calving is greater (Humer et al., 2015). In addition, poor transition cow management, excessive loss of body condition and hypocalcaemia can predispose cows to illness and fluctuating feed intake after calving.

Susceptibility to ruminal acidosis differs between primiparous and multiparous cows. Humer et al. (2018) summarised evidence from the literature suggesting that first-lactation heifers are generally at greater risk of SARA than older cows. Compared with older cows, heifers typically have a less adapted rumen, including reduced rumen papillae development and a less mature microbial ecosystem, reflecting limited prior exposure to high-concentrate diets (Penner et al., 2007; Bramley et al., 2008). Heifers may also exhibit lower chewing activity and saliva production, reducing ruminal buffering capacity. Differences in feeding behaviour are also common, particularly when heifers are fed or housed with socially dominant multiparous cows. In such situations, heifers may have reduced access to the feed bunk and consume fewer, larger meals rather than small, frequent meals, a pattern associated with increased SARA risk (Krause and Oetzel, 2006). Consistent with these mechanisms, multiparous cows have been shown to spend less time below critical reticular pH thresholds than primiparous cows during early lactation (Humer et al., 2015), highlighting the need for targeted feeding and management strategies for first-lactation animals.

Disruptions to forage intake without a corresponding decrease in concentrate feed intake represent a major risk for grazing cattle. Oestrous behaviour, social competition, illness or lameness can negatively affect grazing behaviour and forage intake without affecting the slug feeding of starch-based concentrate at each milking, leading to rapid SCFA production and accumulation and acidification of the rumen.

Evidence also indicates substantial between-cow variation in rumination behaviour, saliva production, microbial ecology and rates of SCFA absorption, contributing to heterogeneous SARA risk within herds. Host inflammatory responsiveness and epithelial barrier function may also influence susceptibility, although translation into management practice remains limited (Steele et al., 2016).

Within herds, cows vary considerably in their susceptibility to ruminal acidosis and their responses to readily fermentable carbohydrates, including ruminal pH dynamics, microbial profiles and inflammatory responses, even in well-managed TMR-based systems (Khafipour et al., 2009; Li et al., 2012; Penner and Beauchemin, 2010; Schmitz et al., 2018; Villot et al., 2018; Hartinger et al., 2024). In grazing systems, the susceptibility of some or all cows to ruminal acidosis may be exacerbated by factors including:

- Access to lush, early vegetative pastures during winter and early spring which are highly fermentable, low in peNDF, and high in CP, and high in potassium and chloride which may contribute to decreased rumen motility

- Day-to-day variation in the quantity and quality of pasture offered as paddocks are rotated, with paddocks varying in area, pasture species and sward height
- Reduced pasture quantity and quality during periods of hot, cold or wet weather and other adverse weather events
- Differences between cows in the quantities of grazed pasture, conserved forages and mixed rations consumed due to parity, social rank, milking order and inherent feeding preferences.
- Adjustments made to cows' allocations of grain-based concentrate in the bail at each milking, or residual feed left in the bail by the previous cow
- Limitations in the ability of bail-feeding systems, particularly in older herringbone dairy parlours, to dispense a consistent quantity of grain-based concentrate into each bail at each milking without separation of coarser ingredients, such as grains and protein meals, from finer ingredients, such as minerals, buffers and rumen modifiers.
- Inadequate trough space per cow on a feedpad when cows are fed grains and other highly fermentable feeds within a partial mixed ration (PMR)
- Heat stress

(Bramley et al., 2012, 2013).

Table 5 Ruminal acidosis risk: Animal factors (grazing and contained housing systems)

Factor	LOW Risk (Green Zone)	MODERATE Risk (Orange Zone)	HIGH Risk (Red Zone)
1. Variation in cow liveweight within herd	Less than 100kg	100 to 150kg	More than 150kg
2. Feeding of first-calvers in the herd to account for their higher inherent acidosis risk	First calvers are fed differentially from older cows (grazing systems) OR fed as separate groups (grazing and contained housing system)		First calvers are not fed differently from older cows
3. Feeding of fresh cows and early lactation cows to account for their higher inherent acidosis risk	Fresh and early lactation cows are fed differentially from post-peak cows (grazing systems) OR fed as separate groups (grazing and contained housing system)		Fresh and early lactation cows are not fed differently from post-peak cows

Environmental risk factors

Environmental stressors modify feeding behaviour and rumen fermentation. Heat stress commonly reduces meal size while increasing feeding frequency and saliva loss associated with panting, collectively elevating acidosis risk (West, 2003). Heat-stressed cows tend to eat less during the day and consume larger, more rapid meals at night, causing a rapid peak in fermentation. Physiological responses to heat stress, including respiratory alkalosis and loss of systemic bicarbonate, further compromise acid-base balance and increase the risk of both ruminal and metabolic acidosis. Extreme weather events and mud may similarly disrupt intake patterns and rumination time. Periods of cold, rainy and windy weather can negatively affect grazing behaviour, reducing pasture intake while cows continue to consume their allocated concentrate feed offered in the bail. The resulting imbalance between fibre and fermentable carbohydrate intake increases the risk of SARA.

Table 6 Ruminal acidosis risk: Environmental factors (grazing and contained housing systems)

Factor	LOW Risk (Green Zone)	MODERATE Risk (Orange Zone)	HIGH Risk (Red Zone)
1. Likelihood of cold stress in the coming 4–6 months	Cows will not be exposed to cold, wet, windy weather conditions over the next 4–6 months.	Cows may be exposed to some periods of cold, wet, windy weather over the next 4–6 months without good shelter but are constantly provided with forage.	Cows will be exposed to persistent cold, wet, windy weather conditions over the next 4–6 months without good shelter and lack access to forage for more than 2 hours outside milking times.
2. Likelihood of heat stress	Very unlikely. Warm-hot weather conditions are not expected in the next 4–6 months.	Unlikely. Warm-hot weather conditions are expected, but cows have adequate access to shade and are provided with effective evaporative cooling in the feeding/housing facility and dairy holding yard.	Very likely. Warm-hot weather conditions are expected. Cows have inadequate access to shade and are not provided with effective evaporative cooling in the feeding/housing facility and dairy holding yard.
3. Likelihood of adverse event such as a flood, bushfire, heat wave or power outage in the coming 4–6 months	Very unlikely	Unlikely	Likely

Management risk factors

Management practices such as inadequate mixing, inadequate feed access, inconsistent feed delivery, rapid diet transitions and insufficient trough space amplify the risk of ruminal acidosis. For that reason, ruminal acidosis in Australian systems should be considered a multifactorial and system-dependent disorder.

Irregular feed delivery promotes large meals followed by extended fasting periods, increasing imbalances in ruminal acid production and removal. Larger meals increase the supply of fermentable organic matter beyond the rumen's buffering capacity, while fasting reduces rumination and saliva flow, exacerbating the decline in ruminal pH (DeVries et al., 2005). Increasing feeding frequency or ensuring continuous pasture access reduces meal size and stabilises ruminal fermentation patterns.

Substantial changes to dairy cow diets should be made gradually to allow the rumen time to adapt to the new feed. Abrupt introduction of highly fermentable diets, concentrates, or rapidly fermentable forages is a primary trigger for ARA and SARA in Australian dairy systems. If these changes occur too abruptly and cow responses are not monitored for early warning signs, rumen function, feed intake and animal health may be disrupted, resulting in reduced milk production, ill health and potentially death.

Gradual step-up adaptation allows:

- rumen bacteria to adapt to fermentative conditions
- ruminal epithelial absorptive capacity to increase
- behavioural adjustment of intake patterns

Failure of any of these adaptive mechanisms increases the risk of acid accumulation (Penner et al., 2007; Steele et al., 2016).

Pasture management and the design and maintenance of facilities can affect cow comfort and time budgets, particularly feeding time. Limited feed bunk space, limited access to water points or uneven pasture allocation increases social competition, encouraging slug feeding and selective intake of concentrates (Cook et al., 2004). Dominant cows often consume highly fermentable fractions first, while subordinate cows experience irregular intake, with both situations associated with ruminal instability.

In pasture-based systems, short grazing bouts on highly digestible pasture, especially following restricted overnight allocation, can mimic slug feeding of concentrates. Long walking distances and milking delays may also reduce grazing time and increase meal size.

Management determines the consistency with which diets are delivered and consumed. Consistent feed access and delivery, together with gradual dietary adaptation, remain among the most effective preventive measures for ruminal acidosis (Cook et al., 2004; Plaizier et al., 2008). Voluntary or involuntary periods of feed restriction, such as long periods off feed after milking, calving events, oestrus-related behaviour or extreme weather events, can predispose cows to SARA during refeeding (Albornoz et al., 2013).

Drinking water

Inadequate access to drinking water or poor-quality stock water represents an often-under-recognised risk factor for ruminal acidosis in dairy cows. Water intake is closely linked to dry matter intake (DMI), saliva production and rumen liquid turnover, all of which are critical for maintaining the balance between ruminal acid production and removal. Restriction of water availability or reduced palatability due to high salinity, contamination or off odours has been shown to reduce DMI and alter feeding patterns, increasing the risk of inconsistent intake or slug feeding when water access is restored.

Poor-quality water may further predispose cows to ruminal acidosis through both direct and indirect mechanisms. Elevated salinity, sulphate concentrations or microbial contamination can reduce voluntary water intake and impair rumen function, while some waterborne pathogens and endotoxins may contribute to systemic inflammation and reduce feed intake. Dehydration reduces rumen fluid volume and passage rate, impairing the dilution and clearance of fermentation acids and increasing the likelihood of a decline in ruminal pH.

The interaction between water availability, feeding behaviour and environmental stress further amplifies the risk of ruminal acidosis. During hot conditions, cows have increased water requirements, and any limitation in supply can compound heat stress-related changes in intake patterns, including reduced meal frequency and increased concentrate consumption during cooler periods. Together, poor water availability or quality can undermine otherwise appropriate diet formulation and feeding management, creating conditions that predispose dairy cows to ruminal acidosis.

See Dairy Australia's Drinking Water Access and Quality for further information on providing cattle with adequate access to good-quality drinking water.

Table 7 Ruminal acidosis risk: Management factors (grazing systems)

Factor	LOW Risk (Green Zone)	MODERATE Risk (Orange Zone)	HIGH Risk (Red Zone)
1. Ryegrass leaf stage at grazing	Autumn/winter: ≥ 3 Spring/summer: ≥ 2½	Autumn/winter: 2 to 3 Spring/summer: 1½ to 2	Autumn/winter: 1 to 2 Spring/summer: 1 to 1½
2. Proportion of milker diet that is grazed legumes, herbs or brassicas	Less than 20% diet dry matter	20–40% diet dry matter	More than 40% diet dry matter
3. Proportion of milker diet that is grazed C4 pastures (e.g. kikuyu) or C4 grazed crops (e.g. forage sorghum)	More than 40% diet dry matter	20–40% diet dry matter	Less than 20% diet dry matter
4. Flat rate or differential bail feeding of concentrates in dairy	Concentrates differentially fed (N/A if concentrates not fed in the dairy)		Flat rate fed
5. Quantity over and above the first 6kg grain fed per cow per day in a PMR instead of the dairy	All grain (N/A if less than 6kg DM of grain is fed per cow per day)		No grain
6. Number of times per day cows are bail fed more than 3kg dry matter of grain per feed	3 times per day (N/A if no more than 3kg DM per feed)	2 times per day	Once per day
7. Level of control of quantity of grain/concentrate dispensed to each cow in the bail	Bulk density of each grain batch is measured. Dairy feed system is regularly calibrated.		Bulk density of each grain batch is not measured. Dairy feed system is not regularly calibrated.
8. Amount of separation of feed ingredients and additives occurring in dairy feeding system	Little or no powdered material is evident in any bails	Small quantity of powdered material is evident in some bails	Significant quantity of powdered material is evident in some bails
9. Length of interval between feeding concentrates and forages	Short (less than 30 minutes)	Moderate (30 to 60 minutes)	Long (more than 60 minutes)
10. Cows' access to grazed or conserved forages/PMR when not being milked	Cows always have access to forage when not being milked	Cows sometimes run out of pasture/conserved forage/PMR	Cows always run out of pasture/conserved forage/PMR
11. Cows hungry when given unrestricted access to large amounts of feed in paddock or elsewhere	Never	On some days	Every day

Factor	LOW Risk (Green Zone)	MODERATE Risk (Orange Zone)	HIGH Risk (Red Zone)
12. Frequency of audits on mixer wagon if PMR/TMR being fed	Every 6 months (N/A if mixer wagon is not used)	Once per year	Never
13. Time given to cows to consume supplementary forages/PMR/pasture	All cows have plenty of time		Some cows are pushed off while they are still eating or have reduced quantity and quality feed available to them, e.g. last cows exiting dairy.
14. Adequate space per cow at hay feeder and/or feed bunk	At least 1 metre per cow	0.75–1 metre per cow	Less than 0.75 metre per cow
15. Consistency of daily feeding regime	Very consistent, with little variation in timing of feed bouts and quantities fed from day to day.	Fairly consistent, but timing of feed bouts and/or quantities fed do change 2–3 days per week.	Very inconsistent, with great variation in timing of feed bouts and quantities fed from day to day.
16. Rate of substantial dietary changes, including introduction of new feeds	Substantial dietary changes, including introduction of new feeds, are done gradually, in steps, over a period of at least 14 days.	Substantial dietary changes, including introduction of new feeds, are done within gradually, in steps, over a period of less than 14 days.	Substantial dietary changes, including introduction of new feeds, are done abruptly.
17. Drinking water quality	Testing of water is done regularly, at least annually, and results indicate it is good quality. A water trough hygiene program is in place.	Testing of water is only done on an ad-hoc basis and results have indicated it is of acceptable quality. A water trough hygiene program is not in place.	Water is not tested at all. A water trough hygiene program is not in place.
18. Drinking water access	Cows have access to drinking water points at the dairy entry and exit, along main laneways and in all paddocks. Cow space and water flow rates at all water troughs are sufficient.	Cows have access to drinking water points at the dairy entry and exit, along most main laneways and in most paddocks. Cow space and/or water flow rates at most water troughs are sufficient.	Water access at the dairy, along main laneways and in paddocks is restricted and/or cow space and/or water flow rates at many water troughs are limited.

Table 8 Ruminal acidosis risk: Management factors (contained housing systems)

Factor	LOW Risk (Green Zone)	MODERATE Risk (Orange Zone)	HIGH Risk (Red Zone)
1. Frequency of TMR formulation review using recent feed test results and herd performance data	Weekly	Monthly or only after problems have become apparent	Rarely or never. Formulations remain unchanged, based on assumed values (book values or old forage test results).
2. Frequency of monitoring of forages for % dry matter and spoilage	Weekly	Monthly or only after problems have become apparent	Rarely or never
3. Forage processing management	Forages are harvested and chopped to recommended lengths, and ration particle size profiles are checked monthly with the PSPS vs recommended targets for each sieve	Chop lengths of forages are generally acceptable but can be inconsistent, and are not checked monthly with the PSPS vs recommended targets for each sieve	Forages chop lengths are poorly managed and therefore sub-optimal and inconsistent, and checked only every 6–12 months
4. Grain processing management	Wheat and barley kernels are reduced to 3–4 pieces and maize and sorghum grain are finely ground (<1mm diam.) to optimise ruminal starch availability without resulting in excessively rapid fermentation, and particle sizes are checked each batch	Reduction in the particle size of grains is generally acceptable but can be inconsistent, and is not checked each batch	Grain processing is poorly managed and therefore sub-optimal and inconsistent, and not checked each batch
5. Feed mixer maintenance and mixer scales calibration	Feed mixer manufacturer's maintenance schedule (particularly knife replacement) is strictly followed and mixer scales are calibrated according to manufacturer's recommendations	Feed mixer is maintained on an ad hoc basis and mixer scales are not regularly calibrated	Feed mixer is poorly maintained and the accuracy of the mixer scales is unknown
6. Following of best practice procedures for TMR loading and mixing, and minimisation of between-operator TMR variation	Operators follow best practice, written SOPs and TMR audits are conducted every 3 months	Operators follow SOPs but they are not best practice and/or permit some between-operator variation	Is opportunity for improvement in SOPs for TMR loading and mixing to follow best practice and reduce between-operator variation
7. Consistency of particle size profile within each TMR batch delivered to cows	Highly consistent, as it is checked monthly by collecting a set of 10 samples from along the feed bunk immediately after a feedout and putting through the PSPS. CVs for middle screen and bottom pan found to be less than 5%	Reasonably consistent, as TMR mix consistency is checked every 6–12 months as part of a TMR audit	Unsure. TMR mix consistency is rarely or never checked

Factor	LOW Risk (Green Zone)	MODERATE Risk (Orange Zone)	HIGH Risk (Red Zone)
8. Consistency of TMR feeding times day to day	Very consistent, with TMR delivered to cows each day within 15 minutes of the scheduled feeding times	Fairly consistent, but timing of TMR deliveries to cows do change 2–3 days per week	Very inconsistent, with great variation in TMR feeding times day to day
9. Pen stocking rate	100% or less for fresh cows and less than 115% for other cows	100–110% for fresh cows and 115–120% for other cows	Greater than 110% for fresh cows and 120% for other cows
10. Feed bunk space	At least 0.75 metre per cow	0.5–0.75 metre per cow	Less than 0.5 metre per cow
11. Cows' access to fresh feed throughout each day between milkings	Fresh feed is available along the entire length of the feed bunk almost all day, with frequent feed push-ups (e.g. every 2–4 hours)	Feed is available most of the time but bunks may become empty or feed is out of reach for short periods as feed is only pushed up a few times each day	Feed is unavailable for more than 4 hours each day, as feed is rarely pushed up after delivery
12. Level of feed refusals	2–5% per day	Less than 2%, greater than 5% or very inconsistent	Feed bunks are regularly empty before the next TMR delivery or excessive feed is being wasted
13. Level of feed sorting by cows	Very little. TMR fed and refusals passed through the PSPS less than 5% different in middle screen and bottom pan	A moderate amount. TMR fed and refusals passed through the PSPS 5–10% different in middle screen and bottom pan	A lot. TMR fed and refusals passed through the PSPS more than 10% different in middle screen and bottom pan, indicating cows are leaving long forage and/or selectively eating concentrates
14. Rate of substantial dietary changes, including introduction of new feeds	Substantial dietary changes, including introduction of new feeds, are done gradually, in steps, over a period of at least 14 days	Substantial dietary changes, including introduction of new feeds, are done within gradually, in steps, over a period of less than 14 days	Substantial dietary changes, including introduction of new feeds, are done abruptly
15. Drinking water quality	Testing of water is done regularly, at least annually, and results indicate it is good quality. A water trough hygiene program is in place	Testing of water is only done on an ad-hoc basis and results have indicated it is of acceptable quality. A water trough hygiene program is not in place	Water is not tested at all. A water trough hygiene program is not in place
16. Drinking water access	Cows have access to drinking water points at the dairy entry and exit, along main laneways and in all paddocks. Cow space and water flow rates at all water troughs are sufficient	Cows have access to drinking water points at the dairy entry and exit, along most main laneways and in most paddocks. Cow space and/or water flow rates at most water troughs are sufficient	Water access at the dairy, along main laneways and in paddocks is restricted and/or cow space and/or water flow rates at many water troughs are limited

Conclusion

Ruminal acidosis should be viewed as a whole-farm risk management challenge rather than simply a nutritional disorder. Although diet fermentability and physically effective fibre are the primary determinants of rumen stability, risk is amplified by factors such as feed delivery routines, transition cow management, environmental stress, water availability and individual animal susceptibility. Consequently, no single metric or intervention can reliably predict or prevent acidosis in all situations.

The most successful farms are those that proactively identify and control multiple risk factors simultaneously. Adequate ration formulation, consistent feeding and management practices, gradual adaptation to dietary changes, adequate fibre intake, effective cow grouping and reliable access to feed and water remain the cornerstones of prevention. Understanding how these risk factors interact is the first step in implementing targeted control strategies, which are explored in the following chapter.

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Chapter 4: Prevention and control of ruminal acidosis

Summary of key points:

- Effective prevention and control of SARA require a systems-based approach. Multiple nutritional considerations should be aligned with the dietary, animal, environmental and management risks.
- Key strategies include balancing carbohydrate fermentability, ensuring adequate peNDF, maintaining consistent feeding patterns, and implementing gradual diet transitions.
- Non-antibiotic rumen modifiers may support rumen function and reduce the risk of SARA. Combining additive classes may provide complementary modes of action.
- Virginiamycin is an antimicrobial registered in Australia for the prevention of ruminal acidosis. Where its use is considered appropriate, it may be incorporated into an integrated prevention and management program, used under veterinary oversight and in accordance with the registered label and relevant regulatory requirements. It should not be regarded as a substitute for appropriate nutritional and feeding management.
- Disease prevention through appropriate husbandry, nutrition, biosecurity and health monitoring is a foundational principle of antimicrobial stewardship (AMS).
- In Australia, regulatory requirements governing the prescribing, handling, manufacture and on-farm delivery of stockfeeds and premixes containing scheduled veterinary products must be followed.
- Veterinarians should use the S4 Medicated Feed Order form to authorise a stockfeed or premix manufacturer to supply S4 medicated feed to a farm.

Nutritional management strategies

Effective mitigation of SARA requires multiple nutritional considerations that are aligned with the dietary, animal, environmental and management risks described in Chapter 3. Prevention is consistently more effective and economical than treatment once rumen dysfunction occurs. This chapter discusses a range of nutritional management strategies and interventions that can help maintain a stable rumen environment and support rumen function, while mitigating the risk of ruminal acidosis in Australian dairy production systems. These should be considered alongside the opportunities to address the ruminal acidosis risk factors discussed in Chapter 3.

Feed evaluation and ration formulation

It is clear across all aspects of ruminant nutrition that what isn't measured can't be managed. Routine, timely measurement of feed dry matter and laboratory nutrient analysis are therefore foundational to managing acidosis risk. Some fundamental feed ingredient specifications required for adequate ration formulation are: 1) dry matter; 2) WSC, starch, NFC and NDF concentrations, including their rate and extent of fermentation (e.g. NDFD 30h, 7h in-vitro starch fermentability); and 3) physically effective fibre supply. Suggested diet formulation parameters for the different stages of the lactation cycle are provided in Table 1.

What isn't measured can't be managed. Timely measurement of feed dry matter and laboratory nutrient analysis are foundational to managing acidosis risk.

Regular dry matter measurements of feeds and forages, particularly those with high moisture content or high variability, will reveal the actual diet dry matter and nutrient supply, as well as potential feed intake. Dry matter content of wet feeds such as silage should be measured weekly, and ideally twice a week when feeding highly variable silage or other wet feeds (e.g. wet citrus pulp or distiller's grains). Over- or under-supply of feeds or forages, and therefore increased acidosis risk, can occur when these measurements are not considered.

Balancing carbohydrate fermentability requires good estimates of the carbohydrate fractions in feeds and forages, together with their rates of fermentation. While NDF is recognised as a carbohydrate fraction with slower ruminal fermentability, this is not always the case, as the fermentation rate depends on the feed source and the stage of plant maturity. For example, the NDF fraction from non-forage fibre sources such as ground almond hulls or citrus pulp may have a faster rate of fermentation than the NDF fraction in mature forages. Therefore, the physical effectiveness of NDF in stimulating rumination, salivation and rumen digesta retention depends not only on particle size, but also on the source of NDF. Forage NDF may also have substantial variability in digestibility due to forage type and family, growing conditions and agronomic practices. Laboratory estimates of 24-hour or 30-hour in-vitro or NIR NDF digestibility values can inform the relative rate and extent of NDF fermentability in the rumen of lactating dairy cows. As 24-hour or 30-hour NDF digestibility value increases, we can expect a faster degradability and disappearance of that forage from the rumen, likely reducing its physically effectiveness. Physically effective NDF is a primary biological defence against ruminal acidosis, and diets deficient in peNDF consistently reduce rumen pH and milk fat concentration (Mertens, 1997; Zebeli et al., 2012).

Starch concentration alone does not fully describe the potential acid load of a feed, as starch sources can differ substantially in their rate and extent of ruminal fermentation. Grain type and processing are important determinants of starch fermentability, with rapidly fermented starch sources having greater potential to increase ruminal acid production. A 7-h in-vitro starch fermentability laboratory analysis can provide a useful relative indication of how rapidly starch is likely to be fermented in the rumen and therefore help distinguish feeds or diets with similar starch concentrations but different ruminal fermentation characteristics.

Non-fibre carbohydrates (NFC) provide an estimate of the total non-fibre carbohydrate fraction of a feed and can be useful for assessing the overall supply of potentially rapidly fermentable carbohydrate. At the diet level, NFC concentration can therefore provide an indication of the total fermentable carbohydrate load, although it does not distinguish between individual carbohydrate fractions or their rates of fermentation. NFC should therefore be considered alongside starch, WSC and measures of carbohydrate fermentability when assessing acidosis risk.

Partial replacement of dietary starch with other fermentable feeds, or with higher-energy-density feeds of lower or slower fermentability, represent a valuable strategy for modulating ruminal fermentability, acid load and the risk of acidosis.

Non-forage fibre sources such as almond hulls, beet pulp, soy hulls and citrus pulp may supply fermentable fibre while partially replacing rapidly degradable starch. These ingredients can support rumen function when used to rebalance carbohydrate fractions, although excessive inclusion may still contribute to the overall dietary fermentability load. Their successful use therefore depends on the composition of the whole diet, rather than on assumed intrinsically safe inclusion levels.

Supplemental fats can also partially replace the dietary load of fermentable carbohydrate while increasing or maintaining diet energy density, offering an alternative strategy to lower acidosis risk. Certain lipid sources may also directly influence rumen microbial populations and fermentation pathways. However, excessive fat inclusion can, in some cases, depress fibre

digestion and intake, indirectly compromising rumen function. Practical use therefore requires moderation and consideration of the overall diet composition (Allen, 2000).

Dietary sugars are rapidly fermented to short-chain fatty acids but typically generate less propionic acid and more butyric acid than starch under stable rumen conditions. Butyric acid tends to be absorbed across the rumen wall faster than propionic acid, potentially contributing to slower SCFA accumulation in the rumen. Moderate sugar inclusion may also enhance microbial protein synthesis and intake. However, high total dietary fermentability or sudden increases in sugar supply can still depress rumen pH. High-sugar forages and molasses-based feeds therefore require gradual adaptation and controlled feeding management (Plaizier et al., 2008).

Grain type, processing method and inclusion rate all determine ruminal starch digestion kinetics (Owens et al., 1998; Huntington, 1997; Table 2). This becomes particularly important in Australian dairy systems given their high reliance on wheat and barley grains, which are both highly fermentable starch sources. Strategies to moderate acid load from rapidly fermentable starch sources include:

- partial substitution of rapidly fermentable cereals with slower-fermenting grains (e.g. replacing wheat grain with corn grain)
- partial substitution of rapidly fermentable cereals with non-forage fibre sources (e.g. replacing wheat grain with soybean hulls or almond hulls)
- limiting quantity of starch fed in the dairy per milking (e.g. feeding only 1 kg of cereal grain in the dairy per milking, with the remainder of the grain fed with other ingredients in the PMR)
- coarse rather than fine milling rapidly fermentable cereals (e.g. dry-rolled wheat kernels broken into three to four pieces rather than finely ground wheat; see Table 1 in Chapter 2 for more detail)

Such approaches reduce rapid ruminal acid production and accumulation, thereby improving rumen stability.

Transition cow dietary adaptation

Gradual increases in dietary fermentable carbohydrates over a 2- to 4-week period support microbial and rumen epithelial adaptation during the transition from pre- to post-calving diets, reducing the risk of excessive SCFA accumulation and epithelial damage (Penner et al., 2007). Fresh cows experience a rapid increase in metabolic demand alongside variable feed intake, making this one of the highest-risk periods for SARA. Effective transition cow management aims to minimise metabolic and health disorders, including suppressed appetite associated with hepatic oxidation post-calving, thereby supporting dry matter intake and energy balance. Practical guidance on implementing robust transition cow programs is available through the Dairy Australia transition cow management resource (Lean and DeGaris, 2021).

Nutritional priorities post-calving include:

- maintaining forage intake, particularly long fibre, immediately post-calving
- avoiding rapid changes to diets containing high amounts of rapidly fermentable starch
- supporting rumen epithelial adaptation to the increased fermentability of the post-calving diet by progressively increasing the daily feeding rate of concentrate over the first 14 days post-calving

Table 9 Suggested diet formulation parameters for ~500kg mature cow with 6 500–8 000L (500–615kg milk solids) production per year. Source: Adapted from Lean and DeGaris (2021; Table 5.2).

Parameter	Far-off Dry Cows (-60 days - -21)	Transition (-21 days - calving)	Fresh Cows (0–40 DIM)	Early/Peak Lactation (40–100 DIM)	Mid Lactation (100–200 DIM)	Late Lactation (>200 DIM)
Dry matter content	—	—	—	40–55%	40–55%	35–50%
Neutral detergent fibre % DM (NDF)	>36%	>36%	>32%	28–32%	30–34%	32–36%
Physically effective NDF % DM	30%	25–30%	>20%	>19–21%	>21–23%	>23–25%
Crude protein (CP) % DM	>12%	14–16%	16–19%	16–18%	14–16%	13–15%
Degradability of CP	80%	65–70%	65–70%	60–65%	65–70%	70–75%
Estimated metabolisable energy (MJ ME/kg DM)	10 (9)*	11	11.5–12	11.5–12.5	10.5–11.5	10.5–11
Metabolisable energy intake (MJ/day) ±	90–100	100–120	160–190	180–240	160–200	140–180
Starch % DM	≤18%	18–22%	20–24%	20–27%	18–24%	15–21%
Sugar % DM	≤4%	4–6%	8%	6–10%	5–8%	4–6%
Ether extract % DM (fat)	3%	4–5%	4–5%	4–6% (max ~7%)	3–5%	2.5–4%
Non-Fibre Carbohydrate % DM (NFC)	<28%	<36%	<40%	36–42%	32–38%	28–34%
Calcium % DM	0.4%	0.5–0.7%	0.8–1%	0.8–1.0%	0.7–0.9%	0.6–0.8%
Phosphorus % DM	0.25%	0.25–0.4%	0.4%	0.35–0.45%	0.30–0.40%	0.25–0.35%
Magnesium % DM	0.3%	≥0.45%	0.3%	0.30–0.35%	0.25–0.30%	0.20–0.25%

* Energy requirements depend on body condition score.

Table 10 Ruminal starch availability for different grains and processing methods suitable for different feeding systems. Source: Dr. David Barber (unpublished, n.d.).

		Grain Type					
		Wheat	Triticale	Barley	Oats	Corn	Sorghum
Processing Method	Steam Flaking	High	High	High	High	High	High
	High Moisture Grain	High	High	High	High	High	High
	Hammer mill Fine	High	High	Moderate	Moderate	Moderate	Moderate
	Disc mill Fine	High	High	Moderate	Moderate	Moderate	Moderate
	Micronised Pellets	High	High	Moderate	Moderate	Moderate	Moderate
	Pellets	High	Moderate	Moderate	Moderate	Moderate	Moderate
	Hammer mill Coarse	Moderate	Moderate	Moderate	Moderate	Low	Low
	Disc mill Coarse	Moderate	Moderate	Moderate	Moderate	Low	Low
	Roller milled	Moderate	Moderate	Moderate	Low	Low	Low

Note: Roller mills should be serviced regularly to ensure all grains are processed correctly.

Feeding System Suitability

TMR/PMR based systems where the majority of the grain is fed in the mixed ration

Pasture/PMR based systems where grain is fed in the dairy

Adaptation to new feeds during lactation

Gradual changes to the diet following the transition period are essential for healthy rumen function and optimal productivity. Changes in the lactating cow diet, such as introducing a new type of feed, may require the rumen epithelium and microbial population to change and adapt. However, this process takes time (Penner et al., 2011). Gradual changes to the diet allow time to monitor how cows are responding and to make adjustments, if necessary, before they receive the full amount. Sufficient levels of fibre are essential for healthy rumen function in lactating cows. Large and abrupt dietary changes may temporarily result in insufficient fibre intake, increasing the risk of SARA. Adding substantial amounts of a new feed to the diet may also alter cow feeding behaviour and negatively affect intake. Gradual feed changes allow time to monitor whether fibre intake remains adequate.

Cows need time to adapt to differences in feed palatability, particularly if they have not been exposed to a feed before. Palatability can also affect the amount consumed by individual cows. This can be compounded by unequal access to feed. Varying concentrations of potentially harmful or toxic compounds may also affect palatability. Sometimes cows have to 'learn' to graze certain crops or eat certain feeds if they have not been exposed to them before. Examples include grazed turnips or other brassicas. Slower learners may consume less, leaving more of the new feed available to quicker learners, which may then consume excessive amounts.

In general, a substantial change in diet composition or feeding rate (e.g. more than 1 to 2 kg DM of concentrate or a change in forage source) should be introduced gradually, in steps, over approximately 14 days to provide sufficient time for most rumen adaptation to occur and to monitor and correct any adverse effects. However, this timeframe may need to be longer than 14 days depending on the magnitude of the dietary change, the types of feed used and the risk factors associated with the diet. Before making any substantial dietary changes or introducing

new feed products or feed types, determine the risks and implement appropriate mitigating actions.

Adjusting lactating cow diets

New feeds or substantial changes to lactating cow diets should be introduced in increments of no more than 2 kg DM/cow, using a minimum of three to four steps spread over 14 days. The final steps can be slightly smaller when approaching the maximum amount to be fed. For example, when introducing 6 kg DM of a new feed, and provided no adverse effects are observed during the changeover, begin with 2 kg on day 1, increase to 3.5 kg on day 4, 5 kg on day 7 and 6 kg on day 10.

Changing from a full TMR to a diet consisting only of grazed pasture and concentrate fed in the bail, or vice versa, will require a longer changeover period of about three weeks. Pasture allocation should be changed in steps of about 2 kg DM/cow every three days, while reducing the quantity of TMR and adjusting its composition. Major changes such as these often require a separate intermediate PMR-type diet to be fed midway through the transition to support a seamless changeover to the new diet. When introducing a new concentrate feed, a more conservative approach is recommended, with the amount adjusted by no more than 1 kg DM/cow at each step.

Changing cows from a grazed pasture-based diet to a conserved forage-based diet, as may be necessary in late spring or early summer, should be done gradually over a 14-day period to help keep cows on their target lactation curve. If the changeover occurs over a shorter timeframe, cows may experience a decline in milk or milk solids yield because of reduced feed digestibility associated with disrupted rumen function or reduced daily feed intake.

Cows should be monitored daily while changes to the milker diet are being implemented, using the routine checks described in Chapter 5.

Feeding management to stabilise rumen function

Consistent feed access, delivery and mixing support rumen stability and help prevent ruminal acidosis. Delivering feed to cows at the same time each day and minimising empty bunk periods reduce variability in meal size and help stabilise ruminal fermentation (DeVries et al., 2005). In a TMR system, irregular feed-out and feed push-up schedules can have particularly serious implications for rumen stability, productivity and health. Well-mixed rations reduce selective intake and within-day carbohydrate surges, lowering the prevalence of SARA compared with poorly managed component feeding (DeVries et al., 2009).

In grazing systems, strategies to mitigate the risk of ruminal acidosis may include a combination of nutritional and management interventions:

- Provision of PMR
- Careful selection of energy sources used in carbohydrate supplements
- Provision of supplemental fibrous forage before access to grazed pastures or forage crops
- Gradual increases in grain feeding and the introduction of new feeds and forages
- Reserving fresh pasture for cows arriving late to the paddock
- Minimising time away from pasture

Feed milling and delivery critical control points

Concentrate feed milling, formulation and delivery processes represent important upstream control points that can predispose dairy cows to ruminal acidosis when inconsistencies occur. Errors in milling, ingredient inclusion or mixing can result in rations that deviate substantially from the intended starch concentration and fermentability, or the intended inclusion levels of buffers and additives, increasing the risk of excessive ruminal acid production and accumulation. Monthly reformulations at the feed mill level, if not accompanied by strict ingredient inclusion limits and validation of the finished feed composition, may unintentionally increase the concentration of rapidly fermentable carbohydrates or decrease ruminal buffering capacity, particularly when alternative ingredients are substituted in response to market or supply pressures.

On-farm feed delivery and inventory management errors may further increase acidosis risk by disrupting the consistency of feed intake. Delivery of feed to the wrong silo, short-term feed shortages or abrupt transitions between batches can lead to sudden changes in fermentable carbohydrate intake, which may increase both the severity and duration of subacute ruminal acidosis. Poor forecasting of on-farm feed demand and supply can result in emergency ration changes or over-reliance on concentrates, compounding the risk.

Variability in the physical characteristics of feeds, particularly grain bulk density and particle size, represents an additional feed-mill-level risk factor. Failure to measure and account for bulk density differences among incoming grain loads can result in substantial errors in nutrient delivery when feed is dispensed on a volumetric basis, increasing variation in starch intake and the risk of ruminal acidosis. Monitoring the bulk density of each load of grain or mixed feed delivered to the farm is necessary to ensure that:

- the bulk density of each load delivered conforms to the supplier's specification
- the intended quantity of grain or mixed feed is consistently fed per cow per day

A rapid check of bulk density can be conducted using a container of known volume (e.g. 1 L) and measuring the weight of feed required to fill it, after taring the empty container on electronic scales.

At the point of feeding, infrequent calibration of the in-parlour feed delivery system may further magnify these inconsistencies, leading to unintended overfeeding of concentrates. Each week, the quantity delivered by the feeding system into each bail should be checked and adjusted if it is not within 5% of the intended amount. Together, these feed-milling and delivery failures can undermine otherwise well-formulated concentrate feeds and rations and create conditions that are highly conducive to ruminal acidosis.

Rumen modifiers

In addition to nutritional management strategies, some feed additives are proposed to support healthy, stable rumen function through mechanisms including stabilising rumen pH, modulating microbial populations and influencing fermentation dynamics. However, evidence that these effects consistently translate into a reduced risk of SARA or improved animal performance varies among rumen modifier classes and products. Their efficacy may also vary with prevailing dietary, animal, environmental and management factors, and different rumen modifiers may be more appropriate under different conditions. The strength and independence of the evidence supporting their use also vary.

It is critical to emphasise that there are no “silver bullet” solutions, and that the effectiveness of rumen modifiers depends on sound nutrition and management as the foundation for optimal animal performance.

The primary drivers of rumen stability remain:

- adequate physically effective fibre supply
- controlled intake and appropriate balance of rapidly fermentable carbohydrates
- consistent feed access and feeding management, with appropriate dietary adaptation

Numerous commercially available rumen modifiers are promoted for their potential to support rumen function and reduce the risk of SARA. These products differ substantially in their active ingredients, mechanisms of action, formulations and supporting evidence. This guideline evaluates evidence at the level of rumen modifier classes and biological mechanisms rather than individual commercial products. The absence of discussion of a specific product should not be interpreted as evidence for or against its efficacy. Nutrition professionals should consider product registration and safety, as well as the quality, relevance and independence of the peer-reviewed research evidence supporting individual products, particularly evidence generated in lactating dairy cows under conditions representative of SARA risk in TMR and/or grazing systems. When selecting rumen modifiers to reduce the risk of acidosis, a critical evaluation of regulatory compliance and evidence-based efficacy should, at a minimum, follow the approach described below under “Evaluating commercial rumen modifier feed additive products”.

Buffers, alkalinisers and silicate clays

Buffers, alkalinisers and silicate clays are used as nutritional interventions to help manage rumen pH. While often grouped together, their effectiveness in managing SARA varies according to their mode of action, source, physical characteristics and inclusion rate.

Rumen buffers

True buffers, such as sodium bicarbonate, resist changes in rumen pH through reversible acid-base reactions. They dissociate in rumen fluid to provide bicarbonate ions, which bind hydrogen ions produced during feed fermentation. This process forms carbonic acid, which equilibrates with carbon dioxide and water, effectively neutralising acid without markedly increasing rumen pH.

Proposed modes of action include:

- resisting rapid declines in rumen pH during periods of high acid production
- complementing the natural buffering capacity provided by saliva
- improving conditions for fibrolytic bacteria that are sensitive to low rumen pH

Research indicates that buffers can improve rumen pH stability and increase the daily pH nadir, reduce the time spent below critical pH thresholds, improve fibre digestibility and rumen function, and potentially increase dry matter intake under acidotic challenge (Shaver et al., 1988; Krause and Oetzel, 2006). Responses vary according to diet, feeding system and inclusion rate. However, sodium bicarbonate may be unpalatable at high inclusion rates, particularly when fed in dairy bail-feeding systems rather than incorporated into a TMR or PMR.

Marine-derived buffers may have potential benefits related to their slower solubility and mineral composition, including lower concentrations of some inflammatory biomarkers and improved production outcomes in both grazing and housed systems. However, the evidence is product-

specific, and responses vary among products, diets and feeding systems (Neville et al., 2019; Neville et al., 2022; Rafferty et al., 2019).

Typical inclusion rates are:

- sodium bicarbonate: 0.8–1.0% of dietary DM (150–250 g/cow/day)
- marine-derived calcareous algae: 0.4–0.6% of dietary DM (75–130 g/cow/day)

Rumen alkalinisers

Alkalinisers, such as magnesium oxide (MgO), act through a different mechanism. They irreversibly bind hydrogen ions, directly increasing rumen pH and providing an alkalinising effect while also supplying magnesium.

Proposed modes of action include:

- increasing baseline rumen pH
- providing additional acid-neutralising capacity
- supplying magnesium for ruminal absorption and systemic metabolism

The effectiveness of magnesium oxide depends largely on its reactivity and solubility. Highly reactive MgO sources dissolve more rapidly in the rumen and are generally more effective at increasing rumen pH and supplying magnesium, whereas poorly soluble products may bypass the rumen to a greater extent and provide less ruminal benefit (Khiaosa-Ard et al., 2023). The reactivity of MgO samples can be assessed against a supplier's specification using the citric acid reactivity test conducted by a specialised laboratory. Lower reactivity levels may require higher product inclusion rates to achieve an effective ruminal alkalinising response. Typical inclusion rates for magnesium oxide are 0.2–0.25% of dietary DM (35–60 g/cow/day).

Limestone is an effective calcium source but is generally not regarded as an effective rumen buffer or alkaliniser because of its low solubility and limited acid-neutralising capacity under ruminal conditions (Cruywagen et al., 2015).

Silicate clays

Silicate clays, such as sodium bentonite, differ fundamentally from true rumen buffers and alkalinisers. Their proposed effects relate primarily to adsorption and ion-exchange properties rather than direct acid neutralisation.

Proposed modes of action include:

- providing ion-exchange capacity within the rumen
- adsorbing moisture and selected compounds
- influencing rumen digesta characteristics

Evidence supporting the use of silicate clays to reduce the risk of SARA is limited (Sulzberger et al., 2016). A critical limitation is that silicate clays such as bentonite do not function as true rumen buffers and have little direct acid-neutralising capacity. Furthermore, the inclusion rates associated with potential benefits (1.5–2 % of the diet) are substantially higher than those typically used for conventional rumen buffering or alkalinising agents. Consequently, silicate clays are not generally considered primary interventions for maintaining rumen pH or preventing SARA, although they may provide ancillary benefits under specific feeding conditions (Dairy Australia, 2020).

Pre-, pro- and post-biotic rumen modifiers

Biological rumen modifiers are proposed to influence rumen function primarily through effects on microbial populations, fermentation and, in some cases, epithelial responses, rather than through direct chemical buffering. Their effects are generally more variable and dependent on the specific product, diet and feeding conditions than those of buffers.

Prebiotics

Prebiotics do not contain live microorganisms; they are substrates that are selectively utilised by host microorganisms. Examples include inulin, fructo-oligosaccharides, mannan-oligosaccharides and β-glucans.

Proposed modes of action include:

- selectively stimulating potentially beneficial rumen microorganisms
- influencing ruminal fermentation pathways
- supporting microbial populations associated with fibre digestion and favourable rumen function

Evidence supporting the use of prebiotics to reduce the risk of SARA in dairy cattle is currently limited. Although some studies have reported favourable changes in rumen microbial populations or fermentation characteristics following supplementation with individual prebiotic products or combinations of prebiotics and probiotics, responses have varied considerably among studies, products and feeding conditions (Uyeno et al., 2015; García Díaz et al., 2018). These findings should not be generalised across all prebiotic products.

Probiotics

Probiotics are live microorganisms that, when administered in adequate amounts, are intended to confer a benefit on the host. In ruminant nutrition, probiotic products may contain live yeasts or selected bacterial species and strains. Products containing enzymes, crude microbial extracts or fermentation products should be distinguished from probiotics unless they also contain viable microorganisms. The term “direct-fed microbial” is commonly used for products containing live, naturally occurring microorganisms.

Proposed modes of action include:

- Maintaining anaerobic rumen conditions through oxygen scavenging
- Stimulating fibrolytic bacteria
- Promoting lactate utilisation and reducing lactate accumulation
- Supporting more favourable patterns of ruminal fermentation

Evidence supporting the use of probiotics to reduce SARA risk is variable and appears to depend on the microbial species, strain, viability, dose, product formulation and feeding conditions (Guedes et al., 2008; Seo et al., 2010; Ban and Guan, 2021). Positive responses have been reported for some products under particular feeding conditions; however, results have not been consistent across studies. Consequently, there is insufficient evidence to support broad recommendations for SARA prevention across all probiotic products.

Postbiotics

Postbiotics are preparations of inanimate microorganisms and/or their components that are intended to confer a benefit on the host. Most postbiotic preparations include microbial fermentation products containing biologically active metabolites; however, composition may vary among products.

Proposed modes of action include:

- stimulating fibrolytic rumen microbes
- supporting rumen epithelial integrity and barrier function
- modulating inflammatory responses associated with ruminal dysfunction

Some studies have reported improvements in specific measures of rumen fermentation, fibre digestibility, epithelial function and inflammatory responses following supplementation with selected microbial fermentation products under SARA challenge conditions in dairy cows (Allen and Ying, 2013; Guo et al., 2022; Guo et al., 2024). However, the available evidence is limited and product-specific, and findings for one formulation should not be extrapolated to other products within this broad category. There is currently insufficient evidence to support broad recommendations for SARA prevention across all postbiotic products.

Phytogenic rumen modifiers

Phytogenic additives comprise a diverse group of plant-derived compounds, such as essential oils, tannins, saponins and plant extracts.

Proposed modes of action include:

- modifying the activity of selected rumen microorganisms
- potentially slowing starch degradation and SCFA release
- reducing ruminal protein degradation and ammonia production
- influencing ruminal fermentation pathways

Evidence supporting the use of phytogenic additives to reduce the risk of SARA remains limited and inconsistent. Responses vary according to the active compounds, inclusion rate, diet composition, product formulation and management system (Ahmed et al., 2022). While some individual compounds and products have produced favourable responses under experimental conditions, these findings should not be generalised across the broad category of phytogenic additives. Further independent research in lactating dairy cattle under commercially relevant feeding conditions is required before broad recommendations can be made.

Stacking solutions

Buffers and alkalinisers are often used together because they act in complementary ways on rumen pH. Buffers primarily reduce the magnitude of post-feeding declines in rumen pH, whereas alkalinisers help maintain a higher baseline rumen pH. When used appropriately, this combination may improve rumen pH stability, support fibre digestion and reduce the severity of an acidotic challenge (Bach et al., 2018; Bach et al., 2023). However, the inclusion rates required to maximise efficacy may exceed practical delivery and cow intake limits, particularly in bail-feeding systems.

Combining rumen modifiers from different classes may also provide complementary effects. For example:

- buffers and alkalinisers may improve rumen pH stability
- buffers combined with pro- or postbiotics may support both pH control and microbial modulation
- pro- or postbiotics combined with phytogenics may provide broader modulation of ruminal fermentation.

The benefits of combining rumen modifiers depend on the underlying diet, feeding system and management, and combinations should be selected according to the specific risks and objectives of the herd.

Ionophore antibiotics

Ionophores (e.g. monensin and lasalocid) are polyether carboxylic acids produced by *Streptomyces* species that act as alkali-metal ion carriers across biological membranes. In ruminants, oral absorption of monensin is partial (~50%); absorbed monensin is extensively metabolised in the liver, and excretion occurs primarily through the bile and faeces. Ionophores transport sodium and other cations across cell membranes in exchange for potassium or protons, disrupting transmembrane ion gradients and lowering intracellular pH in sensitive organisms. In the rumen, this preferentially suppresses susceptible Gram-positive bacteria, including some lactate-producing species, and may affect some protozoal populations, resulting in changes to the ruminal microbial community (Dowling and Baptiste, 2024). Reported functional effects include:

- reduced growth or activity of some lactic-acid producers (e.g. Streptococcus bovis and Lactobacillus spp.), which may reduce D- and L-lactate concentrations and moderate declines in rumen pH during experimental carbohydrate challenges
- changes in the ruminal SCFA profile, typically towards a greater proportion of propionate and lower proportions of acetate and butyrate, which may improve the efficiency of dietary energy use
- reduced ruminal methane production, altered feed intake dynamics and, under some feeding and management conditions, improvements in feed efficiency or production outcomes.

Monensin and lasalocid have both been reported to reduce the severity of experimentally induced ruminal acidosis or associated metabolic disturbances (Duffield et al., 2008), and ionophore supplementation has been associated with improved production outcomes in some studies (Rezaei et al., 2023). Ionophores may reduce the abundance or activity of key lactate-producing rumen bacteria in vitro and in vivo, thereby limiting lactate accumulation when animals are exposed to high-starch challenges. Some experimental challenge studies have reported higher rumen pH and lower D- and L-lactate concentrations when ionophores were provided before the challenge (Nagaraja et al., 1985). Responses may vary with the ionophore, dose, formulation, diet, animal population and experimental model.

The ionophores are listed by the Australian Strategic Technical Advisory Group on Antimicrobial Resistance (ASTAG) as low importance antimicrobials to human AMR because they are not used therapeutically in people. Recent studies, however, have identified ionophore-resistance determinants (e.g. narA/narB encoding the NarAB transporter) on mobile genetic elements that co-occur with clinically important resistance genes (e.g. vancomycin, macrolide, tetracycline determinants) in *Enterococcus faecium* and other species (Frederiksen et al., 2024). These findings have raised a theoretical concern that exposure to an ionophore could, under particular circumstances, co-select for a mobile genetic element carrying additional resistance genes. However, the relevance of these findings to monensin or lasalocid use in dairy cattle, and their implications for human health, have not been established.

Reduced susceptibility to monensin has been induced in *Staphylococcus aureus in vitro* (Warsi et al., 2024) but without clear cross-resistance to therapeutically important agents; the clinical significance of this is uncertain. The overall evidence base is evolving. At present, there is no clearly demonstrated causal association between the use of monensin or lasalocid in cattle

and loss of antimicrobial efficacy in human medicine. Nevertheless, the potential ecological effects of ionophore use, including possible co-selection involving mobile genetic elements, warrant continued surveillance and research.

Practical prescribing guidance for veterinarians

Although experimental evidence indicates that ionophores may moderate some changes associated with ruminal acidosis, products containing monensin or lasalocid should be used only in accordance with their current APVMA-approved label directions. Prevention or treatment of ruminal acidosis should not be inferred as a registered indication unless it is expressly included on the label of the particular product. Appropriate nutritional and feeding management remain the priority for reducing herd risk of ruminal acidosis.

Depending on the active constituent, formulation and product, registered label claims may include the prevention, treatment or control of specified conditions. Examples relevant to dairy cattle may include:

- monensin at 250–300 mg/cow/day for ketosis and bloat control in lactating dairy cattle
- lasalocid for coccidiosis control in calves at 1 mg/kg bodyweight/day

Registration status, approved claims, dose, method of administration, contraindications, withholding periods and other directions vary among products and may change. The current APVMA-approved label should therefore be consulted before recommending or using any product.

New EU rules on the use of ionophores

The Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) has issued advice to Australian livestock industries regarding the use of antimicrobials for growth promotion or increased yield in animals whose products are intended to enter the European Union (EU) supply chain from September 2026. This change will affect all Australian dairy products, as Australia does not currently implement a segregated production system for dairy exports to the EU.

Under these requirements, antimicrobials (such as monensin and lasalocid) must not be administered for the purpose of promoting growth or increasing yield in animals supplying the EU market. The requirements apply to the purpose for which the antimicrobial is used, rather than prohibiting all uses of products containing particular active constituents.

Use for a legitimate disease prevention, control or treatment purpose remains permissible, provided it is consistent with the registered product label and applicable supply-chain requirements. Farmers should also comply with any directions provided by their milk processor, exporter or quality-assurance program.

DAFF recommends that dairy farmers prepare for this change by:

- reviewing all antimicrobial products used or included in feeds and supplements to ensure they are only used for disease control or prevention.
- consulting with veterinarians or nutrition advisors for guidance on complying with new EU rules, if necessary.
- recording the reason for use of any veterinary drugs or feed additives. The reason for using the product may be ‘to prevent or control disease’. Alternatively, farmers can include the

disease listed on the label (e.g. to prevent bloat, treat coccidiosis). These records may be audited by the EU during regular audits of Australia's export systems.

In addition to these DAFF recommendations, farmers should maintain clear and accurate records of the product used, animals treated, date and duration of use, dose, and reason for use. The recorded reason should accurately describe the disease-related purpose and, where applicable, align with the condition specified on the registered product label.

For questions about the above, please contact the department by email at exportstandards@daff.gov.au.

Non-ionophore antibiotics

Virginiamycin

Virginiamycin is an antimicrobial registered by the APVMA with a label claim to "reduce the risk of acidosis caused by high levels of grain in the feed". Virginiamycin is a streptogramin-class antibiotic active principally against Gram-positive bacteria. Systemic absorption of virginiamycin from the gastrointestinal tract is minimal when virginiamycin is administered in feed, so its primary effects in cattle are local to the alimentary tract (Maboni and Gressler, 2024).

Controlled trials and field experience indicate that virginiamycin can reduce the proliferation of lactic-acid producing rumen bacteria, thereby reducing lactate accumulation and helping to maintain ruminal pH during abrupt dietary change to high grain feeding (Coe et al., 1999; de Araújo et al., 2016**)**. This effect underpins its use as a short-term preventive option in high-risk situations, such as feeding during floods or droughts, and the introduction or reintroduction of cattle to high grain-based diets, where a progressive dietary adaptation is not possible (House et al., 2024). These are scenarios in which rapid shifts in fermentable carbohydrate intake can favour lactic-acid producing bacteria and precipitate ARA. Under most circumstances, appropriate nutritional and feeding management should remain the primary preventive approach, and the need to use virginiamycin should be uncommon in dairy production. Any use should comply with the current APVMA-approved product label and relevant veterinary, quality-assurance and supply-chain requirements.

Use of virginiamycin as a feed additive may result in the selection of resistant faecal enterococci with cross-resistance to a related streptogramin antibiotic, quinupristin-dalfopristin, which may be used in human medicine for the treatment of vancomycin-resistant enterococci and other hard to treat infections. Selection pressure from virginiamycin in animal feed has been associated with increased carriage of streptogramin-resistant enterococci and staphylococci in animals (Welton et al., 1998; Werner et al., 1998; Hayes et al., 2001; Soltani et al., 2000). Such bacteria may potentially colonise humans or transfer resistance determinants to bacteria of human health importance (Lu et al., 2002). Studies have reported potential cross-resistance (Hershberger et al., 2004) or co-selection (Aarestrup et al., 2000; Werner et al., 2000) that may reduce susceptibility to clinically important agents, such as quinupristin□dalfopristin and pristinamycin, last□line streptogramin therapies in human medicine for some multi□resistant Gram□positive infections (including vancomycin□resistant *Enterococcus faecium* and certain resistant *Staphylococcus aureus* infections).

Pristinamycin is also a streptogramin used in human medicine for the treatment of infection with multi-resistant *Staphylococcus aureus* and some other Gram-positive anaerobic organisms resistant to other agents, or when other agents are contraindicated or not tolerated by patients (Reid et al., 2010). The clinical importance of pristinamycin for some patients, together with the potential for cross-resistance within the streptogramin class, is relevant to the

listing of virginiamycin by the Australian Strategic Technical Advisory Group on Antimicrobial Resistance (ASTAG) as a high importance antimicrobial.

Practical prescribing guidance for veterinarians

Prior to prescribing virginiamycin, veterinarians should investigate nutritional and feeding management options and consider alternative rumen modifiers. When its use is indicated, the virginiamycin product label states that it must be used in accordance with the AVA Code of Practice for Prescription and Use of Products which Contain Antimicrobial Agents. Virginiamycin is also subject to a label restraint that prohibits off-label use.

The *Antimicrobial Prescribing Guidelines for Dairy Cattle* (House et al., 2024) recommend the following risk management framework when virginiamycin is prescribed for the prevention of ruminal acidosis, consistent with the label claim to "reduce the risk of acidosis caused by high levels of grain in the feed":

- Administer virginiamycin for a period no longer than 28 days, no more frequently than once per year, and specifically for transitioning animals to a high grain diet or during periods with a high risk of acidosis.
- Only prescribe virginiamycin to a specific group of cattle that are identifiable in the clinical records of the veterinarian.
- The prescribing veterinarian must undertake a retrospective review of farm records on the use of the product containing virginiamycin to ensure compliance with prescribing instructions.
- Off-label use of virginiamycin is prohibited (as per the label constraints)

The recommended daily dose for lactating dairy cows is 0.5 mg/kg body weight.

ASTAG antibacterial importance ratings

The Australian Strategic and Technical Advisory Group on Antimicrobial Resistance (ASTAG) is a national expert advisory body that develops and provides advice on antimicrobial resistance-related issues to the Australian Government.

ASTAG publishes *Australia's Importance Ratings and Summary of Antibacterial Uses in Human and Animal Health in Australia* (Australian Strategic and Technical Advisory Group on Antimicrobial Resistance, 2018). The Antibacterial Importance Ratings table within this document categorises each antibacterial as being of 'High', 'Medium' or 'Low' Importance for the mitigation of antibacterial resistance. The ratings reflect the potential severity of the consequences if resistance develops or increases; they do not, by themselves, indicate the likelihood that resistance will occur.

High-importance antibacterials are those that are essential for the treatment or prevention of infections in humans and for which there are few or no treatment alternatives. These have also been termed "last resort" or "last line" antibacterials by the Australian Strategic and Technical Advisory Group on Antimicrobial Resistance (2018). Virginiamycin is classified as an antibacterial of High Importance in Australia. Although virginiamycin is not used in humans, ASTAG notes that its use in animals has the potential to select for cross-resistance to antibacterials used in humans. Virginiamycin belongs to the streptogramin class. Other

members of this class listed by ASTAG include pristinamycin and quinupristin–dalfopristin, both of which may be used in human medicine and classified as being of High Importance.

The *Antimicrobial Prescribing Guidelines for Dairy Cattle* (House et al., 2024) provide specific guidance on the judicious use of virginiamycin in the prevention of ruminal acidosis.

More information is available in the Importance Ratings and Summary of Antibacterial Uses in Human and Animal Health in Australia | Antimicrobial resistance

Tylosin

Tylosin is a macrolide antibiotic produced by *Streptomyces fradiae* that binds reversibly to the 50S ribosomal subunit and inhibits translocation and peptide chain elongation. It is rated as an antibacterial of low importance under the Australian ASTAG rating system but is listed as an antibacterial of high importance by the World Health Organisation (WHO). Tylosin reduces populations of certain Gram-positive and lactic acid-producing organisms in the rumen (Nagaraja et al., 1997; Golder et al., 2023). At routine concentrations, it is predominantly bacteriostatic, although bactericidal activity can occur against highly susceptible organisms or at high concentrations. Tylosin has activity similar to that of erythromycin but is particularly active against many *Mycoplasma* spp. Oral tylosin has poor systemic bioavailability in cattle, meaning that much of the administered dose remains in the gastrointestinal tract, including the rumen, and residues can be recovered from manure (Amarakoon et al., 2016; European Agency for the Evaluation of Medicinal Products [EMEA], 1997; Joint FAO/WHO Expert Committee on Food Additives [JECFA], 2009). This pharmacokinetic profile explains both its effects within the gastrointestinal tract and the selection pressure it may exert on enteric bacteria.

While tylosin is not used in humans, its use may select for resistance to macrolides used clinically in humans, such as erythromycin and clarithromycin, and may contribute to the dissemination of mobile resistance genes (Cazer et al., 2020).

Practical prescribing guidance for veterinarians

In Australia, tylosin is registered to reduce the incidence of liver abscesses in cattle. Liver abscesses may occur following damage to the ruminal epithelium associated with ruminal acidosis. Studies have reported reductions in liver abscess prevalence of approximately 40–70% (Nagaraja & Chengappa, 1998). Tylosin is not registered by the APVMA for the prevention of ruminal acidosis.

Considerations for in-feed antimicrobial use

Antimicrobial resistance (AMR) is recognised as a global health priority due to its adverse effects on public health, animal health and welfare, animal production and the economy (House et al., 2024). AMR occurs when microorganisms, particularly bacteria, develop the ability to survive exposure to antimicrobials that would normally inhibit or kill them, reducing the effectiveness of treatments for infections in humans and animals. AMR threatens human and animal health by increasing morbidity, mortality and costs, while the development of new antimicrobial drugs remains limited.

Awareness of AMR among Australian dairy veterinarians has grown, driven by the prioritisation of antimicrobial stewardship (AMS) by the Australian Veterinary Association, the establishment of the National Centre for Antimicrobial Stewardship (NCAS), the publication of dairy cattle

prescribing guidelines (House et al., 2024), greater professional engagement with AMS guidance in veterinary practice, and the AMR Vet Collective's online courses on antimicrobial use and stewardship (Hardefeldt and Thursky, 2024).

Disease prevention through appropriate husbandry, nutrition, biosecurity and health monitoring is a foundational principle of AMS. Whilst there is no generally accepted definition of what constitutes appropriate antimicrobial use, the Australian Dairy Industry Council, through the Australian Dairy Sustainability Framework, has committed to "using as little as possible, as much as necessary to protect the health and welfare of animals, humans and the environment". Appropriate use of antimicrobials requires consideration of whether antimicrobial treatment is indicated for each condition and, when treatment is required, selection of the appropriate antimicrobial, dose, duration and route of administration to maximise clinical efficacy and minimise the risk of adverse events, including selection for or contribution to antimicrobial resistance. Appropriate use of antimicrobials also recognises the importance of complying with legal requirements to avoid residues in animal products.

Drawing on the Antimicrobial Prescribing Guidelines for Dairy Cattle (House et al., 2024), relevant principles include:

- consider whether evidence-based, non-antibiotic management or treatment options are appropriate for the indication.
- establish and maintain a bona fide veterinarian-client-patient relationship.
- undertake an accurate and appropriate diagnostic workup.
- develop and regularly review a therapeutic plan that considers intended outcomes.
- use all antimicrobial agents, including those considered important for the treatment of refractory infections in human or veterinary medicine, only after careful review and reasonable justification.
- use antimicrobial products in accordance with approved label directions or, where legally permitted, the directions of the prescribing veterinarian, and for an appropriate duration to achieve the therapeutic objective.

Antimicrobial use should not substitute for appropriate animal husbandry, nutrition, disease prevention or veterinary care. Where antimicrobial treatment is being considered, relevant husbandry and management factors should also be reviewed.

Australian Veterinary Association Policy

The Australian Veterinary Association's Policy on use of antimicrobial drugs in veterinary practice (AVA, n.d.) states that:

- Veterinarians must use antimicrobials judiciously, in order to provide optimal healthcare for their patients, reduce the development of antimicrobial resistance (AMR) and preserve these critical medicines for future use.
- Veterinarians should stress to owners the importance of routine preventive healthcare, animal husbandry techniques and infection control procedures to reduce the risk of disease and therefore reduce the need for antimicrobial therapy.
- Infection control procedures and high standards of hygiene should be implemented in veterinary practice.

- Veterinarians should prescribe according to published, evidence-based therapeutic antimicrobial guidelines, where available.

Additionally, the AVA states that antimicrobials should only be used in food-producing animals when their use will result in improved animal health and welfare. Veterinarians should avoid using antimicrobials considered highly important to human health by ASTAG in food-producing animals if at all possible. Ideally susceptibility testing should be performed to ensure that an antimicrobial with a high importance rating is the only option for effective therapy (AVA, n.d.).

For more information: Use of antimicrobial drugs in veterinary practice - Australian Veterinary Association

Regulation of antimicrobials in Australia

In Australia, the process by which stockfeeds and premixes, including those containing scheduled antibiotic rumen modifiers, are handled, manufactured and delivered to farms is complex. Commercial feed mills are required to comply with different regulatory requirements across multiple jurisdictions. Three key aspects are: (1) licensing of stockfeed mills to manufacture medicated feeds, including the nomination of a management representative for each feed mill or site; (2) management of veterinary prescriptions for Schedule 4 and Schedule 6 antimicrobials; and (3) labelling of medicated feed products (Edwards, 2019).

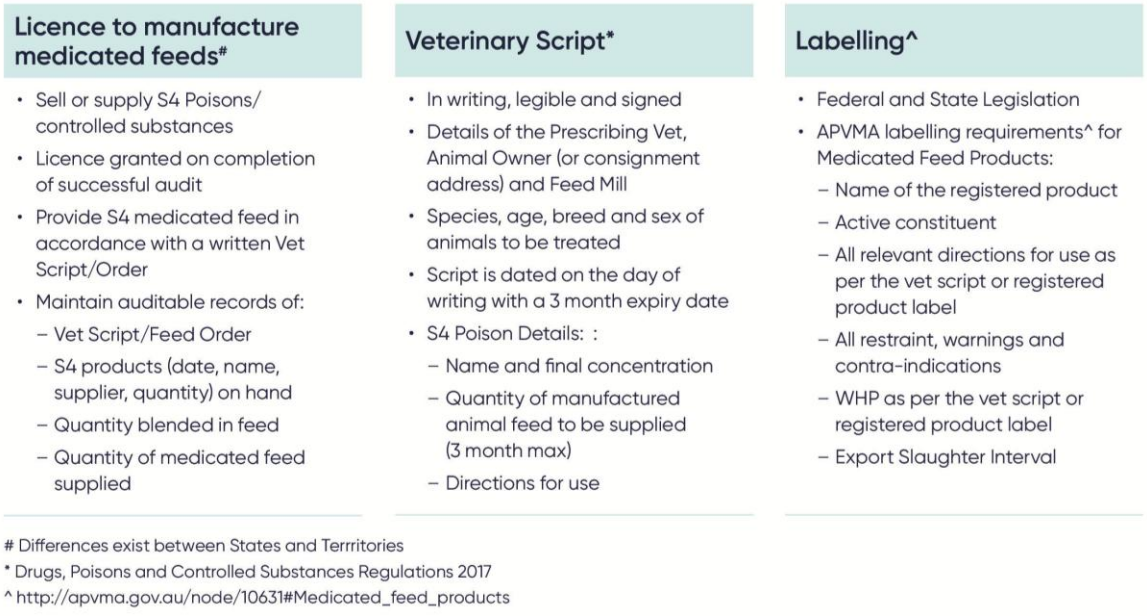

Figure 23 Regulatory requirements for a commercial feed mill licensed to manufacture schedule medicated feeds in Victoria, Australia. Source: Edwards (2019).

It is essential that manufacturers of stockfeeds and premixes containing medication, particularly scheduled veterinary chemical products such as ionophore antibiotics or non-ionophore antibiotic rumen modifiers, have the necessary equipment, operational expertise, processes and administrative capabilities to ensure that:

- veterinary chemical products are handled safely from the point of receipt at the feed mill through to the delivery of the medicated feed to the farm
- stockfeed and premix batch sequencing and production-line flushing protocols are in place to minimise the risk of feed cross-contamination
- veterinary chemical products are evenly distributed throughout each batch of stockfeed or premix at the correct inclusion rate.

Pelleted premixes are preferred to powdered premixes where appropriate because they are easier to handle and, when incorporated into a grain mix or mixed ration, are more likely to remain evenly distributed.

When stockfeeds and premixes are used as vehicles for administering antibiotics and other medications to animals, it is essential that feed mills have robust quality-assurance systems in place. FeedSafe® is a program designed to strengthen the Australian stockfeed industry's commitment to quality assurance and risk mitigation in the manufacture and use of animal feeds. It is based on the principles of Good Manufacturing Practice. To attain FeedSafe® accreditation, stockfeed and premix manufacturers are required to implement a hazard analysis and critical control point (HACCP) system and undergo independent, annual, third-party audits to verify that minimum standards are met in relation to:

- premises and mill buildings
- personnel training and qualifications
- plant and equipment
- raw material security, sourcing and purchasing
- raw material quality and storage
- feed formulation and manufacturing
- product labelling
- supply chain logistics
- product inspection, sampling and testing
- customer complaint investigation.

The S4 medicated feed order is a form used by a veterinarian to authorise a stockfeed or premix manufacturer to supply S4 medicated feed to a farm. The current version of the form was developed and designed by Agriculture Victoria, the University of Melbourne, the Asia-Pacific Centre for Animal Health and the National Centre for Antimicrobial Stewardship (Figure 24).

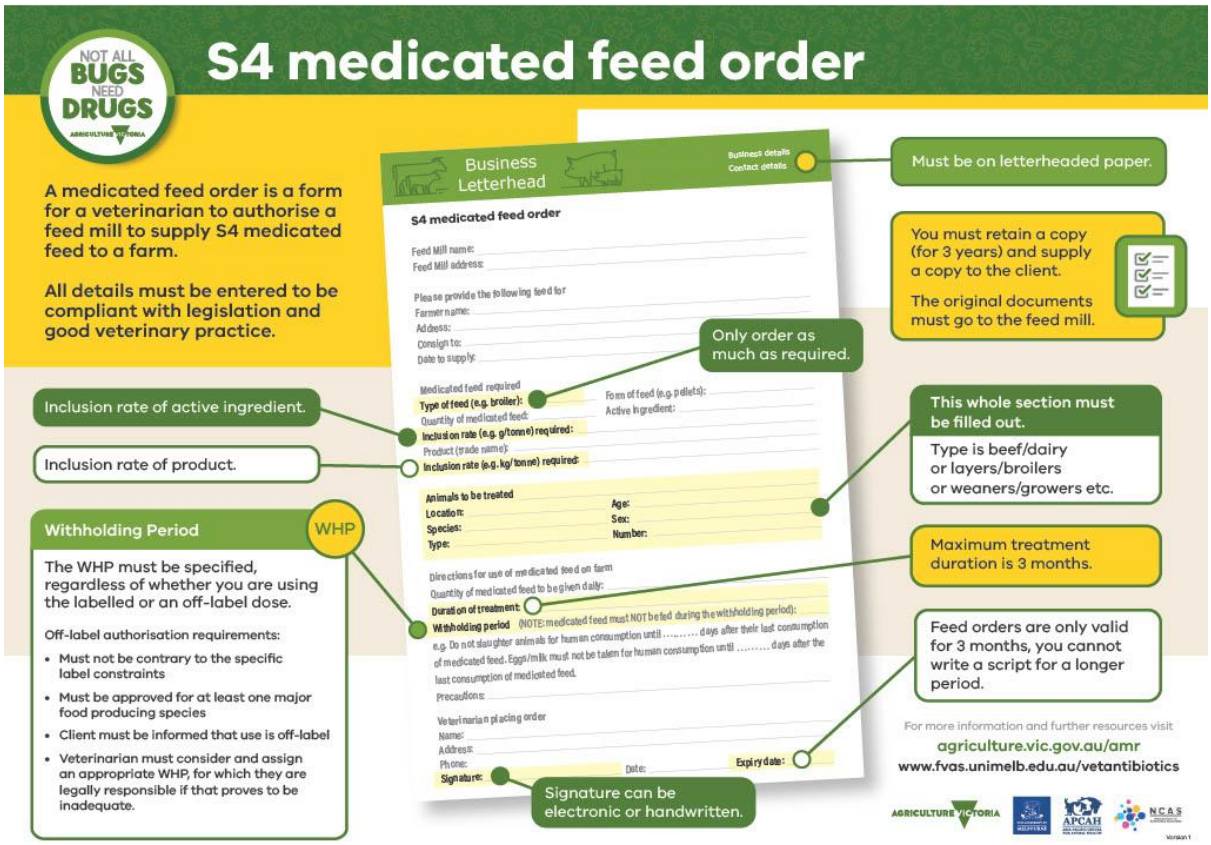

Figure 24 Requirements for a medicated feed order. Source: Agriculture Victoria (2020).

All required details must be entered on the form by the veterinarian to ensure compliance with legislation and good veterinary practice. The form highlights important requirements, including:

- the inclusion rate of the active ingredient
- the inclusion rate of the product
- the withholding period (WHP):
  - the WHP must be specified, regardless of whether the labelled dose or an off-label dose is used
  - for off-label authorisation:
    - the proposed use must not be contrary to specific label constraints (e.g. virginiamycin)
    - the product must be approved for use in at least one major food-producing species
    - the client must be informed that the proposed use is off-label
    - the veterinarian must consider and assign an appropriate WHP and is legally responsible if the assigned WHP proves inadequate
- the veterinarian's signature, which may be electronic or handwritten
- the order, which must be issued on letterheaded paper
- the quantity ordered, which should be limited to the amount required
- completion of the entire 'Animals to be treated' section. The animal type should be specified, for example, beef or dairy cattle, layers or broilers, or weaners or growers
- a maximum treatment duration of three months

- the period for which the order remains valid. S4 medicated feed orders are valid only for a limited period, such as three months in Victoria, and cannot be issued for a longer period.

The veterinarian and the stockfeed or premix manufacturer must retain a copy of the S4 medicated feed order for three years, and a copy must also be provided to the client. The original document must be provided to the stockfeed or premix manufacturer.

Evaluating commercial rumen modifier feed additive products

Given the wide range of commercial products available and the variability in efficacy among products within the same category, it is critical that nutrition advisers and veterinarians apply a rigorous, evidence-based approach when selecting rumen modifiers.

Not all products within a class, such as buffers, alkalinisers, prebiotics, probiotics, postbiotics or phytogenics, deliver the same outcomes. Differences in formulation, active components, inclusion rates and quality control can result in markedly different biological responses. In some cases, product claims may be extrapolated from unrelated studies or studies evaluating different formulations.

Regulatory compliance

Before evaluating product efficacy, users should confirm that the product complies with the relevant Australian regulatory requirements.

Products must either:

1. be registered by the Australian Pesticides and Veterinary Medicines Authority (APVMA), where required, or
2. meet the requirements for products exempt from registration under the excluded nutritional or digestive (END) category. For further information on END products, refer to www.apvma.gov.au.

Products should also:

- comply with relevant APVMA labelling requirements;
- only make claims that are consistent with the supporting peer-review research and applicable regulatory framework, and
- be supported by ingredients or active substances recognised by appropriate regulatory authorities, where relevant, such as the APVMA, the European Union, the Association of American Feed Control Officials (AAFCO), or equivalent bodies.

Table 11 Australian regulatory compliance evaluation for commercial rumen modifier feed additive products.

Requirement or Question	Yes	No
Step 1. Is the product registered by the APVMA, where required?	☐	☐
Step 2. Does the product make a claim to treat or cure a disease or condition? If 'yes', it cannot qualify as an END product and must be registered by the APVMA.	☐	☐
Step 3. If the product is being supplied as an END product, does it meet the following requirements?		

a) Are the active constituents appropriately recognised or listed by a relevant regulatory authority, such as the APVMA, the European Union or AAFCO?	☐	☐
b) Is the marketed product supported by peer-reviewed research published in a reputable scientific journal, and are the claims consistent with the permitted outcomes associated with the recognised ingredients listed in item (a)?	☐	☐
c) Is the product manufactured in an appropriately accredited facility, such as one operating under FAMI-QS, FeedSafe®, Good Manufacturing Practice or an equivalent standard?	☐	☐
d) Does the product label comply with relevant APVMA labelling requirements?	☐	☐

Caution: Product efficacy should only be assessed after regulatory compliance has been confirmed. Recommending or supplying products that do not meet Australian regulatory requirements may expose nutrition advisers, veterinarians, suppliers and farmers to legal, commercial, market access and reputational risks.

Evaluation of product efficacy

To ensure that a product is likely to deliver the expected response under practical conditions, the following questions should be considered:

- **Is the product supported by peer-reviewed research conducted on the same formulation?**
  - Priority should be given to products supported by peer-reviewed studies conducted in lactating dairy cows, under relevant production systems and controlled research conditions.
  - Avoid reliance on studies using different strains, blends, or earlier versions of the product.
- **Is the mode of action clearly defined and biologically plausible?**
  - Products should demonstrate a consistent and plausible mechanism, such as pH stabilisation, microbial modulation or support of ruminal epithelial integrity.
  - Vague or multiple unsubstantiated claims should be treated cautiously.
- **Were the research conditions representative of the target use scenario?**
  - For the mitigation of SARA, studies should include diets with high fermentability, experimentally induced acidotic conditions or other relevant challenge conditions.
  - Responses observed under total mixed ration (TMR) diets may not translate to grazing situations, and vice versa.
- **Are responses consistent across multiple independent studies or meta-analyses?**
  - Evidence from a single study should be interpreted cautiously.
  - Preference should be given to products supported by replicated studies or evidence from multiple datasets.
- **Is the inclusion rate in commercial recommendations aligned with research studies?**
  - Use at doses below those evaluated in research is a common reason for poor field performance.

- Reducing inclusion rates for economic reasons may compromise efficacy

- **Is there evidence that the product does not adversely affect milk quality or market suitability?**
  - Products should not adversely affect milk flavour, odour or processing characteristics at the recommended inclusion rate.
- **Is there evidence of consistent delivery of the active components under practical conditions, such as pelleting and silo storage?**
  - Particularly important for:
    - live microbial products, including microbial viability and colony-forming unit (CFU) counts
    - magnesium oxide reactivity
    - stability and concentration of active phytogenic compounds
    - consistency of other biologically active ingredients \

Table 12 Efficacy evaluation for commercial rumen modifier feed additive products.

Requirement or Question	Yes	No
Is the product supported by peer-reviewed research conducted on the same formulation?	☐	☐
Is the mode of action clearly defined and biologically plausible?	☐	☐
Were the research conditions representative of the target use scenario?	☐	☐
Are responses consistent across multiple independent studies or meta-analyses?	☐	☐
Is the inclusion rate recommended for commercial use aligned with that evaluated in research studies?	☐	☐
Is there evidence that the product does not adversely affect milk quality or market suitability?	☐	☐
Is there evidence of consistent delivery of the active components under practical conditions, such as pelleting and silo storage?	☐	☐

Table 13 Summary of nutritional strategies to mitigate ruminal acidosis risk in Australian dairy production systems.

Nutritional strategy	Key implementation considerations	Contribution to rumen stability	Relevant production systems
Feed evaluation and ration formulation	Routine measurement of feed dry matter; laboratory analysis of WSC, CP, starch, NFC, and NDF; estimation of carbohydrate fermentability and the supply of physically effective fibre	Enables accurate balancing of fermentable carbohydrates and fibre supply, thereby preventing excessive dietary fermentability	Applicable to grazing, PMR and TMR systems
Equipment calibration and maintenance	Routine TMR and PMR mixing audits; maintenance and calibration of feed mixers and in-bail feeding systems according to manufacturers' recommendations	Ensures consistent inclusion and delivery of concentrate feeds and peNDF, avoiding large fluctuations in acid production and ruminal pH	Applicable to grazing, PMR and TMR systems
Maintaining adequate physically effective fibre (peNDF)	Ensure adequate forage inclusion and particle size; avoid excessive forage processing; monitor TMR and PMR particle size distribution and sorting	Stimulates rumination and saliva secretion, increasing ruminal buffering and stabilising rumen pH	Particularly important in PMR and TMR diets, but also relevant in grazing systems based on highly digestible pasture
Balancing carbohydrate fractions in the diet	Balance rapidly fermentable carbohydrates, including WSC and starch, with fibre sources; consider partial replacement of starch with non-forage fibre sources	Supplies fermentable fibre while lowering the ruminal starch load	More common in PMR and TMR systems, but may also be used in concentrate feeds for grazing herds
Strategic use of non-forage fibre sources	Include ingredients such as almond hulls, beet pulp, soy hulls or citrus pulp to partially replace rapidly fermentable starch sources	Supplies fermentable fibre while lowering ruminal starch load	More common in PMR and TMR systems but may also be used in grazing herds concentrate feeding
Management of dietary sugars and rapidly fermentable feeds	Introduce high-sugar feeds or molasses-based ingredients gradually and as part of balanced diets	Prevents abrupt increases in the fermentation rate and ruminal acid production	Relevant in grazing systems (high WSC pasture) and PMR/TMR systems
Use of supplemental fat to moderate fermentable carbohydrate supply	Include dietary fats at moderate rates to increase energy density while reducing the dietary load of fermentable carbohydrates	Reduces ruminal acid production associated with high starch intake	Primarily PMR/TMR systems but applicable in concentrate supplements for grazing cows
Grain type, processing and inclusion rate	Consider differences in ruminal starch degradability among grains; moderate use of rapidly fermentable grains such as wheat and barley; avoid excessive processing intensity	Controls ruminal starch fermentation kinetics and acid production	Particularly important in grazing systems with bail feeding

Nutritional strategy	Key implementation considerations	Contribution to rumen stability	Relevant production systems
Distribution of concentrate feeding	Limit large single meals of grain; distribute concentrates through PMR or multiple feeding opportunities where possible	Reduces large concentrate meals and associated diurnal fluctuations in rumen acid load	Highly relevant in grazing systems with bail feeding
Gradual diet adaptation and transition feeding	Increase fermentable carbohydrate supply gradually over 2–4 weeks; implement structured transition cow feeding programs	Allows rumen microbial populations and the ruminal epithelium to adapt to increased dietary fermentability	Critical for transition cows and diet changes across all production systems
Consistent feed access and ration management	Maintain consistent daily feeding regimes; avoid abrupt changes in grazed forage base; minimise time off-feed and empty-bunk periods; ensure that rations are well mixed to reduce sorting	Stabilises intake patterns and daily ruminal fermentation dynamics	Particularly relevant in PMR/TMR systems
Pasture-based feeding strategies	Provide supplemental fibrous forage before pasture access where required; gradually introduce grains and new feeds; minimise time away from pasture; consider PMR where appropriate	Helps stabilise intake patterns and moderates rapid fermentation associated with highly digestible pasture	Grazing systems
Buffers and alkalinisers	Correct inclusion rates; consider MgO solubility; often used in combination Typical inclusion rates are: • sodium bicarbonate: 0.8–1.0% of dietary DM (150–250 g/cow/day) • marine-derived calcareous algae: 0.4–0.6% of dietary DM (75–130 g/cow/day) • MgO 0.2–0.25% of DMI (35–60 g/cow/day)		Buffers and alkalinisers
Pre-, pro- and post-biotics	Product-specific responses; require evidence-based selection	Modulate microbial populations, stabilise rumen pH, and may support gut epithelial integrity	All systems
Phytogenic additives	High variability; require evidence-based selection	Modify microbial populations and fermentation	All systems
Non-ionophore antibiotics	Use only where clearly justified and in compliance with veterinary and regulatory requirements. The recommended dose rate for virginiamycin is 0.5 mg/kg bodyweight. Non-ionophore antibiotics should not be used as a first-line strategy. Nutritional, management and non-antibiotic rumen modifier interventions should be prioritised to address underlying acidosis risk factors.	May alter rumen microbial populations and fermentation patterns in specific circumstances that predispose cattle to acute ruminal acidosis (ARA)	Use is limited and system-dependent and varies according to regulatory requirements and veterinary oversight

Conclusion

Preventing ruminal acidosis requires a systems-based approach that integrates diet formulation, animal factors, ingredient functionality, feeding management, animal adaptation and targeted use of rumen modifiers. Across Australian dairy production systems, the key principles remain consistent: balancing dietary fermentability, maintaining adequate physically effective fibre, ensuring consistent access to feed and water, and allowing sufficient time for rumen adaptation whenever diets change. These practices support stable rumen function and reduce reliance on corrective interventions after rumen dysfunction has developed.

Important knowledge gaps remain, particularly regarding quantitative definitions of fibre effectiveness under grazing conditions, interactions between starch digestibility and forage intake, digesta buffering capacity and passage rate in pasture systems, and animal-to-animal variability in rumen adaptation. Addressing these gaps will be essential for refining predictive tools and decision-support systems relevant to Australian dairy production systems. Continued research integrating rumen physiology, precision feeding and monitoring technologies, novel feeds, forages and rumen modifiers, and whole-farm systems is therefore warranted.

Because many risk factors for SARA are at times unavoidable in dairy production systems, prevention must be accompanied by ongoing monitoring of individual cows and the herd. Even well-designed feeding programs do not guarantee optimal rumen health under all circumstances. The next chapter therefore examines how ruminal acidosis can be diagnosed and monitored in practice using a combination of animal-based indicators, herd records, ruminal fluid assessment and structured herd-level risk assessment to identify problems early and guide management decisions.

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Chapter 5: Diagnosis and monitoring of ruminal acidosis

Summary of key points:

- Diagnosis of ARA is relatively straightforward and is based on characteristic clinical signs and a history of sudden, uncontrolled access to grain or other rapidly fermentable feeds. In contrast, SARA is more difficult to identify.
- Assessment of SARA requires consideration of multiple indicators, including milk components, faecal characteristics, diet and feeding management, rumination, rumen fill, lameness and ruminal fluid pH.
- A stepwise process should be used to monitor and manage herd-level SARA risk. The farm manager, key farm staff, nutrition adviser and veterinarian should each contribute their relevant knowledge and observations to a shared assessment and action plan.
- Despite its limitations, ruminal fluid pH is a useful biomarker for confirming the prevalence of ruminal acidosis within a herd when interpreted alongside dietary, management, production and animal health information.
- Where a herd is considered at high risk of SARA, the farm manager, nutrition adviser and veterinarian should work together to identify and prioritise the prevailing dietary, animal, environmental and management risk factors. Agreed actions should be implemented effectively and reviewed regularly.

Acute ruminal acidosis (ARA)

As suggested by Golder and Lean (2014), diagnosis of ARA should be based on the following:

- A history of sudden, uncontrolled access to grains or other rapidly fermentable feeds
- Clinical signs as described in Table 1
- The appearance and smell of ruminal fluid
- A ruminal fluid pH of less than 5

Clinical signs may progress rapidly when ruminal disruption is severe, with death occurring within 12 to 24 hours.

Subacute ruminal acidosis (SARA)

An accurate diagnosis of SARA in a herd requires assessment of multiple factors, including milk components, faecal characteristics, diet and feeding management, rumination, rumen fill, ruminal fluid assessment, lameness and blood metabolites (Villot et al., 2018; Mensching et al., 2021; Plaizier et al., 2022; Golder et al., 2023). This assessment is best undertaken collaboratively, drawing on the farm manager's and farm staff's knowledge of recent events and changes, the nutrition adviser's assessment of diet and feeding management, and the veterinarian's assessment of animal health and relevant differential diagnoses. The findings should be integrated into a shared assessment, rather than considered as separate nutritional and animal health assessments. Despite its limitations, ruminal fluid pH is considered an important biomarker of rumen health and disorders such as ruminal acidosis (Enemark, 2008). The severity of ruminal acidosis is influenced by the duration and extent to which ruminal pH remains below a specified threshold.

The ability to diagnose and monitor SARA may be assisted by wearable sensors and ruminal wireless bolus sensors that continuously monitor rumination. Ruminal wireless bolus sensors that continuously monitor ruminal pH require further development before they are suitable for routine use on commercial farms. Transabdominal ultrasonography to measure ruminal mucosal thickness may also have potential as an indicator of SARA. There are currently no blood or urine parameters that are considered reliable standalone indicators of SARA (Oetzel, 2017; Humer et al., 2018).

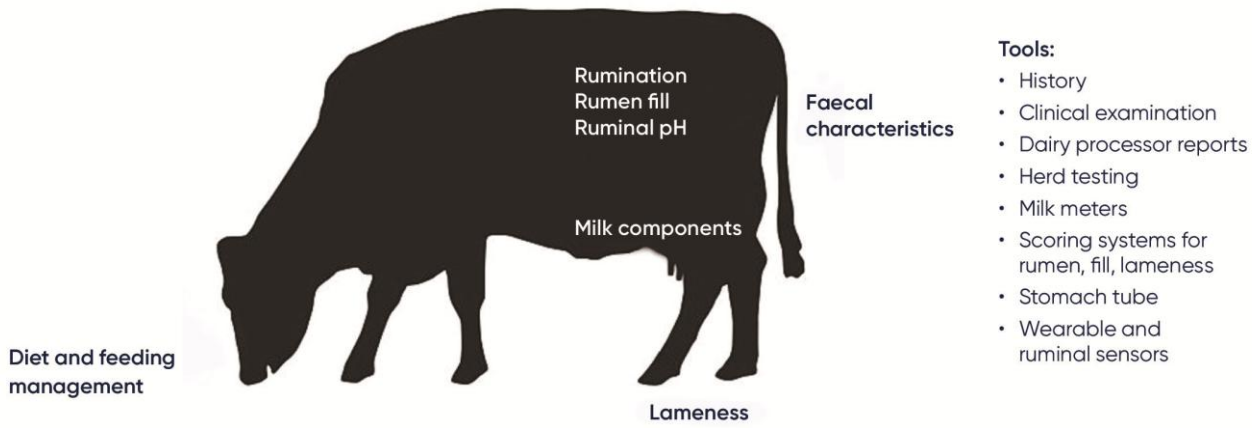

Figure 25 Diagnosing SARA.

Table 14 Typical presentations of ruminal acidosis in a dairy herd. Source: Adapted from Oetzel (2017), Lean and DeGaris (2021), and Christodoulopoulos (2025).

Disorder	Clinical signs of disease or general herd indicators may include:

Acute ruminal acidosis (ARA)	• Dead cows
	• Marked decline in milk yield
	• Acutely sick cows with:
	  • Dehydration
	  • Lethargy
	  • Inappetence
	  • Ruminal distension and atony
	  • Abdominal pain
	  • Severe diarrhoea
	  • Tachycardia
	  • Tachypnoea
	  • Lameness
	  • Staggers, recumbency or coma
	• Many cows with diarrhoea containing large amounts of undigested fibre and grain kernels, gas bubbles and a sweet-sour odour
	• More than 10% of cows lame
	• Some cows with sequelae such as ruminitis, liver abscesses, thromboembolic pneumonia or vena caval syndrome, and epistaxis

Disorder	Clinical signs of disease or general herd indicators may include:
Subacute ruminal acidosis (SARA)	• No obvious clinical signs • Milk production is often good to excellent • Milk fat depression • Some cows off feed or exhibiting cyclic variation in feed intake • Increased feed refusal or post-grazing residuals • Reduced ruminal motility and rumen fill • Reduced fibre digestion • Possible mild diarrhoea, with a lighter colour, sweet-sour odour, gas bubbles and possibly undigested fibre or grain • A higher-than-normal number of thin cows and/or lame cows

On-farm assessment

An adequate diagnosis requires an integrated analysis and interpretation of herd-level and individual cow records, including milk yield and components, feed intake, rumination behaviour, body condition trends and the incidence of lameness or other health issues. This assessment should be undertaken collaboratively by the farm manager, key farm staff, nutrition adviser and veterinarian, with each contributing relevant knowledge of the herd, feeding system, recent events and animal health.

Ruminal pH is a useful metric for confirming the prevalence of ruminal acidosis within a herd, but results should be interpreted alongside dietary, management, production and clinical information rather than in isolation. In addition, recent predisposing events must be considered, such as environmental stressors (e.g., heat stress), changes in feeding management, diet formulation or delivery, feed availability, or other management practices that may have increased the risk of ruminal acidosis.

The nutrition adviser and veterinarian should work in an aligned way with the farm manager to integrate these findings, agree on the most likely contributing risk factors and develop a coordinated action plan. This integrated approach provides a more accurate assessment of acidosis risk and its effects than reliance on ruminal pH measurements alone.

Milk components

Milk fat concentration and the milk fat-to-protein ratio are commonly used as indicators of SARA and low dietary fibre intake, as low ruminal pH depresses milk fat production (Enemark, 2008; Colman et al., 2010; Gozho et al., 2012). More than 10% of cows in a herd having a fat-to-protein ratio that is inverted or close to 1.0 (e.g., 3.1% fat and 3.3% protein), or a rapid fall in milk fat of 0.3–0.5 percentage points within one week, may indicate SARA (Li et al., 2012; Voulgarakis et al., 2023).

Milk fat concentration and the milk fat-to-protein ratio are best assessed on an individual cow basis, taking into consideration the stage of lactation and expected milk composition. Data from herd testing, milk meters or robotic milking units should be used when available. The best way to use milk fat in the assessment of SARA is to monitor the milk fat content of selected cows after the fresh period and compare it with that of herd mates at similar days in milk (Humer et al., 2018). Bulk milk fat concentration and fat-to-protein ratio may be used to monitor herd-level trends in rumen function but should not be used alone to diagnose or exclude ruminal acidosis. A rapid decline in bulk milk fat, particularly a fall of approximately 0.3 percentage points or more within one week, should prompt further investigation when it

coincides with dietary, feeding-management or environmental risk factors. Where available, individual-cow or defined-group milk results are preferable to whole-herd bulk milk results.

Many factors influence milk fat concentration, including stage of lactation, breed, and diet. Therefore, milk fat should not be used as the sole indicator of SARA. For example, the reduction in milk fat concentration associated with SARA is often much smaller than that observed during milk fat depression (MFD). Milk fat depression is characterised by a reduction in both milk fat percentage and milk fat yield, without affecting milk protein concentration. It is associated with subtle changes in rumen fermentation and is typically monitored through milk fat percentage. MFD is most commonly observed when cows are grazing lush pastures or consuming diets high in grain and low in effective fibre.

SARA may be present if more than 10% of cows have a milk fat-to-protein ratio that is inverted or close to 1.0 or either individual cow or bulk milk milk fat concentration falls by 0.3–0.5 percentage points within one week.

Milk fatty acid profile

The concentrations of milk fatty acids, particularly a decline in de novo fatty acid concentration, may serve as indirect indicators of ruminal acidosis. Low ruminal pH alters the ruminal environment and leads to incomplete biohydrogenation of unsaturated fatty acids, with increased synthesis of trans fatty acids, such as trans-10, cis-12 C18:2 (Colman et al., 2010).

Trans-10, cis-12 C18:2 is considered a sensitive fatty acid indicator of SARA and has been associated with milk fat depression in dairy cattle due to its role in inhibiting fatty acid synthesis in the mammary gland (Ramirez et al., 2015). Mid-infrared spectroscopy (MIR) has the potential to assist in the rapid, cost-effective prediction of milk fatty acid profiles.

Faecal characteristics

Changes in the physical characteristics of cow faeces and in faecal pH may occur with SARA (Khorrami et al., 2022), mainly due to alterations in digesta passage rate and hindgut acidification. These changes are often transient and may not be observed, but may include the following (Enemark, 2009):

- Loose consistency
- Light, yellowish colour
- Sweet-sour smell
- Foaminess and gas bubbles
- Some undigested fibre and/or grain particles that are not attributable to suboptimal grain processing

A five-point scoring system (Zaaijer and Noordhuizen, 2003) is commonly used to assess the faecal consistency of a herd through visual assessment of approximately 25 fresh faecal pats across the paddock or pen (Figure 26). However, for most lactating dairy herds, only scores 1–3 are relevant. The ideal faecal score is 3, indicating that the diet is well balanced in terms of fibre, protein and starch. An exemption might be in Autumn or Spring when lush pastures make up a large proportion of the cows' diet and faecal score 2 may be common despite the absence of SARA.

If more than 20% of cows have a faecal score of 1 or 2, this may indicate SARA. Faecal pats on concrete will appear more liquid or runny than those on pasture. It is important to consider within herd variability in pat consistency and identify which cows have liquid or runny manure (e.g. fresh cows, heifers).

Faecal Score 1	Faecal Score 2	Faecal Score 3
		
Very liquid manure with the consistency of pea soup. May 'arc' from the cow's rectum. The bubbles indicate an unstable rumen, fast gut flow and hind-gut fermentation.	Runny manure which does not form a distinct pile. Manure will platter on impact and may form loose piles less than 25mm high.	Manure has a porridge-like consistency. Forms a soft pile 40–50mm high, which may have several concentric rings and a small depression in the middle. Makes a plopping sound when it hits concrete.

Figure 26 Faecal scoring scale with descriptions. Source: Albornoz (n.d.). Reproduced with permission.

Faecal starch is unlikely to be a useful indicator of SARA, as there are many other potential causes of an elevated faecal starch concentration. Faecal starch concentration may be elevated due to increased starch bypassing the rumen when ruminal passage rate is high. Hindgut fermentation may lead to a small decrease in faecal pH. After ruminal pH reaches its nadir, there is a lag of many hours before faecal pH reaches its nadir. The duration of this lag is determined largely by digesta passage rate, which varies according to the feeding system and diet. More research is needed before a reliable faecal pH threshold can be defined as an indicator of SARA (Oetzel, 2017; Humer et al., 2018).

SARA may be present if more than 20% of cows have a faecal score of 1 or 2.

Diet, feeding system, equipment and practices

In grazing production systems, the risk of SARA is highest during periods of lush pasture growth, typically from autumn to early spring, when pastures are low in DM, NDF and peNDF but high in CP and WSC, with very high organic matter digestibility (OMD). These characteristics create a ruminal environment conducive to rapid fermentation and acid accumulation, even when grain supplementation is limited. High intakes of potassium (K), chloride (Cl) and ammonia (NH_3) may further increase rumen osmolarity and reduce rumen motility.

Several characteristics of grazing systems may compound these challenges to ruminal homeostasis. Cows preferentially select forage of higher nutritional quality than the average pasture mass on offer, which may further reduce effective fibre intake. Providing additional high-NDF and high-peNDF feeds can also be difficult during high-risk periods, particularly when pasture appears abundant, conserved forage is limited, or supplementary feeding would increase costs or reduce overall farm profitability.

Over a 24-hour period, cows may have several distinct feeding bouts involving grazed forage, typically consumed over 3–4 hours; grain-based concentrates offered during milking; and, in some systems, hay, silage or a PMR. These feeding patterns can cause fluctuations in SCFA production and ruminal pH, as discussed in Chapter 2. Cows may also spend periods without access to feed after milking while the herd is held together to provide equal access to pasture or conserved forage, or while being moved across a road. These interruptions may increase meal size when feeding resumes.

During summer, pasture availability and nutritional quality are typically reduced. Higher daily inputs of grain-based concentrates, most commonly wheat- or barley-based feeds offered during milking, may therefore be required to maintain DMI and milk production. This increased reliance on rapidly fermentable concentrates can increase the risk of SARA. A subtle increase in post-grazing residuals, for example from 1,500 kg DM/ha to 1,700 kg DM/ha, may indicate reduced pasture DMI and warrant further investigation.

Assessment of these risks should draw on the farm manager's knowledge of grazing allocation and feeding management practices, the nutrition adviser's assessment of pasture and ration composition, and the veterinarian's assessment of cow health and herd-level clinical indicators. Findings should be considered together to identify practical changes that are feasible within the farm system.

In intensive production systems, mixed rations containing around 50% concentrate may be used to support high milk production. However, high concentrate inclusion may reduce the proportion of physically effective neutral detergent fibre (peNDF) in the diet, predisposing cows to SARA. Research indicates that the risk of SARA increases when TMR diets contain less than 15% peNDF, based on particles longer than 8 mm, and more than 25% starch (Khorrami et al., 2021). This risk is exacerbated when cows sort in favour of starchy ingredients, resulting in greater intake of starch and shorter feed particles with low peNDF (Golder and Lean, 2024).

SARA risk increases when TMR diets contain less than 15% peNDF from particles longer than 8mm and more than 25% starch.

Mixed rations with a high concentrate inclusion rate often have a shorter particle length, which can increase feed intake by reducing rumen fill. Shorter particles also provide a greater surface area for microbial enzymatic fermentation, increasing nutrient availability and accessibility (McAllister, 1994). Feed consumption in these systems is usually greatest during the first few

hours after feed delivery. This can intensify ruminal fermentation and acid accumulation, leading to a reduction in ruminal pH.

Rumination

Cyclic feed intake has been described as one of the most consistent signs of SARA (Enemark, 2008). Appetite declines after a meal as ruminal pH falls and ruminal fluid osmolality increases. Appetite is then regained as ruminal pH gradually returns to its normal range. Cows with SARA may also sort mixed rations in an effort to increase their fibre intake (Keunen et al., 2002; De Vries et al., 2008). Changes in cows' feeding behaviour and intake patterns can be difficult to identify. However, in PMR- or TMR-fed herds, the PSPS can be used to compare the particle size distribution of the ration offered with that of the refusals, providing an indication of the degree of particle sorting. In automated feeding systems, such as robotic milking systems, where concentrate is dispensed in increments, data on the intake patterns of individual cows may be available for analysis.

Rumination is a more practical measure that can help identify a risk of SARA in a herd. Rumination, or cud chewing, is a complex process involving regurgitation, remastication, insalivation and deglutition (Grünberg and Constable, 2009). Rumination is driven primarily by the intake of peNDF. Cows tend to ruminate several hours after a meal, primarily when lying down. Hence, more than half of daily rumination may occur at night.

Ruminal motility can be visually evaluated from the left side of the cow through observation, palpation and/or auscultation of the cow's left paralumbar fossa, just behind the last rib. The number of ruminal contractions is then counted over a defined period. Between one and three ruminal contractions per minute is considered normal. Fewer than three contractions over 2 minutes indicates hypomotility, which may be associated with SARA (Grünberg and Constable, 2009).

At the herd level:

- In grazing production systems, the best time to visually assess rumination is 2–3 hours after the herd has entered the day paddock. Carefully observe chewing activity among cows that are lying down. More than 50% of lying cows should be ruminating.
- In intensive production systems where a TMR is fed, rumination may be assessed at any time of day. At least 40% of cows that are not eating should be ruminating (Maekawa et al., 2002).

Assessing rumination

Grazing systems: Assess cows 2–3 hours after they enter the day paddock. More than 50% of cows lying down should be ruminating.

TMR systems: Assess at any time of day. At least 40% of cows that are not eating should be ruminating.

Rumination activity can be monitored using wearable sensors, including collars and ear tags, and ruminal wireless bolus sensors that continuously measure rumination and other health and production parameters, such as eating behaviour and activity, using accelerometers. These devices are becoming more widely used in Australian dairy herds. Unlike current ruminal pH bolus sensors, rumination sensors are not subject to the same limitations associated with progressive loss of accuracy and sensor drift over time. Rumination data generated by these sensors are captured in proprietary dairy herd management software and may be displayed as

total rumination time in minutes per day or per hour. Data on the number of rumination bouts per day and the average length of each bout may also be provided.

Measuring the number of chews per bolus of regurgitated feed may also be useful when assessing the risk of SARA in a herd. However, measurements need to be made over extended periods. The number of chews per bolus varies with the diet consumed, so the resulting data may be difficult to interpret. More research is needed to define practical chewing thresholds for SARA that can be used on farm (Humer et al., 2018).

As a general guide, healthy cows should ruminate for approximately 450 minutes or more per day. Rumination time varies according to breed and the device used to measure it. Jersey cattle may ruminate for approximately 70–100 minutes less per day than Holstein cattle (Gotto and Krogstad, 2025). However, average rumination time, irrespective of breed, is also highly influenced by dietary, animal, environmental and management factors (Abeni, 2022).

Typical daily rumination times range from 420 to 480 minutes in Jersey cattle and from 510 to 560 minutes in Holstein cattle.

While there are no agreed thresholds for the reduction in daily rumination time that indicates SARA risk, based on DeVries and others (2009) the following provisional thresholds could be considered:

- If 15–25% of cows are ruminating for 50–60 minutes less than their individual average rumination time over the previous 3 days, this may indicate that the herd has a low-to-moderate risk of SARA.
- If more than 25% of cows are ruminating for 50–60 minutes less than their individual average rumination time over the previous 3 days, this may indicate that the herd has a high risk of SARA.

Compared with each cow's average over the previous 3 days:

15–25% of cows ruminating for 50–60 minutes less: may indicate low-to-moderate SARA risk

More than 25% of cows ruminating for 50–60 minutes less: may indicate high SARA risk

Any decrease in rumination time of more than 50–60 minutes per cow per day should trigger prompt investigation of the diet, feed delivery, feeding behaviour and relevant animal health factors. Rumination data obtained from collars, ear tags and bolus sensors are not directly comparable, but the devices would be expected to identify broadly similar daily and hourly patterns (Figure 27).

Image pending copyright permission – available at: Rumination data | DairyNZ

Figure 27 Example, comparing ruminations recorded using ear tag, collar and ruminal bolus. Source: DairyNZ (2025).

Rumen fill

Rumen fill is another indicator of dietary adequacy, feed intake and health status. A five-point visual scoring system is used to assess the fullness of the left flank, based on the depth of the paralumbar fossa, where the rumen is located (Figure 28). There are many possible causes of a low proportion of cows in a herd having full rumens, and reduced rumen fill is not specific to SARA. Nevertheless, it is good practice to observe and score rumen fill at the same time as visually assessing rumination. If more than 20% of cows have a rumen fill score of 1 or 2, this may indicate SARA (Burfeind et al., 2010).

More than 20% of cows with a rumen fill score of 1 or 2 may indicate SARA.

Image pending copyright permission – available at Cow-obs.pdf

Figure 28 Five-point scoring system for rumen fill.

Lameness

There are many causes of lameness in dairy cattle, including ruminal acidosis. The mechanisms by which SARA increases the risk of lameness are not well understood, and the appearance of clinical signs may not coincide with SARA episodes. Lameness can occur weeks or months after ruminal disruption, with recent research indicating that, for each day an animal experiences SARA, the likelihood of becoming lame increases by 2.52% (Kofler et al., 2023).

A four-point locomotion scoring system can be used to assess back posture, gait and stride length (Figure 29). It enables cows with subtle locomotion problems to be identified and treated before they become clinically lame (DairyNZ, 2023). The best time to score cows is while they are walking to the parlour. Attention should be paid to cows at the tail end of the herd. Cows may not be obviously lame but may have tenderness in all four feet. This may be indicated by an arched back while walking. At least 90% of cows should have a locomotion score of 0.

At least 90% of cows should have a locomotion score of 0.

Dairy Australia

Lameness scoring

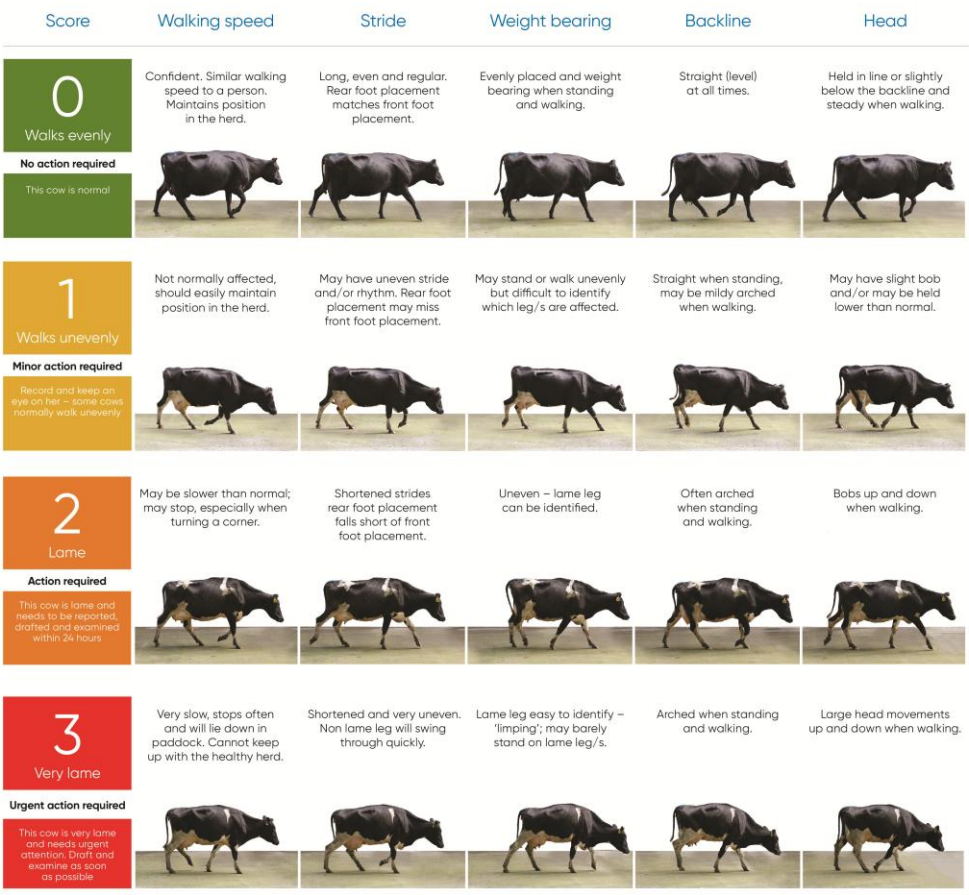

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Figure 29 Four-point locomotion system. Source: Adapted from DairyNZ (2023).

Body condition score

Body condition scoring (BCS) is a practical tool for assessing energy reserves in dairy cows and provides an indirect indicator of nutritional adequacy and rumen function. The Australian dairy industry uses a 1–8 scoring scale, in increments of 0.5, on which lower scores reflect depleted reserves and higher scores indicate excess condition. Loss of body condition, particularly during early lactation, reflects negative energy balance and can be exacerbated by reduced feed intake or compromised rumen function.

Body condition score should not be used as the sole indicator of SARA, as it reflects longer-term changes rather than short-term fluctuations in ruminal pH. When assessed regularly at key stages of lactation (e.g., calving, early and mid-lactation, and dry-off), BCS can help identify nutritional imbalances and feeding management issues that may contribute to the risk of ruminal acidosis. Consistent scoring by trained personnel is important, and results should be interpreted alongside other indicators, such as milk production, milk components, rumination behaviour and faecal characteristics. Monitoring changes in BCS over time within groups of cows can provide useful insights into herd-level nutritional adequacy and overall rumen health.

Refer to the Dairy Australia's "Cow body condition scoring handbook" for more information on scoring methodology and appropriate body condition score targets for your herd.

Ruminal fluid assessment

Ruminal fluid may initially be assessed for colour and odour. A slightly milky-brown colour and a sour odour may be indicative of SARA. Ruminal pH may also help support a diagnosis of ruminal acidosis (Enemark, 2008; Grünberg and Constable, 2009). However, determining the severity of ruminal acidosis in a herd solely from the extent of the decrease in ruminal pH among sampled cows is problematic for several reasons.

Obtaining accurate and highly repeatable measurements of ruminal pH in cattle is challenging because pH is not uniform across the different sacs of the rumen. Within each sac, ruminal pH also varies throughout the day and between days in response to differences in feed intake and feeding sequence (Humer et al., 2018). At least 12 cows should therefore be sampled to obtain meaningful herd-level results, given the inherent variation in ruminal pH among cows fed the same diet and the limitations of available sampling and measurement techniques (Humer et al., 2018; Hartinger et al., 2024).

Ruminal pH also varies naturally among herds and farms because of differences in dietary, animal, environmental and management factors. Each herd therefore has its own baseline ruminal pH profile under normal conditions. Where this baseline is unknown, results from subsequent ruminal fluid sampling should be interpreted with caution.

Ruminal pH and lactate concentration are also poorly correlated with the clinical signs and outcomes of ruminal acidosis (Bramley et al., 2008; Golder et al., 2012). Furthermore, ruminal acidosis can cause a wide range of changes within the rumen and throughout the body, some of which may not be directly attributable to the decrease in ruminal pH.

These changes may include shifts in the rumen microbiome, with increased abundance of some bacterial families and decreased abundance of others (Golder et al., 2023). Bacterial toxins, particularly lipopolysaccharides (LPS), may also be released into the ruminal digesta and induce a localised immune response in the ruminal epithelium (Kent-Dennis et al., 2020). These toxins may subsequently cross the gastrointestinal epithelium and enter the

bloodstream, resulting in a systemic immune response (Zebeli and Ametaj, 2009; Plaizier et al., 2018).

Ruminal acidosis has also been associated with increased ruminal concentrations of numerous compounds, including histamine, methylated amines, glucose, alanine, maltose, uracil, xanthine, ethanol, phenylacetate, lysine, leucine, phenylacetylglycine, propionate, valerate, nicotinate, glycerol, fumarate, putrescine and ethanolamine (Ametaj et al., 2010; Saleem et al., 2012; Golder et al., 2012; Humer et al., 2018).

Sample at least 12 cows to obtain meaningful herd-level results.

Using ruminal fluid collected orally with a stomach tube or by rumenocentesis

Ruminal fluid may be collected for a single-timepoint measurement of ruminal pH using one of two methods:

1. **Rumenocentesis:** a needle approximately 50-100 mm long is inserted through the left abdominal wall and ruminal wall into the ventral ruminal sac, from which ruminal fluid is aspirated. This method should only be performed by a veterinarian.
2. **Stomach tube:** a flexible tube is inserted orally and passed down the oesophagus into the reticulorumen. A vacuum pump is then used to remove ruminal fluid. This method should only be performed by a trained adviser.

Rumenocentesis is the preferred method for collecting ruminal fluid to support confirmation of SARA and is the method upon which pH thresholds used to define a herd's SARA risk status are based. However, ruminal fluid collection using a stomach tube is a useful monitoring tool to help confirm SARA, if samples are consistently collected from the same location in the rumen and are not contaminated with saliva. While rumenocentesis should only be performed by a veterinarian, the stomach tube method may be used by a suitably trained adviser, because it is less invasive. Any person performing ruminal fluid collection should be trained and supervised during the first few procedures.

With rumenocentesis, ruminal fluid is always collected from the ventral sac of the rumen, while, with the stomach tube method, the operator has less control over the location of fluid collection within the rumen. Samples may be collected from the dorsal or ventral sac, which may differ in pH. Furthermore, samples collected using a stomach tube may be contaminated with saliva, which has a pH greater than 8. The pH values of ruminal fluid samples collected using a stomach tube therefore tend to be higher than those of samples collected by rumenocentesis. Ruminal fluid samples collected using a stomach tube have been reported to have pH values that are, on average, 0.28–1.1 units higher than those of samples collected by rumenocentesis (Nordlund et al., 1995; Garrett et al., 1999; Enemark et al., 2004). Measurements obtained using the two methods are only weakly correlated ($R^2 = 0.11$); therefore, values cannot be reliably converted between methods. Standard operating procedures for ruminal fluid collection by rumenocentesis and stomach tube are described below. Additional stomach-tube methods have been developed in recent years and may serve the same purpose (Larsen et al., 2020; Miccoli et al., 2024).

A robust, portable pH meter intended for field use (Figure 30), fitted with a double-junction electrode, should be used to measure the pH of ruminal fluid. While a pen-style probe is less costly, it may become clogged with ruminal contents and is therefore not recommended. Test-paper strips are convenient but are not recommended because their results are unreliable.

Ideally, pH analysis should be performed immediately after collection. If this is not possible, the ruminal fluid should be stored in a capped syringe with all air expelled, refrigerated and analysed within one hour of collection. The pH meter should be calibrated each time it is used, using standard pH 4 and pH 7 buffers. The same instrument can also be used to monitor urine pH when monitoring urine acidification in transition cows.

Figure 30 Example of a portable pH meter that can be purchased from a laboratory instrument supplier with calibration buffers (pH 4 and 7) and electrode storage solution for approximately $400-500. Source: Pacific Sensor Technologies (2026). Reproduced with permission.

Collecting ruminal fluid by rumenocentesis

Equipment required:

- A 16- or 18-gauge, 50–100mm-long stainless-steel needle
- An eccentric-tip syringe
- Clippers
- Surgical scrub
- Sedative (optional)
- A ruminal fluid collection vessel

Procedure:

1. Restrain the animal in a cattle crush or headbail.
2. Administer light sedation (recommended, but not essential).
3. Identify the site for fluid collection: approximately 15–20cm caudoventral to the costochondral junction of the last rib, at the level of the stifle.
4. Clip and surgically prepare the area using surgical scrub and 70% alcohol.
5. Inject 3mL of local anaesthetic subcutaneously at the site using a 25mm (1 inch), 18-gauge needle.
6. Insert the 90–125 mm (3½–5 inch), 16-gauge needle, aiming slightly cranially towards the ventral sac of the rumen.
7. Attach a 20mL syringe and apply gentle, slow suction to collect 3–8mL of ruminal fluid. If the needle becomes blocked, push a small amount of air back through the needle to clear it.

Adapted from Nordlund and Garrett (1994).

Collecting ruminal fluid by stomach tube

Equipment required:

- A stomach tube comprising a flexible vacuum hose with a fenestrated stainless-steel endpiece
- Water-based lubricant, such as veterinary obstetric lubricant
- A mouth gag to safely hold the mouth open
- A manual or electric vacuum pump
- A ruminal fluid collection vessel

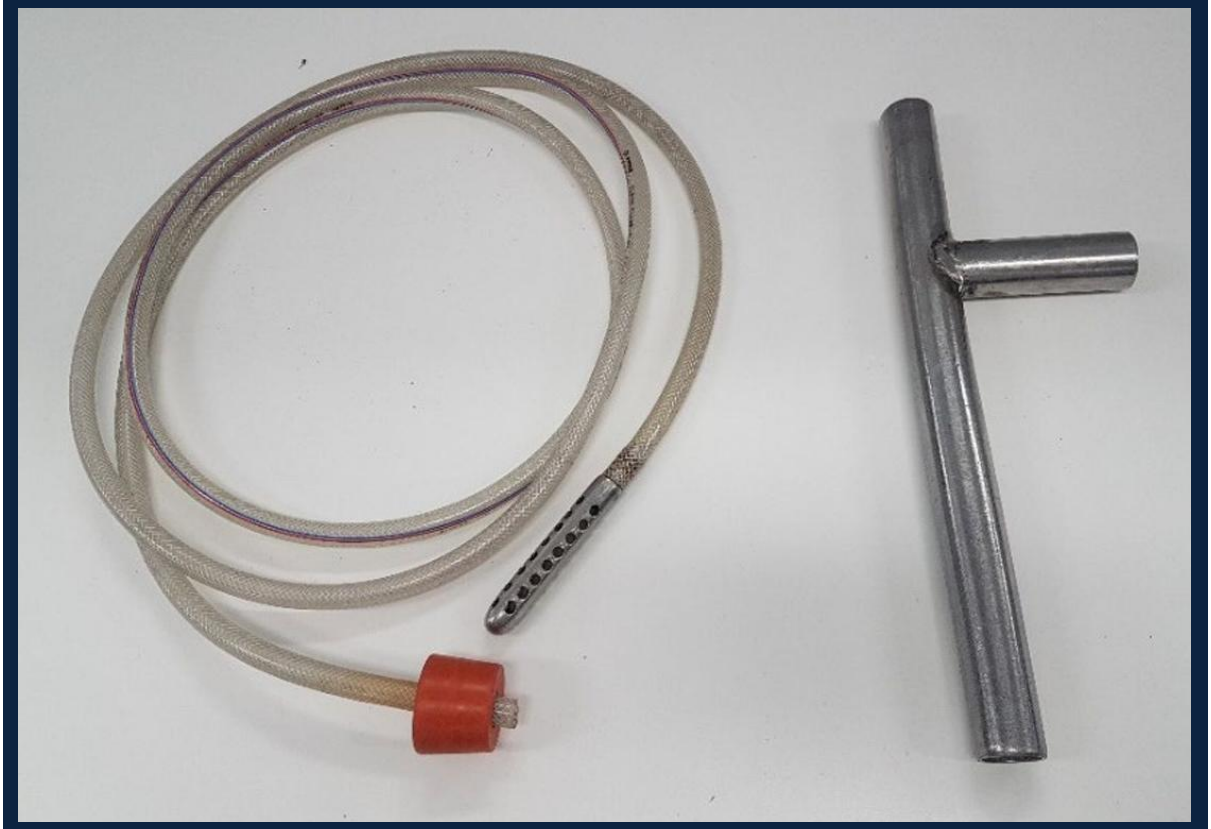

Figure 31 Stomach tube (left) and mouth gag (right). Source: University of Queensland, School of Veterinary Science (2026).

Procedure:

1. Restrain the animal in a cattle crush or headlock. Use only the level of restraint required to perform the procedure safely. Secure the head without excessive elevation or extension of the neck. Turning the head slightly to the right to expose the left side of the neck may make it easier to guide the stomach tube into the oesophagus rather than the trachea.
2. Open the animal's mouth by inserting a thumb or hand into the gap between the incisors and molars.
3. Use the other hand to insert the mouth gag, guiding it into position. Ensure that the gag is secure and positioned between the molars.

4. Insert the lubricated stomach tube just past the gag and towards the back of the throat. After the tube has passed the tongue, the animal may close its throat, preventing further advancement. If this occurs, use a gentle, smooth, back-and-forth movement of the tube to stimulate the animal to swallow and open the throat. Do not apply force. As the animal swallows, gently advance the stomach tube into the oesophagus. Advancement of the tube should be smooth and controlled, using gentle, consistent pressure. Never force the tube.
5. Continue to gently advance the stomach tube until it enters the rumen. The presence of a ruminal odour from the tube may indicate that the endpiece has entered the rumen.
6. With the endpiece positioned within the ruminal fluid, attach the stomach tube to the top of the collection vessel and use the vacuum pump to collect the fluid.
7. Discard the first 200 mL of fluid collected, because it is more likely to be contaminated with saliva. Then collect a further 200 mL of fluid for pH analysis.
8. Kink the stomach tube and remove it from the animal, keeping the tube kinked throughout removal. Remove it in one smooth action over approximately 3 seconds.
9. Carefully remove the mouth gag.
10. Monitor the animal for 5 minutes for abnormal jaw movements or mastication, coughing, difficulty breathing, increased respiratory rate or lethargy. If any of these adverse signs are observed, seek veterinary advice immediately.

Adapted from Grünberg and Constable (2009) and University of Queensland (2022).

Sample when ruminal pH is likely to be lowest

Grazing herds fed concentrates during milking: sample about 4 hours after milking.

TMR-fed herds: sample 4–6 hours after feed-out.

Cows selected for ruminal fluid pH analysis should be sampled around the time of day when ruminal pH is expected to be lowest. In grazing herds fed grain-based concentrates in the milking bail, this is approximately 4 hours after milking. In intensive herds fed a TMR, the recommended sampling window is 4–8 hours after feed-out (Grünberg and Constable, 2009; Humer et al., 2018). However, because ruminal pH may begin to rise more than 6 hours after feed-out, as shown in Figure 10b in Chapter 2: Ruminal function, acidosis and associated disorders, sampling within 4–6 hours is preferable.

Rumen fluid assessment

Sample at least 12 cows from a group at high risk of SARA within the herd, such as early-lactation cows. The results provide an indication of the herd's SARA risk status at the time of sampling.

- **High risk:** If three or more of the 12 cows tested have a ruminal pH of ≤5.5, the herd is considered to be at high risk of SARA
- **Moderate risk:** If two of the 12 cows tested have a ruminal pH of ≤5.5, the herd is considered to be at moderate risk of SARA.
- **Low risk:** If zero or one of the 12 cows tested has a ruminal pH of ≤5.5, the herd is considered to be at low risk of SARA**.**

Adapted from Nordlund et al. (1995), Kleen et al. (2004) and Oetzel (2004).

Using ruminal wireless bolus pH sensor

A ruminal wireless bolus pH sensor enables continuous measurement of ruminal pH, rather than measurement at single timepoints, as occurs with ruminal fluid collection using an oral stomach tube or rumenocentesis. However, currently available ruminal bolus pH sensor technology has several limitations, including higher cost, a limited effective lifespan (approximately 4–8 weeks in some cases), and a gradual loss of accuracy and drift in pH values, usually downwards, following bolus placement. This drift occurs due to electrode ageing and coating and increases measurement error (Villot et al., 2018; Golder and Lean, 2024). Sensor software may be designed to automatically adjust the data to compensate for this drift over time; however, these adjustments may not be entirely accurate.

At least in the near future, ruminal wireless bolus pH sensors will therefore remain useful tools for short-term research studies, but not for long-term monitoring of ruminal acidosis in commercial herds. Furthermore, in a commercial dairy herd, it may be cost-prohibitive to place a ruminal wireless bolus pH sensor in every cow to monitor ruminal acidosis. However, collecting ruminal pH data from sensors placed in 15–20 cows at high risk of ruminal acidosis may be both practical and useful. These may include fresh cows, early-lactation cows and high-yielding cows.

As stated earlier, an episode of ARA has been defined as a ruminal pH below 5.5 for 3 h/d (Castillo-Lopez et al., 2014), whereas an episode of SARA has been defined as ruminal pH below 5.8 for more than 5–6 hours per day (Zebeli et al., 2008). However, slightly higher thresholds may be required when using ruminal wireless bolus pH sensors, as most boluses reside in the cow's reticulum rather than the ventral ruminal sac. The reticulum generally has a slightly higher pH and a narrower range of pH values than the ventral ruminal sac (Humer et al., 2018). A further concern is that the relationship between reticular and ruminal pH may not remain constant (Penner, 2026, pers. comm.).

Protozoal numbers and motility in ruminal fluid

Protozoal numbers and motility in a ruminal fluid sample may be observed under a low-power (×40) microscope. An absence of motile protozoa supports a diagnosis of ARA. However, while changes in protozoal numbers and motility during SARA have been described, these responses are highly variable. Protozoal numbers and motility in ruminal fluid are therefore not considered reliable indicators of SARA (Enemark, 2008).

Ruminal mucosa thickness

Thickening of the ruminal mucosa may occur following SARA. There is potential for veterinarians to visualise the ruminal mucosa and measure its thickness using transabdominal ultrasonography and a portable ultrasound unit (Mirmazhari-Anwar et al., 2013; Neubauer et

al., 2018). The optimal site for ultrasound evaluation may be the intersection of a horizontal line passing through the costochondral junction and a vertical line extending ventrally from the third lumbar vertebra (Mirmazhari-Anwar et al., 2013). A threshold of ≥7.3 mm has been proposed as an indicator of depressed ruminal pH and, consequently, SARA (Humer et al., 2018). However, ruminal mucosa thickness increases with age, so age-specific thresholds would be preferable. Further research is needed before measurement of ruminal mucosa thickness can be recommended as an indicator of SARA.

Ruminal temperature

Many ruminal wireless bolus pH sensors also measure ruminal temperature. While one study (AlZahal et al., 2008) found a negative correlation between ruminal temperature and ruminal pH, other studies have not (Bodas et al., 2014; Humer et al., 2015). The use of ruminal temperature as a diagnostic tool for SARA is therefore not recommended.

Laboratory tests

Blood

Researchers have explored the usefulness of many blood analytes as indicators of SARA. Concentrations of acute-phase proteins (APP) in blood may be elevated during SARA due to inflammation of the ruminal epithelium. However, increased APP concentrations may also be caused by other conditions (Li et al., 2012). Indeed, primiparous cows experiencing different severities of SARA while being fed the same diet may show no differences in blood acute-phase protein concentrations (Hartinger et al., 2024) or in the concentrations of major blood metabolites (Castillo-Lopez et al., 2025). Other studies have reported that blood pH, partial pressure of carbon dioxide (pCO_2), and blood concentrations of sodium (Na), potassium (K), chloride (Cl) and calcium (Ca) may be altered during SARA. However, these changes are transient and small in magnitude.

Urine

Urinary net acid–base excretion (NABE), urinary phosphorus excretion and urinary pH have been explored as potential indicators of SARA but have been found to be of little or no value because of their very low specificity. Therefore, no blood or urine parameters are currently considered useful indicators of SARA (Oetzel, 2017; Humer et al., 2018).

Monitoring and managing herd-level risk of SARA

A structured, step-by-step approach helps ensure that all relevant indicators and risk factors are assessed and that no important components are overlooked. Figure 32 outlines this process for monitoring and managing herd-level risk of SARA. The farm manager, nutrition adviser and veterinarian should share responsibility for applying the process on an ongoing basis.

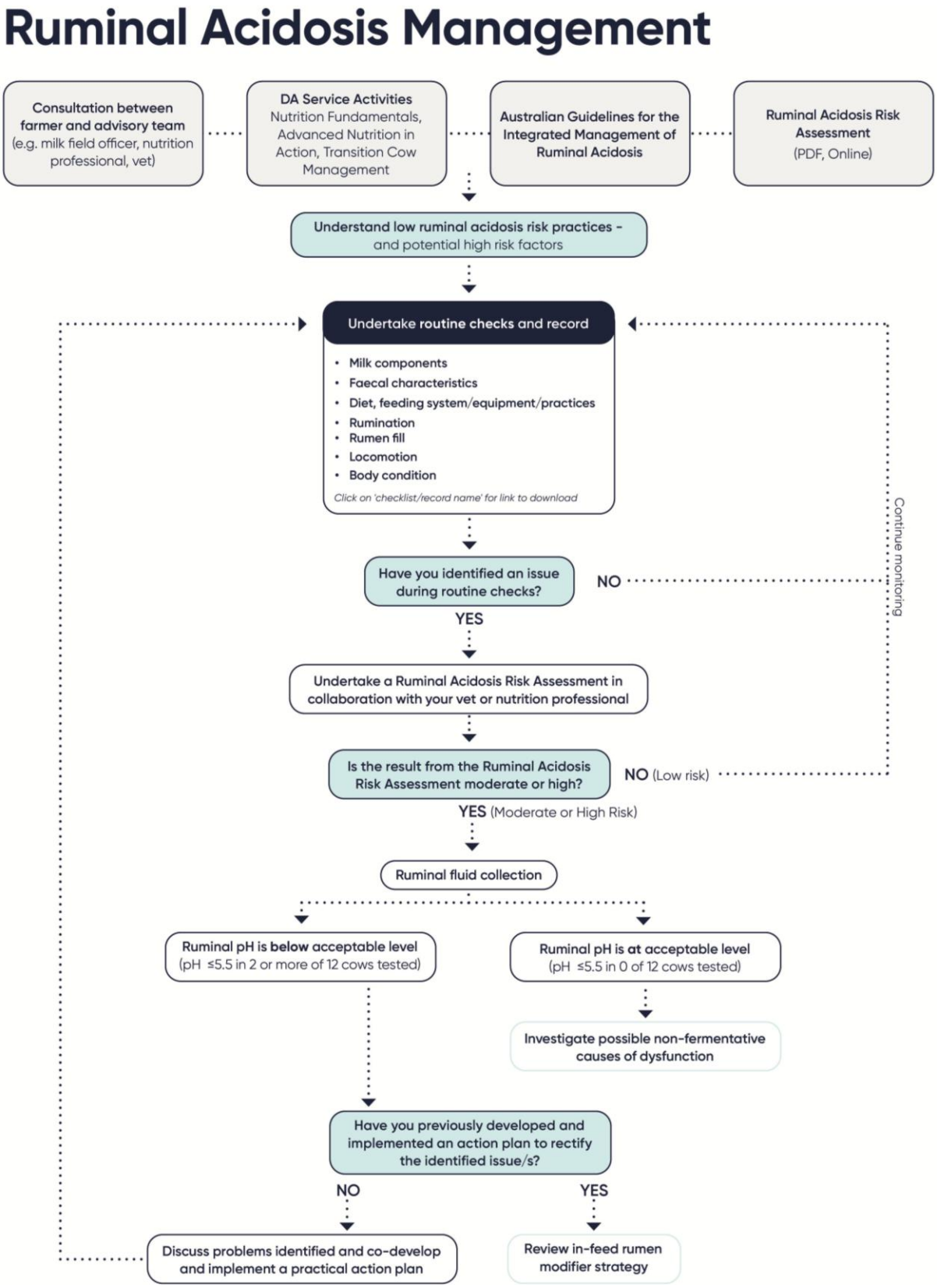

Figure 32 Process for monitoring and managing herd-level risk of SARA with good antimicrobial stewardship. MC-2383 | Sept 2026

Step 1. Routine checks

A series of routine checks should be performed at regular intervals by the adviser and farm manager to detect anomalies that may indicate ruminal dysfunction associated with ruminal acidosis (Table 15).

Table 15 The recommended routine checks to be performed at regular intervals by the adviser and farm manager.

Who	How often	What to check	Further action required if:
Farm manager	Daily, where possible	Milk components	• More than 10% cows have had a milk fat test that has fallen by 0.3 – 0.5 % in the last week based on individual cow milk test data. • More than 10% cows have a milk fat-to-protein ratio that is inverted or close to 1.0 based on individual cow milk test data if available.
Farm manager	Daily	Faecal score and appearance	• More than 20% of fresh pats have a faecal score of 1 or 2 in contained-housing systems, or a score of 1 in grazing systems. • Abnormal colour, odour or bubbles are observed. • Undigested fibre or grain particles are present.
Farm manager	Weekly	Diet, feeding system, equipment and feeding practices	• The diet is not appropriately balanced for NDF, peNDF, starch and WSC. Refer to Table 1 in Chapter 4. • Problems are identified in the design, condition or operation of the feeding system or equipment. • Feeding practices are inconsistent or may contribute to SARA risk.
Farm manager	Weekly	Rumination and rumen fill	• More than 50% of cows that are not eating are not ruminating. • More than 25% of cows are ruminating for at least 50 minutes less than their recent average. • More than 20% of cows have a rumen fill score of 1 or 2.
Farm manager, nutrition adviser and/or veterinarian	Monthly	Herd locomotion score	• More than 10% of cows have a locomotion score of 1 or higher.
Farm manager, nutrition adviser and/or veterinarian	8–10 weeks before drying off; at drying off; at calving; at mating	Body condition score	• Before drying off or at drying off, cows are not on track to achieve the desired BCS at calving. • At calving, more than 15% of cows have a BCS below 4.5/8. • At calving, more than 15% of cows have a BCS above 5.5/8.

			• At mating, the average herd BCS has decreased by more than 0.6 points since calving. • At mating, more than 15% of cows have lost more than one BCS point since calving.

How advisers can support farm managers

Conduct short on-farm training sessions with farm manager and key staff members on how to perform each routine check:

- Milk components
- Faecal score, appearance
- Rumination time
- Rumen fill score
- Locomotion score

Develop a system for use by farm manager and key staff members to record results of each check and compare to acceptable level.

Encourage farm manager and key staff members to participate in group-based extension and education programs run by Dairy Australia such as Nutrition Fundamentals and the Advanced Nutrition in Action (ANIA) program.

Step 2. Risk assessment

The adviser, together with the farm manager, should use the Risk Assessment Tool to identify the herd's risk of SARA (low, moderate or high):

- Overall
- Within each of the four areas: dietary, animal, environmental and management
- For each risk factor within each area

Before using the Risk Assessment Tool, the following activities are recommended to help answer the questions included in the tool:

Assess feed ingredients and mixed rations

1. Assess the relevant physical characteristics of the following feeds, including colour, odour, dry matter content, leaf stage, texture, particle size, chop length, uniformity, weather or pest damage, contaminants and foreign material:
    - Grazed pasture
    - Hay
    - Silage
    - Grain
    - Protein sources
    - Byproducts, including liquid whey and brewers' or distillers' grains

2. Collect representative samples of major feed ingredients and mixed rations using recommended sampling methods and submit them to a feed laboratory for analysis (e.g. concentrations of DM, NDF, NDFD, ADF, starch, WSC, NFC and CP).
3. Review the nutritional specifications and additive inclusions for the pre-calving transition diet, fresh-cow diet and milker diet, as well as the intended daily feeding rate of each diet per cow.
4. Review the daily time budget of the milking herd, including the timing of milking and feeding events, to determine whether cows have enough time throughout the day to rest and consume feed.
5. Using a bucket and a set of scales, weigh the quantity of concentrate, in kilograms, dispensed by the feeding system in the dairy parlour and compare it with the intended feeding rate. In a herringbone parlour, check the consistency of feed quantities dispensed along each side.
6. Conduct a TMR audit when feeding a PMR or TMR.
7. Measure the refusal rate when feeding a TMR at the feed bunk by dividing the amount refused by the amount delivered and multiplying by 100. Consider using the Penn State Particle Separator (PSPS) to assess the particle-size profile of the TMR as delivered and of the refusals if the refusal rate exceeds 5%.
8. Measure the available feed-bunk and loafing space per cow if cows are housed in a contained housing system.

PMR/TMR Audit

A PMR/TMR audit should be carried out at least every six months to identify major deviations from the formulated ration or the target particle-size profile of the mix. The audit should identify whether any of the following 10 factors associated with ingredient loading and mixing may be contributing to variation in the mixed ration (Oelberg, 2015):

1. Worn mixer augers, kicker plates, and knives
2. Mix time after the last added ingredient
3. Unlevel mixers
4. Loading position on the mixer box
5. Load size
6. Hay quality and processing
7. Loading sequence
8. Liquid distribution
9. Vertical mixer auger speed
10. Forage restrictor settings on vertical mixers.

It is recommended that a built-in mixer scale system and software be used to accurately monitor the quantities of feed ingredients mixed and fed out each day and compare them with budgeted quantities.

As part of this audit, 10 samples, each approximately 1.5 L in volume, should be collected from a batch of mixed ration at the mixer's discharge chute while the ration is being fed out at the feed bunk. Each sample should then be assessed separately using the Penn State Particle Separator (PSPS) to estimate the degree of variation in particle-size profile.

The recommended particle distribution across the three PSPS sieves and bottom pan for a typical TMR is as follows (Humer et al., 2018):

- Top: 2-8%
- 2nd sieve: 30-50%
- 3rd sieve: 20-30%
- Bottom pan: less than 20%

Aim for a coefficient of variation (CV) of less than 5% for the proportion of particles retained on the middle sieve and in the bottom pan of the PSPS for optimal mix consistency.

When assessing a typical TMR with the Penn State Particle Separator, aim for:

- Top sieve: 2–8%
- Second sieve: 30–50%
- Third sieve: 20–30%
- Bottom pan: less than 20%

Equipment required for sampling and detailed assessment of diet:

- Hay and silage core sampler
- Pasture quadrant and clippers
- Weigh scale
- Tared bucket
- Penn State Particle Separator
- Feed lab sample bags and submission forms
- Feed drying equipment and an appropriate drying method (microwave, air frier, Koster drier)

The Risk Assessment Tool recommends actions to consider for risk factors rated as presenting a moderate or high risk of SARA based on the responses provided by the adviser and farm manager. These ratings indicate opportunities for improvement.

At this point, if the overall herd risk is rated as high, the adviser may choose to conduct ruminal fluid collection and analysis (Step 3) to support confirmation of the risk assessment.

Alternatively, the adviser and farm manager may choose to bypass this step and proceed directly to co-developing an Action Plan (Step 4), using the recommended actions from the Risk Assessment Tool as prompts.

Step 3. Ruminal fluid collection and assessment

If the adviser chooses to assess ruminal fluid to help confirm ruminal acidosis, it should be collected orally with a stomach tube or by rumenocentesis from at least 12 cows in a high-risk group within the herd, e.g. fresh and early lactation cows, high yielding cows, first calvers.

Ruminal fluid from each cow is assessed for:

- Appearance – Ruminal fluid of a cow with acute ruminal acidosis is watery and milky grey in colour
- Odour – Ruminal fluid of a cow with acute ruminal acidosis has a sour smell
- pH - Conduct pH analysis of samples ASAP and determine herd risk level:
  - Low risk: If 0 or 1 of the 12 cows tested have a ruminal pH ≤ 5.5
  - Moderate risk: If 2 of the 12 cows tested have a ruminal pH ≤ 5.5
  - High risk: 3 or more of the 12 cows tested have a ruminal pH ≤ 5.5

How advisers can support farm managers

- Use a standard operating procedure to collect ruminal fluid and measure pH immediately with a portable pH meter.
- Support less-experienced advisers during their first few sampling sessions.
- Interpret pH results alongside other herd information to assess SARA risk.
- For moderate or high risk, progress to Step 4 and co-develop an action plan.
- For low risk, investigate other possible causes of ruminal dysfunction and involve a veterinarian where appropriate.

Step 4. Action plan to rectify any problems

The adviser and farm manager discuss the problems identified and co-develop and implement a practical action plan to help address them as rapidly as possible. A veterinarian should also be consulted and involved in development of the action plan.

How advisers can support farm managers

- Discuss the key ruminal acidosis risk factors with the farm manager.
- Identify practical opportunities to strengthen nutritional management within the farm's grazing or TMR-based system.
- Consider whether functional feed ingredients could support rumen function, including suitable inclusion rates and adaptation protocols.

- Review the use of rumen modifiers supported by robust evidence and quality assurance, including appropriate inclusion rates and adaptation protocols.
- Summarise the agreed action plan in a brief report, including what will be done, when and by whom.
- Share the action plan with other key advisers involved in its implementation.

Step 5. Review in-feed rumen modifier strategy

If the next round of routine checks and risk assessment indicates that the herd-level risk for SARA is still high despite effective implementation of the Action Plan (step 4), the nutrition adviser and farm manager should seek advice from a veterinarian as to whether targeted, short-term administration of a non-ionophore antibiotic (i.e. virginiamycin) may be indicated to support control of ruminal acidosis in the herd.

How advisers can support farm managers

- Review implementation of the action plan with the farm manager.
- Share findings from the next round of routine checks and ruminal pH assessment with other key advisers.
- Where a veterinarian prescribes a non-ionophore antimicrobial, use an S4 Medicated Feed Order to authorise supply of the medicated feed or premix.
- Follow the core principles of judicious antimicrobial use and the specific recommendations for virginiamycin in the AVA Antimicrobial **Prescribing Guidelines for Dairy Cattle (2024).**

Some cows within a herd may experience repeated episodes of ARA and/or SARA and require individual monitoring and management. First-calving cows, recently calved cows and sick cows are at greatest risk. A similar step-by-step process to that outlined for herd-level monitoring and management in Figure 32 should be applied to these animals.

Conclusion

Diagnosis of ARA is typically straightforward, relying on a history of sudden access to rapidly fermentable feeds, characteristic clinical signs and ruminal fluid assessment. In contrast, herd-level SARA often occurs without obvious clinical signs and therefore requires the interpretation of multiple indicators. No single measure is sufficiently accurate when used on its own; rather, diagnosis should be based on an integrated assessment of milk components, faecal characteristics, rumination, rumen fill, locomotion, body condition, diet, feeding management and, where appropriate, ruminal fluid pH.

Routine monitoring and repeated risk assessment are therefore essential components of effective SARA management. The stepwise process described in this chapter provides a

practical framework for farm managers, nutrition advisers and veterinarians to identify risk factors, confirm herd-level acidosis where necessary and implement corrective actions. Consistent with good antimicrobial stewardship, priority should always be given to addressing underlying dietary, animal, environmental and management risk factors. Short-term use of antimicrobial rumen modifiers should be considered only when these measures have been effectively implemented, and the herd's risk remains high.

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Chapter 6: Supporting better farm management of ruminal acidosis

Taking a team approach

Every farm manager has a network of product and service providers that they use to support their business, including the productivity, health and welfare of their herd. For the monitoring and management of ruminal acidosis, farm managers should work with advisers who have appropriate expertise in ruminant nutrition and herd health management. Together, the farm manager and their advisers should have access to the knowledge and skills needed to assess risk factors, investigate suspected ruminal acidosis, and co-develop and implement action plans to prevent or address problems. Stockfeed and premix suppliers may also support the management of ruminal acidosis, particularly when ration formulation, feed manufacture, product selection or the use of an in-feed non-ionophore antimicrobial is being considered. Other product and service providers who identify concerns about ruminal acidosis should encourage the farm manager to involve advisers with relevant expertise in ruminant nutrition and herd health (Figure 33).

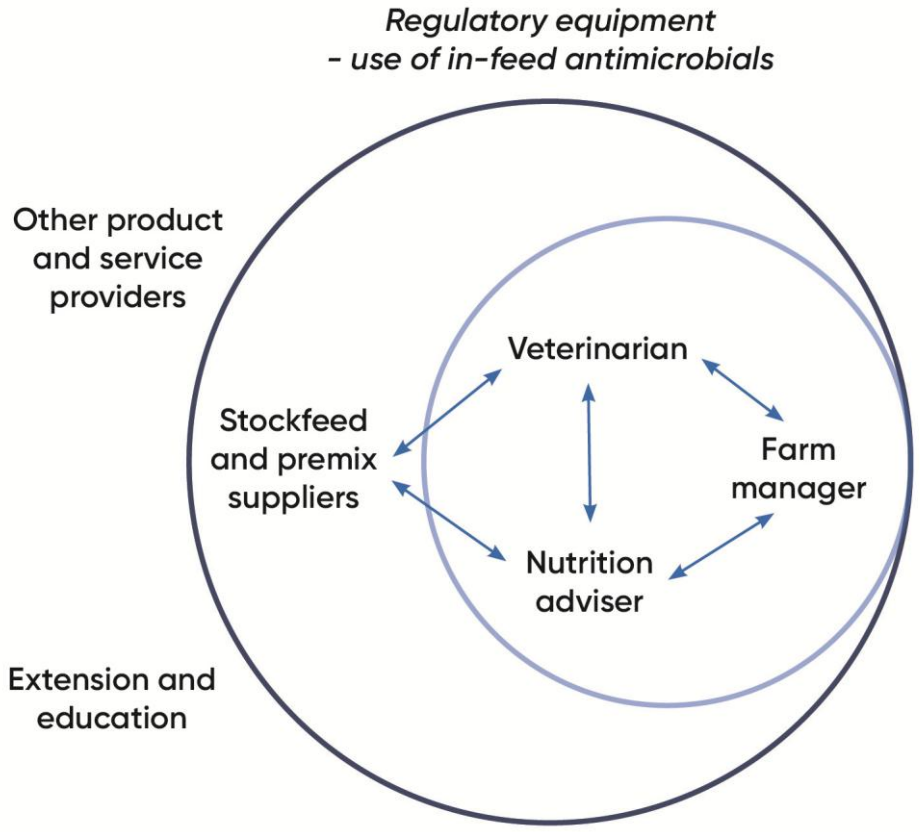

Figure 33 Farmer's advisory network for ruminal acidosis monitoring and management.

Farm managers, ruminant nutrition advisers and veterinarians each bring different knowledge, experience and perspectives to the monitoring and management of herd-level SARA risk. No single person is likely to have all the information required to understand the nutritional, animal health, environmental and management factors operating within a particular farm business. A multidisciplinary approach is therefore required, in which the farm manager, ruminant nutrition adviser and veterinarian contribute their respective expertise, communicate openly and agree on their roles in applying the step-by-step process for monitoring and managing the herd-level risk of SARA (Figure 34).

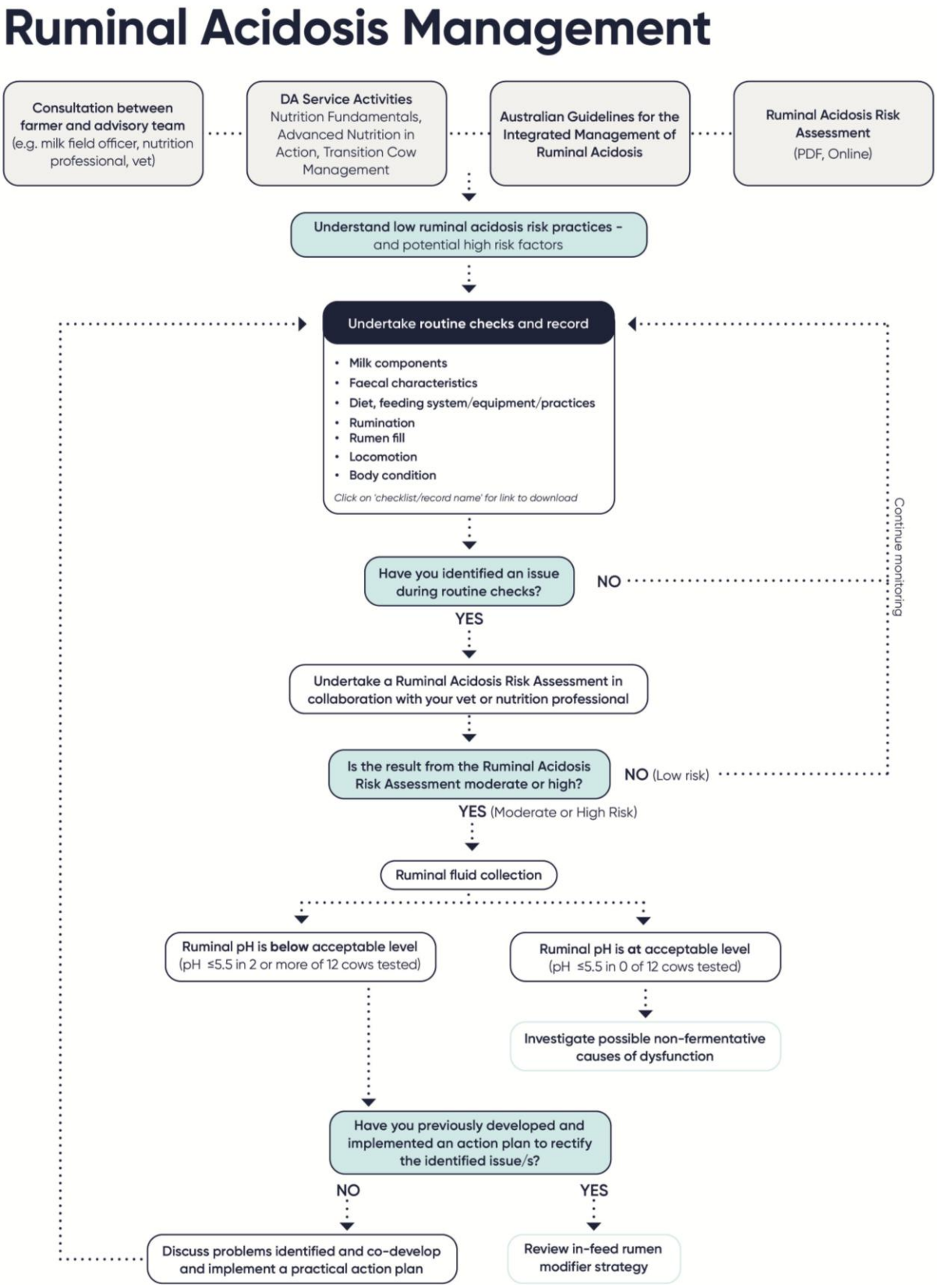

Figure 34 Process for monitoring and managing herd-level risk of SARA. MC-2383 |Sept 2026

Effective collaboration between farm advisory team members in the monitoring, diagnosis and management of ruminal acidosis will minimise the likelihood of:

- misdiagnosing another condition that may mimic or contribute to ruminal dysfunction, such as mycotoxicosis
- overlooking practical nutritional, feeding or management interventions
- inappropriate use of in-feed antimicrobials
- providing conflicting or poorly coordinated advice to the farm manager

This integrated approach will support herd health, animal welfare, productivity and profitability, along with good antimicrobial stewardship.

If a veterinarian attends a farm to treat animals suffering from ARA, this should prompt discussion with the farm manager and nutrition adviser about whether the broader process for monitoring and managing herd-level SARA risk should be reviewed or initiated. Similarly, if a nutrition adviser identifies clinical signs, unexplained production changes or animal health concerns, they should encourage veterinary assessment.

Taking a team approach

As a nutrition adviser:

- What could you strengthen working relationships with veterinarians and stockfeed and premix suppliers in your region?
- How could you communicate your assessment, recommendations and intended outcomes more clearly with farm managers and veterinarians?
- How could you encourage your farmer clients to adopt a team approach to monitoring and managing ruminal acidosis?

As a veterinarian:

- What could you strengthen working relationships with nutrition advisers and stockfeed and premix suppliers in your region?
- How could you communicate your assessment, recommendations and intended outcomes more clearly with farm managers and nutrition advisers?
- How could you encourage your farmer clients to adopt a team approach to monitoring and managing ruminal acidosis?

Conclusion

Ruminal acidosis management begins with sound transition cow management and with avoiding situations in which cows can rapidly consume highly fermentable carbohydrates or experience reduced intakes of physically effective fibre.

With these measures in place, ruminal acidosis management then focuses on monitoring and managing dietary, animal, environmental and management-related risk factors for SARA. Ruminal acidosis risk on a particular farm is constantly changing. Ongoing use of the step-by-step process described in these guidelines is therefore required to monitor and manage SARA, enable early and effective intervention, and minimise its many negative impacts and potential sequelae. Farm managers, nutrition advisers and veterinarians each have an important role in

this process. When they work as a coordinated team, combining farm knowledge with nutritional and veterinary expertise, they are better placed to develop practical and effective responses that support herd health and performance, animal welfare and responsible antimicrobial use.

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