**Implementing Nutritional Strategies to Reduce Methanogenesis in Livestock**

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This chapter delves into the realm of nutritional strategies aimed at mitigating methanogenesis, the production of methane gas, in livestock production systems. Methane, a potent greenhouse gas, emerges primarily from ruminant digestion processes and significantly contributes to global warming. The chapter explores a range of innovative approaches to address this concern, focusing on enhanced feed quality, strategic supplementation, methane inhibitors, fermentation modulation, and dietary adjustments. The chapter commences by highlighting the pivotal role of livestock in anthropogenic greenhouse gas emissions, particularly methane. It underscores the intricate interplay of factors such as land use change, feed production, animal husbandry practices, manure management, and processing in shaping livestock-related emissions. The chapter then delves into the specifics of nutritional strategies, offering a comprehensive overview of each approach's mechanisms and potential benefits. Challenges, considerations, and the importance of maintaining animal welfare and performance throughout these strategies are critically addressed. The significance of individual animal variability, the broader sustainability implications of these strategies, and their potential to reduce methane emissions in livestock production are explored. By examining the interplay of science, environmental concerns, and livestock productivity, the chapter provides a holistic perspective on the journey toward sustainable livestock practices. Ultimately, the chapter underscores the critical importance of mitigating methanogenesis in livestock systems, both for ecological conservation and improved livestock efficiency.

**Introduction**

Methane is a potent greenhouse gas, and livestock, particularly ruminant animals like cattle, sheep, and goats, are substantial contributors to its emission. These animals possess unique digestive systems that foster the growth of methanogenic archaea, resulting in methane production during the breakdown of ingested feed. Addressing this issue is not only vital for curbing climate change but also for optimizing energy utilization within livestock systems. Methanogenesis, the production of methane through microbial activity in the digestive systems of livestock, poses significant challenges in terms of environmental sustainability, feed efficiency, and greenhouse gas emissions. This chapter delves into the various nutritional strategies that can be employed to effectively reduce methanogenesis in livestock, thereby contributing to both ecological conservation and enhanced livestock productivity.

The staggering reality of our planet's environmental challenges comes to the forefront when considering that livestock operations contribute a significant 14.5% to the total annual anthropogenic greenhouse gas (GHG) emissions on a global scale, as highlighted by Gerber et al.'s 2013 study. Livestock influence climate through land use change, feed production, animal production, manure, and processing and transport. Feed production and manure emit CO2, nitrous oxide (N2O), and methane (CH4), which consequently affects climate change. Animal production increases CH4 emissions.

**Livestock's Role in Greenhouse Gas Emissions**

The intricate interplay between livestock and greenhouse gas (GHG) emissions is a crucial facet of the global climate challenge. The principal contributors to livestock-related GHG emissions encompass carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). These emissions hold substantial implications for anthropogenic climate change. Notably, CH4 takes the lead, accounting for the largest portion at 44%, trailed by N2O at 29%, and CO2 at 27%, as underscored by Gerber et al.'s research in 2013.

**a. Distribution of Livestock-Related GHG Emissions**

On a global scale, the cumulative GHG emissions originating from livestock are distributed as follows: livestock contribute to 44% of anthropogenic CH4 emissions, 53% of anthropogenic N2O emissions, and 5% of anthropogenic CO2 emissions. Of particular note is the preeminent role of cattle, responsible for the sector's emissions, contributing a substantial 5.0 gigatonnes of CO2-equivalent emissions. This figure represents a staggering 62% of the sector's total emissions. Intriguingly, both beef and dairy cattle wield comparable emissions profiles. In contrast, other livestock categories like pigs, poultry, buffaloes, and small ruminants register significantly lower emissions, collectively constituting 7% to 11% of the sector's emissions.

**b. Insight into Indian Livestock Emissions**

India's livestock landscape also plays a significant role in global GHG emissions. According to the Department of Animal Husbandry, Dairying, and Fisheries, Ministry of Agriculture, Government of India (2012), enteric CH4 emissions from Indian livestock tally up to 13.27 teragrams (Tg) annually. This statistic implicates cattle and buffalo as the prime contributors, accounting for 6.73 Tg and 6.56 Tg per year, respectively. This combined contribution translates to a substantial 91% of the nation's total emissions from this source. Emission figures further underscore the potency of cattle emissions, with a single cow emitting approximately 220 pounds of methane annually. Although CH4's atmospheric lifespan is shorter compared to CO2, its warming impact is an astonishing 28 times greater.

**c. Deciphering GHG Emission Components**

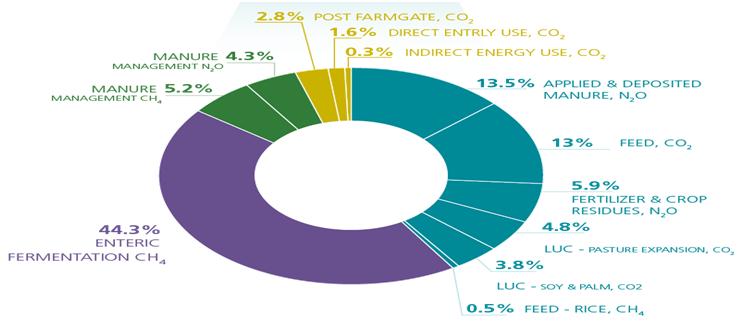
GHG emissions stemming from livestock rearing can be compartmentalized into two key constituents: enteric fermentation and excreta. Enteric fermentation, a predominant contributor, constitutes nearly 90% of the total CH4 emissions from ruminants. The remainder emerges from hindgut fermentation.

**d. Emerging Insights from Research**

Recent strides in research have yielded noteworthy insights. ICAR-NIANP (Bhatta et al., 2017) has meticulously developed a state-wise enteric methane emission inventory, revealing an emission estimate of 9.252 Tg of methane per year from Indian livestock. Remarkably, this figure stands lower than estimations provided by various other agencies.

**e. Visualizing GHG Emissions from Livestock**

This complex interplay of emissions is visually represented in Figure 1, as demonstrated by Bhatta et al.'s research in 2017. This graphical depiction serves as a potent tool in comprehending the magnitude and distribution of GHG emissions arising from livestock activities.



**Fig. 1 GHG Emission from Livestock**

In conclusion, the relationship between livestock activities and GHG emissions emerges as a pivotal arena in the fight against climate change. The nuanced understanding of emissions' sources, distribution, and impacts forms a bedrock for devising targeted mitigation strategies that reconcile the necessity of livestock with the urgency of environmental conservation.

**Nutritional Strategies to Reduce Methanogenesis**

**a. Feeding Management**

Feeding management is one of the most important strategies for CH4 mitigation in ruminants. An integrated approach that considers the rumen microbiota, the animal and the diet seem the best approach to find a long-term solution for reducing enteric CH4 production by ruminants. There is evidence that fresh grass results in lower CH4 losses than dry. Mainly forage diets are often supplemented with sugar-based concentrates to provide a rapidly available source of energy for the rumen microbes or to increase the palatability of the diet DM and hence stimulate the digestibility (Mills *et al.,* 2001).

CH4 production in ruminants tends to increase with maturity of forage fed, and CH4 yield from the ruminal fermentation of legume forages is generally lower than the yield from grass forages (Moss *et al.,* 2000). Using grass-legume mixtures in ruminants’ diets can be beneficial for animals in addition to their known agronomic benefits for increasing biomass yield and reducing the use of fertilizer and reducing methane emission. (Martin *et al.,* 2016) Forage quality has a significant impact on enteric CH4 emissions (Sejian *et al.,* 2011). There is also evidence that using clovers and grasses with high water-soluble carbohydrates (WSC) in animal diets can directly reduce methane emissions (Lovett *et al.,* 2004).

On a concentrate-based diet, fermentation of sugars and starch showed 25 and 15% lesser CH4 yields, respectively, as compared to a roughage diet. The extent to which high-grain diets lower methane emissions depends on the source of the grain. For example, greater reductions can be achieved with maize than barley (Beauchemin and McGinn, 2005). (Beauchemin and McGinn, 2009) observed 23.9% less CH4 on the feeding of maize distillers’ dried grains as compared to the feeding of barley grain in growing beef cattle.

Ration balancing with locally available feed resources at farmer’s doorstep is an effective and easiest way to ameliorate methane emission without compromising the production or health performance of the animals. National Dairy Development Board (NDDB) launched a ration balancing programme (RBP) for the small dairy farmers in different agro-climatic regions of the country.

Replacing structural carbohydrates from forages (cellulose, hemicellulose) in the diet with non-structural carbohydrates (starch and sugars) contained in most energy-rich concentrates is associated with increases in feed intake, higher rates of ruminal fermentation and accelerated feed turnover, which results in large modifications of rumen physio-chemical conditions and microbial populations. This results in a lower CH4 production because the relative proportion of ruminal hydrogen sources declines whereas that of hydrogen sinks increases.

**b. Mineral Supplementation**

Unlike humans, bovines utilise potassium (K +) astheir primary osmotic regulator of water secretionfrom sweat glands. As a consequence, K +requirements are increased (1.4–1.6 % of DM)during the heat stress, and this should be adjustedfor in the diet. In addition, dietary levels ofsodium (Na +) and magnesium (Mg +) should beincreased as they compete with K + for intestinalabsorption. Among micronutrients,zinc is one of the most important in the body. At the cellular level,zinc is essential for cell proliferation and survivaland contributes to genomic stability and antioxidantdefence. Zinc is a potent inducer of Hsp70 incell culture, which isindispensable for adaptation.Chromium facilitates insulin action on glucose, lipid and protein metabolism.Because glucose use predominates duringheat stress, chromium supplementation may improve thermal tolerance or production in heat-stressed animals.

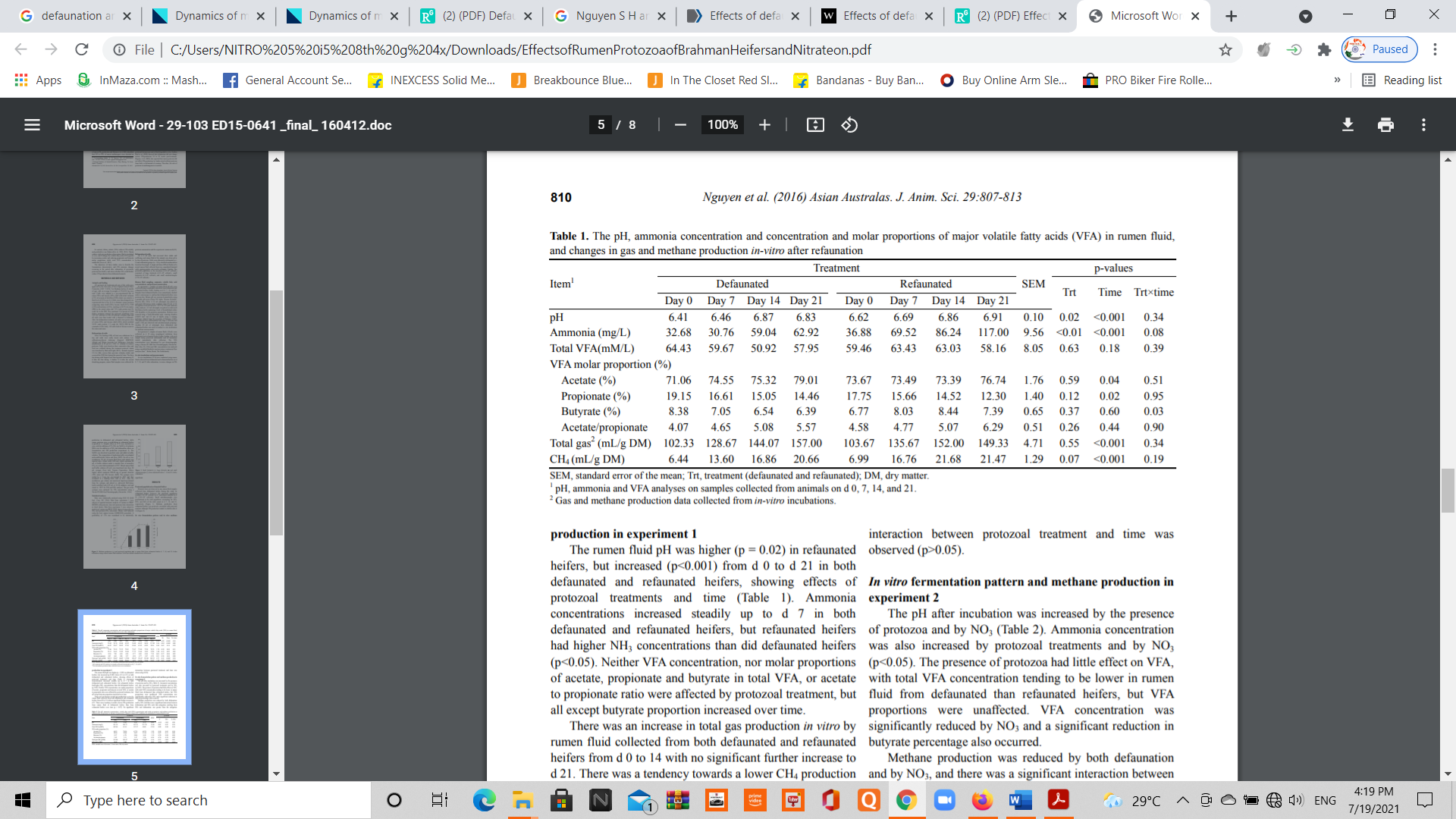
**c. Antioxidant Supplementation**

Nutritional tools such as antioxidant feeding (vit. A, selenium, zinc, etc.) and ruminant-specific live yeast can help. Studies have shown that addition of antioxidant in diets of sheep is able to reduce heat stress and is a good strategy to prevent mastitis, optimise feed intake and reduce the negative impact of heat stress on milk production. Moreover, the use of antioxidant such as vit. E, vit. A, selenium and selenium-enriched yeast helps in reducing the impact of heat stress on the oxidant balance, resulting in improved reproductive efficiency (Sejian *et al.,* 2014). Vitamin C along with electrolyte supplementation has also been reported to ameliorate the heat stress in buffaloes.

**d. Defaunation**

Defaunation is the complete removal of protozoa from the rumen ecology and consequently reduces methane release by 20–30 %. Defaunation also markedly increases the total bacterial number, whereas it reduces the number of methanogens which may be due to the loss of preferable colonisation sites for them at which they associated symbiotically with protozoa.

Nguyen *et al.,* (2016) experimented (In table 1) on Ten Brahman heifers to know the effect of Effects of Rumen Protozoa on Fermentation and In vitro Methane Production. Cattle were adapted to a pre-experimental diet and then changed to an experimental diet of for 10 d to eliminate rumen protozoa comprising oaten chaff (70%), lucerne chaff (21%), of coconut oil distillate (COD) (4.5%) and molasses (4.5%), resulting in 88.1% dry matter (DM) in the mixed ration and 7.9% crude protein and 5% crude fat in the DM. This combined 18 d period of COD dietary treatment reduced the protozoal population from 3.91×105 cells/mL to 0.58×105 cells/mL of rumen fluid and all cattle were then treated with a chemical to defaunated. After the defaunation treatment, all cattle were given a diet of oaten (70%) and lucerne chaff (30%) which included 10.5% crude protein; 1.3 crude fat; 88.8% DM for the remainder of the study. All cattle had ad libitum access to the ration and water.

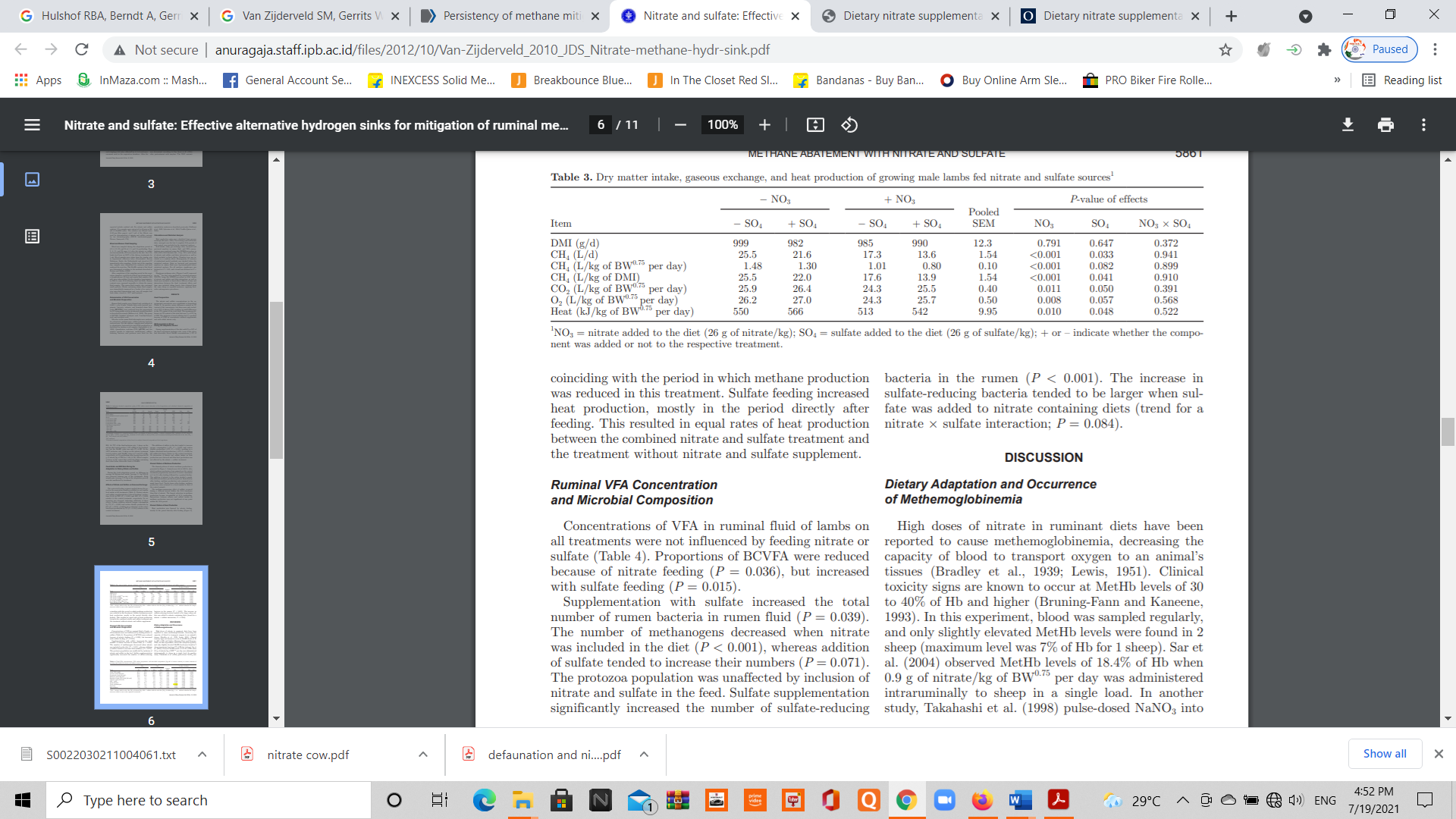


**f. Mitigation through Chemical Inhibitors**

**I. Nitrates and Sulphates**

Nitrates may serve as a terminal electron acceptor and therefore may behave as alternate hydrogen sink and can be converted to ammonia and used in the rumen as a source of nitrogen. In the rumen, sulphate is reduced to sulphide. Sulphate-reducing bacteria (SRB) in the large intestine of human and pig outcompete those of methanogenic bacteria (MB) and thus reduce methane production. Stoichiometric calculations show that reducing methane emissions in a sheep by 50 % would require ingestion of 0.75 moles of sulphate or nitrate per day. Adding sulphate to the diet of sheep also reduced CH4 production, and when both nitrate and sulphate were added, the effect on CH4 production was additive.

Van Zijderveldet *et al.,* 2010 experimented (In table 3) on 20 crossbred texel lambs to know the effect of nitrate and sulphate supplementation on methane production. 5 lambs were randomly allocated within a block to 1 of the 4 dietary treatments. Treatments consisted of a control treatment (no addition of nitrate or sulfate), a nitrate treatment (inclusion of 2.6% nitrate in dietary DM), a sulfate treatment (inclusion of 2.6% sulfate in dietary DM), and a treatment including both molecules in the diet (2.6% nitrate and 2.6% sulfate). Statistical analysis revealed that Methane production decreased with both supplements (nitrate: −32%, sulfate: −16%, and nitrate + sulfate: −47% relative to control).



**II. Organic Acids**

Fumaric and malic acids, the direct metabolic precursors of propionate, have also been studied as alternative hydrogen sinks in the rumen (Van Zijderveld *et al.,* 2010). Inclusion of malic and fumaric acids or their sodium salts or the intermediates of carbohydrate degradation in diets results in shifting rumen fermentation towards propionate and hence less methane production. Addition of sodium fumarate consistently decreased methane production in vitro by 2.3–41 %.

**III. onophores**

Among ionophore antibiotics, monensin is the most studied in ruminants, besides lasalocid, Salinomycin, nigericin and gramicidin. Monensin specifically targets bacteria producing H2 and formate. It reduces the amount of H2 available for methanogenic bacteria and attaches to the cell membrane of ruminal bacteria and protozoa, resulting in a decrease in the proportion of acetate relative to propionate in the rumen and thereby effectively lowering CH4 production by up to 76 % in vitro and to an average of 18 % in vivo. In a meta-analysis of 22 controlled studies, monensin (given at 32 mg/kg DM) reduced CH4 emissions by 19 ± 4 g/animal/day (*P* < 0.001) in beef steers. The corresponding reductions in dairy cows were 6 ± 3 g/animal/day (*P* = 0.065) for monensin given at 21 mg/kg DM.

**IV. Dietary Lipids**

Vegetable and animal lipids are also considered useful in terms of reduced rumen methanogenesis (Brask *et al.,* 2013). 10to 25 % reduction of methane may be achievable through the addition of dietary oils to the diets of ruminants (Beauchemin *et al.,* 2008). Possible mechanisms by which added lipid can reduce methane production include: (a) by reducing fibre digestion (mainly in long-chain fatty acids), (b) by lowering dry matter intake (if total dietary fat exceeds 6–7 %), (c) through direct inhibition of activities of different microbes including methanogens, (d) through suppression of rumen protozoa.

The addition of different oils (soya, coconut, canola, linseed, rapeseed, sunflower, etc.) to ruminant diets has been shown to reduce methane production between 18 % and 62 % in sheep, beef cattle (Beauchemin and McGinn, 2006) and dairy cows (Brask *et al.,* 2013). A wide range of essential oils (derived from garlic, thyme, oregano, cinnamon, rhubarb, frangula, etc.) has been shown to decrease methane production in vitro in a dose-dependent manner, but at high doses, the decrease in methanogenesis was accompanied by adverse effects on fermentation such as reduction in VFA production and feed digestibility (Patra and Yu 2012).

**g. Propionate Enhancers**

Within the rumen, hydrogen produced by the fermentation process may react to produce either methane or propionate. By increasing the presence of propionate precursors (e.g., pyruvate, oxaloacetate, malate, fumarate, citrate, succinate, etc.), more of the hydrogen is used to produce propionate and methane production is reduced (O’Mara, 2004).

Propionate precursors can be introduced as a feed additive for livestock receiving concentrates. The propionate precursor malate also occurs naturally in grasses, and research is being conducted to identify affordable natural sources, e.g., alfalfa and engineered feedstocks with high concentrations of propionate precursors. As propionate precursors naturally occur in the rumen, they are likely to be more readily acceptable than antibiotic or chemical additives.

**h. Manipulation of Rumen Microbial Ecosystem**

**I. Yeast Culture**

Yeast cultures reduce methane production in three ways: (1) by reducing protozoa numbers, (2) by increasing butyrate or propionate production and (3) by stimulating acetogens to compete with methanogens or to co-metabolise hydrogen, thereby decreasing methane formation (Chaucheyras *et al.,* 2008).

However, only limited information is available on the effects of yeasts (i.e.,*Saccharomyces cerevisiae* and *Aspergillus oryzae*) on methane production, and most of the studies were conducted in vitro.

**II. Methane Oxidisers**

Methane-oxidising bacteria (methanotrophs) could also be introduced as direct-fed microbial preparations. The oxidation reaction would compete with the production of methane, which is a strictly anaerobic process. Methanotrophs are a unique group of methylotrophic bacteria, which utilise methane as their sole carbon and energy source (Sejian *et al.,* 2015)

**III. Use of Bacteriocins**

Bacteriocins are antimicrobial proteinaceous substances that are ubiquitous in nature and produced by a variety of Gram-negative and Gram-positive bacteria. They are typically narrow-spectrum antibacterial substances under the control of plasmid and play a role in competition among microbial species for niches within the rumen system.

McAllister and Newbold (2008) reported that bacteriocins could prove effective in directly inhibiting methanogens and redirecting H 2 to other reductive bacteria, such as propionate producers or acetogens. The most well-known bacteriocin is nisin. Nisin obtained from *Lactobacillus lactis* ssp. *lactis* has also been shown to decrease methane production in vitro. A combination of nisin and nitrate, an alternative electron receptor, has been reported to reduce methane emissions in sheep (Sar *et al.,* 2005).

Bovicin HC5, the semi-purified bacteriocin produced by *Streptococcus bovis* HC5 from the rumen, has been reported to suppress methane production by 50 % in vitro (Lee *et al.,* 2002). Recently, highly specific antibacterial activity of PRA-1 produced by *Lactobacillusplantarum* TUA1490L against methanogens was reported by (Asa *et al.,* 2010).

**IV. Fungal Metabolites**

Secondary fungal metabolites from *Monascus* spp. reduced enteric methane emissions in sheepby 30 % in a short-term trial. Reduction ofmethane was accompanied, both in vitro andin vivo, by a shift in VFA pathways, decreasingthe acetate to propionate ratio. The main microbialmodifications observed were reduction inmethanogen numbers, suggesting a specific and toxic effect on this microbial group. Methaneemissions and the acetate to propionate ratio remained numerically less in the 2 weeks posttreatment as compared with measures before treatment (Morgavi *et al.,* 2013).

**V. Secondary Plant Metabolites – Tannin and Saponins**

Tannins are the most explored plant secondary metabolites as a modulator of the digestion processes in ruminants. Hydrolysable tannins tend to act by directly inhibiting rumen methanogens, whereas the effect of condensed tannins on CH4 production is more through inhibition of fibre digestion. On the other hand, saponins inhibit CH4 emissions through an indirect mechanism of reducing protozoa that are associated with methanogens. Saponins as such or in the form of Phyto-sources have been explored as a possible intervention for reducing enteric methane emission (Sirohi *et al.,* 2014). Soapnut (*Sapindus mukorossi)* is a valuable medicinal known for their high saponin content (~10%). A significant reduction in CH4 production (*in vitro*) is reported, when various extracts of soapnut have been used (Malik *et al.,* 2009). Currently, limited information is available in the public domain whether combined supplementation of Phyto-sources possessing two different biomolecules (tannins and saponins) has any synergistic impact on enteric CH4 emission.

Therefore in vitro and in vivo studies (Poornachandra *et al.,* 2019) were conducted at the institute to ascertain whether the combined supplementation of tamarind seed husk (tannins) and soapnut fruit pulp (saponins) has a synergistic negative impact on the rumen methanogenesis. From these studies, it was concluded that combined formulation of tamarind seed husk and soapnut in 60:40 and supplementation at 5.1% level of the diet could decrease the enteric methane emission by 20% as compared to control diet.

**Challenges and Considerations in Implementing Methane-Reduction Strategies**

Efforts to curtail methanogenesis in livestock systems present a complex interplay of challenges and considerations that demand meticulous attention. The successful implementation of methane-reduction strategies hinges upon a delicate balance between environmental objectives and livestock welfare. This section delves into the multifaceted challenges that need to be navigated and the vital considerations that guide these strategies.

**1. Animal Health and Performance:**

The welfare and productivity of livestock remain at the forefront of any intervention. The introduction of nutritional strategies should be carried out with a keen eye on their potential impact on animal health and performance. This encompasses monitoring digestive processes, nutrient utilization, and overall well-being. Any compromise on these aspects could negate the benefits of methane reduction, highlighting the necessity of a comprehensive approach that safeguards the animals' physiological equilibrium.

**2. Sustainability Assessment:**

While the primary objective of methane-reduction strategies is mitigating its impact on climate change, the broader environmental consequences demand scrutiny. The intricate relationship between methane, other greenhouse gases, and resource utilization warrants a holistic sustainability assessment. This entails evaluating potential trade-offs and unintended outcomes that might arise from these strategies. The path toward sustainability necessitates not only reduced methane emissions but also a net-positive impact on the environment.

**3. Embracing Individual Variation:**

The intricacies of livestock physiology introduce another layer of complexity: individual variation. Animals within the same species respond differently to various nutritional interventions. Genetics, age, and dietary preferences underscore this variability, impacting the efficacy of methane-reduction strategies. Tailoring these approaches to suit the unique needs of each animal and accounting for their diverse responses is a dynamic challenge that demands a nuanced, personalized approach.

**Conclusion**

The intricate nexus between livestock activities and greenhouse gas (GHG) emissions underscores the pressing need for comprehensive strategies that balance the demands of food production with environmental sustainability. The statistics and insights presented in this discourse emphasize the pivotal role of livestock in the global emissions landscape and underscore the urgency of implementing mitigation measures. Livestock's contribution of 14.5% to annual anthropogenic GHG emissions serves as a stark reminder of the industry's profound impact on climate change. The emissions trio - carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) - emerges as the key players in this ecological drama. Methane, with its substantial 44% share, leads the pack, followed by N2O at 29% and CO2 at 27%. This distribution highlights the unique and varied mechanisms through which livestock influence climate dynamics.

Globally, livestock's share in the emissions pie is even more telling. Anthropogenic CH4 emissions are significantly influenced, with livestock contributing to 44% of the total. Similarly, 53% of anthropogenic N2O emissions and 5% of anthropogenic CO2 emissions can be attributed to livestock activities. Cattle, the focal point of the sector, bear the brunt of responsibility, accounting for a remarkable 62% of emissions. Beef and dairy cattle share comparable emission levels, while other livestock categories contribute 7% to 11% of emissions. In India, the situation is equally significant, with cattle and buffalo assuming the leading roles in enteric methane emissions. The alarmingly potent warming impact of methane, despite its shorter atmospheric lifespan, reinforces the criticality of addressing livestock emissions.

However, these challenges do not stand without potential solutions. Research breakthroughs have yielded insights into mitigation strategies. Strategies range from improving feed quality and production to innovative additives, inhibitors, and fermentation modulation techniques. In the grand tapestry of climate change, livestock's role as both a contributor and a potential solution presents an opportunity for transformative change. As we seek to nourish a growing global population while safeguarding our planet, the dialogue between science, policy, and practice becomes paramount. The integration of sustainable practices, technological innovation, and informed policies will pave the way toward a future where livestock can coexist harmoniously with a climate-resilient world.

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