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Review on Feed Associated Options to Reduce Greenhouse Gas Emissions from Ruminant Animals

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Abstract
Animal production is a significant source of greenhouse gas (GHG) emissions worldwide. This review aimed to summarize the current status of feed associated options from ruminants and its implication for their reduced GHG emissions. The emission of greenhouse gases (GHG) from ruminant livestock is influenced by different factors such as dietary characteristics as well as the fermentation conditions in the rumen. So, reducing greenhouse gas emissions by changing nutrient composition (e.g. shifting towards concentrate based diets, use of forages at an earlier stage of maturity). Feed additives have been comprehensively studied in vitro and in vivo for their methane reducing potential. The use of fodder trees has been developed through the process of pelleting; Leucaena leucocephala leaf pellets (LLP), Moringa oleifera pellets, and Red macroalgae (Asparagopsis taxiformis) pellets can be used as good sources of protein to supplement ruminant feeding. Feed additives containing plant secondary compounds (tannins, saponins, essential oil), and ionophores (monensin, lasalocid). This approach could help to decrease rumen protozoa and methanogens and thus reduce the production of methane gas. Considerable additional research is still needed in order to use both conventional and non-conventional feed resources their potential to affect greenhouse gas emissions by the animals.

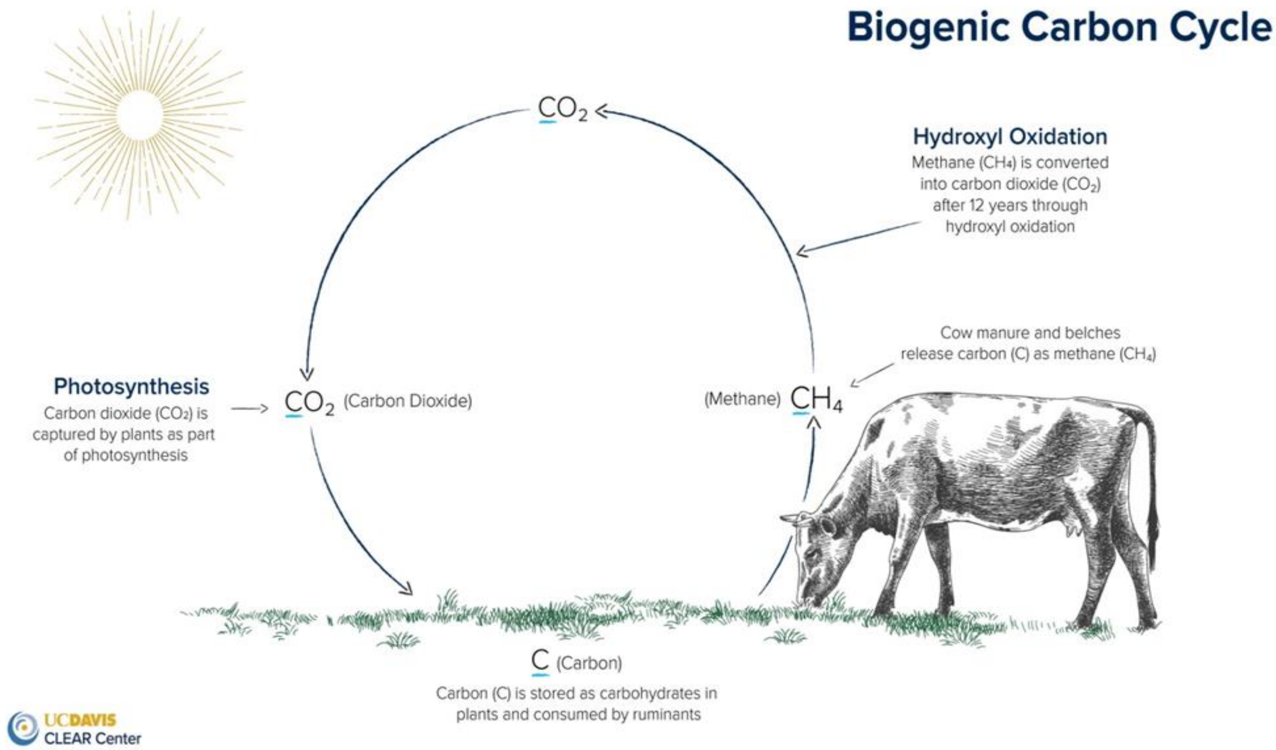
Keywords: Feed, Greenhouse gas, Methane, and Ruminant

1. Introduction

Livestock greenhouse emissions of 44%, 29%, and 27% are CH_4, N_2O, and CO_2 respectively [1]. Regardless of the species, ruminant livestock is the largest source of methane (CH_4) emissions, with more than 90% coming from enteric fermentation and the rest from manure [1,2]. Cattle account for 77 percent of these emissions (2.5 Gt), buffalo for 13 percent (0.43 Gt), and small ruminants (sheep and goats) for the remainder (0.31 Gt) are the most common ruminant livestock kinds that release CH4, produce about 3.3 Gt CO_2 eq. of enteric methane annually (FAO, 2021). Berhanu et al. (2019) reported that the enteric CH4 emissions from ruminants in Ethiopia increased by 12% or ≈ 6197 Gg CO_2-eq. in 2017 as compared to the year 2011. Greenhouse gas, such as those contained in the grass, hay, silage, and grains are a major part of bovine diets and are emitted from these biogenic sources during the fermentation of starches, lipids, and proteins in the digestive system of cattle (enteric fermentation) and later in the feces and urine [3]. The production of enteric CH_4 from ruminants is mainly affected by feed intake and feed quality which, in turn, defines the total energy and nutrient intake and consequently animal performance. Feeding animals to improve feed efficiency and performance has the added benefit of reducing greenhouse gas emissions [4]. Rumen digestion of feed components by the bacteria, protozoa, and fungi, under anaerobic conditions, results in the production of volatile fatty acids (VFA), mainly acetate, propionate, and butyrate used by the animal as a source of energy, and the production of gases (CO_2 and CH_4) eliminated through eructation (belch) [5,6].

Diverse parameters influence greenhouse gas formation in the digestive tract or downstream effects in the farming system, such as digestibility, the chemical composition of the diet, and the presence of functional additives in the ration [1]. To reduce Greenhouse gas emissions from livestock systems must incorporate strategies associated with animal feed and nutrition and ultimately evaluate their effect through productive parameters [4].There is potential for reducing enteric greenhouse gas emissions through a variety of approaches with a focus on the use of feed additives, dietary manipulation, and forage quality [7]. Therefore, the objective of this paper is to review and illustrate current information on feed-related solutions for reducing ruminant greenhouse gas emissions.

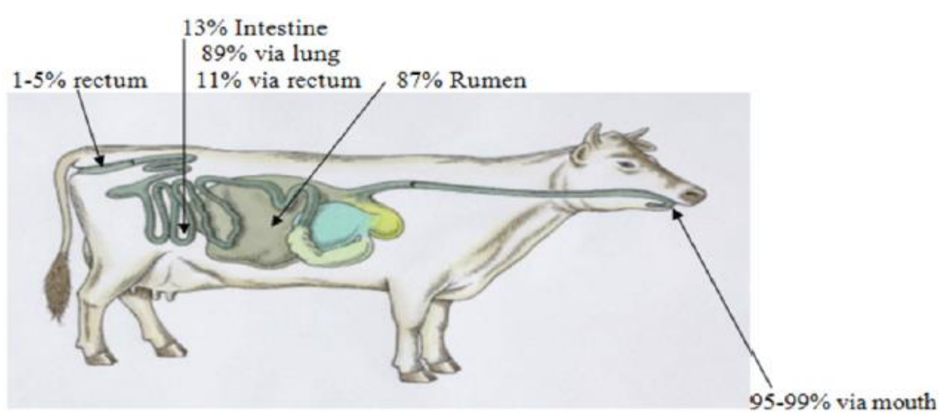
2. General views of Greenhouse gas (GHG) emission in Ruminant livestock



Sources: https://clear.ucdavis.edu/explainers/biogenic-carbon-cycle-and-cattle

Figure 1: Biogenic-carbon-cycle

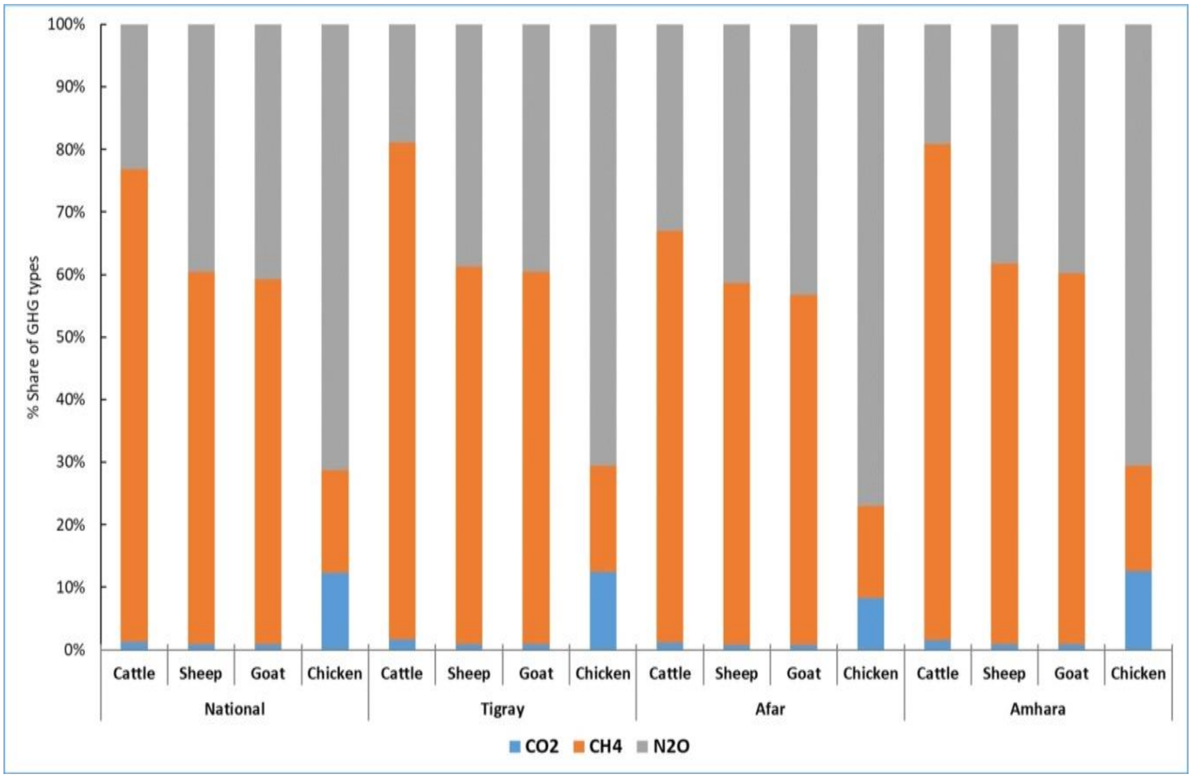
Ruminant livestock contributes to climate change by producing a considerable amount of anthropogenic greenhouse gas emissions. Greenhouse emissions (GHGs) emitted from livestock are CO_2, CH_4, and N_2O, coming from respiration, enteric fermentation, and manure management respectively, with CH_4 and N_2O having the highest global warming potential [8]. The primary source of CH_4 from ruminant livestock is the process of enteric fermentation during rumination [9]. Initial microbial breakdown (essential in ruminant digestion) occurs in the rumen, or large forestomach, where microbial fermentation converts fibrous feed into products digested and utilized by the animal [10]. Rumination promotes digestion of cellulose and hemicelluloses through hydrolysis of polysaccharides by microbes and protozoa, which is followed by microbial fermentation generating H_2 and CO_2. Methane is produced as a by-product of enteric fermentation and carbohydrate digestion and is expelled through the mouth via eructation [11].



Source: Vanlierde et al., 2017

Figure 2: Greenhouse gas emitted from the ruminant animal through the mouth via eructation

Livestock management practices and feed resources have great functions for the cause of greenhouse gas emissions through animals.; Greenhouse gas production varies by animal type and is proportional to the animal's weight and feed intake. In a very recent study in Ethiopia year wise total GHG emissions from the four species of animals (cattle, sheep, goat, and chicken) at the national level showed an increasing trend (92.9 Mt CO_2-eq in 2003/4 to 146.8 Mt CO_2-eq in 2017/18) [12].



Source: Menghistu et al., 2021

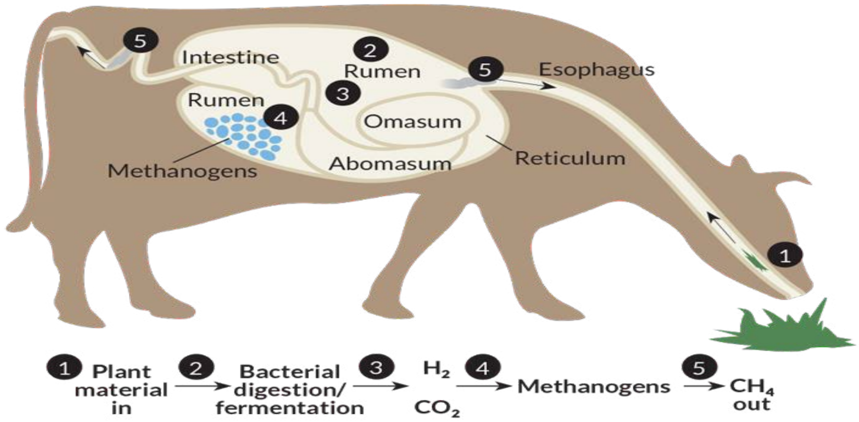
Figure 3: Percent of emission of GHGs from Livestock species in Ethiopia (national level) and the study regions (2013/14-2017/18

2.1 Feed associated option to reduce greenhouse gas emitted from ruminant animals

2.1.1 Animal dietary manipulation

The most promising options for reducing GHG emissions at the livestock management level include improving animal production through dietary changes. The combination of dietary and rumen manipulation options, including feed additives, is expected to reduce enteric methane emissions by over 30% in the next decade without compromising animal productivity and health [13]. Nitrogen (N) excretion rates, which affect N2O emissions from manure, are based on dry matter consumption (DMC) and its N content (Verge et al., 2012). Therefore, dietary manipulation to optimize protein consumption, and thus improve the efficiency of N utilization, is one of the most effective measures to reduce emissions from manure [14]. Optimizing N supply to animals can achieve between 12 and 21% less N excretion and 15–33% less N volatilization losses in livestock fed according to the physiological status of the animals [15].

Also, plants species such as Lolium perenne, Trifolium repens, and Plantago lanceolata, which may exhibit diuretic properties have the potential to reduce the urinary-N loading in individual urine patches by increasing the urination frequency of grazing animals (Des roseaux et al., 2020). Therefore, dietary manipulation is one of the approaches that used to reduce the enteric greenhouse gas emission from ruminant animals. Dietary strategies can be divided into two main categories: i) improving the forage quality and changing the proportion of the diet and ii) dietary supplementation of feed additives that either directly inhibits methanogens [16].The diet has a predominant factor affecting the microbial community composition in the rumen on the host and the rumen environment as reported by Henderson et al. (2015).



Sources: Wilson, 2019

Figure 4: Diet and Greenhouse gas

Animal category	Measured gas	Feeding measures	Results	Authors
Beef steer	Enteric CH_4	The supplementation of grazing animals with maize grain	CH_4 emissions of dung from 4.0 to 1.7 g CH_4-C/m^2 compared with dung from non-supplemented animals	Lombardi et al., 2021
Holstein Friesian cows	Enteric CH_4	Supplementation with 3-nitrooxypropanol 3-NOP by mixing it with roughage or incorporating it into a concentrate pellet	Reduction in CH_4 yield (23-24%) with no difference weather 3-NOP is mixed with roughage or incorporated into concentrate pellet	Van Wesemael et al., 2019
Jersey cows	Enteric CH_4 CO_2	The gradual transition from indoor winter feeding to outdoor spring grazing	Grazing has no significant impact on average CH_4 and CO_2 concentrations and CH_4: CO_2 between animals	Szalanski et al., 2019
Hereford heifers	Enteric CH_4	Using contrasting levels of pasture quality	A reduction of 14% in enteric CH_4 emissions with high quality forage compared to low quality one	Dini et al., 2017
crossbred Charolais and purebred Luing	Enteric CH_4	Feeding two different diets (concentrate-straw or silage-based)	Lower CH_4 (18%-25%) when a high proportion of the concentrate (92% DMI) rather than equal amounts of concentrate and forage in the diet was fed	Duthie et al., 2017

Table 1: Impacts of diet manipulation on GHG emissions

2.1.2 Improved Forage

Forages contain structural carbohydrates, such as neutral detergent fiber (NDF), and have been linked to increased CH_4 production [17]. A high reduction in enteric methane emissions can be achieved by increasing the forage quality combined with the management of stocking rates and rotational grazing strategies

[18]. Harvesting forages at the right time, depending on the type of forage, is important to maximize the amount and digestibility of nutrients supplied by forages [7]. Improving DE% and CP% content of available feed through the introduction of improved forage, improved natural pasture, and supplementation of concentrate feed is predicted to reduce CH4 emission by 23% and 18% for indigenous cattle and crossbred dairy cattle, respectively [19].

There is a large number of shrubs and trees, both legume and non-legume species with great potential for ruminant production in the tropics which contain a wide variety of secondary compounds with potential methane-suppressing properties. According to a recent report, except maize stover, all multipurpose forage species such as Lablab purpureus, Crotalaria juncea, Moringa stenopetala, Cajanus cajan, Sesban sesban, and Leuceana leucocephala have significant CH4 reduction potential and high levels of Crude Protein content that could be used for CH4 mitigation while simultaneously enhancing protein supply in ruminant forage diets in southern Ethiopia [20].

Multipurpose forage species	GP, mL/0.2 g DM	CH4, mL/0.2 g DM	CH4 Concentration (%)
Maize stover	144.06 (37.60)b	44.33 (1.41)a	31.73 (7.30)a
L. purpureus	206.40 (54.12)	33.00 (4.71)b	16.25 (1.20)
C. juncea	155.71 (30.43)ab	35.67 (1.41)b	23.45 (5.50)c
M. stenopetala.	169.80 (33)a	40.50 (2.60)a	24.16 (3.17)c
S. sesban	137.20 (43.64)b	40.67 (1.41)a	31.06 (8.80)ab
C. cajan	67.40 (26.73)	32.83 (2.21)b	52.22 (17.60)
L. leucocephala	142.40 (37.6)b	35.17 (1.2)b	25.48 (5.90)bc

Sources: Berhanu et al., 2019

Table 2: Total gas production (GP), CH4 production, and concentration (as a proportion (%) of total GP) of multipurpose forage species.

2.1.3 Feed supplementation

A. Supplementation of Moringa (Moringa oleifera)

The incorporation of leaves, flour, seeds, or extracts of Moringa oleifera, the natural capacity of the species to inhibit methanogenesis, has reported successful results in research carried out in goats and beef cattle. Moringa oleifera leaves extract 20ml was supplemented of lactating Nubian goats without affecting ruminal pH and ammonia-N, M. oleifera extracts increased total short-chain fatty acids (SCFA), branched-chain SCFA, and propionic acid concentrations; however, the extract linearly decreased acetic/propionic ratio and calculated methane production [21].

The effects of Moringa oleifera seed inclusion in a beef cattle diet on rumen fermentation and methane generation on total gas production (ml/day; Table 2.3) where gas production was enhanced in the M10 and M20 treatments and decreased in the M40 treatment compared to Control [22]. With increasing Moringa seed concentrations in the diet, CH4 generation (percent and ppm of total gas) was linearly decreased.

Components	Treatment				
	Control	M10	M_{20}	M_{40}	SEM
Total gas (ml/day)	1823.9^{ab}	2170.2^{a}	2065.6^{ab}	1609.7^{b}	144.6
CH4 (%)	7.1^{a}	7.2^{a}	5.8^{b}	3.6^{c}	0.28
CH4 (ppm of total gas)	4.2^{a}	3.5^{ab}	3.0^{b}	2.4^{b}	0.39
CH4 (mg/day)	92.9^{ab}	111.9^{a}	77.3^{b}	41.8^{c}	7.55
CH4 (mg/g DM incubated)	6.2^{ab}	7.5^{a}	5.2^{b}	2.8^{c}	0.5
CH4 (mg/g DM disappeared)	9.0^{ab}	10.9^{a}	9.0^{b}	5.1^{c}	0.39

Source: Lins et al., 2019

Table 3: Effect of inclusion of Moringa seed in the diet on in vitro gas production using a Rusitec system

Control=no Moringa seeds; M_{10}=100 g/kg dry matter (DM) of concentrates inclusion of Moringa seeds; M_{20}=200 g/kg DM of concentrates inclusion of Moringa seeds; M_{40}=400 g/kg DM of concentrates inclusion of Moringa seeds; CH_4=methane.
Values in the same row followed by different superscript letters are significantly different at P<0.05. Level of significance indicated by *P<0.05, **P<0.01, ns=not significant.

B. Supplementation of Red macroalgae (Asparagopsis taxiformis)

Asparagopsis contains the active compound bromoform which inhibits the production of methane during digestion. Asparagopsis inclusion resulted in a consistent and dose dependent reduction in enteric CH_4 production over up to 80% CH_4 reduction at the 3% offered rate compared with the group fed no Asparagopsis (Li et al., 2016). Inclusion of Asparagopsis armata in lactating dairy cows' diet decreased CH_4 by 26.4% at the low (0.5%) level of A. armata inclusion and 67.2% at the high (1%) level of inclusion (Roque et al., 2019). The red macroalgae Asparagopsis taxiformis has the potential to reduce methane (CH_4) production from beef cattle by up to ~99% when added to Rhodes grass hay; a common feed in the Australian beef industry (Roque et al., 2019). Beef cattle fed an Asparagopsis included in the high grain TMR at 0.05%, 0.10%, and 0.20% of diet OM resulted in the decrease of CH_4 production without affecting either meat quality grading or consumer sensory evaluations (g/kg DMI) of 9%, 38%, and 98%, respectively (Kinley et al., 2020). Recent studies using red macroalgae (seaweed) Asparagopsis spp. as a feed supplement has shown to reduce ruminant enteric methane (CH_4) production up to 99% in vitro with no differences were found in ADG, carcass quality, strip loin proximate analysis, and shear force, or consumer taste preferences (Roque et al., 2021.

Source: Roque et al., 2019

Figure 5: Red macroalgae (Asparagopsis taxiformis)

2.1.4 Supplementation of Feed additives

A. Tannins

Tannins occur in many plants suitable for feeding, especially in the tropics and subtropics. Tannins plant secondary metabolites (PSM), play an important role in the efforts to reduce the emissions of CH_4 from ruminant species. When plant secondary metabolites are included in the feed, they alter the availability of nutrients and metabolites and/or inhibit ruminal microbial bacteria, protozoa, fungi, and archea populations [23]. In a recent in vitro study, the same concentration of chestnut tannins was fermented, and methane produced was reduced by 12.5% compared to the control [24]. Silvopastoral systems use forage species such as Leucaena leucocephala, Tithonia diversifolia, and Gliricidia sepium, which contain significant amounts of tannins in their leaves and stems [25]. Many types of forages known to contain tannin extracts have been shown to decrease methane production (Table 4).

Scientific name	Family	Part of plant	Tannins	Saponins	Methane reduction(%) over control ration	Authors
Leucaena leucocephala	Fabaceae	Forage	+		20	Montoya-Flores et al., 2020
Leucaena leucocephala	Fabaceae	Forage	+		14	Molina et al.,2016
Enterolobium cyclocarpum + Gliricidia sepium	Fabaceae	Pods + forage	+	+	6.3	Molina-Botero et al., 2019
Samanea saman	Fabaceae	Pods	+	+	50	Salazar et al.,2018

Table 4: Effect of plant species or plant extracts containing secondary metabolites on enteric methane reduction in ruminants as measured in open-circuit respiration chambers

Source	Study	Secondary compound	Microorganisms affected	Authors
Dolichos labla	In vitro	Condensed tannins	↓Fungi; ↑Methanogens; ↓R. flavefaciens; ↓F. Succinogenes	Abdalla et al., 2012
Leucaena leucocephala	In vitro	Condensed tannins	↓Fungi; ↑Methanogens; ↓R. flavefaciens; ↓F. Succinogenes	Abdalla et al., 2012
Cajanus cajan	In vitro	Condensed tannins	↓Fungi; ↓Methanogens; ↓R. flavefaciens; ↓F. succinogenes;	Abdalla et al., 2012
Mangosteen peel	In vivo	Condensed tannins	↑Total baceteria; ↓Methanogens; ↓R. flavefaciens; =F. succinogenes; = R. albus	Wanapat et al., 2014

Table 5: Effect of secondary metabolites on rumen microorganisms

B. Saponins

Saponins play an important role in the efforts to reduce the emissions of CH_4 from ruminant species. Saponins are complex compounds that are composed of a saccharide attached to a steroid or triterpene and have a soapy character due to their surfactant properties. Saponins are present in a wide variety of tropical trees and shrubs and ruminant species eagerly consume their foliage or pods while browsing [26]. Many studies have reported reductions of methane through an inhibitory effect of saponins on methanogens in the rumen (Table 4) In vivo study on Mangosteen peel contains saponins ↑Total baceteria; ↓Methanogens; ↓R. flavefaciens;=F. succinogenes; = R. albus [27].

C. Supplementation of essential oils (EO)

Supplementation of essential oils plays an important role in the efforts to reduce the emissions of CH_4 from ruminant species. Essential oils are produced in special cells in different parts of the plants, including roots, seeds, fruit, leaves, flowers, bark, petals, and stems [28]. The beneficial effects of essential oil on the animal such as antioxidant, anti-inflammatory, immune status, and antimicrobial have been shown against a wide variety of microorganisms either gram-positive or Gram-negative bacteria, fungi, viruses, and protozoa, but more effective against the Gram-positive, because most active compounds present in essential oils are lipophilic [20]. In vivo study on Origanum vulgare L.contain essential oil affected on rumen microorganisms ↑Ruminal fungi; ↓Protozoa; ↑R. flavefaciens, R. albus and F. succinogenes [29].

D. Nitrates

Adding nitrate to ruminant diets can be an effective CH4 mitigation strategy because nitrate competes with methanogens for H2 in the rumen. Nitrate (NO_3 –) is reduced to nitrite (NO_2 ; $NO_3 + H_2$! $NO_2 + H_2O$) and further to ammonia (NH_4 + ; $NO_2 + 3H_2 + 2H$+!NH_4 + + $2H_2O$) by rumen microbes. However, small quantities of nitrous oxide may also be produced (Latham et al. 2016). Methane production reduced 14.6% in cattle supplemented with nitrate at 17.7 g/kg DM [30]. Nitrates can replace CO_2 as an electron acceptor, forming ammonia, instead of CH_4, as an alternative H_2 sink in the rumen [31]. Cattle have shown promising results with nitrate supplementation, indicating reductions in enteric CH_4 production, of up to 50%, especially when supplementing forage-based diets [32,33].

Nitrite Adding level/dosage	CH_4 reduction	Authors
10 g nitrate/kg feed DM	10%	Velazco et al., 2014
20 g/day for beef cattle grazing low-quality pasture	6.5%	Callaghan et al,2014
lactating dairy cows fed 20 g nitrate/kg of diet DM	15%	Nolan et al., 2016,and Lee and Beauchemin, 2014

Table 6: Effect of Nitrite on Enteric Methane Reduction in Ruminants

E. Ionophores

The most effective antibiotic in ruminant fermentation is monensin, although others such asnigercin, gramicidin, and lasalocid are available [34]. Antibiotic ionophores, of which Monensin is the most routinely used, have been reported to reduce CH_4 emissions in ruminants [35]. The dosage of monensin required to reduce direct CH_4 emissions are ~32 to 36 mg/kg BW in beef cattle and 21 mg/kg BW in dairy cattle (Appuhamy et al., 2013), whereas for increasing feed efficiency the required dosage can range from 10 to 40 mg/kg of DM [36]. In contrast, reported no suppression effect of monensin on CH_4 output when it was administered to dairy cattle (0.024 g/kg DM), but there was an increase in the proportion of a biohydrogenation intermediate, thus altering rumen metabolism patterns (Benchaar, 2020).

3. Conclusion

From livestock, ruminants are the primary producers of greenhouse gas. Reducing options can be broadly categorized into dietary and rumen manipulation. Enteric methane emissions are strongly correlated to dry matter intake and somewhat sensitive to diet composition. Dietary manipulation methods include increasing feed digestibility, such as concentrate to forage ratio, or increasing fats and oils, which are associated with lower methane emissions. These reduce digestible fiber that are positively related to methane production and more energy passing the rumen without being degraded, respectively. Rumen manipulation through feed additives can be further classified based on the mode of action: Rumen environment modifiers indirectly affect emissions and direct methanogenesis inhibitors. The rumen environment modifiers act on the conditions that promote methanogenesis. These include ionophores, plant bioactive compounds such as essential oils and tannins, development of pellet products such as moringa olifera, and LLP (Leucaena leaf pellet), and nitrate rich feeds that serve as alternative hydrogen sinks and directly compete with methanogens thereby reducing methane emissions. The inhibitor category includes 3-nitroxypropanol and seaweeds containing halogenated compounds. Seaweed, in particular Asparagopsis spp., reduced emissions intensity (g/kg milk) by up to 67% in dairy and emissions yield (g/kg dry matter intake) by up to 98% in beef cattle and better to demonstrate this technology [37-61].

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