Factors Influencing Dietary Tannin Inclusion in Dairy Diets: A review

Lindokuhle Christopher Mhlongo¹*, Cresswell Mseleku², Thando Tenza² and Ignatius Verla Nsahlai²

¹Department of Animal Science, University of the Free State, Bloemfontein, South Africa
²Department of Animal and Poultry Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa

*Corresponding Author: Lindokuhle Christopher Mhlongo, E-Mail: chrisokuhle@gmail.com

ABSTRACT

The objective of this paper was to evaluate factors affecting tannin dietary inclusion on enteric methane emission (CH₄) and performance in dairy cows. Dairy production contributes to the greenhouse effect as it naturally emits enteric CH₄. Therefore, this has sparked a need to control enteric methane emissions using anti-methane natural compounds such as tannins. Even at moderate dietary inclusions, tannin use in animal diets can occasionally reduce dairy performance and enteric CH₄. This is due to the fact that most studies employ tannins to reduce enteric CH₄ in dairy cows excluding other influential factors by focusing on the tannin inclusion effect alone. Therefore, there is a need to study different factors that influence the effect of tannins on enteric CH₄ and dairy performance regardless of dietary tannin inclusion to improve the control of enteric CH₄ at no expense to dairy performance. Hence, there is a need to identify factors that affect dietary tannin inclusion, such as tannin source, diet and animal factors that need consideration to prevent the control of enteric CH₄ by tannins at the expense of animal performance. This approach would inform future studies relevant to the use of tannins in dairy diets to improve the effect of this treatment through in vivo and in vitro studies to ensure dairy production is harmless to the environment while meeting production targets.

Keywords: Animal-environment relationship, Dairy production, Enteric methane emissions, Tannins.

INTRODUCTION

The importance of dairy products to human health as a source of proteins remains undisputed. This animal production provides milk, meat, and by-product commodities such as hides to provide food security. The increase in human population necessitates an increase in animal production to meet the nutritional requirements for the survival of humanity. This demand would accelerate the negative effect of animal production on the environment. Dairy and beef production are two major sources of livestock-related enteric methane (CH₄) emissions (Caro et al., 2016). A by-product of rumen fermentation, which occurs when feed is transformed into nutrients, is CH₄. However, CH₄ gas is a greenhouse gas with a heating power of 25-folds or more than that of carbon dioxide (Rira et al., 2015) and constitutes about 55% of gases released by ruminants (Rira et al., 2015). Controlling CH₄ emissions in dairy cattle is a challenge due to the intensification of the dairy industry.

This challenge has sparked interventions into the control of ruminal digestion to discriminate against the production of CH₄ gas to promote animal production that is harmless to the environment (Nawab et al., 2020). Therefore, phytochemicals can potentially restrict the pathway of microorganisms involved in the formation of CH₄ without negatively affecting the environment (Patra and Puchala, 2023). Condensed tannins are natural polyphenolic phytochemicals found in tropical and temperate foliage that can decrease methanogens and fibre digestion (Jayanegara et al., 2015). This lowers the availability of hydrogen molecules, which are needed for the formation of CH₄ during fermentation. Another benefit of condensed tannin inclusion in dairy rations is the promotion of small-intestinal absorption of proteins by forming a protein-tannin complex that shields proteins from premature digestion in the rumen (Anas et al., 2015).
Dietary inclusion of tannins is influential when studying the effect of condensed tannin inclusion on CH$_4$ emissions and ruminant performance (Denninger et al., 2020). It is claimed that including condensed tannin at a rate of less than 3% in animal diets reduces CH$_4$ emissions without changing milk parameters (Naumann et al., 2017). Contrarily, a different study found that tannins reduced CH$_4$ while impairing milk production (Huyen et al., 2016). Milk yield and quality, nutritional digestibility, and feed intake appear to be impaired and exhibit different responses (Henke et al., 2017) when condensed tannins are included in dairy rations to decrease CH$_4$ production (Cardoso-Gutierrez et al., 2021).

The dietary inclusion of condensed tannins in dairy rations has been the main factor considered for the control of CH$_4$ emissions without affecting milk parameters (Avila et al., 2020b), but the results produced are conflicting. The conflicting effects of tannin sources on CH$_4$ and ruminant performance could be credited to the structural chemistry of tannins. Tannins consist of prodelphinidins (PD) or procyanidins (PC) in their structural chemistry and the PD to PC ratio differs in different tannin sources (Quijada et al., 2018). The inclusion level (<2%) of dietary Acacia mearnsii condensed tannins demonstrated a decrease in CH$_4$ and no effect on milk yield or quality, although protein digestibility was decreased (Alves et al., 2017a). The 3% inclusion of Mimosa tenuiflora extract failed to decrease CH$_4$ (Lima et al., 2019). It has been established that A. mearnsii condensed tannins (400 g/d) decrease both CH$_4$ and milk yield (Williams et al., 2020). Other studies have proven that the inclusion level (0–3%) of quebracho or A. mearnsii condensed tannins does not affect milk yield even though CH$_4$ was not measured (Henke et al., 2017; Gerlach et al., 2018). Some studies reported that dietary inclusions of condensed tannins up to 7.5% or 10% could be used without affecting the milk yield or quality (Griffiths et al., 2013; Kapp-Bitter et al., 2020).

These milk performance variations for different dietary tannin inclusions suggest that other factors may need consideration to reduce CH4 without negatively impacting milk production and feed intake. Therefore, factors that influence the condensed tannin effect on dairy performance and CH$_4$ need to be identified. This would improve the discovery of a dietary inclusion of tannins that depresses CH$_4$ without depressing milk or intake performance. The objective of this review was to describe tannin source, dietary and animal factors that affect tannin results on dairy performance and enteric CH$_4$, and the effects of A. mearnsii tannins on dairy performance and enteric CH$_4$.

1. Intrinsic factors affecting tannin activity
The chemical composition influences the effect of tannins on animal performance and CH$_4$. This can be attributed to the tannin effect being different depending on tannin sources.

1.1. Structural Form
The structural formation of condensed tannins consists of prodelphinidins (PD) or procyanidins (PC) in nature (Quijada et al., 2018). Condensed tannins have both structures, but one of these structures tends to be dominant, resulting in a varying PD/PC ratio per source of condensed tannins. A higher PD/PC ratio of condensed tannins has been found to reduce in vitro CH$_4$ emissions better than an inverse form of the ratio (Niderkorn et al., 2020). Higher PD/PC ratio condensed tannins may possess the rumen-digestion-resistant 5-deoxy flavan-3-ol subunit by stimulating the exertion of persistent anti-methanogenesis (Niderkorn et al., 2020). The explanation offered is that condensed tannins with a low PD/PC ratio may contain the typical 5-hydroxyl group and this hydroxyl group is susceptible to breakdown during ruminal digestion (Naumann et al., 2018).

Available studies have used PD-condensed tannins from sainfoin pellets and PC-condensed tannins from hazelnut pericarp and there have been contrasting results. In vivo Sainfoin inclusion decreased CH$_4$ emissions with increased milk yield without the depression of protein digestibility (Huyen et al., 2016). Hazelnut inclusion in vivo decreased CH$_4$ emissions without a change in milk yield (Terranova et al., 2021). These limited studies demonstrate that condensed tannin sources with a higher PD/PC ratio are more effective in controlling CH$_4$ emissions and have positive effects on milk performance. These findings imply that studies that use condensed tannins to decrease CH$_4$ emissions in dairy diets need to consider the PD/PC ratio of the tannin source to improve the incorporation of condensed tannins in animal diets to prevent deleterious effects on animal performance.

1.2. Molecular weight
Observations show that high molecular weight (MW) condensed tannins exert a higher depression of CH$_4$ emission and acetate concentration than low MW condensed tannins (Saminathan et al., 2015; Petlum et al., 2019). High MW condensed tannins can decrease CH$_4$ and protein digestibility without decreasing dry matter digestibility (Saminathan et al., 2015). The positive association
between reduced protein digestibility and the high MW of condensed tannins suggests that using a moderate MW condensed tannins is recommended. This would prevent tannins from decreasing CH₄ emissions and animal performance parameters. Condensed tannins with higher MW are associated with high protein binding ability which decreases CH₄ but renders proteins unavailable for absorption in the small intestines and depresses milk performance (Saminathan et al., 2015; Petlum et al., 2019).

High MW condensed tannins may lack a consistent effect on methanogens. Higher MW condensed tannins decrease hydrophilic methanogen order (Methanomicrobiales, Methanopyrales, Methano-coccales, Methanobacterales, Methanocellales and Methanosarcinales) and increase the methylamine using methanogens (Methanoplasmatales or Thermoplasmatales) (Saminathan et al., 2016). Therefore, the mode of action of high MW condensed tannins may not be broad-spectrum but only based on suppressing a certain methanogen group. Such inconsistent effects of tannins may result in the proliferation of other methanogens. Conversely, tannin effect on methanogens may be coated because condensed tannins may fail to affect protozoa which may benefit methanogens as they depend on protozoa for methanogenesis (Sarnataro et al., 2020). This could be the cause of condensed tannin inclusions being ineffective on CH₄ emissions in some studies (Focant et al., 2019).

2. Dietary factors

Tannins influence ruminant performance by modulating crude protein digestion and fibre digestibility. The chemical composition of the diet supplemented with tannins also influences the effect of tannins on ruminant performance and CH₄.

2.1. Crude protein digestibility

One of the main challenges that result from the addition of condensed tannins to animal diets is the suppression of crude protein digestibility (Zhang et al., 2019). The compromise of crude protein digestibility suppresses milk production parameters (Henke et al., 2017). There is a suggestion that aiming for crude protein content that is excessive in the basal diet could counter the suppression of crude protein digestibility by dietary condensed tannins which affect milk parameters (Denninger et al., 2020). Finding the crude protein inclusion level to use in a condensed tannin-enriched diet without affecting milk production remains less studied. Diets enriched with 20.4% crude protein content and 2.5% A. mearnsii tannins supported conditions that increased CH₄ emissions. In that study, there was an increased acetate-to-propionate ratio and decreased propionate and total tract digestibility (Koenig and Beauchemin, 2018). In a tanniferous diet with low crude protein, there has been an observation that protein synthesis remains unchanged when protein digestibility is also unchanged (Avila et al., 2020b).

Manipulation of tannin sources seems to be part of the solution to increase protein synthesis and offer moderate protein digestibility that can maintain animal performance. Bayberry condensed tannins (3%) depressed protein digestibility more than A. mangium condensed tannins (Zhang et al., 2019). A similar trend persisted when Leucaena leucocephala decreased protein digestibility more than A. saligna condensed tannins in Barki rams (El-Zaïat et al., 2020). Identifying tannin sources with low suppression of protein digestibility could preserve animal performance. High protein content in the diet increases protein digestibility and milk production without influencing CH₄ (Niu et al., 2016). However, findings remain contrasting regarding dietary protein content in relation to CH₄ emissions and protein digestibility.

Higher dietary protein content (15.2-18.5%) increased the digestibility of crude protein but did not affect CH₄ emissions, milk yield and feed intake (Niu et al., 2016). Increasing protein levels (10-19%) in the concentrate sometimes increases CH₄ emissions (Van Dung et al., 2019). Increasing the crude protein content (14.1-18.1%) in the diet did not affect protein digestibility and CH₄ emissions (Hynes et al., 2016), thus, suggesting that the protein content in the diet may need to be below 18% for CH₄ emissions to decrease and increase the impact of condensed tannins addition in animal diets for controlling CH₄. The addition of quebracho tannin extract (0-2%) in a diet with 16% crude protein decreased protein digestibility and did not affect CH₄ emissions (Beauchemin et al., 2007).

2.2. Fiber digestion

Condensed tannins seem to exert their CH₄ depression ability by decreasing fiber-digesting and methanogenic microorganisms (Díaz Carrasco et al., 2017). This is often attributed to condensed tannins increasing propionate formation over that of acetate from the pyruvate (Moats et al., 2018). Fiber digestion promotes the release of H₂ needed for the formation of CH₄. Promoting the lower acetate-to-propionate ratio by condensed tannins decreases the H₂ needed for the formation of CH₄ (Geneviève et al., 2018). Formation of strategies to ensure that condensed tannins remain effective in stimulating CH₄ suppression by decreasing fiber-digesting microorganisms and methanogens is needed. Exertion
of this effect by condensed tannins on methanogens may depend on the absence of microbes that counter the tannin-protein complex, decreasing the ruminal digestion of crude protein. *Selenomonas ruminantium* bacteria are reported to exert a the premature dissociation of the tannin-protein complex (Díaz Carrasco et al., 2017). The blend of quebracho and chestnut tannins increased *S. ruminantium* population (Díaz Carrasco et al., 2017). There has also been a further demonstration of increasing acetate and gas production in cultures with prior condensed tannins adaptation (Hoehn et al., 2018).

These studies demonstrate that the resistance of rumen microbes to condensed tannins may occur. Therefore, information on the response of fibrolytic microbes to sources of condensed tannins is necessary to improve the control of CH₄ production using condensed tannins.

### 2.3 Substrate

The source of the basal diet remains part of the contributing factors in the conflicting results found when condensed tannins are incorporated in dairy diets to decrease CH₄ without limiting animal performance. Adding condensed tannins in accordance with the basal diet source could assist in decreasing CH₄ emissions without depressing milk production and other performance parameters. Increasing the concentrate-to-forage ratio (40:60 and 60:40) suppressed CH₄ emissions (Na et al., 2013). Increasing forage levels (37.4% or 53.3%) decreased milk yield and feed intake but increased CH₄ emissions per day without affecting protein digestibility (Niu et al., 2016). This suggests that a certain forage-to-concentrate ratio in the total-mixed ration could suppress CH₄ emission and improve milk production parameters. Hence, the addition of condensed tannins in the diet may lack suppression of CH₄ emissions and the improvement of milk production if the concentrate-to-forage ration in the total mixed ration is low. This could explain findings that demonstrated that total mixed ration enriched with condensed tannins (0-2%) did not affect yield, fat and protein of milk, dry matter intake and CH₄ emission (Denninger et al., 2020).

The selective mixing of pastures in pasture-based animals could suppress CH₄ and enhance milk yield in animal diets by condensed tannins in pasture-based dairy cows. Including white clover in ryegrass pasture at a rate of 0-60% increased milk yield and CH₄ suppression (Lee et al., 2004). Feeding less fibrous and highly digestible pastures or tannin-rich pastures can improve the efficacy of tannin sources inclusion level to control methanogenesis without affecting animal parameters.

### 3. Animal factors

The effect of dietary tannins on ruminant performance may be influenced by lactation factors, gut infestations, animal genetics, and how rumination time and digesta passage rate respond to dietary tannins.

#### 3.1 Lactation

The current findings have shown that dietary condensed tannin inclusion levels are suitable for inclusion in diets of dry cows as milk yield may be interrupted. As days in milk increase, CH₄ emissions increase in dairy cows (Wall et al., 2012; Alstrup et al., 2015). The explanation for this observation was that as days in milk increase, the passage rate in cows decreases, causing feed to be retained in the rumen, increasing the digestibility of fibre, which is conducive to CH₄ formation (Alstrup et al., 2015). The increase in parity of the animal has also been associated with the increase in CH₄ (Bittante et al., 2018). Further findings have shown that primiparous cows have a diverse methanogenic population compared to multiparous cows (Kumar et al., 2015). This suggests that as parity increases methanogens of different survival modes persist making the need for a rumen fermentation additive that can control various methanogen archaea at one time essential. This further emphasizes the need to understand the effect of condensed tannins per methanogen type in cows at different parities to control CH₄ production without limiting animal performance.

#### 3.2 Gut infestations

Gastrointestinal nematode infestations have increased CH₄ in ruminants (Fox et al., 2018). The mechanism by which gastrointestinal nematodes increase CH₄ in the rumen is unclear but could be attributed to these parasites contributing to the effects that support CH₄ production such as fibre digestion. Gastrointestinal nematodes have been associated with an increased protozoa population, producing hydrogen that methanogens use to produce CH₄ (Szulc et al., 2020). The effect of gastrointestinal nematodes on CH₄ may influence the tannin effect on CH₄. It has been reported that nematode infestations render condensed tannins ineffective against CH₄ emission (Lima et al., 2019). Future studies need to investigate the effect of condensed tannins on gastrointestinal nematodes and CH₄ emissions in one experiment to better understand the relationship between condensed tannins inclusion levels and CH₄ per gastrointestinal infestation in animals.

Studies on the control of gastrointestinal nematodes using condensed tannins need to consider investigating the effect of condensed tannins on the different life stages of these parasites. Findings suggest that dietary condensed tannin
supplementation can decrease faecal egg count and larval populations of gastrointestinal nematodes (Pathak, 2013; Costa-Júnior et al., 2014). Drenching condensed tannins according to body weight to control gastrointestinal nematodes is a promising intervention as it can control gastrointestinal nematodes (Ahmed et al., 2014; Mhlongo, 2018). This intervention is more practical for uniformly controlling gastrointestinal nematodes in animals. An in vitro study demonstrated that condensed tannins decrease eggs' hatchability and larval development (Molan and Faraj, 2010). In most studies, the response to condensed tannins of gastrointestinal nematodes has been conducted more in small rather than large stock. Liver flukes rather than nematodes being the main parasites affecting cattle limit the extrapolation of the response of nematodes to condensed tannins in cattle. Studying the response of CH₄ emissions in infested cattle fed condensed tannins may improve the development of the inclusion level that decreases CH₄ without disrupting animal performance.

3.3. Animal genetics

Understanding the effect of genetics on CH₄ is part of the under-considered factors that could assist in better controlling CH₄ emission and performance in animals using condensed tannins. Crossbred cows emit more CH₄ than purebred cows (Pedreira et al., 2009). The breed also affects CH₄ emissions as Jersey cows were found to emit less CH₄ than the Holstein-Friesian breed (Ricci et al., 2014). The lactation stage influences CH₄ in cows as dry cows have been found to emit less CH₄ than lactating cows (Dall-Orsoletta et al., 2016). Ruminant animal species influence CH₄ emissions in animals as cattle have been found to emit more CH₄ gas than sheep or goats (Giamouri et al., 2023). Animals with a lower feed intake emit fewer CH₄ emissions (Bell et al., 2011). Rumination time has a genetic positive correlation with the yield of milk and protein and a negative genetic correlation with CH₄ yield (López-Paredes et al., 2020).

3.4. Digesta passage rate

Tannin dietary additions decrease nutrient digestibility (Ahnert et al., 2015). Tannins decrease fiber digestion which affects the digesta passage rate. This is due to the positive correlation between feed intake and the passage rate of digesta (Al-Kindi et al., 2017). Increased mean retention time (MRT) of digesta has been found to increase CH₄ emission and the digestion of fibre and organic matter which form conditions that favour the production of CH₄ gas (Huhtanen et al., 2016). Low MRT decreases CH₄ emissions by prioritising energy for the improvement of the efficiency of microbial protein synthesis instead of volatile fatty acids (VFAs) (Tymensen et al., 2012). This implies that this technique removes hydrogen which is needed for the formation of CH₄ gas by decreasing the acetate-to-propionate ratio. Contrary to the rumen, the addition of carob leaf condensed tannins increased MRT of liquid digesta in the intestines, total gastrointestinal tract (GIT), omasum and abomasum, and foregut, but solid digesta MRT increased in the intestines and total GIT (Silanikove et al., 2001).

Quebracho tannin inclusion (2 or 4%) did not affect total MRT, caecum MRT or passage rate in the mixing compartment (Al-Kindi et al., 2017). A. mearnsii condensed tannin (0–2.25%) decreased the disappearance rate of rumen solids, digestion rate in the rumen and passage rate of undigested residues (Tseu et al., 2020). The difference in the effect of condensed tannins on the passage rate of digesta may be due to feed intake. These studies demonstrated that feed intake increased when the passage rate was not changed but decreased where the passage rate increased.

3.5. Rumination Time

Regarding the feeding behaviour of ruminants, higher rumination time has been associated with high CH₄ emissions (Watt et al., 2015). This finding makes studying the feeding behaviour of animals fed condensed tannin-enriched diets important for improving animal performance and decreasing CH₄ emissions. A. mearnsii condensed tannin extract powder inclusion (0–2.25%) (Tseu et al., 2020) and Mimosa tenuiflora condensed tannin extract inclusion (0–3%) (Lima et al., 2019) did not affect the total ruminating time but decreased total eating time. Wherein chestnut condensed tannin powder inclusion (0–10%) (Kapp-Bitter et al., 2020) and tanniferous Sainfoin hay inclusion (0–1%) (Scharenberg et al., 2009) lacked an effect on rumination and eating time. Mimosa tenuiflora condensed tannins extract (0–7.5%) increased ruminating, eating and chewing time and decreased idling time (Nascimento et al., 2021).

This result suggests that animals fed diets with added condensed tannins tend to adopt strategies to compensate for the decrease in digestibility that is associated with condensed tannin addition. Those strategies may include decreasing eating time by eating the feed in small amounts to deal with the astringent effect in tannin-enriched feeds if the condensed tannins used have high astringency. This also suggests that the astringency of the condensed tannins may disturb the normal breakdown of feed in animals. This results in increased rumination time to break down the feed into smaller particles. Rumination time seems to also be influenced by the
lactation stage of the animal. Cows in early lactation ruminate less due to the smaller rumen size but gradually ruminate more as the rumen increases in size and so does CH₄ emission (López-Paredes et al., 2020). This suggests inclusion level of the effect of condensed tannins on CH₄ emission and milk production needs to correlate with the lactation stage to improve the CH₄-decreasing while maintaining the milk production effect on condensed tannin-rich diets.

4. A. mearnsii tannin effect on dairy performance

A. Mearnsii is one of the most commonly used tannin sources to control CH₄ and improve dairy production. However, this tannin source has contrasting dairy performance and CH₄ results (Lazzari et al., 2023). The contrast in results may be due to a low understanding of the effect of this tannin source on nutrient digestibility, feed intake, and rumen fermentation using similar dietary inclusions.

4.1. Rumen volatile fatty acids

Rumen volatile fatty acids (VFAs) influence CH₄ and milk performance. Acetate correlates with milk fat (Seymour et al., 2005) and CH₄. While propionate negatively correlates with CH₄ and positively correlates with milk performance (Wu et al., 2021), A. mearnsii tannins need to be studied for their effect on rumen VFAs. The addition of A. mearnsii tannins (0–41 g/d) decreased acetate but increased propionate and the acetate–propionate ratio (ATPR) (Carulla et al., 2005). Dietary inclusions (0–1.49% DM) of A. mearnsii tannins have been noted for decreased ATPR and acetate and increased propionate and total VFAs (Krueger et al., 2010). Dietary inclusions of A. mearnsii tannins (0–1.5%) did not affect acetate, propionate, butyrate, ATPR or total VFAs (Perna Junior et al., 2022). Adding 0-2.5% of A. mearnsii tannins affected ATPR, butyric acid, decreased propionnic acid, and did not affect acetic acid (Koenig and Beachemin, 2018). Encapsulated or non-encapsulated A. mearnsii tannin did not affect rumen VFAs at 2% dietary inclusions (Ibrahim and Hassen, 2022). Dietary inclusions of A. mearnsii tannins have been found to have no effect on rumen VFAs except for decreasing acetate and butyrate (Avila et al., 2020a). These results suggest that tannins have a contrasting effect on rumen VFAs, which may lead to an inconsistent effect on CH₄ and milk performance.

4.2. Milk performance

Tannins benefit milk performance as they bind to proteins in the rumen. The protein-tannin complex reduces rumen crude protein digestion, increasing crude protein digestion in the small intestines. Increased rumen undegradable protein increases milk yield (Mikolayunas-Sandrock et al., 2009). Adding A. mearnsii tannins (2% DM) has been found to not affect milk yield and milk fat or protein percentages (Alves et al., 2017b; Orlandi et al., 2020a). The dietary addition of A. mearnsii tannins (0–2% DM) did not affect milk parameters (Avila et al., 2020b). Inclusion at 0-3% of A. mearnsii tannins has been reported to have no effect on milk parameters (Gerlach et al., 2018). The addition of 0-1% of A. mearnsii tannin in diets has been reported to have no effect on milk parameters (Orlandi et al., 2020). Drenching cows with A. mearnsii tannin (0–400 g/day) decreased milk yield and fat but did not affect milk protein (Williams et al., 2020). Similarly, Grainger et al., (2009) drenched cows with A. mearnsii tannins and noted decreased milk yield and no effect on milk protein or fat percentages. These results demonstrate that dietary inclusions of A. mearnsii of 0-3% are ineffective in modulating milk parameters while drenching 200–400 A. mearnsii would negatively affect milk yield.

4.3. Nutrient intake

Dairy performance relies on the optimum nutrient intake to maintain dairy production. A. mearnsii tannins need to be evaluated for their effect on the intake to prevent the decrement of CH₄ at the expense of milk performance. Dietary incorporation of A. mearnsii tannins (0–2% DM) has been noted to have no effect on the intake of DM, OM and NDF (Avila et al., 2020a). Similarly, the addition of A. mearnsii tannins (4.2% DM) did not affect DM, OM, CP or NDF intakes (Adejoro et al., 2020). The addition of lipid-encapsulated or none-encapsulated A. mearnsii (0 or 4% DM) tannin did not affect DM, OM, NDF or ADF intake (Adejoro et al., 2019). Intraruminal infusion of A. mearnsii tannins (0–6% DM) decreased DM, OM, and NDF intake (Kozloski et al., 2012). Dietary supplementation of A. mearnsii tannins (0–8% DM) decreased DM, CP, and ether extract intake (de S. Costa et al., 2021a). These results show that A. mearnsii inclusion of up to 4% does not affect the intake of nutrients. However, nutrient intake decreases when the inclusion of A. mearnsii tannins increases to 8%. This may be due to the astringent effect of tannins that decreases intake. Interventions such as encapsulation of tannins have been tried to evade the effect of tannin astringency (Adejoro et al., 2019).

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4.4. Nutrient digestibility

A. Mearnsii tannins are to be investigated for their effect on nutrient digestibility to prevent the limitation of dairy performance. This is due to the effect of tannins ability to control CH₄ by decreasing fiber and crude protein digestion in the rumen. Supplementation of A. mearnsii tannins decreased DM, NDF, ADF and hemicellulose digestibility but did not affect CP digestibility (Carulla et al., 2005). A. mearnsii tannins addition in diets decreased only crude protein digestibility (Avila et al., 2020b). The dietary addition of lipid-encapsulated A. mearnsii tannins (0–4% DM) increased the digestibility of DM, OM, CP, NDF and ADF (Adejoro et al., 2020). A. mearnsii addition in diets (0–8%) decreased the digestibility of DM, OM, CP and NDF (de S. Costa et al., 2021a). A. mearnsii tannins additions (0–2% DM) increased DM and decreased NDF digestibility (Avila et al., 2020b). The addition of A. mearnsii tannins at a rate of 0.6 DM (Perna Junior et al., 2022) and 0.77% DM (Orlandi et al., 2020a) did not affect the digestibility of nutrients. These studies show that moderate inclusions of A. mearnsii tannins do not affect nutrient digestibility. However, 8% tannin inclusion in diets will likely decrease nutrient digestibility. This may be due to the tannin-protein complex not reasonably reversing in the abomasum and small intestines to allow nutrient digestibility. This shows that encapsulation of tannins may be beneficial in preventing the adverse effect of tannins on nutrient digestibility.

4.5. Enteric CH₄

Dietary inclusions of A. mearnsii tannins (0–2% DM) decreased CH₄ (Alves et al., 2017b). Dietary inclusions of A. mearnsii tannins (0–20%) decreased in vitro CH₄ (Hassanat and Benchaar, 2013). Inclusions of A. mearnsii tannins (0–4.2% DM) did not affect CH₄ (Adejoro et al., 2020). Acacia mearnsii addition in diets (0–1.5% DM) decreased CH₄ (Perna Junior et al., 2022). Dietary A. mearnsii tannins (0–4% DM) decreased CH₄ but had a better effect when they were not encapsulated (Adejoro et al., 2019). Drenching A. mearnsii tannins (0–263 g/d) decreased CH₄ (Grainger et al., 2009). However, 0.06% DM of A. mearnsii tannins decreased CH₄ (Perna Junior et al., 2022). Condensed tannins control CH₄ by decreasing rumen microbial populations. Tannin decreases CH₄ by reducing methanogens and fibrolytic rumen populations. During fermentation, fibrolytic microbes release H₂, which methanogens use for methanogenesis. Dietary inclusions of A. mearnsii tannins (0–2% DM) decreased protozoa populations (Entodinium) (Avila et al., 2020b). Dietary additions of A. mearnsii tannins (0–0.6% DM) did not affect protozoa populations (Kozloski et al., 2012). Tannin introduction to animals by drenching rather than diet incorporation may be a more effective way to control CH₄ without affecting feed palatability.

CONCLUSION

Basal diet source, mode of action of the tannin source, condensed tannin source, crude protein content, lactation stage, animal genetics, gut health, rumination time, molecular weight of tannin source, on-farm applicability, digesta passage rate and structural form of condensed tannins may influence the effect of the inclusion level of condensed tannins on the control of CH₄ production and performance in ruminants. There is a lack of consistent consideration of these factors in some of the available studies when exploring the inclusion of condensed tannins in the control of CH₄ production, which perpetuates the inconsistent results. These variables need to be considered to improve the consistency of the effect of the condensed tannins as a treatment for reversing CH₄ production and improving performance in ruminants.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the research data and tools used in this review.

REFERENCES

Effects of black wattle (Acacia mearnsii) condensed tannins on intake, protozoa population, ruminal fermentation, and nutrient digestibility in jersey steers. Animals 10 https://doi.org/10.3390/ani10061011.


Factors influencing dietary tannin ..........


