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Inclusion of Sorghum in Ruminant Diets Towards Methane Emission Mitigation and Improved Meat Quality: A Review

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ABSTRACT

Sorghum is among the less widely used crops yet it is ranked the fifth most important cereal crop after wheat, maize, rice and barley. The grain's nutritional value is similar to that of maize and wheat and the phenolic profile is more abundant and varied than other common cereal grains. Sorghum has been largely included in ruminant diets as an energy source and research findings show insignificant differences in the performance parameters in livestock fed sorghum-based diets, with some studies suggesting sorghum as a more efficient alternative to maize. The narrative review focuses on opportunities for reducing rumen methanogenesis through dietary inclusion of sorghum as well as discussing the impact on relative abundance of microbiota and meat quality. The grain possesses qualities that can potentially influence the reduction of greenhouse gas emissions in ruminant livestock production, relative abundance of rumen microbes and meat quality. However, there is very little information on the influence of sorghum grain-based diets on the rumen bacterial community composition and their relationship with ruminal metabolites. Further investigations are required to add more knowledge on the effect of sorghum grain-based diets on meat quality.

Key words: Gut microbiota, Meat quality, Methanogenesis, Sorghum.

Sorghum is among the most important yet least utilised staple crops (Macauley and Ramadjita, 2015). The crop is drought tolerant, has wide adaptation compared to other staple cereals like wheat, maize and rice (Meherunnahar *et al*., 2018). Sorghum has a unique phenolic profile that is more abundant and diverse than other common cereal grains (Shen *et al*., 2018). These phenolic compounds are not found in other major cereals and can modify the nutritional value of the individual grains, with some of them resulting in reduced protein digestibility in livestock feed (Wu *et al*., 2012). Phytochemical compounds found in sorghum include condensed and hydrolysable tannins, phenolic acids, anthocyanins, phytosterols, flavonoids and policosanols (Dykes, 2019). These phytochemicals have high antioxidant activity and may provide health benefits commonly associated with fruits (Xiong *et al*., 2019).

Tannins are known to have both non-nutritive, negative effects as well as beneficial effects (Jeronimo *et al*., 2016). The chemical structure and rate of inclusion in diets as well as other factors such as animal species and physiological status will determine the extent to which livestock is either negatively or positively affected by the use of tannins (Jeronimo *et al*., 2016). Positive effects of tannins on animal growth and performance were reported by Salem (2010) in a study that fed sheep diets containing tannins. Decreased ammonia concentration and decreased protein degradation in the rumen which increased protein available in post-ruminal sites were attributed to tannins. Inclusion of tannins in livestock diets also has the potential to enhance meat lipid and protein oxidative stability, improve shelf life by increasing the resistance of the refrigerated or frozen meat to oxidation (García *et al*., 2019). The main challenge with inclusion of tannins in animal diets, however, is the lack of complete information on dosage and side effects on digestion due to the vast sources of tannins (Singh and Kumar, 2020).

Very little information is available on the impact of sorghum grain-based diets on rumen microbiota dynamics and meat quality as sorghum has been largely included in ruminant diets as an energy source. Several research findings revealed that there is no significant difference in the performance parameters in livestock fed sorghum as an energy source (Ncube *et al*., 2014). Baran *et al*. (2008) also suggested that sorghum grain could be used as a cost-effective alternative to wheat as a source of energy for beef cattle. A study by Yahaghi *et al*. (2012) found positive results on growth and performance in finishing Iranian Baluchi lambs when maize was replaced with sorghum in barley-based diets and suggested sorghum as a better energy source.

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The nutritional composition of sorghum grain is comparable to that of maize and ranks second to maize in total available energy among the cereal grains (Jimoh and Abdullahi, 2017). The grain's protein content is similar to that of wheat and maize, with a higher fat content than that of wheat or rice as shown in Table 1. Sorghum is also a rich source of B-complex (β-carotene) vitamins, although the available quantity of vitamins and minerals varies with the agro-ecological zones in which the sorghum is grown (Jimoh and Abdullahi, 2017).

Sorghum grain possesses other qualities that can potentially influence the reduction of greenhouse gas (GHG) emissions (de Oliveira *et al*., 2007), relative abundance of rumen microbes and meat quality (Sun *et al*., 2018). The rumen microbiome is a complex ecosystem that consists of bacteria, archaea, protozoa and fungi involved in the fermentation of undigestible feed substrates (Malmuthuge *et al*., 2015). Rumen microbiota composition is influenced by a number of factors including the composition of different diets (Tajima *et al*., 2001). An understanding of how the rumen functions, the microbial diversity and dynamics is crucial for the optimization of efficiency in productivity and is also key to reduction of greenhouse gases (GHGs) emissions from ruminants (Hassan *et al*., 2020). Altering fermentation patterns is considered as one of the most effective ways to reduce enteric methane (Haque, 2018; Tadesse, 2014) and improve meat quality by increasing its oxidative stability. The aim of this review, therefore, is to discuss opportunities to mitigate enteric methane emission through dietary manipulation as well as the impact of sorghum-based diets on gut microbiota dynamics and meat quality.

Dietary inclusion of sorghum and enteric methane production

Livestock production is estimated to contribute between 9 and 11% of total anthropogenic greenhouse gas (GHG) emissions (Pickering *et al*., 2015) implicated in influencing global warming (Min *et al*., 2020). Approximately 44% of these GHG emissions are in the form of methane (Rojas-Downing *et al*., 2017). Enteric methane produced from the rumen is the largest single source of livestock emissions among the greenhouse gases and a major contributor to global warming (Haque, 2018). Methane is formed by anaerobic archaea coupled with bacteria, protozoa and fungi in the rumen ecosystem and represents a loss of 2 to 12% (Patra, 2012) of gross energy of feeds. The production of methane is an indicator of loss of energy from feedstuffs that could have been channelled towards production and this is of concern to livestock producers and nutritionists (Moumen *et al*., 2016).

Dietary manipulation is regarded as the most effective and straightforward method for enteric methane abatement compared to other methods such as selective breeding which is slow and may result in loss of favourable traits (Matthews *et al*., 2019). Ruminal populations of methanogenic microorganisms are affected by chemical and physical quality of the feed (Pedreira *et al*., 2013), hence fermentation processes can be manipulated to alter the rumen microbiome. Defaunating agents and antibiotics have commonly been used to alter rumen fermentation patterns in order to improve the productivity of ruminants and reduce methane production. However, most of the chemical additives have adverse effects to host animals and have a temporary impact on methane production (Kataria, 2016). Nutritionists and microbiologists are continuously exploring less adverse, alternative natural substances to reduce methane emission and its global warming effects. Feeding condensed tannins in ruminant production for the reduction of enteric methane is one such form of dietary manipulation (Naumann *et al*., 2017). Tannins and other phytochemical compounds have been found to be toxic to some of the gut microbes, especially ciliate protozoa, fibre degrading

Table 1: Nutritional composition of red sorghum, white maize, wheat and rice.

Nutrient %	Red sorghum	White maize	Wheat	Rice
	a	b	c	d
Crude protein (Avg % DM)	10.2	9.3	12.6	10.4
Crude fibre (Avg % DM)	3.7	2.2	2.6	0.4
Ether extract (Avg % DM)	3.6	4.3	1.7	1.2
Ash (Avg % DM)	1.8	1.4	1.8	0.8
Gross energy (MJ/kg DM)	18.9	18.7	18.2	18
Calcium (g/kg DM)	0.5	0.6	0.7	0.5
Phosphorus (g/kg DM)	3.4	2.8	3.6	3.2
Potassium (g/kg DM)	2.4	8.3	4.6	1.3
Sodium (g/kg DM)	7	0.0	0.0	3
Iron (% Protein)	3.4	-	78	-
Lysine (% Protein)	2.2	3.5	2.9	3.7
Methionine (% Protein)	1.5	1.6	1.6	2.4
Leucine (% Protein)	13.7	11.7	6.5	8

Sources: a- Sorghum Grain | Feedipedia, (n.d.), b- ("Maize grain | Feedipedia," n.d.), c- Wheat Grain | Feedipedia, (n.d.) d- Rice Grain, Polished | Feedipedia, (n.d.).

bacteria and methanogenic archaea. Tannins can therefore be included in diets as a method to inhibit proliferation of such microbes in order to reduce enteric methane production (Cieslak *et al*., 2013).

The use of tannins in ruminant diets has received moderate attention despite showing huge potential to decrease enteric methane production (Aboagye and Beauchemin, 2019). Tropical and temperate plants have abundant tannins and their use may be a cost- effective approach for livestock producers to reduce enteric methane emissions (Piñeiro-Vázquez *et al*., 2015). Condensed tannins in forage species such as high tannin sorghum may also be used as a practical means of reducing ruminal degradation of forage protein, thereby increasing protein absorption in the small intestine (Addisu, 2016). Minor cereal crops such as sorghum and millets are considered to have relatively lower carbon footprints compared to those of major cereal crops and as such can be included in diet formulations to reduce carbon footprints in the world (Wang *et al*., 2018).

Research by Méndez-Sánchez *et al*. (2019) studied the effects of high tannin sorghum (HTS) diets on rumen fermentation and methane production *in vitro* using a batch culture system and observed that HTS diets decreased methane concentration by 2.96% compared to maize-based diets. It was also concluded that there were no major differences between HTS and low tannin sorghum (LTS) in terms of methane production. The same study also showed that sorghum-based diets produced 14.56% (mL/g DM) less methane compared to the maize-based diets. Although dry matter digestibility in HTS diets was compromised, the results showed a reduction in methane and gas production. High concentrations of sorghum grain in diets may compromise digestibility, nonetheless, the grain was found to be a suitable, economic substitution for maize and a viable option to decrease enteric methane production in ruminants (Méndez-Sánchez *et al*., 2019). These findings are also supported by Soltan *et al*. (2021) who found that dietary inclusion of LTS at 75% in place of maize increased ruminal microbial biomass production for optimal lamb growth, performance and reduced methane emission.

There is still need to quantitatively summarise the effects of tannins on methane emissions from ruminants despite increasing information from previous research (Jayanegara *et al*., 2012). Mitigation effect on methane production is not the same for all condensed tannins, but is determined by the concentration and structure of the condensed tannins in diets (Min *et al*., 2003).

Effects of sorghum-based diets on rumen microbiome dynamics

The ruminant digestive tract is estimated to be populated by over 5000 species of microorganisms, with the rumen being the most diversely populated (Cholewinska *et al*., 2021). The Diversity of the rumen population in both species richness and evenness is considered beneficial, as this ensures the stability of the microbiome (Cholewinska *et al*., 2021; Henderson *et al*., 2015). High species richness results in diverse gut microorganisms functionality and ability to use fractions of the substrate resources in the digestive tract, in turn ensuring efficient use of limiting resources (Celi *et al*., 2017). The diversity of the rumen microbiome also makes it possible for producers to feed by-products such as distillers' grain that would otherwise have limited value (Latham *et al*., 2017). Gut microbiota engineering has potential to improve the health, production efficiency as well as quality of products from food-producing animals (Khafipour *et al*., 2016).

Diet manipulation can completely modify the substrates available to the rumen microbiota, leading to variations in gut microbiota species richness, diversity, function and changes in fermentation end-products (Petri *et al*., 2013). Switching from a low energy to a high energy diet can significantly disrupt the microbiome, ultimately reducing the value of the feed as the microbiome does not fully break down the biomass, leaving less nutrients available for absorption by the host's digestive system (Khafipour *et al*., 2016). Research findings by Mao *et al*. (2016) showed that goats fed diets with a high concentration of maize had a significant influence on the structure of rumen bacteria, especially their diversity and composition. The same study showed that increasing the concentration of maize grain in diets had a significant negative effect on microbial diversity, with diets containing less or no maize associated with more microbiome species richness. The influence of sorghum grain-based diets on the rumen bacterial community composition and their relationship with ruminal metabolites remains largely unknown. There is need for further investigations as not much is known about the nature of the rumen microbiome in ruminants fed different diets (Petri *et al*., 2013).

Findings of a study by Piñeiro-Vázquez *et al*. (2015) associated the presence of condensed tannins in diets with a reduction in protozoa population by up to 79% and a decrease in rumen methanogens by up to 33%. Other investigations carried out using sorghum-based diets showed high concentrations of protozoa in the rumen. The variations in the bacterial and protozoal population due to increase in dietary starch were attributed to a decline in ruminal pH (Castillo-Lopez and Domínguez-Ordóñez, 2019). The inclusion of high tannin sorghum grain in ruminant livestock diets could therefore have significant effects on the relative abundances of ruminal microbiota at the phylum level but this requires validation. The rumen is an intricate ecosystem and it is recommended that any analysis of the impact of plant components on the populations of methanogens should take into account the entire population of methane producing microbiota as well as their individual orders or species (Cieslak *et al*., 2013). The numerous sources of tannins results in a great diversity in their antimicrobial activity and this requires continuous research, identification and selection of tannins that are effective and specific to target microbes (Huang *et al*., 2018).

A decrease in protozoal population is not always associated with a decrease in microbiota responsible for methane production. A study by Bhatta *et al*. (2015) showed the varied effects tannins had on the protozoal population. This is probably due to the fact that some tannins have a direct effect on methane producing bacteria that is not associated with protozoa. Other researchers have demonstrated that suppressing the growth of protozoa or defaunation resulted in a decline in the methanogen population associated with protozoa, for example, species belonging to Methanobacteriaceae (Belanche *et al*., 2014). A corresponding increase in the number of free-living Methanobacteriales was also observed as a result of suppressing the proliferation of protozoa (Goel and Makkar, 2012). However, a reduction in the number of protozoa is not always associated with a decrease in the number of methanogens as some studies have only observed limited correlations between methanogens and methanogenesis. A decrease in the population of one methanogen may result in the proliferation of another (Cieslak *et al*., 2013).

Impact of sorghum grain-based diets on meat quality

Meat is one of the main sources of fats, especially saturated fatty acids (SFA) in human diets. Saturated fatty acids have been implicated in causing unfavourable effects on human health such as increasing the risk of cardiovascular disease and cancer, especially in developed countries (Nieto and Ros, 2012). Diets high in SFA contribute to the increase in Low Density Lipoprotein (LDL) cholesterol level, which is positively related to the occurrence of heart disease (Briggs *et al*., 2017). However, some monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), particularly long-chain n-3 PUFA have been shown to be beneficial to human health (DiNicolantonio and O'Keefe, 2017). The consumption of fatty acids such as (C14:0 and C16:0) and monounsaturated trans fatty acids is not recommended and their concentration in meat can be reduced by increasing the proportions of PUFA absorbed by food producing animals through dietary manipulation (Nieto and Ros, 2012).

Proanthocyanidins in sorghums are usually regarded as anti-nutrients, but Larrain *et al*. (2007) observed similar or improved growth rates in animals fed high-tannin sorghum diets as compared to animals fed maize based diets. It was also observed by Larraín *et al*. (2008) that steers fed a mixture of high tannin sorghum (HTS) and maize grain diet (1:1) and those fed a maize based ration had a dressing percentage of 60.5 and 63.1%, respectively. Diets containing HTS at 50% inclusion produced steers with similar weight and carcass characteristics as those steers fed maize-based diets. The study also found that complete replacement of maize with HTS produced leaner meat and animals with similar estimated amounts of boneless, closely trimmed retail cuts.

Studies in recent years have seen increasing interest in improving the quality of meat and meat products through inclusion of plants rich in tannins in ruminant diets (Jeronimo *et al*., 2016). Flavour and colour are among the meat palatability and sensory properties by which meat quality is readily assessed by consumers. Oxidative processes result in deterioration of meat quality thereby negatively affecting decisions on consumer purchase (Larrain *et al*., 2007). Oxidative processes also negatively affect colour and flavour in red meat, which may result in sensory degradation or off-flavours especially during storage (Domínguez *et al*., 2019). Manipulating or altering feed ingredients in animal diets is considered to be the best technology available to alter and improve the oxidative stability of meat in ruminants. Tannins are known to have antioxidant activity and some studies show that inclusion of tannins in ruminant diets may improve the animal antioxidant status (Huang *et al*., 2018; Jeronimo *et al*., 2016; López-Andrés *et al*., 2013). High tannin sorghums contain condensed tannins, which have both *in vitro* and *in vivo* antioxidant activity and their inclusion in livestock diets has potential to increase antioxidants in high-grain diets for meat producing livestock. The use of high tannin sorghums (HTS) diets to improve oxidative stability and general quality of meat by reducing oxidative damage in muscle requires further research.

Zhong *et al*. (2016) found that substitution of finely ground corn with equal amounts of finely ground sorghum in lamb diets improved meat colour through increased antioxidant tannin deposition in the meat and also protected the lambs against *Haemonchus contortus* infection. Sun *et al*. (2018) also found that sorghum-based diets improved lamb growth and meat quality by decreasing yellowness of meat during storage compared to maize-based diets. Similar results were found by Luciano *et al*. (2009) where inclusion of tannins in sheep diets improved the stability of fresh lamb in terms of its colour by maintaining redness and decreasing rate of degradation during extended refrigeration.

The aforementioned results by Larrain *et al*. (2007) showed that oxidative stability of muscle tissue was affected in different ways depending on the species studied and the difference is likely related to contrasting digestive physiology and microbial metabolism and modifications of proanthocyanidins in the rumen. It was also found that it is possible to accelerate or delay discoloration and lipid oxidation in muscle tissue by changing the ingredients in the diets fed to the animals. Results also showed that finishing steers with HTS did not affect Warner-Bratzler shear, sensory attributes and fatty acid composition of muscle tissue (Larraín *et al*., 2008).

CONCLUSION

Sorghum grain is mainly incorporated in diets as an energy source and may be successfully used as a complete or partial replacement of maize in livestock diets. The review has shown that sorghum grain may be a viable option to mitigate methane production in ruminants. There is, however, need for further research to come up with comprehensive information on dosage, side effects on digestion and the issue of resistance due to prolonged exposure to tannins. Finally, the influence of sorghum grain-based diets on the rumen bacterial community composition and their relationship with ruminal metabolites remains largely unknown. Further investigations are required to get more knowledge on the effects of sorghum grain-based diets on the rumen microbiome as well as meat quality.

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Conflict of interest statement

Authors certify that there is no conflict of interest with any financial, personal, other people or organizations related to the material discussed in the manuscript.

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