

edible nuts. *Intern. J. Mol. Sci.* 10(12), 5485–5497. <https://doi.org/https://doi.org/10.3390/ijms10125485>.

Kardel, M., Taube, F., Schulz, H., Schutze, W., Gierus, M., 2013. Different approaches to evaluate tannin content and structure of selected plant extracts - review and new aspects. *J. Appl. Bot. Food Qual.* 166, 154–166. <https://doi.org/10.5073/JABFQ.2013.086.021>.

Kaske, M., Engelhardt, W.V., 1990. The effect of size and density on mean retention time of particles in the gastrointestinal tract of sheep. *British J. Nutr.* 63(3), 457–465. <https://doi.org/10.1079/bjn19900133>.

Knapp, J.R., Laur, G.L., Vadas, P.A., Weiss, W.P., Tricarico, J.M., 2014. Invited review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions. *J. Dairy Sci.* 97(6), 3231–3261. <https://doi.org/10.3168/jds.2013-7234>.

Kobayashi, Y., 2010. Abatement of methane production from ruminants: Trends in the manipulation of rumen fermentation. *Asian-Aust. J. Anim. Sci.*, 410–416. <https://doi.org/doi:10.5713/ajas.2010.r.0123>.

Krishnan, S., Bhosale, R., Singhal, R.S., 2005. Microencapsulation of cardamom oleoresin: Evaluation of blends of gum arabic, maltodextrin and a modified starch as wall materials. 61, 95–102. <https://doi.org/10.1016/j.carbpol.2005.02.020>.

Krueger, W., Gutierrez-Banuelos, H., Carstens, G.E., Min, B.R., Pinchak, W.E., Gomez, R.R., Anderson, R.C., Krueger, N.A., Forbes, T.D.A., 2010. Effects of dietary tannin source on performance, feed efficiency, ruminal fermentation, and carcass and non-carcass traits in steers fed a high-grain diet. *Anim. Feed Sci. Technol.* 159, 1-9. <https://doi.org/https://doi.org/10.1016/j.anifeedsci.2010.05.003>.

Ku-vera, J.C., Jiménez-ocampo, R., Valencia-salazar, S.S., Montoya-flores, M.D., Molinabotero, I.C., Arango, J., Gómez-bravo, C.A., Aguilar-pérez, C.F., Solorio-sánchez, F.J., 2020. Role of Secondary Plant Metabolites on Enteric Methane Mitigation in Ruminants. *Frontiers Vet. Sci.* 7, 584. <https://doi.org/10.3389/fvets.2020.00584>.

Kumar, R., Horigome, T., 1986. Fractionation, characterization and protein precipitating capacity of the condensed tannins from *Robinia pseudoacacia* (L.) leaves. *J. Agric. Food Chem.*, 34, 3, 487–489. <https://doi.org/10.1021/jf00069a029>.

Kumar, R., Singh, M., 1984. Tannins: their adverse role in ruminant nutrition. *J. Agr. Food Chem.* 32, 3, 447-453. <https://doi.org/10.1021/jf00123a006>.

Kumar, S., Choudhury, P.K., Carro, M.D., Griffith, G.W., Dagar, S.S., Puniya, M., Calabro, S., Ravella, S.R., Dhewa, T., Upadhyay, R.C., Sirohi, S.K., Kundu, S.S., Wanapat, M., Puniya, A.K., 2013. New aspects and strategies for methane mitigation from ruminants. *Appl. Microbiol. Biotechnol.* 1-15. <https://doi.org/10.1007/s00253-013-5365-0>.

Landau, S., Perevolotsky, A., Bonfil, D., Barkai, D., Silanikove, N., 2000. Utilization of low



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

quality resources by small ruminants in Mediterranean agro-pastoral systems: The case of browse and aftermath cereal stubble. *Livest. Prod. Sci.*, 64, 39–49.

Lascano, C., Avila, P., Stewart, J., 2003. Intake, digestibility and nitrogen utilization by sheep fed with provenances of *Calliandra calothyrsus* Meissner with different tannin structure. *Arch. Latinoam. Prod. Anim.* 11, 21–28.

Lawal, I.B., 2022. Unpublished data from M. Sc. Dissertation. Department of Animal Science, University of Pretoria, South Africa.

Leahy, S.C., Janssen, P.H., Attwood, G.T., Mackie, R.I., McAllister, T.A., Kelly, W.J., 2022. Electron flow: key to mitigating ruminant methanogenesis. *Trends Microbiol.* 30(3), 209–212.

Lee, S.H., Shinde, P.L., Choi, J.Y., Kwon, I.K., Lee, J.K., Pak, S.I., Choi, W.T., Chae, B.J., 2010. Effects of tannic acid supplementation on growth performance, blood hematology, iron status and faecal microflora in weanling pigs. *Livest. Sci.* 131((2-3), 281-286. <https://doi.org/https://doi.org/10.1016/j.livsci.2010.04.013>.

Lee, S.S., Hsu, J.T., Mantovani, H.C., Russell, J.B., 2002. The effect of bovicin HC5, a bacteriocin from *Streptococcus bovis* BC5, on ruminal methane production in vitro. *FEMS Microbiol. Lett.* 217, 51–55.

Leng, R.A., 2008. The potential of feeding nitrate to reduce enteric methane production in ruminants. A Report to the Department of Climate Change Commonwealth Government of Australia, Canberra, ACT, Australia. Retrieved on 31/12/2022 at www.penambulbooks.com.

Li, Z., Liu, N., Cao, Y., Jin, C., Li, F., Cai, C., Yao, J., 2018. Effects of fumaric acid supplementation on methane production and rumen fermentation in goats fed diets varying in forage and concentrate particle size. *J. Anim. Sci. Biotechnol.* 9(21), 1–9. <https://doi.org/10.1186/s40104-018-0235-3>.

Lin, B., Lu, Y., Salem, A.Z.M., Wang, J.H., Liang, Q., Liu, J.X., 2013. Effects of essential oil combinations on sheep ruminal fermentation and digestibility of a diet with fumarate included. *Anim. Feed Sci. Technol.* 184, 24–32. <https://doi.org/doi:10.1016/j.anifeedsci.2013.05.011>.

Liu, H.W., Dong, X.F., Tong, J.M., Zhang, Q., 2011. A comparative study of growth performance and antioxidant status of rabbits when fed with or without chestnut tannins under high ambient temperature. *Anim. Feed Sci. Technol.* 164(1-2), 89-95. <https://doi.org/https://doi.org/10.1016/j.anifeedsci.2010.09.020>.

Liu, H.W., Zhou, D.W., Li, K., 2013. Effects of chestnut tannins on performance and antioxidative status of transition dairy cows. *J. Dairy Sci.* 96(9), 5901-5907. <https://doi.org/https://doi.org/10.3168/jds.2013-6904>.



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Llonch, P., Haskell, M.J., Dewhurst, R.J., Turner, S.P., 2017. Review: current available strategies to mitigate greenhouse gas emissions in livestock systems: an animal welfare perspective. *Animal* 11(2), 274–284. <https://doi.org/10.1017/S1751731116001440>.

Lochab, B., Shukla, S., Varma, I.K., 2014. Naturally occurring phenolic sources: monomers and polymers. *RSC Adv.* 4, 21712–21752.

Macheboeuf, D., Lassalas, B., Ranilla, M.J., Carro, M.D., Morgavi, D.P., 2006. Dose response effect of diallyl disulfide on ruminal fermentation and methane production in vitro. *Reprod. Nutr. Dev.* 46, S103.

Macheboeuf, D., Morgavi, D.P., Papon, Y., Mousset, J.L., Arturo-Schaan, M., 2008. Dose-response effects of essential oils on in vitro fermentation activity of the rumen microbial population. *Anim. Feed Sci. Technol.* 145, 335–350. <https://doi.org/doi:10.1016/j.anifeedsci.2007.05.044>.

Mahanani, M.M.P., Kurniawati, A., Hnim, C., Anas, M.A., Yusiati, L.M., 2020. Effect of (*Leucaena leucocephala*) Leaves as Tannin Source on Rumen Microbial Enzyme Activities and In Vitro Gas Production Kinetics. *IOP Conf. Ser.: Earth Environ. Sci.* 478 012088. <https://doi.org/10.1088/1755-1315/478/1/012088>.

Maheri-Sis, N., Chaichi Semsari, M., Eshratkhah, B., Sadaghian, M., Gorbani, A., Hassanpour, S., 2011. Evaluation of the effects of Quebracho condensed tannin on faecal egg counts during naturally acquired mixed nematode infections in Moghani sheep. *Annals Biol. Res.* 2(2), 170–174.

Makkar, H.P.S., Dawra, R.K., Singh, B., 1987. Protein Precipitation Assay for Quantitation of Tannins: Determination of Protein in Tannin-Protein Complex. *Analyt. Chem.* 166, 435–439.

Makkar, H.P.S., Bluemmel, M., Borowy, N.K., Becker, K., 1993. Gravimetric determination of tannins and their correlations with chemical and protein precipitation methods. *J. Sci. Food Agric.* 61, 161–165.

Makkar, H.P.S., 2000. Quantification of Tannins in Tree and Shrub Foliage. A laboratory manual for the FAO/IAEA Co-ordinated Research Project on Use of Nuclear and Related Techniques to Develop Simple Tannin Assays for Predicting and Improving the Safety and Efficiency of Feeding Ruminants on Tanniniferous Tree Foliage. <https://doi.org/10.1007/978-94-017-0273-7>.

Makkar, H.P.S., 2003. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. *Small Rum. Res.* 49, 241–256. [https://doi.org/10.1016/S0921-4488\(03\)00142-1](https://doi.org/10.1016/S0921-4488(03)00142-1).

Makkar, H.P.S., 2005. In vitro gas methods for evaluation of feeds containing phytochemicals. *Anim. Feed Sci. Technol.* 123(124), 291–302.



Mamvura, C.I., Cho, S., Mbiriri, D.T., Lee, H., Choi, N., 2014. Effect of Encapsulating Nitrate in Sesame Gum on In vitro Rumen Fermentation Parameters. *Asian-Australas. J. Anim. Sci.* 27(11), 1577–1583.

Marino, D.J., 2005. Ethyl Acetate. *Encyclopedia of Toxicology (Second Edition)*, 277-279. <https://doi.org/10.1016/B0-12-369400-0/00390-2>.

Martin, C., Morgavi, D.P., Doreau, M., 2010. Methane mitigation in ruminants: from microbe to the farm scale. *Animal*, 4(03), 351–365. <https://doi.org/10.1017/s175173110999620>.

Martínez, J.P.Q., Ruiz, J.C.R., Campos, M.R.S., 2018. Release kinetic studies of Stevia rebaudiana extract capsules from sodium alginate and inulin by ionotropic gelation. *Adv. Mater. Sci. Eng.* 2018.

Martinez, T.F., McAllister, T.A., Wang, Y., Reuter, T., 2006. Effects of tannic acid and quebracho tannins on in vitro ruminal fermentation of wheat and corn grain. *J. Sci. Food Agric.* 86, 1244–1256.

McAllister, T.A., Bae, H.D., Yanke, L.J., Cheng, K.J., Muir, A., 1994. Effect of condensed tannins from birdsfoot trefoil on endoglucanase activity and the digestion of cellulose filter paper by ruminal fungi. *Can. J. Microbiol.* 40, 298–305. <https://doi.org/doi:10.1139/m94-048>.

McAllister, T.A., Newbold, C.J., 2008. Redirecting rumen fermentation to reduce methanogenesis. *Austral. J. Experim. Agric.* 48, 7–13.

McAllister, T.A., Okine, E.K., Mathison, G.W., Cheng, K.J., 1996. Dietary, environmental and microbiological aspects of methane production in ruminants. *Can. J. Anim. Sci.* 76, 231–243.

McDonald, P., Edwards, R., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A., Wilkinson, R.G., 2011. *Animal Nutrition*. 7th Ed., Harlow, Pearson education, Prentice Hall, England. pp 712.

McIntosh, F.M., Williams, P., Losa, R., Wallace, R.J., Beever, D.A., Newbold, C.J., 2003. Effects of essential oils on ruminal microorganisms and their protein metabolism. *Appl. Environ. Microbiol.* 69(8), 5011–5014. <https://doi.org/10.1128/AEM.69.8.5011-5014.2003>.

McNabb, W.C., Peters, J.S., Foo, L.Y., Waghorn, G.C., Jackson, F.S., 1998. Effects of condensed tannins prepared from several forages on the in vitro precipitation of ribulose-1,5-bisphosphate carboxylase (Rubisco) protein and its digestion by trypsin (EC2.4.21.1). *J. Sci. Food Agric.* 77, 201–212.

McNabb, W.C., Waghorn, G.C., Peters, J.S., Barry, T.N., 1996. The effect of condensed tannins in *Lotus pedunculatus* on the solubilization and degradation of ribulose-1,5-bisphosphate carboxylase (EC 4.1.1.39; Rubisco) protein in the rumen and the sites of Rubisco digestion. *Br. J. Nutr.* 76, 535–549. <https://doi.org/doi:10.1079/BJN19960061>.



McNabb, W.C., Waghorn, G.C., Barry, T.N., Shelton, I.D., 1993. The effects of condensed tannins in *Lotus pedunculatus* on the digestion and metabolism of methionine, cystine and inorganic sulphur in sheep. *Br. J. Nutri.* 70, 641–661.

McNeill, D., Osborne, N., Komolong, M., Nankervis, D., 1998. Condensed tannins in the genus *Leucaena* and their nutritional significance for ruminants. In *Proceedings of the ACIAR Workshop, Hanoi, Vietnam, 9–14 February 1998*; ACIAR: Canberra, Australia., 205–214.

McSweeney, C.S., Palmer, B., McNeill, D.M., Krause, D.O., 2001. Microbial interactions with tannins: Nutritional consequences for ruminants. *Anim. Feed Sci. Technol.* 91(1–2), 83–93. [https://doi.org/10.1016/S0377-8401\(01\)00232-2](https://doi.org/10.1016/S0377-8401(01)00232-2).

Mehran, M., Masoum, S., Memarzadeh, M., 2020. Microencapsulation of *Mentha spicata* essential oil by spray drying: Optimization, characterization, release kinetics of essential oil from microcapsules in food models. *Ind. Crops Prod.* 154, 112694.

Méndez-Ortiz, F.A., Sandoval-Castro, C.A., Ventura-Cordero, J., Sarmiento-Franco, L.A., Torres-Acosta, J.F.J., 2018. Condensed tannin intake and sheep performance: A meta-analysis on voluntary intake and live weight change. *Anim. Feed Sci. Technol.* 245, 67–76.

Menke, K.H., Steingass, H., 1988. Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. *Anim. Res. Dev.* 28, 7–55.

Mergeduš, A., Janžekovi, M., Škorjanc, D., Šumenjak, T.K., 2022. Growth Performance, Meat Quality, and Fecal Microbial Population in Limousin Bulls Supplemented with Hydrolyzable Tannins. *Agric.* 12, 939. <https://doi.org/10.3390/agriculture12070939>.

Mijena, D., Getiso, A., 2021. Feeding and Nutritional Strategies to Reduce Methane Emission from Large Ruminants: Review. *J. Aquac. Livest. Prod.* 2(1), 1–9.

Miller, T.L., 1995. Ecology of methane production and hydrogen sinks in the rumen. *Rumin. Physiol. Dig. Metab. Growth, Reprod.* 317–331.

Millet, S., Maertens, L., 2011. The European ban on antibiotic growth promoters in animal feed: From challenges to opportunities. *Vet. J.* 187(2), 143–144. <https://doi.org/10.1016/j.tvjl.2010.05.001>.

Min, B.R., Hart, S.P., 2003. Tannins for suppression of internal parasites. *J. Anim. Sci.* 81, 102–109.

Min, BR., Solaiman, S., Shange, R., Eun, J.S., 2014. Gastrointestinal bacterial and methanogenic archaea diversity dynamics associated with condensed tannin-containing pine bark diet in goats using 16S rDNA amplicon pyrosequencing. *Int. J. Microbiol.* 11.

Min, B.R., Barry, T.N., Attwood, G.T., McNabb, W.C., 2003. The effect of condensed tannins



on the nutrition and health of ruminants fed fresh temperate forages: A review. *Anim. Feed Sci. Technol.* 106(1–4), 3–19. [https://doi.org/10.1016/S0377-8401\(03\)00041-5](https://doi.org/10.1016/S0377-8401(03)00041-5).

Min, B.R., Pinchak, W.E., Anderson, R.C., Fulford, J.D., Puchala, R., 2006. Effects of condensed tannins supplementation level on weight gain and in vitro and in vivo bloat precursors in steers grazing winter wheat. *J. Anim. Sci.* 84(9), 2546–2554. <https://doi.org/10.2527/jas.2005-590>.

Min, B.R., Pinchak, W.E., Anderson, R.C., Puchala, R., 2015. Bloat Mitigation Potential of Plant Tannins and Yucca Extracts based on in Vitro Ruminal Fermentation and Methane Gas Production from Wheat Forage. *Int. J. Res. Studies Agric. Sci.* 1(6), 1–13.

Min, B.R., Castleberry, L., Allen, H., Parker, D., Waldrip, H., Brauer, D., Willis, W., 2019. Associative effects of wet distiller's grains plus solubles and tannin-rich peanut skin supplementation on in vitro rumen fermentation, greenhouse gas emissions, and microbial changes. *J. Anim. Sci.* 97(11), 4668–4681. <https://doi:10.1093/jas/skz317>.

Minho, A.P., Bueno, I.C.S., Gennari, S.M., Jackson, F., Abdalla, A.L., 2008. In vitro effect of condensed tannin extract from acacia (*Acacia mearnsii*) on gastrointestinal nematodes of sheep. *Brazilian J. Vet. Parasitol.* 17(1), 144–148. <http://www.ncbi.nlm.nih.gov/pubmed/20059834>.

Mir, Z., Acharya, S.N., Mir, P.S., Taylor, W.G., Zaman, M.S., Mears, G.J., Goonewardene, L.A., 1997. Nutrient composition, in vitro gas production and digestibility of fenugreek (*Trigonella foenum-graecum*) and alfalfa forages. *Can. J. Anim. Sci.* 77, 119–124.

Missio, A.L., Tischer, B., dos Santos, P.S.B., Codevilla, C., de Menezes, C.R., Barin, J.S., Haselein, C.R., Labidi, J., Gatto, D.A., Petutschnigg, A., Tondi, G., 2017. Analytical characterization of purified mimosa (*Acacia mearnsii*) industrial tannin extract: Single and sequential fractionation. *Separ. Purif. Technol.* 186, 218–225. <https://doi.org/10.1016/j.seppur.2017.06.010>.

Moreira, G.D., Lima, P.d.M.T., Borges, B.O., Primavesi, O., Longo, C., McManus, C., Abdalla, A., Louvandini, H., 2013. Tropical tanniniferous legumes used as an option to mitigate sheep enteric methane emission. *Trop. Anim. Health Prod.* 45(3), 879–882. <https://doi.org/10.1007/s11250-012-0284-0>.

Morgavi, D.P., Forano, E., Martin, C., Newbold, C.J., 2010. Microbial ecosystem and methanogenesis in ruminants. *Animal*, 4:7, 1024–1036. <https://doi.org/10.1017/S1751731110000546>.

Moss, A.R., Jouany, J.-P., Newbold, J., 2000. Methane production by ruminants: its contribution to global warming. *Annal. Zootech.* 49(3), 231–253. <https://doi.org/10.1051/animres:2000119>.

Mould, F.L., Morgan, R., Kliem, K.E., Krystallidou, E., 2005. A review and simplification of the in vitro incubation medium. *Anim. Feed Sci. Technol.* 123–124, 155–172.



<https://doi.org/10.1016/j.anifeedsci.2005.05.002>.

Mueller-Harvey, I., 2006. Unravelling the conundrum of tannins in animal nutrition and health. *J. Sci. Food Agric.* 86, 2010–2037. <https://doi.org/10.1002/jsfa.2577>.

Munin, A., Edwards-lévy, F., 2011. Encapsulation of Natural Polyphenolic Compounds; a Review. *Pharm.* 3, 793-829. <https://doi.org/10.3390/pharmaceutics3040793>.

Murdiati, T., McSweeney, C., Lowry, J., 1992. Metabolism in sheep of gallic acid, tannic acid and hydrolysable tannin from terminalia oblongata. *Aust. J. Agric. Res.* 43, 1307–1319.

Murray, R., Bryant, A., Leng, R., 1976. Rates of production of methane in the rumen and large intestine of sheep. *Br. J. Nutr.* 36, 1–14.

Nagpal, R., Puniya, A.K., Griffith, G.W., Goel, G., Puniya, M., Sehgal, J.P., Singh, K., 2009. Anaerobic rumen fungi: potential and applications. *Agric. Important Micro-Organisms II*, 375–393.

Narjisse, H., Elhonsali, M.A., Olsen, J.D., 1995. Effects of oak (*Quercus ilex*) tannins on digestion and nitrogen balance in sheep and goats. *Small Rum. Res.*, 18, 201-206.

National Research Council, N.R.C., 2007. Nutrient requirements of small ruminants: Sheep, goats, cervids, and new world camelids. National Academy of Sciences, Washington DC, US. The national Academy Press. pp. 384.

Naumann, H.D., Hagerman, A.E., Lambert, B.D., Muir, J.P., Tedeschi, L.O., Kothmann, M.M. 2014. Molecular weight and protein-precipitating ability of condensed tannins from warm-season perennial legumes. *J. Plant Interactions* 9(1), 212–219. <https://doi.org/10.1080/17429145.2013.811547>.

Naumann, H.D., Tedeschi, L.O., Zeller, W.E., Huntley, N.F., 2017. The role of condensed tannins in ruminant animal production: Advances, limitations and future directions. *Revista Brasileira de Zootecnia* 46(12), 929–949. <https://doi.org/10.1590/S1806-92902017001200009>.

Nawab, A., Tang, S., Gao, W., Li, G., Xiao, M., An, L., Wu, J., Liu, W., 2020. Tannin Supplementation in Animal Feeding; Mitigation Strategies to Overcome the Toxic Effects of Tannins on Animal Health: A Review. *J. Agric. Sci.* 12(4), 217–230. <https://doi.org/10.5539/jas.v12n4p217>.

Newbold, C., Ramos-Morales, E., 2020. Ruminal microbiome and microbial metabolome: effects of diet and ruminant host. *Animal* 14(1), 78–86.

Newbold, C.J., Lopez, S., Nelson, N., Ouda, J.O., Wallace, R.J., Moss, A.R., 2005. Propionate precursors and other metabolic intermediates as possible alternative electron acceptors to methanogenesis in ruminal fermentation in vitro. *Br. J. Nutr.* 94, 27–35.



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

<https://doi.org/doi:10.1079/BJN20051445>.

Niwinska, B., 2013. Digestion in Ruminants. In: Chang, C. (Eds.), Chapter 11 - Carbohydrates - Comprehensive Studies on Glycobiology and Glycotechnology. INTECH, pp. 245–258.

Nolan, J.V., Hegarty, R.S., Hegarty, J., Godwin, I.R., Woodgate, R., 2010. Effects of dietary nitrate on fermentation, methane production and digesta kinetics in sheep. *Anim. Prod. Sci.* 50, 801–806.

Novilla, M.N., 2018. Ionophores. In: Gupta, R.C. (Eds.), *Veterinary toxicology: basic and clinical principles*. Third edition. Chapter 78. pp. 1073–1092.

Ogawa, S., Yazaki, Y., 2018. Tannins from *Acacia mearnsii* De Wild. Bark: Tannin Determination and Biological Activities. *Molecules* 23, 837. <https://doi.org/10.3390/molecules23040837>.

Ogino, A., Orito, H., Shimadad, K., Hirooka, H., 2007. Evaluating environmental impacts of the Japanese beef cow–calf system by the life cycle assessment method. *Anim. Sci. J.* 78, 424–432.

Ørskov, E.R., McDonald, I., 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *J. Agric. Sci. Camb.* 92:(1970), 499–503.

Papas, A.M., Sniffen, C.J., Muscato, T.V., 1984. Effectiveness of Rumen-Protected Methionine for Delivering Methionine Postruminally in Dairy Cows. *J. Dairy Sci.* 67(3), 545–552. [https://doi.org/10.3168/jds.s0022-0302\(84\)81337-5](https://doi.org/10.3168/jds.s0022-0302(84)81337-5).

Pathak, A.K., Dutta, N., Banerjee, P.S., Goswami, T.K., Sharma, K., 2016. Effect of condensed tannins supplementation through leaf meal mixture on voluntary feed intake, immune response and worm burden in *Haemonchus contortus* infected sheep. *J. Parasit. Dis.* 40, 100–105.

Patra, A., Park, T., Kim, M., Yu, Z., 2017. Rumen methanogens and mitigation of methane emission by anti-methanogenic compounds and substances. *J. Anim. Sci. Biotechnol.* 8(1), 1–18. <https://doi.org/10.1186/s40104-017-0145-9>.

Patra, A.K., Saxena, J., 2009. Dietary phytochemicals as rumen modifiers: a review of the effects on microbial populations. *Antonie Van Leeuwenhoek.* 96, 363–375.

Patra, A.K., Saxena, J., 2011. Exploitation of dietary tannins to improve rumen metabolism and ruminant nutrition. *J. Sci. Food Agric.* 91, 24–37.

Patra, A.K., Yu, Z., 2014. Effects of vanillin, Quillaja saponin, and essential oils on in vitro fermentation and protein-degrading microorganisms of the rumen. *Appl. Microbiol. Biotechnol.* 98, 897–905.



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Patra, A.K., Yu, Z., 2015. Effects of adaptation of in vitro rumen culture to garlic oil, nitrate, and saponin and their combinations on methanogenesis, fermentation, and abundances and diversity of microbial populations. *Front Microbiol.* 6, 1434.

Patra, A.K., 2012. Enteric methane mitigation technologies for ruminant livestock: A synthesis of current research and future directions. *Environ. Monitor. Assess.* 184(4), 1929–1952. <https://doi.org/10.1007/s10661-011-2090-y>.

Patra, A.K., Kamra, D.N., Agarwal, N., 2006. Effect of plant extracts on in vitro methanogenesis, enzyme activities and fermentation of feed in rumen liquor of buffalo. 128, 276–291. <https://doi.org/10.1016/j.anifeedsci.2005.11.001>.

Patra, A.K., Saxena, J., 2010. Phytochemistry. A new perspective on the use of plant secondary metabolites to inhibit methanogenesis in the rumen. *Phytochem.* 71(11–12), 1198–1222. <https://doi.org/10.1016/j.phytochem.2010.05.010>.

Pattanaik, B.N., Mandalia, H.C., 2011. Ethyl Acetate: Properties, Production Processes and Applications - A Review. *Int. J. Curr. Res. Rev.* 03(12), 23–40.

Pereira, A.M., Lurdes, M.D., Enes, N., Borba, A.E.S., 2022. Alternative pathways for hydrogen sink originated from the ruminal fermentation of carbohydrates: Which microorganisms are involved in lowering methane emission? *Anim. Microb.* 4(1), 1–12. <https://doi.org/10.1186/s42523-021-00153-w>.

Pérez, V., Doce, R.R., García-Pariente, C., Hervás, G., Carmen Ferreras, M., Mantecón, Á.R., Frutos, P., 2011. Oak leaf (*Quercus pyrenaica*) poisoning in cattle. *Res. Vet. Sci.* 91(2), 269–277. <https://doi.org/10.1016/j.rvsc.2010.12.015>.

Perry, B., Sones, K., 2007. Poverty reduction through animal health. *Sci.* 315, 5810, 333–334. <https://doi.org/10.1126/science.1138614>.

Piñeiro-Vázquez, A.T., Canul-Solís, J.R., Alayón-Gamboa, J.A., Chay-Canul, A.J., Ayala-Burgos, A.J., Aguilar-Pérez, C.F., Solorio-Sánchez, F.J., Ku-Vera, J.C., 2015. Potential of condensed tannins for the reduction of emissions of enteric methane and their effect on ruminant productivity. *Arch. Med. Vet.* 47, 263–272.

Pineiro-Vazquez, A.T., Jimenez-Ferrer, G., Alayon-Gamboa, J.A., Chay-Canul, A.J., Ayala-Burgos, A.J., Aguilar-Perez, C.F., Ku-Vera, J.C., 2018. Effects of quebracho tannin extract on intake, digestibility, rumen fermentation, and methane production in crossbred heifers fed low-quality tropical grass. *Trop. Anim. Health Prod.* 50, 29–36. <https://doi.org/DOI 10.1007/s11250-017-1396-3>.

Porter, L.J., Hrstich, L.N., Chans, B.G., 1986. The Conversion of Procyanidins and Prodelphinidins to Cyanidin and Delphinidin. *Phytochem.* 2, 223–230. [https://doi.org/10.1016/S0031-9422\(00\)94533-3](https://doi.org/10.1016/S0031-9422(00)94533-3).



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Pressure to Gas Production Conversion, 2014. Ankom Technology: Mecedon, NY, USA. https://www.ankom.com/sites/default/files/documentfiles/RFS005_Pressure_to_Gas_Producti on_Conversion.pdf. Accessed on 13/07/2018.

Prevolnik, M., Škrlep, M., Brus, M., Pugliese, C., Čandek-Potokar, M., Škorjanc, D., 2012. Supplementing pig diet with 0.2% sweet chestnut (*Castanea sativa* Mill.) wood extract had no effect on growth, carcass or meat quality. *Acta Agricul. Slov.* 100(3), 83-88.

Priolo, A., Waghorn, G.C., Lanza, M., Biondi, L., Pennisi, P., 2000. Polyethylene glycol as a means for reducing the impact of condensed tannins in carob pulp: effects on lamb growth performance and meat quality. *J. Anim. Sci.* 78(4), 810–816. <https://doi.org/10.2527/2000.784810x>.

Rahman, K., 2007. Studies on free radicals, antioxidants, and co-factors. *Clin. Interv. Aging* 2, 219–236.

Reed, J.D., 1995. Nutritional Toxicology Polyphenols in of Tannins and Related Forage Legumes. *J. Anim. Sci.* 73, 1516–1528. <https://doi.org/doi:/1995.7351516x>.

Ribeiro, L.G., Machado, F.S., Campos, M.M., Guimaraes, R., Tomich, T.R., Reis, L.G., Coombs, C., 2015. Enteric methane mitigation strategies in ruminants: a review. *Rev. Columb. Cie. Pec.* 28, 124–143. <https://doi.org/10.17533/udea.rccp.v28n2a02>.

Rira, M., Morgavi, D.P., Genestoux, L., Djibiri, S., Sekhri, I., Doreau, M., 2019. Methanogenic potential of tropical feeds rich in hydrolyzable tannins. *J. Anim. Sci.* 97, 2700–2710. <https://doi.org/10.1093/jas/skz199>.

Robertson, L.J., Waghorn, G.C., 2002. Dairy industry perspectives on methane emissions and production from cattle fed pasture or total mixed rations in New Zealand. *Proc. New Zeal. Soc. Anim. Prod.* 62, 213–218.

Rojas-downing, M.M., Nejadhashemi, A.P., Harrigan, T., Woznicki, S.A., 2017. Climate Risk Management Climate change and livestock: Impacts, adaptation, and mitigation. *Clim. Risk Man.* 16, 145–163. <https://doi.org/10.1016/j.crm.2017.02.001>.

Romero-Pérez, A., Okine, E.K., Guan, L.L., Duval, S.M., Kindermann, M., Beauchemin, K.A., 2016. Effects of 3-nitrooxypropanol and monensin on methane production using a forage-based diet in rusitec fermenters. *Anim. Feed Sci. Technol.* 220, 67–72. <https://doi.org/DOI 10.1016/j.anifeedsci.2016.07.013>.

Rossi, F., Maurizio, M., Francesco, M., Giovanna, C., Gianfranco, P., 2003. Rumen degradation and intestinal digestibility of rumen protected amino acids: Comparison between in situ and in vitro data. *Anim. Feed Sci. Technol.* 108(1–4), 223–229. [https://doi.org/10.1016/S0377-8401\(03\)00131-7](https://doi.org/10.1016/S0377-8401(03)00131-7).

Russell, J.B., 2002. *Rumen Microbiology and and Its Role in Ruminant Nutrition*. Publisher:



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Department of Microbiology, Cornell University, Ithaca, NY, USA.

Salami, S.A., Valenti, B., Bella, M., O'Grady, M.N., Luciano, G., Kerry, J.P., Jones, E., Priolo, A., Newbold, C.J., 2018. Characterisation of the ruminal fermentation and microbiome in lambs supplemented with hydrolysable and condensed tannins. *FEMS Microbiol. Ecol.* 94(5), 1–13.

Saminathan, M., Tan, H.Y., Sieo, C.C., Abdullah, N., Ling Wong, C.M.V., Abdulmalek, E., Ho, Y.W., 2014. Polymerization degrees, molecular weights and protein-binding affinities of condensed tannin fractions from a leucaena leucocephala hybrid. *Molecules* 19(6), 7990–8010. <https://doi.org/10.3390/molecules19067990>.

Sanchez, V., Baeza, R., Galmarini, M.V., Zamora, M.C., Chirife, J., 2013. Freeze-Drying Encapsulation of Red Wine Polyphenols in an Amorphous Matrix of Maltodextrin. *Food Bioprocess Technol.* 6(5), 1350–1354. <https://doi.org/10.1007/s11947-011-0654-z>.

Santoso, B., Kume, S., Nonaka, K., Kimura, K., Mizokoshi, H., Gamo, Y., Takahashi, J., 2003. Methane emission, nutrient digestibility, energy metabolism and blood metabolites in dairy cows fed silages with and without galacto-oligosaccharides supplementation. *Asian-Austral. J. Anim. Sci.* 16, 534–540.

Santoso, B., Mwenya, B., Sar, C., Gamo, Y., Kobayashi, T., Morikawa, R., Kimura, K., Mizokoshi, H., Takahashi, J., 2004. Effects of supplementing galactooligosaccharides, *Yucca schidigera* or nisin on rumen methanogenesis, nitrogen and energy metabolism in sheep. *Livest. Prod. Sci.* 91, 209–217.

Sar, C., Mwenya, B., Pen, B., Morikawa, R., Takaura, K., Kobayashi, T., 2005. Effect of nisin on ruminal methane production and nitrate/nitrite reduction in vitro. *Aust. J. Agric. Res.* 56, 803–810.

Schofield, P., 2000. Gas Production Methods. In: D'Mello, J.P.F. (Eds.), Chapter 10 - Farm Animal Metabolism and Nutrition. CABI Publishing, New York, USA. pp. 443.

Schofield, P., Pell, A.N., 1995. Validity of Using Accumulated Gas Pressure Readings to Measure Forage Digestion In Vitro. *J. Dairy Sci.* 78(10), 2230–2238. [https://doi.org/10.3168/jds.S0022-0302\(95\)76850-3](https://doi.org/10.3168/jds.S0022-0302(95)76850-3).

Schofield, P., Pitt, R.E., Pell, A.N., 1994. Kinetics of fiber digestion from in vitro gas production. *J. Anim. Sci.* 72, 2980–2991. <https://doi.org/10.2527/1994.72112980x>.

Seeram, N., Lee, R., Hardy, M., Heber, D., 2005. Rapid large scale purification of ellagitannins from pomegranate husk, a by-product of the commercial juice industry. *Sep. Purif. Technol.* 41(1), 49–55. <https://doi.org/10.1016/j.seppur.2004.04.003>.

Sejian, V., Bhatta, R., Malik, P.K., Madijagan, B., Al-Hosni, Y.A.S., Sullivan, M., Gaughan, J.B., 2016. Livestock as Sources of Greenhouse Gases and Its Significance to Climate Change.



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

In: Moya, B.L., Pous, J. (Eds.), Chapter 11 - Greenhouse Gases. pp. 1–19. Intech. <https://dx.doi.org/10.5772/62135>.

Sharp, R., Ziemer, C.J., Stern, M.D., Stahl, D.A., 1998. Taxon-specific associations between protozoal and methanogen populations in the rumen and a model rumen system. *FEMS Microbiol. Ecol.*, 26, 71–78. doi:10.1016/S0168-6496(98)00024-5.

Shreck, A., 2013. Use of alkaline treated crop residues as partial grain replacements for finishing cattle. Unpublished Doctoral Dissertation; University of Nebraska-Lincoln. USA.

Silanikove, N., Perevolotsky, A., Provenza, F.D., 2001. Use of tannin-binding chemicals to assay for tannins and their negative postingestive effects in ruminants. *Anim. Feed Sci. Technol.* 91(1–2), 69–81. [https://doi.org/10.1016/S0377-8401\(01\)00234-6](https://doi.org/10.1016/S0377-8401(01)00234-6).

Singh, B., Sahoo, A., Sharma, R., Bhat, T.K., 2005. Effect of polyethylene glycol on gas production parameters and nitrogen disappearance of some tree forages. *Anim. Feed Sci. Technol.* 123-124, 351–364. <https://doi.org/10.1016/j.anifeedsci.2005.04.033>.

Sirohi, S.K., Goel, N., Pandey, P., 2012. Efficacy of different methanolic plant extracts on anti-methanogenesis, rumen fermentation and gas production kinetics *in vitro*. *Open Vet. J.* 2, 72–77.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., 2007. Agriculture. In: Metz, O.R., Davidson, P.R., Bosch, R.D., Meyer, L.A. (Eds.), *Climate Change: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge, United Kingdom, Cambridge University Press.

Soares, S., Mateus, N., De Freitas, V., 2007. Interaction of different polyphenols with bovine serum albumin (BSA) and human salivary alpha-amylase (HSA) by fluorescence quenching. *J. Agric. Food Chem.* 55, 6726-6735.

Soltan, Y.A., Patra, A.K., 2021. Ruminal Microbiome Manipulation to Improve Fermentation Efficiency in Ruminants. In: Kumar, D.A. (Ed.), *Animal Feed Science and Nutrition - Production, Health and Environment*; Intech: London, England. pp. 1-21.

Soltan, Y.A., Morsy, A.M., Sallam, S.M.A., Louvandini, H., Abdalla, A.L., 2012. Comparative *in vitro* evaluation of forage legumes (prosopis, acacia, atriplex, and leucaena) on ruminal fermentation and methanogenesis. *J. Anim. Feed Sci.* 21(4), 759–772. <https://doi.org/10.22358/jafs/66148/2012>.

Soltan, Y.A., Morsy, A.M., Sallam, S.M.A., Lucas, R.C., Louvandini, H., Kreuzer, M., Abdalla, A.L., 2013. Contribution of condensed tannins and mimosine to the methane mitigation caused by feeding *Leucaena leucocephala*. *Arch. Anim. Nutr.* 67(3), 169–184. <https://doi.org/10.1080/1745039X.2013.801139>.



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Sophal, C., Khang, D.N., Preston, T.R., Leng, R.A., 2013. Nitrate replacing urea as a fermentable N source decreases enteric methane production and increases the efficiency of feed utilization in Yellow cattle. *Livest. Res. Rural Dev.* 25, 1–7.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C., 2006. Livestock's long shadow environmental issues and options. *Livestock Environment and Development (LEAD)*, and Food and Agricultural Organization (FAO). pp. 416. Retrieved on 29/7/2022 from <http://www.virtualcentre.org>.

Stewart, E.K., Beauchemin, K.A., Dai, X., MacAdam, J.W., Christensen, R.G., Villalba, J.J., 2019. Effect of tannin-containing hays on enteric methane emissions and nitrogen partitioning in beef cattle. *J. Anim. Sci.* 97, 3286–3299.

Stover, M.G., Watson, R.R., Collie, R.J., 2016. Chapter 2 - Pre- and Probiotic Supplementation in Ruminant Livestock Production. In: *Probiotic, Prebiotic and Symbiotic. Biocactive Foods in Health Promotion*. pp. 25–36.

Sun, K., Liu, H., Fan, H., Liu, T., Zheng, C., 2021. Research progress on the application of feed additives in ruminal methane emission reduction: a review. *Peer J.* 9, e11151. <https://doi.org/10.7717/peerj.11151>.

Takahashi, J. 2006. Emission of GHG from livestock production in Japan. In: Soliva, C.R., Takahashi, J., Kreuzer, M. (Eds.), *Greenhouse gases and animal agriculture: An update. International congress series 1293*. Elsevier, Amsterdam, Netherlands. pp. 1–20.

Tan, H.Y., Sieo, C.C., Abdullah, N., Liang, J.B., Huang, X.D., Ho, Y.W., 2011. Effects of condensed tannins from *Leucaena* on methane production, rumen fermentation and populations of methanogens and protozoa in vitro. *Anim. Feed Sci. Technol.* 169(3–4), 185–193. <https://doi.org/10.1016/j.anifeedsci.2011.07.004>.

Tavendale, M.H., Meagher, L.P., Pacheco, D., Walker, N., Attwood, G.T., Sivakumaran, S., 2005. Methane production from in vitro rumen incubations with *Lotus pedunculatus* and *Medicago sativa*, and effects of extractable condensed tannin fractions on methanogenesis. *Anim. Feed Sci Technol.* 123-124, 403–419. <https://doi.org/10.1016/j.anifeedsci.2005.04.037>.

Taylor, J., Taylor, J.N.R., Belton, P.S., Minnaar, A., 2009. Kafirin Microparticle Encapsulation of Catechin and Sorghum Condensed Tannins. *J. Agric. Food Chem.* 57, 7523–7528. <https://doi.org/10.1021/jf901592q>.

Teather, R., Forster, R., 1998. Manipulating the rumen microflora with bacteriocins to improve ruminant production. *Can. J. Anim. Sci.* 78, 57–69.

Tedeschi, L.O., Muir, J.P., Naumann, H.D., Norris, A.B., Ramírez-restrepo, C.A., Mertens-talcott, S.U., 2021. Nutritional Aspects of Ecologically Relevant Phytochemicals in Ruminant Production. *Front. Vet. Sci.* 8, 628445. <https://doi.org/10.3389/fvets.2021.628445>.

Terrill, T.H., Waghorn, G.C., Woolley, D.J., McNabb, W.C., Barry, T.N., 1994. Assay and



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

digestion of ¹⁴C-labelled condensed tannins in the gastrointestinal tract of sheep. *Br. J. Nutr.* 72, 467–477. <https://doi.org/doi:10.1079/BJN19940048>.

Theodorou, M.K., Williams, B.A., Dhanoa, M.S., McAllan, A.B., France, J., 1994. A simple gas production method using a pressure transducer to determine the fermentation kinetics of ruminant feeds. *Anim. Feed Sci. Technol.* 48, 185–197. [https://doi.org/10.1016/0377-8401\(94\)90171-6](https://doi.org/10.1016/0377-8401(94)90171-6).

Tiemann, T.T., Lascano, C.E., Wettstein, H.-R., Mayer, A.C., Kreuzer, M., Hess, H.D., 2008b. Effect of the tropical tannin-rich shrub legumes *Calliandra calothyrsus* and *Flemingia macrophylla* on methane emission and nitrogen and energy balance in growing lambs. *Animal* 2, 790–799.

Tiemann, T.T., Avila, P., Ramírez, G., Lascano, C.E., Kreuzer, M., Hess, H.D., 2008a. In vitro ruminal fermentation of tanniniferous tropical plants: Plant-specific tannin effects and counteracting efficiency of PEG. *Anim. Feed Sci. Technol.* 146, 222–241. <https://doi.org/10.1016/j.anifeedsci.2007.12.009>.

Tilley, J.M.A., Terry, R.A., 1963. A two-stage technique for the in vitro digestion of forage crops. *J. Brit. Grassland Soc.* 18, 104–111.

Tolve, R., Galgano, F., Condelli, N., Cela, N., Lucini, L., Caruso, M.C., 2021. Optimization model of phenolics encapsulation conditions for biofortification in fatty acids of animal food products. *Foods* 10, 881. <https://doi.org/10.3390/foods10040881>.

Tondi, G., Pizzi, A., 2009. Tannin-based rigid foams: Characterization and modification. *Ind. Crops Prod.* 29, 356–363. <https://doi.org/10.1016/j.indcrop.2008.07.003>.

Ungerfeld, E.M., Kohn, R.A., 2008. The role of thermodynamics in the control of ruminal fermentation. *Rumin. Physiol.* 90, 8686. <https://doi.org/10.3920/978-90-8686-566-6>.

United Nation, 2013. World population projected to reach 9.6 billion by 2050. United Nations Department of Economic and Social Affairs. Retrieved on 31/12/2022 from <http://www.un.org/development/desa/en/news/population/un-report-world-population-project/htm>.

Van Der Watt, E., Pretorius, J.C., 2001. Purification and identification of active antibacterial components in *Carpobrotus edulis* L. *J. Ethnopharmacol.* 76, 87–91. [https://doi.org/10.1016/S0378-8741\(01\)00197-0](https://doi.org/10.1016/S0378-8741(01)00197-0).

van Niekerk, W.A., Hassen, A., Snyman, L.D., Rethman, N.F.G., Coertze, R.J., 2009. Influence of mineral composition and rumen degradability of *Atriplex nummularia* (Hatfield Select F1) plants on selection preference of sheep. *Afr. J. Range Forage Sci.* 26, 91–96.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Symposium: carbohydrate methodology, metabolism, and nutritional implications in dairy cattle. *J. Dairy Sci.* 74, 3583–3597.



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Van Soest, P.J., 1994. *Nutritional Ecology of Ruminants*. 2nd Edition, Cornell University Press, Ithaca, London. pp. 122.

van Zijderveld, S.M., Fonken, B., Dijkstra, J., Gerrits, W.J.J., Perdok, H.B., Fokkink, W., Newbold, J.R., 2011. Effects of a combination of feed additives on methane production, diet digestibility, and animal performance in lactating dairy cows. *J. Dairy Sci.* 94, 1445–1454. <https://doi.org/doi:10.3168/jds.2010-3635>.

van Zijderveld, S.M., Gerrits, W.J.J., Apajalahti, J.A., Newbold, J.R., Dijkstra, J., Leng, R.A., Perdok, H.B., 2010. Nitrate and sulfate: Effective alternative hydrogen sinks for mitigation of ruminal methane production in sheep. *J. Dairy Sci.* 93, 5856–5866. <https://doi.org/doi:10.3168/jds.2010-3281>.

Vargas-ortiz, L., Andrade-yucailla, V., Barros-rodr, M., Lima-orozco, R., Mac, E., Contreras-barros, K., Guishca-cunuhay, C., 2022a. Influence of *Acacia Mearnsii* Fodder on Rumen Digestion and Mitigation of Greenhouse Gas Production. *Animals* 12, 2250. <https://doi.org/10.3390/ani12172250>.

Vargas-ortiz, L., Chavez-garcia, D., Barros-rodr, M., Andrade-yucailla, V., Lima-orozco, R., Mac, E., Guishca-cunuhay, C., Zeidan, A., Salem, M., 2022b. Rumen Function and In Vitro Gas Production of Diets Influenced by Two Levels of Tannin-Rich Forage. *Fermentation* 8, 607. <https://doi.org/10.3390/fermentation8110607>.

Vasta, V., Nudda, A., Cannas, A., Lanza, M., Priolo, A., 2008. Alternative feed resources and their effects on the quality of meat and milk from small ruminants. *Anim. Feed Sci. Technol.* 147, 223–246. <https://doi.org/10.1016/j.anifeedsci.2007.09.020>.

Veneman, J.B., Muetzel, S., Hart, K.J., Faulkner, C.L., Moorby, M., Perdok, H.B., 2015. Does Dietary Mitigation of Enteric Methane Production Affect Rumen Function and Animal Productivity in Dairy Cows? *PLoS One* 10(10), 1–18.

Versfeld, D.B., Le Maitre, D.C., Chapman, R.A., 1998. Alien invading plants and water resources in South Africa. A Preliminary Assessment. A Report to the Water Research Commission. WRC Report No. 99/98. pp. 443.

Waghorn, G.C., Tavendale, M.H., Woodfield, D.R., 2002. Methanogenesis from forages fed to sheep. *Proc. New Zeal. Grassl. Assoc.* 64, 159–165.

Waghorn, G., 2008. Beneficial and detrimental effects of dietary condensed tannins for sustainable sheep and goat production — Progress and challenges. *Anim. Feed Sci. Technol.* 147, 116–139. <https://doi.org/10.1016/j.anifeedsci.2007.09.013>.

Waghorn, G.C., Shelton, I.D., McNabb, W.C., 1994. Effects of condensed tannins in *Lotus pedunculatus* on its nutritive value for sheep 1. Nitrogenous aspects. *J. Agric. Sci.* 123, 99–107.

Wallace, R.J., Wood, T.A., Rowe, A., Price, J., Yanez-Ruiz, D.R., Williams, S.P., Newbold,



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

- C.J., 2006. Encapsulated fumaric acid as a means of decreasing ruminant methane emission. *International Congress Series*. 1293, 148–151. <https://doi.org/10.1016/j.ics.2006.02.018>.
- Wang, Y., Douglas, G.B., Waghorn, G.C., Barry, T.N., Foote, A.G., 1996. Effect of condensed tannins in *Lotus corniculatus* upon lactation performance in ewes. *J. Agric. Sci.* 126, 353–362.
- Webb, E.C., 1994. Synthesis of long chain fatty acids in ruminants and their effects on meat quality. pp. 58-59.
- Wischer, G., Greiling, A.M., Boguhn, J., Steingass, H., Schollenberger, M., Hartung, K., Rodehutschord, M., 2014. Effects of long-term supplementation of chestnut and valonea extracts on methane release, digestibility and nitrogen excretion in sheep. *Animal* 8(6), 938–948. <https://doi.org/10.1017/s1751731114000639>.
- Wolin, M.J., Miller, T.L., Stewart, C.S., 1997. Microbe-Microbe Interactions. In: Hobson, P.J., Stewart, C.S. (Eds.), *The Rumen Microbial Ecosystem*. Blackie Academic & Professional, London, pp. 467–491.
- Wood, T.A., Wallace, R.J., Rowe, A., Price, J., Yáñez-Ruiz, D.R., Murray, P., Newbold, C. J., 2009. Encapsulated fumaric acid as a feed ingredient to decrease ruminal methane emissions. *Anim. Feed Sci. Technol.* 152, 62–71. <https://doi.org/10.1016/j.anifeedsci.2009.03.006>.
- Woodward, S.L., Waghorn, G.C., Ulyatt, M.J., Lassey, K.R., 2001. Early indications that feeding *Lotus* will reduce methane emissions from ruminants. *Proc. New Zeal. Soc. Anim. Prod.* 61, 23–26.
- Wu, H., Meng, Q., Zhou, Z., Yu, Z., 2019. Ferric citrate, and nitrate, saponin and their combinations affect in vitro ruminal fermentation, production of sulphide and methane and abundance of select microbial populations. *J. Appl. Microbiol.* 127, 150–158. <https://doi.org/10.1111/jam.14286>.
- Yang, W.Z., Benchaar, C., Ametaj, B.N., Chaves, A.V., He, M.L., McAllister, T.A., 2007. Effects of garlic and juniper berry essential oils on ruminal fermentation and on the site and extent of digestion in lactating cows. *J. Dairy Sci.* 90, 5671–5681.
- Zhang, J., Xu, X., Cao, Z., Wang, Y., Yang, H., Azarfar, A., Shengli, L., 2019. Effect of Different Tannin Sources on Nutrient Intake, Digestibility, Performance, Nitrogen Utilization, and Blood Parameters in Dairy Cows. *Animals* 9, 507. <https://doi.org/10.3390/ani9080507>.
- Zhang, Z., Wang, Y., Si, X., Cao, Z., Li, S., Yang, H., 2020. Rumen methanogenesis, and fermentation, rumen, rumen fermentation and microbial community response to nitroethane, 2-nitroethanol, and 2-nitro-1-propanol: an in vitro study. *Animals* 10, 479. <https://doi.org/10.3390/ani10030479>.



Zhou, H.C., Lin, Y.M., Wei, S.D., Tam, N.F.Y., 2011. Structural diversity and antioxidant activity of condensed tannins fractionated from mangosteen pericarp. *Food Chem.* 129, 1710–1720. <https://doi.org/10.1016/j.foodchem.2011.06.036>.

Zhou, X., Meile, L., Kreuzer, M., Zeitz, J.O., 2013. The effect of lauric acid on methane production and cell viability of *Methanobrevibacter ruminantium*. *Adv. Anim. Biosci.* 4(2), 458.



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA