Research Article

Innovative Strategies for Methane Mitigation: The Role of Durian Seed Nanoemulsions (DSN) in *In vitro* Studies

Efi Rokana[1*], Zein Ahmad Baihaqi[1,2], Ahsin Daroini[3], Fadlilatul Taufany[4]

[1]Program of Animal Husbandry, Faculty of Agriculture, Universitas Islam Kadiri, Kediri, East Java, Indonesia; [2]Research Center for Animal Husbandry, Research Organization for Agriculture and Food, National Research and Innovation Agency (BRIN), Bogor, West Java, Indonesia; [3]Program of Agribusiness, Post-graduates program, Universitas Islam Kadiri, Kediri, East Java, Indonesia; [4]Department of Chemical Engineering, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo, , Surabaya, East Java, Indonesia.

Abstract | The livestock sector, particularly ruminants, contributes to global warming through methane emissions, which are a significant source of greenhouse gases. These emissions also have a reciprocal impact on the ruminant sector, as climate change and unstable weather conditions affect the availability and quality of forage for livestock. This research, conducted using the Theodorou method on an in vitro scale with rumen fluid from cattle obtained via fistula, aims to explore the potential of *Durio zibethinus* seed waste in the form of nanoemulsion preparations for reducing methane gas emissions. Qualitative analyses confirmed the presence of tannins, flavonoids, alkaloids, saponins, and steroids in the Durian Seed Nanoemulsion (DSN). Quantitative assessments revealed flavonoid content at 4.2 mg RE/g dry weight, total phenolic content at 9.1 mg GAE/g dry weight, and total tannin content of 7.6%, with 4.4% as condensed tannins and 3.2% as hydrolysable tannins. In vitro gas production experiments showed that while the incorporation of DSN did not significantly affect gas production kinetics from soluble or potentially degradable feed fractions ($p > 0.05$), methane production was significantly reduced with increasing DSN levels ($p < 0.05$). These findings highlight DSN's potential as an effective additive for mitigating methane emissions in ruminant feed, suggesting that the active compounds in *Durio zibethinus* seed could play a key role in promoting more sustainable livestock practices.

Keywords | Feed additive, Methane, Reduction, *Durio zibethinus seeds*, Ruminant

Received | September 28, 2024; **Accepted** | January 25, 2025; **Published** | May 15, 2025
***Correspondence** | Efi Rokana, Program of Animal Husbandry, Faculty of Agriculture, Universitas Islam Kadiri, Kediri, East Java, Indonesia; **Email:** efi@uniska-kediri.ac.id
Citation | Rokana E, Baihaqi ZA, Daroini A, Taufany F (2025). Innovative strategies for methane mitigation: The role of durian seed nanoemulsions (DSN) in *In vitro* studies. J. Anim. Health Prod. 13(2): 340-345.
DOI | https://dx.doi.org/10.17582/journal.jahp/2025/13.2.340.345
ISSN (Online) | 2308-2801

INTRODUCTION

The ruminant farming sector is a major source of greenhouse gas emissions, particularly methane (CH4), which significantly contributes to global warming. Methane has a global warming potential approximately 23 times greater than carbon dioxide (Terefe et al., 2024). Rising global temperatures pose a critical environmental challenge (Richardson *et al.*, 2023). Omeme and Mona (2025) stated that methane possesses a significantly higher warming potential, being 21 times more effective at trapping heat in the atmosphere than carbon dioxide, thereby accelerating global warming. Additionally, Debbarma *et al.* (2023) identify various sources of methane, with emissions from methanogenic bacteria during the digestion process in ruminants being a significant contributor.

Baihaqi *et al*. (2023) demonstrated that Carica fruit seeds can effectively reduce methane emissions, control *Haemonchus contortus*, and are safe for rumen fermentation in ruminants. Additionally, research by Baihaqi *et al*. (2020a), (2020b), (2020c), along with studies by Sakti *et al*. (2024); Rokana *et al*. (2024); Prasetyo *et al*. (2024); Lokapirnasari *et al*. (2024); Prayudi *et al*. (2023); Lisnanti *et al*. (2023) and Baihaqi *et al*. (2024a), (2024b), highlighted that various active compounds derived from plant-based agro-industrial waste have been successful as alternative treatments, including bio-anthelmintics, bio-antibacterials, methane-reduction agents, and enhancers of livestock productivity.

The selection of durian seeds for this study is based on the fact that the waste from these seeds causes environmental pollution and is abundant in quantity (Gamay *et al*., 2024). Strategies to reduce excessive methane emissions can involve the use of active plant compounds (Baihaqi *et al*., 2023). Gamay *et al*. (2024) stated that durian seed waste contains active plant compounds that are largely underutilized. Zhao *et al*. (2024) reported that flavonoid compounds inhibit populations of methanogenic bacteria and protozoa in the rumen, improving organic matter digestibility and increasing populations of *Fibrobacter succinogenes*. Nascimento *et al*. (2021) noted that tannins promote microbial protein synthesis by forming protein-tannin complexes that inhibit methanogenic bacteria. Rira *et al*. (2019) suggested that plant bioactives could function as feed additives to reduce CH4 production and greenhouse gas emissions. Furthermore, the formulation of nanoemulsion preparations enhances the solubility of active substances, facilitating their absorption and bioavailability in the gastrointestinal tract (Singh *et al*., 2009). Dhakal *et al*. (2024) advocate for using plant bioactives as feed additives to reduce CH4 emissions and overall greenhouse gas output. Therefore, this research aims to investigate the potential of compounds from *Durio zibethinus* seed nanoemulsions in mitigating methane emissions.

MATERIALS AND METHODS

Location and Material

Research on the analysis of *Durio zibethinus* seed nanoemulsions for methane reduction was conducted at the National Research and Innovation Agency. The *Durio zibethinus* seeds were collected from community gardens in Kediri Regency, Indonesia, and were used for the extraction process..

Preparation of *Durio zibethinus* Seeds Nanoemulsions

The *Durio zibethinus* seeds were collected during the durian fruit season in June 2024 through direct collection, then oven-dried at 55°C and ground into powder. The powder was extracted using ethanol as a solvent. The nanoemulsion formulation consisted of the ethanol extract of *Durio zibethinus* seeds, Tween 80, and phosphate buffer. The preparation of this formulation followed the method outlined in previous research by Harmi (2014). The extract of *Durio zibethinus* seeds at concentrations of 5% and 10%, along with 3 ml of Tween 80, was dissolved in the buffer solution and homogenized to a final volume of 100 ml. The extract mixture, along with the other ingredients, was blended until homogeneous using a centrifuge for 30 minutes at a speed of 10,000 rpm, with temperatures ranging from 10°C to 30°C.

Identification of Bioactive Compounds In Nanoemulsions

The bioactive components of the *Durio zibethinus* seeds nanoemulsions were qualitatively identified using the method outlined by Adeyemi *et al*. (2017). Quantitative analysis of the total phenolic content in fruit peel waste was performed using the Folin-Ciocalteu method and expressed in mg of gallic acid. Concurrently, the total flavonoid content in fruit peel waste was analyzed using a colorimetric method, with results expressed in mg of rutin, following the procedure by Sari *et al*. (2023).

Prepare for *In vitro* Gas Production

Bali cattle rumen fluid samples were collected from Faculty of Animal Science, Universitas Gadjah Mada (Yogyakarta, Indonesia). This research used a feed ingredient design consisting of complete feed and the addition of *Durio zibethinus* seeds nanoemulsions with percentages of 3%, 5% and 7%. The results of the proximate analysis of the feed ingredients used are presented in Table 1.

Table 1: Chemical composition of complete feed.

Feed name	DM %	Percentage Based on Dry Matter (DM) (%)					
		Ash	CP	CF	CFiber	NFE	TDN
Complete feed	89.91	4.21	14.32	4.83	26.71	59.60	65.11

Note: CP= Crude Protein; CF = Crude Fat; Cfiber = Crude Fiber; NFE= Nitrogen-Free Extract; TDN= Total Digestible Nutrient .

The fermentation substrate used in each treatment was 300 mg. All samples were put into a syringe filled with rumen buffer fluid in triplicate. Then, according to Theodorou methods (Theodorou *et al*., 1994), incubation using a water bath. Gas production was measured at 0, 2, 4, 6, 8, 12, 24, 36, and 48 hours and the gas collection for methane analysis was conducted at hour 24.

Statistical Analysis

The research design in this study is divided into 4 treatments, consisting of a control treatment and 3 different concentrations of Durian Seed Nanoemulsion (DSN). One treatment in this study consists of 7 replications. The research results related to rumen fermentation characteristics were analyzed using a two-way analysis of variance and Duncan's multiple range test. Significant research results were stated with $p < 0.05$. The analyses were performed using IBM Statistical Package for the Social Sciences version 20 (IBM Corp., Chicago, USA). Data were presented as mean ± standard deviation (SD).

RESULTS

The results of qualitative observations (Table 2) of plant bioactivity showed that *Durio zibethinus* seeds tested positive for the presence of tannins, flavonoids, alkaloids, saponins, and steroids.

Table 2: Analyses of qualitative phytochemicals of *Durio zibethinus* seeds (DSN).

Secondary metabolite	DSN
Tannin	+
Flavonoid	+
Alkaloid	+
Saponin	+
Steroid	+

The results of the quantitative analysis of bioactive compounds in this study, including flavonoids, total phenols, and tannins, are presented in Table 3. The flavonoid content of the *Durio zibethinus* seed nanoemulsion was 4.2 mg RE/g dry weight (dw), the total phenolic content was 9.1 mg GAE/g dw, and the total tannin content was 7.6%, with condensed tannins accounting for 4.4% and hydrolysable tannins at 3.2%.

As shown in Table 4, statistical analyses revealed that incorporating DSN did not significantly affect gas production kinetics from soluble feed fractions (a), potentially degradable feed fractions (b), the fractional rate of gas production (c), or total gas production (a+b) ($p > 0.05$). However, DSN significantly reduced methane production, with a notable decrease in methane emissions observed when DSN was administered at higher levels ($p < 0.05$).

DISCUSSION

The results of this quantitative plant bioactive study are consistent with the research found by Aisyah *et al.* (2024), who studied the same plant parts, specifically the durian seeds. Baihaqi *et al.* (2023) stated that *Carica pubescens* seeds contain bioactive compounds both qualitatively and quantitatively, with details of flavonoid content at 3.1 mg RE/g dw, total phenol at 9.5 mg GAE/g dw, and total tannin at 5.4% have successfully provided a significant methane reduction effect, positively causing death to worms in the abomasum of ruminant livestock, and also did not disrupt rumen fermentation characteristics. Króliczewska *et al.* (2023) stated that plant parts containing active plant compounds have the potential to be utilized as herbal medicine, aiding in methane emission reduction and serving various sectors.

Table 3: The quantification of *Durio zibethinus* seeds.

Material	Flavonoids content (mg RE/g dw)	Total phenolic (mg GAE/g dw)	Tannin total (%)	Condensed tannin, CT (%)	Hydrolyzed tannin, HT(%)
DSN	4.2	9.1	7.6	4.4	3.2

Table 4: In vitro assessment of rumen gas production following the addition of DSN.

Parameter	Treatment group			
	DSN 0%	DSN 3%	DSN 5%	DSN 7%
Gas production from soluble feed fraction (a; ml/300 mg/dry matter)[ns]	11.27 ±0.31	11.26 ±0.30	11.24 ±0.29	11.23 ±0.28
Gas production from potentially degraded feed fractions (b; ml/300 mg/dry matter)[ns]	114.01 ±0.30	113.99 ±0.28	113.97 ±0.27	113.95 ±0.26
Fractional rate of gas production (c; ml/hour)	0.05 ±0.00	0.05 ±0.00	0.05 ±0.00	0.05 ±0.00
Potential gas production (a+b; ml/300 mg dray matter)[ns]	125.28 ±0.38	125.27 ±0.36	125.25 ±0.34	125.24 ±0.32
CH_4 (ppm)	15.31 ±0.32[a]	11.15 ±0.49[b]	8.37 ±0.18[c]	6.21 ±0.14[d]

a-d: Different superscripts in a row indicate significant difference ($p<0.05$) between means.

Table 4 may demonstrate these effects of DSN supplementation on rumen gas production kinetics. The findings of the recent study align with prior research conducted by Acosta-Lozano *et al.* (2023), which stated that the addition of *Acacia mearnsii*, which contains tannins, did not significantly affect gas production parameters but resulted in a significant decrease in methane production along with the tannin content in the plant. This effect is likely due to a reduction in methanogenic archaea and ruminal protozoa and the formation of tannin complexes. Additionally, Baihaqi *et al.* (2023) added that the addition of *Carica pubescens* seeds also did not significantly change gas production but could significantly reduce methane production. In contrast to the findings of Liu *et al.* (2023), who found that the isolated silibinin from the fruit of *Silybum marianum* (chrysanthemum plant) resulted in a decrease in total gas production and methane in line with the high silibinin content.

The active compounds in DSN aqueous extract successfully provided an effect for methane reduction. The findings were in line with those reported by previous researchers, Martins *et al*. (2024), who conducted a meta-analysis of various references, stated that several methane mitigation interventions using β-cyclodextrin, *Leptospermum pattersoni, Salix caprea, Heracleum* spp., *nitroglycerin, Fructulus Ligustri*, and *Sesbania grandiflora*. According to Lambo *et al*. (2024), they highlighted the regulatory mechanisms of medicinal plants (MP) and emphasized the critical gaps that need addressing to enhance their efficacy. MP has the potential to decrease enteric methane production by 8-50% through regulating rumen fermentation pathways, shifting hydrogen towards propionogenesis, and modifying the diversity, structure, and population of methanogens and protozoa in the rumen.

Lins *et al*. (2018) noted that the inclusion of Moringa seeds containing tannins did not significantly affect ($p>0.05$) total gas production. In vitro gas testing serves as a parameter for evaluating rumen microbial conditions and digestibility. This study demonstrated that administering DSN effectively reduced methane emissions, particularly as the percentage of DSN increased. These outcomes align with previous research suggesting that certain active plant compounds can lower methane production. For instance, tannic acid, salicylic acid, and quercetin have been shown to decrease rumen methane formation after 48 hours of incubation, exhibiting a significant reduction compared to the control using corn silage (Nørskov *et al*., 2023). Furthermore, the addition of tannin extract from *Acacia mearnsii* has been proposed as a strategy for methane reduction, although it did not affect the production of short-chain fatty acids, despite the decrease in rumen CH_4 levels (Junior *et al*., 2022).

CONCLUSIONS AND RECOMMENDATIONS

The results of the exploration using nanoemulsion from *Durio zibethinus* seeds (DSN) significantly reduced methane levels, likely due to the active compounds in the durian seeds. Further research is needed to determine the optimal concentration for direct application to ruminant livestock (in vivo).

ACKNOWLEDGEMENTS

This study was supported by Kementerian Pendidikan dan Kebudayaan, Direktorat Jenderal Pendidikan Tinggi, Riset dan Teknologi Republik Indonesia, Regular Fundamental Research Scheme, with Grant number 029/SP2H/PT/LL7/2024

NOVELTY STATEMENTS

This study pioneers the use of Durian Seed Nanoemulsions (DSN) as a cutting-edge nanomaterial-based approach for methane mitigation in in vitro conditions. Unlike conventional methods, DSN harnesses nanotechnology to enhance bioavailability, reactivity, and targeted efficacy, offering a highly efficient, plant-derived, and sustainable alternative. By optimizing nanoparticle properties, this research provides breakthrough insights into methane reduction mechanisms, paving the way for next-generation, nano-based strategies in sustainable livestock production and environmental conservation.

AUTHOR'S CONTRIBUTIONS

ER, ZAB, AD, FT: Designed the study and collected samples and performed examinations. All authors have drafted and revised the manuscript. All authors have read, reviewed, and approved the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

REFERENCE

Acosta-Lozano N, Barros-Rodríguez M, GuishcaCunuhay C, Andrade-Yucailla V, Contreras-Barros K., SandovalCastro S, Elghandour MMKY, Zeidan MSA (2023). Potential Effect of Dietary Supplementation of Tannin-Rich Forage on Mitigation of Greenhouse Gas Production, Defaunation and Rumen Function. Vet. Sci., 10: 467. https://doi.org/10.3390/vetsci10070467

Adeyemi MA, Ekunseitan DA, Abiola SS, Dipeolu MA, Egbeyale LT, Sogunle OM (2017). Phytochemical Analysis and GC-MS Determination of *Lagenaria breviflora* R. Fruit. Int. J. Pharmacogn. Phytochem. Res., 9(7): 1045-1050.

Aisyah S, Harioputro DR, Nurwati I (2024). The potential of durian seed (Durio zibethinus Murr.) as natural resources with antioxidant activity and total flavonoid content. The 1st International Conference of Health Institut Kesehatan Mitra Bunda. NST Proc., 14-19.

Baihaqi ZA, Widiyono I, Nurcahyo W (2019). Prevalence of gastrointestinal worms in Wonosobo and thin-tailed sheep on the slope of Mount Sumbing, Central Java, Indonesia. Vet. World, 12(11): 1866–1871. https://doi.org/10.14202/vetworld.2019.1866-1871

Baihaqi ZA, Widiyono I, Angeles AA, Suwignyo B, Nurcahyo W (2023). Anthelmintic activity of Carica pubescens aqueous seed extract and its effects on rumen fermentation and methane reduction in Indonesian thin-tailed sheep: An in vitro study. Vet. World, 16(7): 1421–28. https://doi.org/10.14202/vetworld.2023.1421-1428

Baihaqi ZA, Widiyono I, Angeles AA, Suwignyo B (2022). Alternative strategies of plant metabolite secondary "Tannin" for methane emissions reduction on ruminant livestock: A review of the last 5 years literature. Adv. Anim. Vet. Sci., 10(3): 599–606. https://doi.org/10.17582/journal.

aavs/2022/10.3.599.606

Baihaqi ZA, Widiyono I, Nurcahyo W (2020a). In vitro anthelmintic activity of aqueous and ethanol extracts of Paraserianthes falcataria bark waste against Haemonchus contortus obtained from a local slaughterhouse in Indonesia. Vet. World, 13(8): 1549–1554. https://doi.org/10.14202/vetworld.2020.1549-1554

Baihaqi ZA, Widiyono I, Nurcahyo W (2020b). Potential of Carica pubescens fruit peel as an alternative method to control Haemonchus contortus in small ruminants. Livestock. Res. Rural. Dev., 32(7): 106.

Baihaqi ZA, Widiyono I, Nurcahyo W (2020c). Prevalence naturally infected gastrointestinal parasites and complete blood count condition on Wonosobo sheep at Wonosobo District, Central Java, Indonesia. Biodiversitas, 21 (7): 3057-3061. https://doi.org/10.13057/biodiv/d210724

Baihaqi ZA, Sofyan A, Suwignyo B, Angeles AA, Widiyono I, Nurcahyo W, Ibrahim A, Putri EM, Wulandari (2024a). In vivo study: The effects of Carica pubescens seed extract on the anthelmintic activity, feed digestibility, performance, and clinical parameters of thin-tailed sheep. IOP Conf. Ser. Earth Environ. Sci. 1341 012119. https://doi.org/10.1088/1755-1315/1341/1/012119

Baihaqi ZA, Anggrahini S, Wulandari, Sakti AA, Ibrahim A, Putri EM (2024b). Anthelmintic potential of Swietenia mahagoni seed waste against *Haemonchus contortus* in Indonesian small ruminant. IOP Conf. Ser. Earth Environ. Sci., 1417 012045. https://doi.org/10.1088/1755-1315/1417/1/012045

Debbarma S, Talukdar J, Sarma A, Maurya P, Deka D, Barkalita L (2023). Microbial Genomics and Modulation in Ruminants: An Environmental Perspective with Special Reference to Methane Migration. In: Mukhopadhyay, C.S., Choudhary, R.K., Panwar, H., Malik, Y.S. (eds) Biotechnological Interventions Augmenting Livestock Health and Production. Livestock Dis. Manag. Springer, Singapore. https://doi.org/10.1007/978-981-99-2209-3_13

Dhakal M, Ghimire S, Karki G, Deokar GS, Al-Asmari F, Nirmal NP (2024). Fruit Waste: Potential Bio-Resource for Extraction of Nutraceuticals and Bioactive Compounds. In: Sarkar, T., Pati, S. (eds) Bioactive Extraction and Application in Food and Nutraceutical Industries. Methods Protoc. Food Sci. Humana, New York, NY. https://doi.org/10.1007/978-1-0716-3601-5_13

Gamay RAJ, Botecario PN, Sanchez PDC, Alvarado MC (2024). Durian (Durio zibenthinus) waste: a promising resource for food and diverse applications—a comprehensive review. Food Prod. Process Nutr., 6: 27. https://doi.org/10.1186/s43014-023-00206-4

Goushki MN, Shiri MA, Nozari M (2023). Estimation of Gas Emissions using the Land GEM Model from the Landfill of Baft County, Kerman, Iran. Environ. Monit. Assess., 195: 1444. https://doi.org/10.1007/s10661-023-11943-x

Harmi L (2014). Preparation of Nanogingerol from Ginger Extract (*Zingiber officinale* Rosc) Using a Homogenizer with a Combination of Composition Inversion and Temperature. (Thesis). Bogor: Bogor Agricultural University.

Junior FP, Nogueira RGS, Carvalho RF, Orlandi CEC, Rodrigues PHM (2022). Use of tannin extract as a strategy to reduce methane in Nellore and Holstein cattle and its effect on intake, digestibility, microbial efficiency and ruminal fermentation. J. Anim. Physiol. Anim. Nutr., (Berl)107(1):89-102. https://doi.org/10.1111/jpn.13702

Króliczewska B, Pecka-Kiełb E, Bujok J (2023). Strategies Used to Reduce Methane Emissions from Ruminants: Controversies and Issues. Agriculture, 13: 602. https://doi.org/10.3390/agriculture13030602

Lambo MT, Ma H, Liu R, Dai B, Zhang Y, Li Y (2024). Review: Mechanism, effectiveness, and the prospects of medicinal plants and their bioactive compounds in lowering ruminants' enteric methane emission. Animal, 18 (4): 1 – 14. https://doi.org/10.1016/j.animal.2024.101134

Lins TOJD, Terry SA, Silva RR, Pereira LGR, Jancewicz LJ, He ML, Wang Y, McAllister TA, Chaves AV (2018). Effects of the inclusion of Moringa oleifera seed on rumen fermentation and methane production in a beef cattle diet using the rumen simulation technique (Rusitec). Animal, 13(2): 283–291. https://doi.org/10.1017/S1751731118001428

Lisnanti EF, Lokapirnasari WP, Hestianah EP, Al Arif MA, Baihaqi ZA (2023). The effectiveness of giving marsh fleabane (Pluchea indica l.) Water extract on broiler hematology and blood glucose. Adv. Anim. Vet. Sci., 11(8): 1348-1356. https://doi.org/10.17582/journal.aavs/2023/11.8.1348.1356

Liu Y, Ma M, Yuan Y (2023). The potential of curcumin-based co-delivery systems for applications in the food industry: Food preservation, freshness monitoring, and functional food. Food Res. Int., 171: 113070: 1- 14. https://doi.org/10.1016/j.foodres.2023.113070

Lokapirnasari WP, Al-Arif MA, Hidayatik N, Safiranisa A, Arumdani DF, Zahirah AI, Yulianto AB, Lamid M, Marbun TD, Lisnanti EF, Baihaqi ZA, Khairullah AR, Kurniawan SC, Pelawi EBS, Hasib A (2024). Effect of probiotics and acidifiers on feed intake, egg mass, production performance, and egg yolk chemical composition in late-laying quails, Vet. World, 17(2): 462–469. https://doi.org/10.14202/vetworld.2024.462-469

Martins LF, Cueva SF, Lage CFA, Ramin M, Silvestre T, Tricarico J, Hristov AN (2024). A meta-analysis of methane-mitigation potential of feed additives evaluated in vitro, J. Dairy Sci., 107(1): 288-300. https://doi.org/10.1016/S0022-0302(23)00819-6

Nascimento TVC, Oliveira RL, Menezes DR, De Lucena ALF, Queiroz MAA, Lima AGVO, Rebeiro RDX, Bazzera LR (2021). Effects of condensed tannin-amended cassava silage blend diets on feeding behavior, digestibility, nitrogen balance, milk yield and milk composition in dairy goats. Animal, 15 (1): 1. https://doi.org/10.1016/j.animal.2020.100015

Nørskov NP, Battelli M, Curtasu MV, Olijhoek DW, Chassé E, Nielsen MO (2023). Methane reduction by quercetin, tannic and salicylic acids: influence of molecular structures on methane formation and fermentation in vitro. Sci. Rep., 13 (1): 1 – 11. https://doi.org/10.1038/s41598-023-43041-w

Omemen, K.M. and Mona, O.A. 2025. Climate Change: Key Contributors and Sustainable Solutions. Int. J. Electr. Eng. And Sustain., 3(1), 10–27. Retrieved from https://ijees.org/index.php/ijees/article/view/105

Prasetyo EN, Rokana E, Baihaqi ZA, Samudi S (2024). Anthelmintic effects of Podang mango (Mangifera indica) fruit peel waste extract through in vivo application on Indonesian Etawa goat production and health, Vet. World, 17(6): 1291-1298. https://doi.org/10.14202/vetworld.2024.1291-1298

Prayudi SKA, Effendi MH, Lukiswanto BS, Az Zah-Ra RL, Benjamin MI, Kurniawan SC, Khairullah AR, Silaen OSM, Lisnanti EF, Baihaqi ZA, Widodo A, Riwu KHP (2023). Detection of genes on escherichia coli producing extended spectrum β-lactamase isolated from the small intestine of ducks in traditional markets Surabaya City, Indonesia. J. Adv. Vet. Res., 13(8): 1600-1608.

Richardson D, Kath J, Byrareddy VM, Monselesan DP, Risbey JS, Squire DT (2023). Synchronous climate hazards pose an increasing challenge to global coffee production. PLOS Clim 2(3): e0000134. https://doi.org/10.1371/journal.pclm.0000134

Rokana E, Fatimah IR, Dianingtyas BD, Hasanah N, Wulandari, Baihaqi ZA (2024). Impact of various fiber sources in ration formulas on feedlot performance of sheep in Indonesia. J. Anim. Health Prod., 12(3): 325-330. https://doi.org/10.17582/journal.jahp/2024/12.3.325.330

Rira M, Diego PM, Lucette G, Sihem D, Ines S, Michel D (2019). Methanogenic potential of tropical feeds rich in hydrolyzable tannins. J. Anim. Sci., 97: 2700–2710. https://doi.org/10.1093/jas/skz199

Sakti AA, Baihaqi ZA, Suwignyo B, Sofyan A, Herdian H, Kustantinah (2024). Anthelmintic activity of red macroalgae Acrocystis sp. and Acanthophora sp. etanolic extract against *Haemonchus contortus* in sheep in vitro. IOP Conf. Ser. Earth Environ. Sci., 1360-012004. https://doi.org/10.1088/1755-1315/1360/1/012004

Sari KRP, Ikawati Z, Danarti R, Hertiani T (2023). Micro-titer plate assay for measurement of total phenolic and total flavonoid contents in medicinal plant extracts. Arabian J. Chem., 16 (9): 1. https://doi.org/10.1016/j.arabjc.2023.105003

Singh B, Bandopadhyay S, Kapil R, Singh R, Katare OP (2009). Self-emulsifying drug delivery systems (sedds): formulation deveploment, characterization, and applications. Crit. Rev. Ther. Drug Carrier Syst., 26(5): 427-521. https://doi.org/10.1615/CritRevTherDrugCarrierSyst.v26.i5.10

Suwignyo B, Baihaqi ZA, Utomo R, Sarmin, Widiyono I (2017). Effects of different feed restrictions on kacang goats. Pak. J. Nutr., 16: 236-41. https://doi.org/10.3923/pjn.2017.236.241

Terefe G, Mulugeta E (2024). CABI, Assessing the impact of climate action mitigation strategies from livestock production: A review – Solution for greenhouse gases mitigation, CABI Reviews, https://doi.org/10.1079/cabireviews.2024.0013

Terefe,G. and Mulugeta, W. 2024. Assessing the impact of climate action mitigation strategies from livestock production: A review – Solution for greenhouse gases mitigation. CABI Reviews, doi:10.1079/cabireviews.2024.0013

Theodorou MK, Williams BA, Dhanoa MS, McAllan AB, 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

Zhao S, Wu L, Xiang Y, Zhang F (2024). Forecasting short-term methane based on corrected numerical weather prediction outputs. J. Cleaner Prod., 460: https://doi.org/10.1016/j.jclepro.2024.142500