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Mitigation of Carbon Emissions and Enhancement of Lactational and Physiological Indices in West African Dwarf Does Using *Daniella oliveri* Essential Oil-Based Diets

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Abstract

This study evaluated the effects of *Daniella oliveri* essential oil (DOE) supplementation on enteric methane production, milk yield, immune response, and oxidative stress indicators in lactating West African Dwarf (WAD) does. Twenty-one does with comparable initial body weights (10.55 ± 0.60 kg) were randomly allotted to three dietary treatment groups (n = 7) using a completely randomized design over a 50-day feeding period. Dietary supplementation with DOE significantly improved ($P < 0.05$) milk yield, serum immunoglobulins (IgG, IgA, and IgM), triiodothyronine (T3), and superoxide dismutase (SOD) activity, with the highest responses observed in does fed the highest DOE inclusion level (T3). Antioxidant status was also enhanced, as evidenced by significant increases ($P < 0.05$) in catalase, glutathione peroxidase, glutathione reductase, and total antioxidant capacity in the T2 and T3 groups. Conversely, enteric methane emissions, malondialdehyde (MDA), and cortisol concentrations were significantly reduced in DOE-supplemented animals relative to the control group ($P < 0.05$). The results indicate that DOE supplementation enhances lactational performance, strengthens immune function, and improves oxidative stability while concurrently reducing methane emissions, demonstrating its potential as a climate-smart nutritional strategy for sustainable dairy goat production. Based on the observed responses, supplementation at 10 ml DOE/kg diet was considered the optimal inclusion level for improving productivity and physiological wellbeing in WAD does.

Keywords: *Small ruminants, dairy goats, tropical phytogenic, climate smart agriculture, methane, immune status.*

Introduction

Over the last decade, the application of essential oils (EOs), which are aromatic plant-derived extracts, has increased considerably in animal health and production systems (Anaso et al., 2021a,b; 2025c; Anaso and Olafadehan, 2025; Elazab et al., 2025). These oils contain biologically active compounds, particularly polyphenolics, which have been reported to modulate ruminal fermentation and enhance nutrient utilization in ruminants (Kholif et al., 2018; Anaso et al., 2025a-g). Studies investigating the effects of EOs on milk production in dairy cattle have produced variable outcomes, ranging from a 6.7% reduction to a 5% improvement compared with control diets (Patra, 2011). Positive effects including increased energy-corrected milk yield and feed efficiency (Kholif et al., 2018; Elcoso et al., 2019), improved milk yield and composition (Matloup et al., 2017; Kholif et al., 2018; 2021), as well as marginal responses (Blanch et al., 2016), have been documented. These observations suggest that terpenes and other antioxidant constituents transferred into milk may improve its oxidative stability. In addition, EO supplementation has been associated with elevated concentrations of unsaturated fatty acids (UFAs) and conjugated linoleic acid (CLA) isomers in milk (Kholif and Olafadehan, 2021; Anaso and Chibuogwu, 2026), thereby enhancing the nutritional quality of milk for both animals and consumers.

Essential oils have further been shown to influence ruminal starch and protein degradation, ammonia production, volatile fatty acid (VFA) synthesis, and methane (CH_4) emissions through their antimicrobial activities against methanogenic archaea and hyper-ammonia-producing bacteria (Kholif and Olafadehan, 2021; Anaso and Ajogi, 2026). However, these beneficial effects may sometimes be accompanied by reduced fiber degradability (Patra and Yu, 2012).

Recent studies have identified essential oils as promising natural alternatives to synthetic growth promoters in livestock production (Anaso et al., 2024a-d). Daniella oliveri, a multipurpose medicinal tree commonly found in the savannah regions of West Africa, has attracted increasing scientific interest because of its rich phytochemical composition and therapeutic potential. The essential oil derived from D. oliveri contains numerous bioactive compounds with antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory properties (Anaso and Alagbe, 2025a-c; Anaso, 2026a,b). Previous phytochemical analyses have revealed that the oil is rich in terpenoids and other secondary metabolites capable of exerting beneficial physiological effects in animals (Anaso et al., 2024c). Compounds such as limonene, β-pinene, γ-terpineol, camphene, and related monoterpenes contribute to the oil's antioxidant and aromatic properties, while also exhibiting antimicrobial and health-promoting activities (Anaso et al., 2024a,d). Nevertheless, excessive concentrations of certain phytoconstituents may pose toxicological

risks, thereby necessitating proper dosage evaluation before inclusion in animal diets (SCLabs, 2016; Anaso et al., 2023).

In response to the increasing global concern over antimicrobial resistance and restrictions on the use of antibiotics in livestock production, attention has shifted toward the development of effective phytogenic feed additives (Anaso, 2023a,b). Although the beneficial effects of several plant essential oils on animal productivity and health have been documented, information regarding the influence of Daniella oliveri essential oil (DOE) on lactational performance, oxidative stress biomarkers, immunological responses, and enteric methane emissions in dairy goats remains limited. Therefore, this study was designed to evaluate carbon emissions, lactational performance, oxidative stress indices, and immunological parameters in West African Dwarf does fed diets supplemented with Daniella oliveri essential oil.

Materials and Methods

Collection of Daniella oliveri Seeds and Extraction of Essential Oil

Seeds of Daniella oliveri were collected from the Federal Capital Territory, located within the southern Guinea savannah agro-ecological zone of Nigeria. The harvested seeds were air-dried under shade to preserve their phytochemical constituents and bioactive properties. After adequate drying, the seeds were milled into a fine powder and stored at room temperature prior to essential oil extraction (Anaso, 2025a,b).

For the extraction procedure, 100 g of the powdered seed sample was subjected to steam distillation. The powdered material was mixed with 700 mL of distilled water and heated at 100 °C for 3 h using a stainless-steel distillation apparatus equipped with a condenser. This process enabled the volatilization of the essential oil, which was subsequently condensed into liquid form. The resulting essential oil was collected as droplets using a Clevenger-type apparatus according to the procedures described by Anaso (2023b) and Anaso and Alagbe (2025).

Experimental site

The experimental trial was carried out at the Co-farms Green Aid Revolution and Morugo Farms experimental station, geographically positioned between latitudes 08°51' and 09°37' North and longitudes 07°20' and 07°51' East. This location experiences an annual rainfall range between 1,145 mm and 1,631 mm. Seasonal temperature patterns show that during the wet season, ambient temperatures fluctuate between 25.8°C and 30.2°C, while in the dry season, temperatures soar to between 36°C and 42°C (Anaso et al., 2024b). Relative humidity, as reported by Anaso (2025b), averages approximately 60% during the rainy season and drops to about 30% in the dry season (Anaso and Alhassan, 2025).

Experimental animals, management and diets

Twenty-one clinically healthy West African Dwarf (WAD) does with similar initial body weights (28.73 ± 0.40 kg) were randomly assigned to three dietary treatment groups, with seven animals per treatment, using a completely randomized design. The animals were housed individually in standard pens measuring 1.9 m^2 within a larger corral structure measuring 10 × 15 × 8 m. Prior to the commencement of the experiment, the housing facility was thoroughly disinfected to maintain optimal sanitary and biosecurity conditions.

The feeding trial lasted for 84 days and was conducted in accordance with the nutritional recommendations of the National Research Council (NRC, 2007) for growing sheep. The composition of the experimental diets is presented in Table 1. Feed was offered at 5% of the animals' body weight on a dry matter basis, with weekly adjustments made according to changes in body weight. Feed intake was carefully monitored to ensure accuracy and minimize wastage. Animals were fed twice daily at 8:00 a.m. and 4:00 p.m., and clean drinking water was provided ad libitum throughout the study.

The does were randomly allotted to one of three dietary treatments. Group T1 served as the control and received the basal diet without supplementation, whereas Groups T2 and T3 received diets supplemented with Daniella oliveri essential oil (DEO) at inclusion levels of 5 mL/kg and 10 mL/kg feed, respectively.

Milk yield

Goats were machine milked twice daily at 07:00, and 16:00 h. Milk yield for individual does was recorded daily.

Immune function was assessed by quantifying immunoglobulin classes (IgA, IgG, and IgM), also using Stanbio-specific kits per Elghalid et al. (2020).

Oxidative stress markers evaluated included triiodothyronine (T3), total antioxidant capacity (TAC), and the enzymatic activities of malondialdehyde (MDA), superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR), and cortisol. These were likewise analyzed using the aforementioned commercial kits and standardized methodologies.

Methane production was calculated by the equation of Wolin (1960): CH4 = (acetic + (2 × propionic)) - fermentative CO2; where fermentative CO2 = (acetic/2) + (propionic/4) + (1.5 × butyric).

Results and Discussion

Table 1 presents the effects of Daniella oliveri essential oil supplementation on milk yield, enteric methane emissions, immunological parameters, and oxidative stress indices in West African Dwarf does. Supplementation with Daniella oliveri essential oil (DEO) significantly increased ($P < 0.05$) milk yield, serum concentrations of immunoglobulins G, A, and M, triiodothyronine (T3), and superoxide dismutase (SOD), with the highest values observed in does fed the highest DEO inclusion level (T3). Antioxidant defense capacity, as evidenced by elevated activities of catalase, glutathione peroxidase, glutathione reductase, and total antioxidant capacity, was significantly improved in the T2 and T3 groups ($P < 0.05$). Conversely, enteric methane emissions, malondialdehyde (MDA), and cortisol concentrations were significantly reduced in DEO-supplemented groups relative to the control ($P < 0.05$).

Milk yield progressively increased across the treatment groups. Essential oils are known to influence milk production in ruminants, although their effects largely depend on the type, dosage, and chemical composition of the oil used (Kholif and Olafadehan, 2021). The observed improvement in milk yield may be attributed to enhanced feed utilization, increased nutrient availability, and improved energy efficiency, as well as the selective inhibition of pathogenic microorganisms while promoting beneficial rumen microbes, thereby optimizing ruminal fermentation (Kholif et al., 2018; Anaso et al., 2025b; Anaso and Alagbe, 2025c).

The calculated methane (CH_4) values indicated that DEO supplementation reduced enteric methane production. Essential oils exert varying effects on methanogenesis depending on their phytochemical composition. They may directly suppress methanogenic archaea and/or indirectly decrease methane production by inhibiting microbial metabolic pathways associated with methanogenesis (Beauchemin and McGinn, 2006; Kholif and Olafadehan, 2021; Anaso et al., 2025b). In addition, EOs may alter the structure of archaeal communities and interfere with methanogenic activity, ultimately lowering methanogen abundance and methane output (Ohene-Adjei et al., 2008). Similarly, Wang et al. (2009) reported that supplementation of sheep diets with oregano-derived essential oil reduced methane production.

Immunoglobulins, particularly IgG, IgM, and IgA, are major components of the adaptive immune system and function as the first line of humoral defense by neutralizing toxins, binding pathogens, and preventing microbial attachment to mucosal surfaces (Anaso et al., 2025a; Anaso, 2025). The elevated concentrations of these immunoglobulins in the DEO-supplemented groups (T2 and T3) indicate enhanced immune responsiveness, likely due to the antioxidative and immunomodulatory bioactive compounds present in the essential oil. These findings corroborate the observations of Anaso et al. (2025d), who reported improved immunoglobulin profiles following dietary supplementation with essential oils.

Triiodothyronine (T3), an important thyroid hormone involved in metabolic regulation, growth, development, and thermoregulation, was also significantly increased in DEO-supplemented does, suggesting improved metabolic activity and physiological efficiency (Anaso et al., 2025a).

Malondialdehyde (MDA), a widely recognized biomarker of lipid peroxidation and cellular membrane damage, was significantly reduced in T2 and T3, indicating lower oxidative stress levels in these groups. This reduction may be attributed to the free radical scavenging activities of phenolic compounds present in DEO. These phytochemicals, including ketone derivatives, catechins, and volatile oils, have been reported to inhibit oxidative damage through the neutralization of superoxide and hydroxyl radicals (Anaso et al., 2025a; Anaso et al., 2025d).

The antioxidative effects observed may further be linked to the bioactive constituents of DEO, including limonene, α-pinene, β-caryophyllene, oleic acid, heptadecanoic acid, and related monoterpenes and sesquiterpenes, which possess antimicrobial, anti-inflammatory, and antioxidant activities. These compounds may also contribute to the reduction in cortisol concentration, a stress-related hormone released during physiological stress and hypoglycemia, thereby reflecting improved physiological stability in DEO-fed does (Anaso, 2023a; 2023b).

Superoxide dismutase (SOD), an essential antioxidant enzyme responsible for converting toxic superoxide radicals into hydrogen peroxide and molecular oxygen, was significantly elevated in T2 and T3. This increase suggests an enhanced antioxidant defense system and is consistent with earlier reports by Anaso et al. (2025a,b), who documented improved antioxidant enzyme activities following dietary supplementation with herbal and essential oil additives. However, the optimal activity of SOD depends largely on adequate micronutrient availability in the diet (Anaso et al., 2025d).

Glutathione-related activities, measured through glutathione peroxidase (GPx) and glutathione reductase (GR), were also significantly increased in the treatment groups, indicating enhanced intracellular protection against reactive oxygen species (ROS). Glutathione plays a crucial role in maintaining cellular integrity by preventing oxidative damage to lipids, proteins, and nucleic acids, while also stabilizing apolipoprotein B (Anaso et al., 2025a). The increased glutathione activity observed in T2 and T3 therefore suggests that DEO supplementation improved redox balance and strengthened cellular antioxidant defenses.

Furthermore, the bioactive phytochemicals present in DEO may function as natural acetylcholinesterase inhibitors, thereby preserving acetylcholine required for smooth muscle contractions, including gastrointestinal motility. This mechanism may contribute to enhanced digestion and nutrient absorption efficiency (Anaso et al., 2025a).

Activities of antioxidant enzymes such as catalase, glutathione peroxidase, and glutathione reductase were significantly enhanced in the DEO-supplemented groups. These enzymes are essential in detoxifying hydrogen peroxide and other reactive oxygen species by catalyzing their conversion into water and oxygen, thereby protecting tissues against oxidative injury and maintaining cellular homeostasis (Anaso et al., 2025a).

Table 1: Effects of Daniella oliveri Essential Oil Supplementation on Milk Yield, Methane Emissions, Immunological Responses, and Oxidative Stress Indices in West African Dwarf Does

Parameter	***T1***	***T2***	***T3***	***SEM***
Milk yield (g/day)	226^{c}	291^{b}	378^{a}	30.03
Methane emission	6.55^{a}	2.28^{b}	2.21^{b}	0.16
Immunoglobulin G (mg/100 mL)	4998.22^{c}	6740.82^{b}	6857.27^{a}	101.50
Immunoglobulin A (mg/mL)	0.30^{c}	0.38^{b}	0.54^{a}	0.06
Immunoglobulin M (mg/mL)	3.72^{c}	5.09^{b}	5.63^{a}	0.69
Triiodothyronine (nmol/L)	1.99^{c}	6.09^{b}	6.63^{a}	0.99
Malondialdehyde (nmol/L)	0.82^{a}	0.38^{b}	0.36^{b}	0.08
Superoxide dismutase (nmol/mL)	787.55^{c}	979.51^{b}	1063.91^{a}	13.07
Catalase (U/gHb)	2860.47^{b}	3090.82^{a}	3206.66^{a}	21.85
Glutathione peroxidase (U/gHb)	283.60^{b}	301.01^{a}	305.01^{a}	3.59
Cortisol (ng/mL)	18.71^{a}	9.56^{b}	9.08^{b}	0.20
Total antioxidant capacity (nmol)	1.04^{b}	1.52^{a}	1.62^{a}	0.04
Glutathione reductase (IU/10^{11} RBC)	2.38^{b}	3.08^{a}	3.27^{a}	0.60

Conclusion

The results indicate that dietary supplementation with Daniella oliveri essential oil (DEO) enhances lactational performance, strengthens immune function, and improves oxidative stability in West African Dwarf does, while concurrently reducing enteric methane emissions. Collectively, these responses underscore its potential as a climate-smart feed additive for improving productivity and environmental sustainability in dairy goat production systems. Based on the observed physiological and productive responses, a supplementation level of 10 mL DEO/kg diet was identified as the most effective dose for optimizing performance and health status in WAD does.

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