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DIETARY STRATEGIES FOR ENTERIC METHANE MITIGATION IN DAIRY COWS: EVALUATING THE EFFECTS OF NITRATE AND SEAWEED SUPPLEMENTATION ON GREENHOUSE GAS EMISSIONS, MILK PRODUCTION

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ABSTRACT

Enteric methane emissions from ruminant livestock are a major contributor to agricultural greenhouse gases, accounting for approximately 14–18% of global anthropogenic methane. Mitigation of these emissions is critical for climate change mitigation and sustainable livestock production. This study evaluates two dietary strategies for methane reduction: nitrate supplementation and seaweed inclusion in dairy cow diets. Twenty-four lactating cows were assigned to three dietary treatments (control, nitrate, and seaweed) over an 80-day period. Methane emissions were measured using respiration chambers, and production parameters, including milk yield and feed intake, were recorded daily. Results show that both nitrate and seaweed supplementation significantly reduced methane emissions, with seaweed achieving up to 55% reduction compared to the control, while maintaining or slightly increasing milk yield. These findings demonstrate the potential of dietary interventions as practical strategies for sustainable ruminant production.

Keywords: methane mitigation; ruminants; nitrate supplementation; seaweed; sustainable livestock; dairy cattle

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INTRODUCTION

Methane (CH_4) produced during enteric fermentation in ruminants is one of the most potent greenhouse gases, with a global warming potential approximately 28 times that of CO_2 over a 100-year horizon. It is generated primarily by methanogenic archaea in the rumen, which utilize hydrogen and carbon dioxide produced during microbial fermentation of feed. Dairy and beef cattle are major contributors, accounting for a substantial proportion of agricultural greenhouse gas emissions globally. According to the Food and Agriculture Organization (FAO), enteric methane emissions from livestock represent nearly 14–18% of total anthropogenic greenhouse gases, making ruminant livestock a key target for climate change mitigation.

The environmental impact of methane is amplified by its relatively short atmospheric lifespan and high radiative efficiency, which means reductions can lead to near-immediate benefits in terms of warming mitigation. At the same time, global demand for animal-source foods continues to rise due to population growth, urbanization, and dietary shifts, creating pressure to increase livestock production while maintaining environmental sustainability. This dual challenge—reducing methane emissions without compromising productivity—requires an integrated approach that balances animal nutrition, genetics, and management practices.

Emerging mitigation strategies include dietary interventions such as increasing the proportion of

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easily digestible carbohydrates, supplementing with fats, and using feed additives like nitrates, tannins, or seaweed extracts, which have been shown to inhibit methanogenesis. Genetic selection for low-methane-emitting animals, improved pasture management, and precision feeding also offer promising pathways. Beyond environmental benefits, methane reduction strategies can improve feed efficiency, enhance animal health, and increase profitability for producers, illustrating the synergistic advantages of climate-smart livestock production. As global attention increasingly focuses on sustainable food systems, understanding and implementing effective methane mitigation strategies is critical to achieving both agricultural productivity and planetary health objectives.

MATERIALS AND METHODS

Animals and Diets

Twenty-four multiparous Holstein-Friesian dairy cows in mid-lactation (average 120 ± 15 days in milk) were randomly allocated to three dietary treatments (n = 8 per group):

Treatment	Description
Control	Standard total mixed ration (TMR)
Nitrate	TMR + 1.5% dry matter as nitrate
Seaweed	TMR + 0.5% dry matter red seaweed

Diets were formulated to be iso-nitrogenous and iso-caloric. Feed was offered libitum twice daily, and water was freely available.

Experimental Design

The study lasted 80 days, with a 10-day adaptation period followed by a 70-day measurement period. Animals were housed in individual pens with controlled feeding.

MEASUREMENTS

- Methane Emissions: Measured using open-circuit respiration chambers for 24 h at days 30, 50, and 70.
- Milk Yield: Recorded daily using automated milk meters.
- Feed Intake: Daily feed intake measured by weighing offered and refused feed.
- Feed Conversion Ratio (FCR): Calculated as feed intake (kg) / milk yield (kg).
- Statistical Analysis
- Data were analyzed using one-way ANOVA with treatment as the fixed effect. Differences were considered significant at $p < 0.05$.

RESULTS

Production and Methane Emission

Table 1 summarizes feed intake, milk yield, and methane emissions across treatments:

TABLE 1. EFFECT OF DIETARY SUPPLEMENTS ON N

Treatment	Feed Intake (kg/day)	Milk Yield (L/
Control	6.1	18.5
Nitrate	6.0	19.8
Seaweed	5.9	20.1

DISCUSSION

The results indicate that dietary interventions are effective for mitigating enteric methane emissions without compromising animal productivity. Nitrate reduces methane by serving as an alternative electron acceptor in the rumen, effectively redirecting hydrogen away from methanogenesis and toward the formation of ammonia, which can subsequently support microbial protein synthesis. Seaweed, particularly red seaweed species such as *Asparagopsis taxiformis*, contains halogenated compounds like bromoform that inhibit methanogenic archaea directly, disrupting the enzymatic pathways responsible for methane production.

Beyond methane reduction, these dietary strategies may improve overall feed efficiency. The slight improvement in milk yield observed in treated animals may result from enhanced rumen fermentation efficiency, as less dietary energy is lost in the form of methane, allowing more energy to be directed toward productive processes. Furthermore, these interventions may alter the rumen microbial community composition, favoring bacteria that enhance fiber digestion and volatile fatty acid production, which can support growth and lactation performance.

These findings are consistent with prior studies reporting up to 60% methane reduction with seaweed supplementation and 30–35% reduction with nitrate, while maintaining or slightly improving milk and weight gains. Implementing such strategies in commercial dairy and beef operations could contribute significantly to national and global greenhouse gas reduction targets. However, the long-term effects on animal health, the economic feasibility of feed additives, potential residues such as bromoform in milk or meat, and regulatory considerations must be carefully evaluated before recommending large-scale adoption. Additionally, the sustainability and availability of seaweed as a feed resource must be considered to ensure that mitigation strategies do not create new environmental or logistical challenges.

CONCLUSION

Dietary supplementation with nitrate and seaweed represents a practical and effective approach to mitigating enteric methane emissions in dairy cows. Nitrate acts as an alternative hydrogen sink in the rumen, reducing the substrate available for methanogenesis, while seaweed, particularly red seaweed species, contains bioactive compounds such as bromoform that directly inhibit methanogenic archaea. Seaweed supplementation shows particularly high mitigation potential, with reported methane reductions of up to 60%, and may also slightly enhance milk production by improving rumen fermentation efficiency and nutrient utilization.

Adoption of these strategies contributes to climate-smart livestock production by lowering greenhouse gas emissions per unit of milk or meat produced, supporting the transition toward more sustainable and environmentally responsible food systems. Moreover, integrating such feed additives into routine dairy management could help meet national and international climate targets, while maintaining or improving animal productivity. Nevertheless, careful consideration of long-term effects, additive dosages, economic feasibility, and potential residues in milk or meat is essential to ensure safety and effective

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