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Greenhouse Gas Emission Reduction Potential of Lavender Meal and Essential Oil for Dairy Cows

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Abstract: This research aims to evaluate the potential of lavender meal (LM) and lavender essential oil (LEO) to mitigate methane emissions by dairy cows. Locally grown lavender was collected fresh for this purpose, and its oil was extracted using the cold-press method. The resultant LEO and LM and whole lavender (WL) were added to dairy cow concentrate feed at 0%, 0.05%, and 0.10%, and their effects on vitro gas production values and gas concentrations were subsequently assessed. Out of the 30 bioactive compounds isolated from LEO, linalool and linalyl acetate were the most common—accounting for 70.4% of the total. The lavender dose had a significant influence on gas production for up to 12 h. No significant variations were found across the lavender forms when gas kinetics, in vitro degradability, and predicted energy values were compared. The addition of WL to the concentrate feed of dairy cows produced the greatest quantities of methane, carbon dioxide, and hydrogen sulfide, whereas LEO resulted in the lowest values. In contrast, no significant difference in ammonia content was found across the various lavender forms added into dairy cow concentrate feed. The results of this research suggest that adding 0.05–0.10% LM and LEO to concentrate feed may decrease greenhouse gas emissions from dairy cows.

Keywords: lavender; byproduct; essential oil; methane; dairy cow; gas production

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1. Introduction

A substantial amount of greenhouse gas (GHG) emissions, such as methane (CH_4) and nitrous oxide, come from livestock production—making it one of the main drivers of climatic change in the Anthropocene period [1,2]. Livestock production is responsible for around 13% of the world's GHG emissions [3]. CH_4 emissions, in particular, are significant contributors due to the fact that their potential to trigger global warming is 28 times more than that of carbon dioxide (CO_2) [3]. CH_4 production results in a loss of energy availability for the host ruminant animal, which typically accounts for between 2% and 12% of the overall energy availability [4]. As a result of ruminants' inability to convert this carbon into usable energy, the production of CH_4 has a negative impact on both the environment and the productivity and profitability of ruminant farming [5]. It is clear, therefore, that feasible methods of minimizing enteric CH_4 make livestock husbandry an important player in addressing climate change mitigation.

Selecting high-feed-efficiency animals, decreasing the forage-to-concentrate ratio in the diet, supplementing with nitrate and fat, and introducing feed additives are all effective

ways to lower enteric CH_4 emissions. Essential oils (EOs) are one of the most common feed additives that are incorporated into the diet, along with ionophores [6], saponins [7], tannins [8], and flavonoids [9]. Fragrant plants, such as lavender, rosemary, rose, peppermint, and cypress, generate EOs to deter herbivorous insects and dangerous microorganisms and/or serve as signaling molecules [10]. EOs are known to have secondary metabolites that are both volatile and lipophilic, and their method of action in reducing CH_4 emissions has been the subject of several hypotheses. For example, it is believed that EOs may affect microbial activity by accumulating in the lipid bilayer and the cytoplasm [11]. Furthermore, it has been hypothesized that EOs raise propionate levels, hence reducing the amount of H_2 available to produce CH_4 [12].

Lavender, which belongs to the Lavandula genus (*Lamiaceae* family), is one of the most valued medicinal and fragrant plants of economic relevance, and it is produced for industrial uses [13]. Lavender EO (*Lavandula angustifolia* Mill., LEO) production is between 300 and 500 tons per year [13], whereas total EO production from all lavender species and hybrids is over 1500 tons per year [14]. Low efficiency, around 1% in mass, is produced by conventional and industrial ways of processing medicinal and fragrant plants, leading to massive quantities of solid and liquid waste [15]. Thus, natural waste valorization becomes inevitable if we are to lessen the impact on GHG emissions. Food-feed competitiveness issues, environmental ramifications, and the need for safer animal products may all be addressed by switching to alternatives that have been bioactively improved in place of traditional feed resources, as proven in previous research [16,17].

LEO contains 1,8-cineole, camphor, borneol, linalool, and linalyl acetate, which provide it with its potent antioxidant and antibacterial properties [18]. As mentioned earlier, LEO extracted from flowers is preferable for use in the formulation of cosmetics and other personal care products. This is due to the fact that linalyl acetate, which is present in the flower extract and contributes to the extract's signature aroma, is present in the flower extract [19]. However, the LEO extracted from the leaves and stems is superior for medicinal and insecticidal applications because of its greater 1,8-cineole and camphor content [19]. Lavandulol, eucalyptol, and geraniol are among the additional antibacterial and antifungal compounds isolated in LEO [20].

Although there have been limited evaluations of LEO's impact on CH_4 production [21,22], to the best of our knowledge, there has been no research investigating the effect of different amounts of lavender waste utilized during LEO extraction on CH_4 production in dairy cows in vitro. Therefore, the current study tested the hypothesis that different lavender forms would have different effects on CH_4 reduction due to the variation in bioactive components and the high antioxidant and antibacterial properties previously shown to be present in EOs obtained from the different parts of lavender (flower, leaf, stem). Thus, the objective of this study was to explore the effects of additional different lavender forms (whole lavender (WL), lavender meal (LM), and LEO) and doses (0, 0.05% and 0.010%) on the in vitro gas production and CH_4 ratio of dairy cows.

2. Materials and Methods

2.1. Chemical Composition of Diets

AOAC [23] methods were used to perform the proximate analysis of the dairy cow concentrate feed, whole lavender, and defatted lavender meal used during these in vitro studies. Briefly, the dry matter (DM) and ash content of the samples were determined by drying them at 102 °C overnight and ashing them in a muffle furnace for three hours at 550 °C. The crude protein (CP) ratio was calculated by multiplying the nitrogen content of samples by 6.25. Analyses of neutral detergent fibers (NDF) and acid detergent fibers (ADF) were conducted using a method described by Van Soest et al. [24]. Using the methodology of the ISO 10520 standard [25], the amount of starch in the samples was determined. The results of the chemical analyses of dairy cow concentrate feed are listed in Table 1.

Table 1. Chemical composition of dairy cow concentrate feed.

Item	g/kg (Dry Matter Basis)
Dry matter (g/kg fresh matter basis)	898.7
Crude protein	203.8
Ash	74.0
Ether extract	31.3
Acid detergent fiber	105.3
Neutral detergent fiber	254.3
Starch	260.3

2.2. Extraction and Characterization of Lavender Essential Oil

The current study utilized the cold-press method to extract oil from freshly harvested lavender, as 99.9% of all industrial and commercial essential oils are cold-pressed [26]. Locally cultivated lavender (*Lavandula angustifolia* Mill.) was freshly gathered from Tekirdag, Turkey (41.0° N, 27.5° E; located 5 m above sea level, with an annual mean temperature of 10.5 °C, and a total precipitation of 482 mm per year). Volatile compounds in the LEOs were characterized using a headspace solid-phase microextraction and gas chromatography/mass spectrometry (HS-SPME and GC/MS) approach, as detailed in earlier papers by Riu-Aumatell et al. [27]. Extraction was carried out using an SPME instrument (Supelco, Bellefonte, PA, USA) outfitted with a 10 mm fiber covered with 100 µm polydimethylsiloxane. A 5 mL sample of LEO was transferred to a 10 mL vial and extracted in headspace mode (a distance of 20 mm from the liquid surface) at 50 °C for 40 min with magnetic stirring. After extraction, the SPME apparatus was inserted into a gas chromatograph (Shimadzu GCMS-QP2010, Kyoto, Japan), maintained at 250 °C for 5 min, and equipped with a flame ionization detector. RTX-5 fused silica capillary columns were employed (Restek, Bellefonte, PA, USA; 30 m, id: 0.25 mm, ft: 0.25 µm). As the carrier gas, helium was used. The injector and detector had temperatures of 250 °C and 280 °C, respectively. In splitless injection mode, the temperature program ranged from 40 °C (held for 5 min) to 240 °C (held for 10 min) at a rate of 4 °C/min.

2.3. In Vitro Gas Production and Fermentation Characteristics

For each experimental group, about 1 kg of dairy cow concentrate feed was crushed and homogenized with 0, 0.05%, and 0.10% WL, LM, and LEO, respectively. The in vitro incubation of samples was performed with calibrated 100 mL glass syringes in triplicate in a 39 °C water bath for 48 h. The research did not use any animals directly; rather, 3 freshly slaughtered 2-year-old Holstein cattle were used in the extraction of rumen liquor. That liquor was pooled and subsequently filtered through four layers of cheesecloth. It was captured in a vessel pre-warmed to 39 °C and taken to the laboratory within 20 min. On each occasion, approximately 200 mg of dry samples were incubated in six replicates in glass syringes. Using pre-warmed glass syringes at 39 °C, 30 mL of rumen liquor-buffer mixture free of particles was injected under continuous injection of CO_2 as described by Menke and Steingass [28]. The total gas volume of each sample was determined at 3, 6, 12, 24, and 48 h, and the volume was corrected using blank bottles and alfalfa hay standard samples. The contents of CH_4, carbon dioxide (CO_2), ammonia (NH_3), and hydrogen sulfide (H_2S) were determined using a CH_4 analyzer (MX6 iBrid, Industrial Scientific Corporation, Pittsburgh, PA, USA) according to the protocol described by Goel et al. [29] after 24 h of incubation.

The cumulative gas production of samples was fitted to an exponential model proposed by Ørskov and McDonald (1979), by utilizing the Solver function in Excel (Equation (1)) [30].

$$Y = a + b(1 - e^{-ct}) \quad (1)$$

It is indicated in Equation (1) that Y is the volume (mL) of gas produced at time t; a is the volume (mL) of gas produced from the instantly soluble fraction of samples; b is the

volume of gas produced from the insoluble fraction of samples; c is the gas production rate constant (mL/h); and t is the time of incubation (h).

In order to calculate the metabolizable energy content (ME, (MJ/kg DM)), organic matter digestibility (OMD, (% DM)), and net energy lactation (NEL, (MJ/kg DM)) of samples, the following Equations (2) and (3) of Menke et al. [31] and Menke and Steingass [28] were used, respectively.

$$\text{ME (MJ/kgDM)} = 2.20 + 0.136\ \text{GP} + 0.057\ \text{CP} \quad (2)$$

$$\text{OMD (\% DM)} = 14.88 + 0.889\ \text{GP} + 0.45\ \text{CP} + 0.0651\ \text{Ash} \quad (3)$$

$$\text{NEL (MJ/kgDM)} = 0.101\ \text{GP} + 0.051\ \text{CP} + 0.112\ \text{EE} \quad (4)$$

In Equations (2)–(4), DM represents dry matter; GP is the net production of gas over a 24-h period (mL/200 mg); CP and EE are crude protein and ether extract, respectively, expressed in g/kg DM.

2.4. Statistical Analysis

This study utilized SAS-JMP software version 13.2 (SAS Institute Inc., Cary, NC, USA) to create a 3 × 3 factorial arrangement with the MIXED procedure, taking lavender form (WL, LM, LEO) and dosage (0%, 0.05%, and 0.10%) as the fixed effects, and experimental error as the random effect. The means were compared using Duncan's multiple range test, at the level of $p < 0.05$, which is considered to be a statistically significant difference.

3. Results

Table 2 provides a summary of the bioactive compounds identified by the HS-SPME and GC-MS approach in the LEO. Of the 30 compounds identified from LEO, the two most abundant were linalool (38.3%) and linalyl acetate (32.1%), together accounting for 70.4% of the total. The other most prevalent compounds in LEO were 4-terpinyl acetate (5.20%), neryl acetate (4.82%), β-farnesene (4.47%), caryophyllene (3.77%), and ocimene (2.21%), which together accounted for 20.47%.

Table 2. Percentage of volatile components isolated from lavender essential oils.

Number	R. Time	Area	Area%	Compounds
1	13.685	101,576	0.15	DL-Limonene
2	13.742	212,507	0.32	1,8-Cineole
3	13.900	57,827	0.09	Geranyl tiglate
4	14.342	1,085,072	1.61	α-Pinene
5	14.600	54,210	0.08	Farnesene
6	14.931	1,487,834	2.21	Ocimene
7	17.663	25,783,120	38.30	Linalool
8	18.338	525,190	0.78	Octenyl acetate
9	18.925	103,882	0.15	3-Octyl acetate
10	19.136	830,531	1.24	Alloocimene
11	19.619	236,533	0.35	Camphor
12	20.723	339,739	0.51	Borneol
13	20.920	591,330	0.88	Lavandulol
14	21.269	3,496,970	5.20	4-Terpinyl acetate
15	21.899	506,098	0.75	Linalyl propionate
16	24.722	21,628,616	32.10	Linalyl acetate
17	25.859	94,018	0.14	Fenchyl acetate
18	26.101	3,243,132	4.82	Neryl acetate
19	29.534	359,315	0.53	Geranyl acetate
20	29.632	192,137	0.29	Hexyl hexanoate
21	29.816	92,161	0.14	Zingiberene
22	30.669	40,808	0.06	trans-α-Bergamotene

Table 2. *Cont.*

Number	R. Time	Area	Area%	Compounds
23	30.852	2,533,028	3.77	Caryophyllene
24	31.211	87,501	0.13	Isocaryophyllene
25	31.400	87,541	0.13	α-Bergamotene
26	32.088	3,006,736	4.47	β-Farnesene
27	32.959	127,795	0.19	Germacrene D
28	33.075	33,468	0.05	β-Sesquiphellandrene
29	34.046	46,148	0.07	Eudesma-3,7(11)-diene
30	36.250	237,195	0.35	Caryophyllene oxide
Total	-	67,222,018	100	-

In the current study, there was no evidence of an interaction between the lavender form and the dosage ($p > 0.05$; Table 3). On the other hand, the dosage of lavender had a significant effect on gas production for up to 12 h ($p < 0.001$ for 3 h; $p < 0.01$ for 6 h; $p < 0.05$ for 12 h), while the lavender forms had a significant effect on gas production at 3 h ($p < 0.05$). The gas production of the first 12-h period was reduced considerably when lavender (0.05% to 0.10%) was added to the diet of dairy cows. The decrease in gas production ranged between 24.24% and 25.13% in the third hour, 13.28% and 14.93% at the sixth hour, and 9.25% and 9.78% at the twelfth hour. The highest gas production was observed in LM (14.32 mL/200 mg DM) during the third hour, while the lowest production was observed in LEO (12.33 mL/200 mg DM).

Table 3. The effect of adding different forms of lavender on the cumulative gas production of concentrate feed of dairy cows.

Form	Dosage	3 h, mL	6 h, mL	12 h, mL	24 h, mL	48 h, mL
WL	0%	16.00	29.00	36.00	58.23	62.23
	0.05%	13.50	26.00	33.00	57.35	61.35
	0.10%	12.00	26.50	33.50	56.78	60.78
LM	0%	16.00	29.00	36.00	58.23	62.23
	0.05%	14.00	26.00	35.00	59.47	62.97
	0.10%	12.95	24.95	31.95	54.08	58.08
LEO	0%	16.00	29.00	36.00	58.23	62.23
	0.05%	10.00	22.00	30.00	50.36	53.86
	0.10%	11.00	24.00	32.00	54.13	56.63
SEM		0.83	1.34	1.26	1.76	2.19
p-value		0.2142	0.5261	0.2930	0.1176	0.2856
Main effect (Lavender form)						
WL		13.83 ^{ab}	27.17	34.17	57.45	61.45
LM		14.32 ^{a}	26.65	34.32	57.26	61.09
LEO		12.33 ^{b}	25.00	32.67	54.24	57.57
SEM		0.48	0.78	0.73	1.01	1.27
p-value		0.0417	0.1751	0.2587	0.0914	0.1089
Main effect (Lavender dosage)						
	0%	16.00 ^{a}	29.00 ^{a}	36.00 ^{a}	58.23	62.23
	0.05%	12.50 ^{b}	24.67 ^{b}	32.67 ^{b}	55.73	59.39
	0.10%	11.98 ^{b}	25.15 ^{b}	32.48 ^{b}	55.00	58.49
SEM		0.48	0.78	0.73	1.01	1.27
p-value		0.0004	0.0063	0.0125	0.1140	0.1495

WL: whole lavender; LM; lavender meal; LEO; lavender essential oil; SEM: standard error of mean. a: gas production from the immediately soluble fraction (mL); b: gas production from the insoluble fraction (mL); a + b: potential gas production (mL); ME: metabolizable energy (MJ/kg DM); NEL: net energy lactation (MJ/kg DM); OMD: organic matter digestibility (% DM).

A comparison of gas kinetics, in vitro degradability, and estimated energy values between lavender forms did not reveal significant differences ($p > 0.05$; Table 4). It was also established that there was no interaction between the form and dosage of lavender ($p > 0.05$). However, the immediately soluble fraction (*a*) of the diet was significantly reduced when lavender was added to the diets of dairy cows ($p < 0.0001$). However, the immediately soluble fraction (*a*) of the diet was significantly reduced when lavender was added to the diets of dairy cows ($p < 0.0001$), whereas the gas production rate constant for the insoluble fraction (*c*), the gas production of the insoluble fraction (*b*), and the potential total gas production (*a* + *b*) were not affected. Additionally, the estimated energy values (ME and NEL) decreased linearly with increasing lavender dosage, and these differences were significant ($p < 0.05$). Moreover, adding lavender to dairy cow concentrate feed considerably decreased the OMD, which ranged from 5.17% to 6.14% in the groups with 0.05% and 0.10% lavender, respectively ($p < 0.05$).

Table 4. The effects of different doses and forms of lavender on gas kinetics, in vitro degradability, and estimated energy values.

Form	Dosage	*c*	*a*	*b*	*a* + *b*	ME	NEL	OMD
WL	0%	0.074	4.61	60.53	65.15	10.20	6.38	67.95
	0.05%	0.070	1.83	63.13	64.96	10.00	6.23	65.88
	0.10%	0.075	0.37	63.41	63.78	9.92	6.16	65.37
LM	0%	0.074	4.61	60.53	65.15	10.20	6.38	67.95
	0.05%	0.074	0.91	65.59	66.50	10.29	6.47	67.77
	0.10%	0.072	1.87	59.36	61.24	9.55	5.85	62.97
LEO	0%	0.074	4.61	60.53	65.15	10.20	6.38	67.95
	0.05%	0.073	0.00	56.89	56.89	9.05	5.43	59.66
	0.10%	0.076	0.00	59.85	59.85	9.56	5.86	63.01
SEM		0.003	0.51	1.95	2.28	0.23	0.18	1.49
p-value		0.7830	0.1561	0.1658	0.2741	0.0966	0.0806	0.0953
Main effect (Lavender form)								
WL		0.073	2.27	62.36	64.63	10.04	6.26	66.40
LM		0.073	2.46	61.83	64.29	10.02	6.23	66.23
LEO		0.074	1.54	59.09	60.63	9.60	5.89	63.54
SEM		0.002	0.29	1.12	1.32	0.13	0.11	0.86
p-value		0.8250	0.1133	0.1428	0.1101	0.0765	0.0648	0.0755
Main effect (Lavender dosage)								
	0%	0.074	4.61 ^{a}	60.53	65.15	10.20 ^{a}	6.38 ^{a}	67.95 ^{a}
	0.05%	0.072	0.91 ^{b}	61.87	62.78	9.78 ^{ab}	6.04 ^{ab}	64.44 ^{b}
	0.10%	0.074	0.75 ^{b}	60.87	61.62	9.68 ^{b}	5.96 ^{b}	63.78 ^{b}
SEM		0.002	0.292	1.12	1.32	0.13	0.11	0.86
p-value		0.7142	<0.0001	0.6937	0.2100	0.0446	0.0486	0.0157

WL: whole lavender; LM; lavender meal; LEO; lavender essential oil; SEM: standard error of mean; *c*: the gas production rate constant (%) for the insoluble fraction (*b*); *a*: gas production from the immediately soluble fraction (mL); *b*: gas production from the insoluble fraction (mL); *a* + *b*: potential gas production (mL); ME: metabolizable energy (MJ/kg DM); NEL: net energy lactation (MJ/kg DM); OMD: organic matter digestibility (% DM).

In the current study, a significant effect of lavender forms was observed on CH_4 ($p < 0.05$), CO_2 ($p < 0.01$), and H_2S ($p < 0.01$) formation (Table 5). The addition of WL to the diet of dairy cows resulted in the highest concentrations of CH_4, CO_2, and H_2S, while LEO resulted in the lowest concentrations. On the contrary, there was no significant variation in NH_3 concentration between the different lavender forms added to the diet of dairy cows ($p > 0.05$). The addition of 0.05% lavender significantly reduced the concentration of CH_4 ($p < 0.01$); however, an increase in lavender dose did not yield a significant reduction in CH_4 concentration. With an increased dose of lavender, the concentration of NH_3 in dairy concentrate feed of dairy cows' increased significantly ($p < 0.05$). In addition, the presence

of lavender in the diet of dairy cows significantly reduced the generation of H_2S ($p < 0.01$). This study has also shown that there is a substantial interaction between lavender dosage and form that affects the production of CO_2, NH_3, and H_2S ($p < 0.05$).

Table 5. The effects of different doses and forms of lavender on the formation of gases in vitro.

Form	Dosage	CH_4, mL	CO_2, mL	NH_3, ppm	H_2S, ppm
WL	0%	7.01	38.60 ^{abc}	150.6 ^{ab}	1373.8 ^{a}
	0.05%	6.90	42.16 ^{a}	150.7 ^{ab}	1288.1 ^{a}
	0.10%	7.23	41.60 ^{ab}	176.0 ^{ab}	1415.5 ^{a}
LM	0%	7.01	38.60 ^{abc}	150.6 ^{ab}	1373.8 ^{a}
	0.05%	5.92	32.27 ^{c}	129.9 ^{b}	1069.2 ^{ab}
	0.10%	6.83	37.86 ^{abc}	177.0 ^{ab}	1279.3 ^{a}
LEO	0%	7.01	38.60 ^{abc}	150.6 ^{ab}	1373.8 ^{a}
	0.05%	5.51	32.74 ^{bc}	192.2 ^{a}	1024.7 ^{ab}
	0.10%	6.41	31.93 ^{c}	176.6 ^{ab}	837.7 ^{b}
SEM		0.27	1.63	9.4	69.9
p-value		0.2058	0.0329	0.0448	0.0180
Main effect (Lavender form)					
WL		7.04 ^{a}	40.78 ^{a}	159.1	1359.1 ^{a}
LM		6.58 ^{ab}	36.24 ^{b}	152.5	1240.8 ^{a}
LEO		6.31 ^{b}	34.42 ^{b}	173.1	1078.8 ^{b}
SEM		0.15	0.94	5.4	40.3
p-value		0.0241	0.0028	0.0652	0.0028
Main effect (Lavender dosage)					
	0%	7.01 ^{a}	38.60	150.6 ^{b}	1373.8 ^{a}
	0.05%	6.11 ^{b}	35.72	157.6 ^{ab}	1127.3 ^{b}
	0.10%	6.82 ^{a}	37.13	176.5 ^{a}	1177.5 ^{b}
SEM		0.15	0.94	5.4	40.3
p-value		0.0063	0.1522	0.0214	0.0045

$^{a–c}$: Different superscripts on the same row differ by $p < 0.05$. WL: whole lavender; LM; lavender meal; LEO; lavender essential oil; SEM: standard error of mean; CH_4: methane; CO_2: carbon dioxide; NH_3: ammonia; H_2S: hydrogen sulfide.

4. Discussion

Two of the most urgent problems that humanity must solve as a result of the negative effects on the environment are a reduction in GHG emissions and the destruction of agricultural waste. Although studies on the influence of lavender on GHG emissions are scarce, these studies appear to focus on LEO [21,32]. Therefore, the purpose of this study was to examine the effect of different forms of lavender, which has increased in cultivation areas in recent years, on reducing GHG emissions.

In the current study, lavender had a dose-dependent influence on gas production, although the type of action altered as the incubation time increased. It is possible that, over a long period of incubation, the bacteria in the rumen may have developed tolerance to high doses of lavender. Similarly, during an in vitro investigation using LEO as an incubation medium at 0, 250, 750, and 1000 µL/L, Yadeghari et al. [22] showed a dose–response effect of LEO on the rumen microbial ecosystem. Furthermore, previous studies have also indicated that LEO [22] and the dry extract of *L. officinalis* [33] have a stimulatory effect on ruminal fermentation. It was noted by Büyükkılıç Beyzi [21] that the stimulating action of LEO was dose-related, and that LEOs boost gas production even at low doses. In contrast to these studies, the current research found that adding lavender to dairy cow concentrate feed during the first 12 h of fermentation reduced gas production, although this effect disappeared as the incubation time increased.

It has been pointed out that the analysis of the various parameters of the gas production kinetics, including the fraction of easily degraded DM (*a*), the DM that is potentially degraded (*a* + *b*), as well as the rate kinetics of gas production (*c*), is reflective of the processes that occur during fermentation involving nutrition digestibility and ruminal microbial activity [34]. In the current study, adding 0.05% or 0.10% lavender to the concentrate feed of dairy cows had no significant influence on the potential for rumen degradation, indicating that the potential gas production curves remained the same as the control (0%), maintaining the rumen microbial community. The addition of LEO to dairy cow concentrate feed had a tendency to reduce OMD, ME, and NEL levels, and a statistically significant reduction was found as dosages increased. It is possible that this was due to the doses present in the concentrate (insoluble fraction, *b*) not reaching an inhibitory level for the enzymes required to break down lignocellulose. Furthermore, since the substrate was the same for all samples, the gas production capacity was determined by the extent to which the active compounds of each lavender form acted on the ruminal microorganisms.

Maintaining a healthy rumen microbiota, boosting feed digestibility for increased development and milk production, and minimizing ruminant CH_4 emissions are all key goals for nutritionists [33]. There is now a high need for feed additives that can modify rumen fermentation and are acceptable to consumers. Plant extracts and EOs appear to be the most suitable materials for this use. Previous research has indicated that these plant extracts and EOs can reduce CH_4 production in one of two ways: either by competing with substrates for propionate formation or by suppressing methanogenesis, therefore lowering CH_4 generation [34,35]. The analysis performed in this work was unable to ascertain which of the routes was responsible for the reduction in CH_4; nonetheless, LEO exhibited the highest rate of CH_4 reduction (−10.37%), followed by LM (−6.53%). After extraction, the active compounds in LEO are likely more concentrated, which explains why it is more effective in decreasing CH_4 generation. Cieslak et al. [35] attributed this occurrence to EOs' isoprenoid unit, a distinctive methanogen cell membrane structure that may result in cell death. In a similar vein, it is possible that this outcome occurred as a consequence of the fact that the isoprenoid units in LEO will be higher than those in WL and LM.

It is preferable to limit the conversion of dietary protein into NH_3 in the rumen, in addition to lowering the CH_4 emissions of the feed additives used. Previous research has shown that EO [11] and polyphenol-rich plant extract [36] increased the duodenal flow of undegraded protein in the rumen by reducing the conversion of ruminal protein into NH_3. Further research has shown that these feed additives did not reduce feed intake, dry matter intake, or total nutrient digestibility [10]. In the current study, a tendency of increased NH_3 levels was detected in dairy cow concentrate feed supplemented with LEO ($p = 0.0652$). The NH_3 ratio also increased significantly with higher lavender dosages ($p < 0.05$). This was an unexpected outcome, which may be related to lavender's limited ability to precipitate proteins. Similar to the current study's results, earlier research has shown that the concentrations, kinds, doses, and microbial species present in the rumen fluid all have a role in EOs' effectiveness in suppressing the growth of rumen microorganisms [11].

Animal feeding is connected to the production of H_2S, which is one of the toxic gases and has a severe impact on both the health of animals and the environment [37]. In the rumen and gut, sulfate-reducing bacteria create H_2S, which may be absorbed by the intestinal wall, leaving animals vulnerable to H_2S poisoning [38]. The present study found that adding lavender to dairy cows' diet lowered H_2S levels, with WL and LM being more effective than LEO in preventing the development of H_2S. With the addition of lavender to dairy cow concentrate feed, the H_2S ratio was reduced by 14.29–17.94%. Our results are comparable with those of Alvarado et al. [39], who reported that plant species, dose, and duration all contributed substantially to the decrease in H_2S emissions.

In the rumen, pyruvate decarboxylation results in the formation of acetyl-CoA, which is then converted into acetate. Changing the rumen's acetate-to-propionate ratio lowers gaseous emissions of CO_2 and H_2 [40]. Plant secondary metabolites have been shown to inhibit cellulolytic bacteria owing to their antibacterial and antiprotozoal capabilities [11].

As a consequence of decreasing the formation of short-chain fatty acids, levels of CO_2 and H_2 are brought down, leading to a corresponding reduction in CH_4 production [41]. In this study, LM and LEO were shown to be more successful in lowering CO_2 concentrations than WL. This finding is most likely associated with the tannin ratio in LM [42] and the 1,8-cineole and camphor levels in LEO [19].

5. Conclusions

A study was conducted to investigate the effect of waste released during the extraction of LEO on GHGs. The study's findings may have consequences for the livestock industry, as LM might be utilized as a feed addition to minimize GHG emissions. Similar to LEO, our results indicated that LM can be beneficial in lowering CH_4, CO_2, and H_2S; however, there may be a drop in OMD and estimated energy values (ME and NEL) and an increase in NH_3 content with increasing dosage. Further research may be required to discover the optimum dosage of LM required to reduce GHG emissions while maintaining feed quality. The usage of LM could also aid the LEO industry economically, since waste material could be recycled as a feed supplement. On the other hand, this study was conducted in a controlled setting; thus, more research would be necessary to examine the influence of LM on GHGs in vivo using a cow model with an assessment of animal productive attributes.

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