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## Rosehip Fruit Residue, Tobacco Leaf, Nettle Herb, and Nettle Seed Cake as Potential Ruminant Feeds: Nutritional Value, *In Vitro* Digestibility, Gas Production and Methane Emissions

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### Abstract

This study aimed to evaluate the nutritional composition, *in vitro* digestibility, *in vitro* gas production, and methane emissions of four unconventional feed sources: rosehip fruit residue (RFR), tobacco leaf (TBL), nettle herb (NTH), and nettle seed cake (NTC) for potential use in ruminant rations. Feed samples were analysed for their chemical composition and cell wall structural components. *In vitro* gas production technique (Hohenheim) was conducted to determine fermentation kinetics, organic matter digestibility (OMD), metabolizable energy (ME), and net energy for lactation (NE<sub>L</sub>). Daisy Incubator was used to determine *in vitro* true digestibility (IVTD) of samples. In addition, an infrared methane analyzer was used to estimate methane production. The results indicated that NTC is a protein-rich material (27.91% CP) that can be used as a feed ingredient in animal diets, with potential for reducing methane emissions. Nettle herb and TBL had high crude protein contents (26.75% and 24.24%, respectively), superior digestibility (IVTD 83.74% and 87.67%, respectively), produced higher total gas volumes after 24 hours of incubation (36.46 and 33.01 mL/200 mg DM, respectively), and methane production of 7.45 and 3.56 mL, respectively. These results indicate their potential as valuable protein sources in ruminant feeding. Rosehip fruit residue and NTC recorded lower gas production (14.25 and 15.30 mL/200 mg DM at 24 hours) and methane production (3.29 and 2.06 mL, respectively). These unconventional materials, promising potential as alternative feed sources in animal nutrition, can be used when properly balanced in rations. When combined with traditional roughages and concentrated feeds, they can be used partially, especially in ruminant feeding. Further *in vivo* studies are recommended to evaluate the effects of these feed sources on feed intake, nutrient utilisation, animal performance, and methane mitigation under practical feeding conditions.

**Keywords:** Animal feeds; Rosehip residue; Tobacco leaf; Nettle; gas production; Methane emission; *In vitro* digestibility; Ruminant nutrition

### 1. Introduction

Global livestock production is increasingly challenged by rising feed costs, competition with human food resources, and environmental concerns associated with enteric methane emissions [1, 2]. Consequently, exploring non-conventional and sustainable feed sources is critical to enhance feed security while mitigating the environmental footprint of ruminant production systems [3].

Plant by-products and underutilized biomass such as fruit residues, herbaceous plants, and oilseed cakes are gaining attention due to their potential to partially replace conventional feeds without compromising animal performance [4, 5]. Rosehip (*Rosa canina*) fruit residue, a by-product of herbal tea and extract industries, is rich in polyphenols, dietary

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fiber, and residual sugars, suggesting possible fermentable energy value and antioxidant benefits in animal rations [6]. Similarly, tobacco (*Nicotiana tabacum*) leaves, though traditionally avoided due to nicotine content, have high crude protein and mineral levels, and recent studies have explored their safe inclusion at limited levels in ruminant rations after proper processing [7, 8].

Nettle (*Urtica dioica*) herb and nettle seed cake are promising unconventional feed sources. Nettle herb is known for its high protein content, minerals, and bioactive compounds such as flavonoids and phenolic acids, which may enhance rumen fermentation and support animal health [9,10]. Nettle seed cake, a by-product remaining after oil extraction, is particularly rich in protein and fat, suggesting its potential as a supplementary protein and energy source in ruminant rations [10]. In addition to their nutritive value, these non-conventional feeds contain diverse secondary metabolites (such as polyphenols, tannins, and alkaloids) that can modulate rumen fermentation and potentially reduce methane emissions [11,12]. However, a comprehensive evaluation of the nutritional composition, *in vitro* digestibility, fermentation characteristics, and methane mitigation potential of these feeds is essential before their practical inclusion in ruminant rations.

Therefore, the objective of this study was to assess the chemical composition, *in vitro* true digestibility, gas production, and methane emissions of rosehip fruit residue, tobacco leaf, nettle herb, and nettle seed cake as potential feed sources for ruminants. The results will provide insights into their potential roles in sustainable ruminant feeding strategies.

## 2. Materials and methods

### 2.1. Sample Collection and Preparation

This study evaluated four potential feed resources: rosehip fruit residue (RFR), tobacco leaf (TBL), nettle herb (NTH), and nettle seed cake (NTC). The RFR was sourced as a by-product from a local herbal tea manufacturing facility. Tobacco leaves were harvested from mature plants grown in Samsun Province, Türkiye, then air-dried and ground for analysis. Nettle herb, consisting of the entire aerial portion of the plant, was collected prior to flowering from natural populations, shade-dried to preserve nutrient quality, and ground. Nettle seed cake, a residual product remaining after cold-press oil extraction, was obtained from a commercial oil-processing plant. All samples were dried under ambient conditions, milled to pass through a 1-mm screen using a laboratory mill, and stored in airtight containers at room temperature until chemical and *in vitro* analyses were conducted.

### 2.2. Chemical Analyses

Dry matter (DM), crude protein (CP), and ash contents were analysed following standard protocols described by the AOAC [13]. Ether extract (EE) content was analyzed using the Ankom XT<sup>15</sup> extraction system [14]. Cell wall structural components, including neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL), were determined using the method of Van Soest et al. [15] with an ANKOM<sup>2000</sup> Fiber Analyzer system. Hemicellulose content was calculated by subtracting ADF from NDF, while cellulose was determined as ADF minus ADL. Organic matter (OM) and nitrogen-free extract (NFE) were determined by calculation. Chemical analyses were conducted in triplicate and expressed on a dry matter basis.

### 2.3. *In Vitro* Gas Production Technique

The Hohenheim gas test (gas production technique) was used to assess the *in vitro* gas production of the feeds [16]. Samples were ground to pass through a 1 mm sieve, and approximately 250 mg of air-dried material, corresponding to 200 mg of DM, was accurately weighed into calibrated glass syringes. Each sample was incubated with buffered rumen fluid, and gas production was measured at 3, 6, 9, 12, 24, 48, 72, and 96 hours. Final gas production results were expressed as mL/200 mg DM. Measurements were corrected by subtracting gas volumes recorded in blank syringes containing only the rumen fluid-buffer mixture, and all data were standardised using alfalfa hay (forage standard) as a reference feed.

Organic matter digestibility (OMD), metabolizable energy (ME), and net energy lactation (NEL) contents were calculated from the amount of gas production (GP: 24-hour gas amount), CP, EE, and ash content of the feeds using the following equations [16, 17]:

$$\text{OMD (\%)} = 14.88 + 0.8893 \text{ GP} + 0.448 \text{ CP} + 0.651 \text{ Ash}$$

$$\text{ME (MJ/kg DM)} = 2.20 + 0.136 \text{ GP} + 0.0574 \text{ CP} + 0.002859 \text{ CP}^2$$

$$NE_L \text{ (MJ/kg DM)} = 0.101 \text{ GP} + 0.051 \text{ CP} + 0.112 \text{ EE}$$

## 2.4. Methane Measurement

Methane production of the feeds was determined using an infrared methane analyzer (Europa GmbH, Erkrath, Germany). After recording the 24-hour gas production volumes during the *in vitro* gas production assay, residual gases within the syringes were sampled and analyzed for methane concentration. Methane volume (mL) was calculated by multiplying the total gas production at 24 hours by the percentage of methane detected in the sample, according to the following formula:

$$\text{Methane production (mL)} = \text{Total gas production (mL)} \times \text{Methane (\%)}$$

## 2.5. *In Vitro* True Digestibility

*In vitro* true digestibility (IVTD) of the feeds was assessed using the ANKOM DaisyII Incubator [18]. The same rumen fluid collected for the *in vitro* gas production assays was used in these digestibility evaluations. The DaisyII system includes four separate jars functioning as artificial rumens. For each feed sample, approximately 0.50g was placed into F57 filter bags, and the bags were then submerged in the jars for a 48-hour incubation period. Each feed was tested in three replicates to ensure consistency. After incubation, the bags were removed, thoroughly rinsed, and analyzed for NDF content to determine the residue. IVTD was calculated using the following equation:

$$\text{IVTD, \%} = 100 - ((C - (A \times D)) \times 100 / B)$$

Where: A is the tare weight of the F57 bag, B is the amount of NDF in the original dry sample, C is the amount of NDF remaining in the bag after incubation, and D is the blank bag correction factor.

## 2.6. Data Analysis

Statistical comparisons among feedstuffs were not performed, as the primary objective of this study was to provide descriptive information on their nutritional composition and fermentation characteristics. Accordingly, results are presented as mean values to illustrate each feed's potential in ruminant nutrition. The means and standard deviations of the data obtained in the study were determined, and the similarities and differences between the results of this study and those of similar studies were evaluated through comparison.

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## 3. Results and discussion

### 3.1. Nutritional Composition and Cell Wall Components

The chemical composition and cell wall structural components of the evaluated potential feed sources are presented in Table 1. The nutritional profiles of the evaluated unconventional feeds reveal their potential as feed sources for ruminants. Organic matter contents were high across all feedstuffs, with values of 97.45%, 93.85%, 80.70%, and 77.44% for RFR, NTC, NTH, and TBL, respectively. The OM content of RFR (97.45%) indicates minimal mineral content, supporting its inclusion as a fiber-rich energy source. Ash content varied notably, with a higher value in TBL (22.56%) and a lower value in RFR (2.55%). The ash content of the TBL is higher than in most common forages (usually <10%), suggesting that tobacco leaves are mineral-rich.

Crude protein contents varied considerably among the evaluated potential feed sources, ranging from 7.51% to 27.91%. Nettle seed cake had high CP content (27.91%), similar to conventional oilseed cakes such as sunflower or cottonseed meal. Nettle herb contained 26.75% CP, placing it within the range of commonly used high-protein plants such as alfalfa and moringa, and making it particularly useful for improving low-protein diets. The CP content of TBL (24.24%) is higher than that of many traditional roughages and even surpasses some legume forages, indicating its potential as a valuable protein supplement. The evaluated potential feed sources exhibited high CP contents, suggesting their suitability as alternative protein sources in animal feed. The high CP content in NTH and NTC aligns with findings by Abera et al. [19], who reported nettle-based materials containing up to 30 % CP and showing promise as protein sources in ruminant rations. Tobacco leaf showed considerable CP, corroborating the observations of Fatica et al. [20] that tobacco waste contains appreciable protein levels, although nicotine content must be monitored before inclusion in ruminant rations. In contrast, RFR contained only 7.51% CP, consistent with previous reports by Borşa et al. [21], which indicate that rosehip residues are low in protein but rich in fiber and polyphenols. The EE content was relatively low in NTC, NTH, and RFR; however, TBL exhibited a high value of 4.67%, which likely contributes to the increased energy density of the material.

Crude fiber was higher in RFR (61.86%), followed by NTC (42.03%) and NTH (30.18%), while TBL showed lower CF content (16.34%). Nettle seed cake is relatively high in CF (42.03%), along with significant cellulose (23.50%) and hemicellulose (20.30%), indicating that although the cake is fibrous, a meaningful portion is potentially fermentable by ruminants. Regarding fiber fractions, RFR showed high NDF and ADF contents, measured at 78.61% and 62.02%, respectively. The high CF and NDF contents of RFR suggest its limited fermentability and energy contribution. However, its fiber could be useful in rations requiring effective fiber to stimulate rumen function [22]. The NTH and NTC exhibited similar NDF values (65.58% and 65.30%, respectively), whereas TBL recorded a lower NDF value (28.97%). The NDF and ADF values of NTC suggest a balanced fiber fraction suitable for ruminant inclusion, consistent with the nutritional evaluation of oilseed cakes reported by Rakita et al. [23].

Tobacco leaf is relatively low in structural carbohydrates, as indicated by NDF (28.97%) and ADF (14.18%) contents. These values are lower than those of most roughages (e.g., NDF in grass hay typically ranges from 45% to 65%). The low ADF and ADL (3.65%) indicate a good digestibility potential, assuming the presence of anti-nutritional factors is minimal or well-managed. Compared to other leafy plant residues, such as moringa leaves or mulberry leaves, which are also high in protein (20–28%) and moderately fibrous (NDF 30–40%), TBL composition is quite comparable [24]. The major concern with TBL is its content of nicotine and other alkaloids, which can be toxic to animals. Studies have shown that nicotine levels in tobacco leaf can range from 0.3–8%, depending on the variety and processing [25, 26]. These alkaloids can affect feed intake, rumen fermentation, and animal health. However, if nicotine is effectively reduced by processing (e.g., ensiling, extraction), the leaf might be used in limited proportions in ruminant rations.

Acid detergent lignin was high in RFR (25.51%) and NTC (21.50%), intermediate in NTH (10.49%), and low in TBL (3.65%). The high ADL content of NTC indicates a substantial lignin fraction, which can negatively impact digestibility. Hemicellulose content ranged from 14.79% in TBL to 33.94% in NTH. Cellulose content was highest in RFR (36.51%), followed by NTC (23.50%), NTH (21.15%), and TBL (10.54%). Hemicellulose and cellulose contents varied among feeds, with NTH showing higher hemicellulose content, which supports its potential fermentability in the rumen [22].

**Table 1** Chemical composition and cell wall structural components of rosehip fruit residue, tobacco leaf, nettle herb, and nettle seed cake (as DM%)

Parameters	RFR	TBL	NTH	NTC
Organic matter	97.45 ± 0.17	77.44 ± 0.02	80.70 ± 0.06	93.85 ± 0.11
Ash	2.55 ± 0.17	22.56 ± 0.20	19.30 ± 0.06	6.15 ± 0.11
Crude protein	7.51 ± 0.04	24.24 ± 0.27	26.75 ± 0.04	27.91 ± 0.03
Ether extract	1.78 ± 0.03	4.67 ± 0.10	1.04 ± 0.19	0.73 ± 0.20
Crude fiber	61.86 ± 1.12	16.34 ± 1.59	30.18 ± 3.60	42.03 ± 0.29
Nitrogen-free extracts	26.30 ± 1.01	32.20 ± 1.69	22.73 ± 3.69	23.19 ± 0.01
Neutral detergent fiber	78.61 ± 0.38	28.97 ± 2.40	65.58 ± 2.23	65.30 ± 0.55
Acid detergent fiber	62.02 ± 0.49	14.18 ± 0.01	31.64 ± 2.82	45.00 ± 0.45
Acid detergent lignin	25.51 ± 0.41	3.65 ± 0.42	10.49 ± 2.96	21.50 ± 0.45
Hemicellulose	16.59 ± 0.12	14.79 ± 2.41	33.94 ± 0.60	20.30 ± 0.10
Cellulose	36.51 ± 0.08	10.54 ± 0.41	21.15 ± 0.13	23.50 ± 0.90

RFR: rosehip fruit residue, TBL: tobacco leaf, NTH: nettle herb, NTC: nettle seed cake. Values are presented as Mean ± Standard deviation.

### 3.2. *In Vitro* Gas Production

The cumulative *in vitro* gas production of RFR, TBL, NTH, and NTC measured over a 96-hour incubation period is presented in Table 2. At 3 hours of incubation, NTH and TBL recorded higher gas volumes, producing 14.86 mL and 13.36 mL/200 mg DM, respectively. Rosehip fruit residue generated 7.78 mL/200 mg DM, while NTC recorded lower gas production at this time point, with only 2.45 mL per 200 mg DM. At 24 hours, the *in vitro* gas production amount was higher in NTH (36.46 mL), followed by TBL (33.01 mL), with NTC and RFR recording 15.30 mL and 14.25 mL per 200 mg DM, respectively. The higher value in the NTH suggests its rapid degradation and fermentability in the rumen. This is consistent with Nocek & Russell [27], who emphasized nettle herb's fermentable carbohydrate fractions and protein solubility, enhancing microbial biomass production and energy yield.

Between 24 and 48 hours, the rate of gas production slowed slightly. The NTH and TBL continued to produce the most gas, reaching 40.36 mL and 38.65 mL, respectively, at 48 hours. At 96-hour incubation, NTH exhibited higher total gas production (45.20 mL/200 mg DM), demonstrating its high fermentability. TBL produced a slightly lower total volume of 40.09 mL, while NTC reached 27.39 mL. Rosehip fruit residue consistently recorded lower cumulative gas production throughout the incubation, with a final value of 15.68 mL/200 mg DM.

The relatively low gas production of RFR is consistent with its high fiber and lignin contents (Table 1), which likely limited microbial fermentation, as similarly reported for high ADF feed by Van Soest [22] and Getachew et al. [28]. The NTH exhibited higher cumulative gas production and fermentation rates, indicating its high degradability. This aligns with previous reports conducted by Andualem et al. [29], indicating that nettle herb is a rapidly fermentable forage rich in soluble carbohydrates and protein. Tobacco leaf also showed high gas production, suggesting its potential as a fermentable protein-rich feed. However, caution should be exercised due to possible nicotine content in tobacco leaf, which may affect feed intake and animal health at higher inclusion levels. Rosehip fruit residue produced lower cumulative gas volumes, reflecting its high lignin and fiber content, which limits microbial degradation. Nettle seed cake demonstrated moderate gas production, likely due to its residual oil extraction processing and lower fiber digestibility. These findings align with those of Olivares-Palma et al. [30], who reported that oilseed press cakes, although protein-rich, retain cell wall structures that limit rapid fermentation.

Final pH values after 96 hours of incubation were within typical rumen fluid ranges for all feeds, which indicates that the buffer used in the present study was not exhausted. In this respect, this indicates that the study was conducted safely in terms of the buffer amount. In addition, these pH results indicate that fermentation of all evaluated feeds occurred without excessive acid accumulation, suggesting their suitability for rumen fermentation without causing significant pH depression.

### 3.3. Gas Production Parameters, Methane Production, and Digestibility

The gas production kinetics and fermentation characteristics indicate varying degradability potentials among all four unconventional plant-based feed sources examined in this study (Table 3). Nettle herb exhibited a higher gas production rate (0.15 mL/h) and potential gas production (a+b: 41.73 mL), suggesting rapid and extensive microbial fermentation, supporting previous findings by Andualem et al. [31] and Pashachalandari et al. [32] on nettle's high fermentable carbohydrate and protein solubility, enhancing digestibility.

Tobacco leaf also showed high total gas production (39.03 mL) with a moderate gas production rate (0.11 mL/h), indicating good fermentability. Kilic et al. [7] reported similar patterns for tobacco by-products, emphasizing their appreciable OMD and high IVTD, as observed in the present study. Its  $NE_L$  value (3.85 kcal/kg DM) further demonstrates its potential as an energy supplement when used within safe nicotine thresholds.

Rosehip fruit residue recorded lower total gas production (15.59 mL) and digestibility indices (OMD 32.46%, IVTD 38.20%). Its high fiber and lignin contents (Table 1) limit microbial degradation, as noted in other fruit residues with elevated ADF and ADL fractions [22]. However, its methane production (3.29 mL) was lower, suggesting potential use to reduce enteric methane emissions when included in forage-based rations. Nettle seed cake presented a lower gas production rate (0.03 mL/h) and potential gas production (28.70 mL), with relatively low OMD (38.49%) and IVTD (53.28%). This indicates limited degradability, likely due to its fiber matrix. Yet, it remains a valuable protein source (27.91% CP) with moderate energy density.

Table 3 shows that the methane production of the evaluated feeds varied between 2.06 mL to 7.45 mL. Nettle herb produced a higher methane volume of about 7.45 mL, while TBL and RFR generated similar methane emissions of 3.56 mL and 3.29 mL, respectively. The methane results for TBL are comparable to those reported by Kilic et al. [7], who found that tobacco meals produced moderate methane volumes and higher emissions than tobacco straws due to their higher protein and digestible organic matter content. Furthermore, Can and Kilic [33] investigated methane production from tobacco straw silages treated with additives. They observed that untreated tobacco straw produced methane levels similar to those recorded for TBL in the present study, while certain silage additives reduced methane emissions. This suggests that processing methods may further optimise tobacco by-products for environmentally sustainable feeding.

Additionally, NTC had lower methane production, measured at 2.06 mL. This suggests that NTC can serve as a low methane feed source and, when included in ruminant rations at appropriate rates, could contribute to the reduction of enteric methane emissions without compromising yields. A study conducted by Jayanegara et al. [12] found that feeds containing bioactive compounds such as tannins or phenolic acids, which are present in nettle and rosehip, can influence

ruminal methanogenesis. However, in the current study, NTH's high fermentability likely contributed to its greater methane output despite its bioactive content.

Metabolizable energy (ME) content was higher in NTH, reaching 7.16 MJ/kg DM, while TBL showed a slightly lower ME value of 6.69 MJ/kg DM. Rosehip fruit residue and NTC had lower estimated energy values at 4.73 and 4.28 MJ/kg DM, respectively. Net energy lactation (NE<sub>L</sub>) in TBL and NTH showed moderate values (3.85 and 3.68 MJ/kg DM), whereas RFR and NTC recorded notably lower NE<sub>L</sub> contents (2.02 and 1.55 MJ/kg DM, respectively). Nettle seed cake exhibited low energy values but may be beneficial as a protein source in low-energy diets, given its favorable CP content and low methane production.

*In vitro* true digestibility (IVTD) results indicated that TBL had a higher digestibility, with an IVTD of 87.67%. Nettle herb also exhibited high digestibility at 83.74%. In contrast, NTC and RFR showed considerably lower IVTD values, measured at 53.28% and 38.20%, respectively. These findings suggest that TBL and NTH possess superior ruminal degradability and energy availability compared to RFR and NTC. These findings are consistent with their previously observed low NDF and ADL contents, which are known to favor rumen microbial fermentation and organic matter degradability [22].

**Table 2** *In vitro* gas production amounts (mL/200 mg DM) and final pH after 96 hours of incubation for rosehip fruit residue, tobacco leaf, nettle herb, and nettle seed cake

	Incubation time (hours)								pH
	3	6	9	12	24	48	72	96	
<b>RFR</b>	7.78 ± 0.88	8.81 ± 0.65	10.37 ± 1.71	11.53 ± 0.89	14.25 ± 0.56	15.03 ± 0.73	15.42 ± 0.94	15.68 ± 0.91	6.80 ± 0.02
<b>TBL</b>	13.36 ± 2.64	22.13 ± 3.45	27.37 ± 3.60	29.34 ± 3.71	33.01 ± 4.16	38.65 ± 5.20	39.70 ± 5.59	40.09 ± 5.41	6.81 ± 0.01
<b>NTH</b>	14.86 ± 2.52	28.27 ± 2.00	31.62 ± 2.36	33.85 ± 2.34	36.46 ± 2.07	40.36 ± 2.27	42.96 ± 2.94	45.20 ± 2.22	6.37 ± 0.09
<b>NTC</b>	2.45 ± 0.32	6.61 ± 0.31	6.99 ± 0.63	8.88 ± 1.25	15.30 ± 0.64	20.97 ± 1.41	24.56 ± 1.15	27.39 ± 1.43	6.29 ± 0.01

RFR: rosehip fruit residue, TBL: tobacco leaf, NTH: nettle herb, NTC: nettle seed cake. Values are presented as Mean ± Standard deviation.

**Table 3** Gas production parameters, methane production, OMD, ME, NE<sub>L</sub>, and IVTD of rosehip fruit residue, tobacco leaf, nettle herb, and nettle seed cake

	c (mL/h)	a+b (mL)	Methane (mL)	OMD (%)	ME (kcal/kg DM)	NE <sub>L</sub> (kcal/kg DM)	IVTD (%)
<b>RFR</b>	0.08 ± 0.01	15.59 ± 0.93	3.29 ± 0.20	32.46 ± 0.50	4.73 ± 0.08	2.02 ± 0.06	38.20 ± 1.29
<b>TBL</b>	0.11 ± 0.02	39.03 ± 5.51	3.56 ± 0.78	57.76 ± 3.70	6.69 ± 0.57	3.85 ± 0.42	87.67 ± 0.27
<b>NTH</b>	0.15 ± 0.01	41.73 ± 2.49	7.45 ± 0.35	47.30 ± 1.84	7.16 ± 0.28	3.68 ± 0.21	83.74 ± 1.43
<b>NTC</b>	0.03 ± 0.01	28.70 ± 1.17	2.06 ± 0.17	38.49 ± 1.57	4.28 ± 0.09	1.55 ± 0.06	53.28 ± 0.47

RFR: rosehip fruit residue, TBL: tobacco leaf, NTH: nettle herb, NTC: nettle seed cake, c: gas production rate, a+b: total gas production, OMD: organic matter digestibility, ME: metabolizable energy. NE<sub>L</sub>: net energy lactation, IVTD: *in vitro* true digestibility. Values are presented as Mean ± Standard deviation.

#### 4. Conclusion

This study showed that nettle herb and tobacco leaf are rich in protein, highly digestible, and rapidly fermentable, making them promising potential protein sources for ruminants. However, the use of tobacco leaves requires caution due to the potential presence of alkaloid residues, which limit their free use. Nettle seed cake also provides high protein with moderate digestibility and minimal methane emissions, supporting its role as a sustainable feed source. Although

rosehip fruit residue has low protein and digestibility, its high fiber content can benefit rumen health if used appropriately. These unconventional materials, which show potential as alternative feed sources in animal nutrition, can be effectively used when properly processed and balanced in rations. They can partially replace traditional forages or concentrates, especially in ruminant feeding systems. Their utilization not only offers nutritional value but also supports sustainable livestock production by promoting the use of agro-industrial byproducts and reducing feed costs. Additionally, these feed sources could enhance feed availability, reduce reliance on traditional protein sources, and contribute to lower methane emissions. Further *in vivo* studies are needed to confirm their practical feeding value and safety.

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## Compliance with ethical standards

### *Disclosure of conflict of interest*

The authors declare that there is no conflict of interest.

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