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Nutritional and Hormonal Responses of Dairy Goats Fed Palm Fatty Acid Distillate and Mangrove Fruit (*Sonneratia alba*)

Elihasridas [1], Roni Pazla [1]*, Novirman Jamarun [1], Yolani Utami [1], Antonius [2], Zaitul Ikhlas [3] and Gusri Yanti [4]

[1]Department of Animal Nutrition and Feed Technology, Faculty of Animal Science, Andalas University, Jl. Unand Campus Limau Manis, Padang 25175, West Sumatra, Indonesia
[2]Research Center of Animal Husbandry, National Research and Innovation Agency, Jl. Raya Jakarta-Bogor, Cibinong 16915, West Java, Indonesia
[3]Graduate Program, Faculty of Animal Science, Andalas University, Jl. Unand Campus Limau Manis, Padang 25175, West Sumatra, Indonesia
[4]Faculty of Social, Science and Education, Prima Nusantara Bukittinggi University, Jl. Kusuma Bhakti No 99 Kubu Gulai Bancah, Bukittinggi 26111, West Sumatra, Indonesia
***Corresponding author:** ronipazla@ansci.unand.ac.id

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ABSTRACT

The present work focuses on evaluating the use of palm fatty acid distillate (PFAD) and mangrove fruit extract (*Sonneratia alba*) as sources of tannin supplementation, examining their effects on feed intake, nutrient digestibility, milk production and quality, and hormonal response in dairy goats. The experiment employed a randomized block design with four treatment groups: control diet (T1), ration + 6% PFAD + 0.5% mangrove fruit extract (T2), ration + 6% PFAD + 1.0% mangrove fruit extract (T3), and ration + 6% PFAD + 2.0% mangrove fruit extract (T4). This study measured the following parameters: dry matter and nutrient intake; dry matter and organic matter; crude protein digestibility; milk production and composition; and hormone levels of cortisol, oxytocin, and prolactin. The results indicated that the use of PFAD and mangrove fruits did not affect feed intake or milk production (P>0.05); however, it significantly improved nutrient digestibility (P<0.05). The treatment also significantly increased milk fat content and decreased cortisol levels, while oxytocin and prolactin levels increased (P<0.05). Therefore, combining PFAD and mangrove fruits can improve nutrient utilization efficiency, milk quality, and hormone balance in dairy goats without affecting feed intake or milk production.

Keywords: Dairy Goats, Palm Fatty Acid Distillate, *Sonneratia alba,* Nutrient Digestibility, Milk Quality.

INTRODUCTION

In developing countries, particularly in regions with limited feed resources and increasing demand for livestock production, goat milk represents an important source of animal protein. The dairy goat's ability to adapt to low-quality feed is a big plus, and it gets the best out of tropical forages. Nonetheless, the limitations of low feed intake, suboptimal rumen fermentation, and high methane emissions still take their toll on goat milk production. Furthermore, these unfavorable factors influence the quantity and quality of milk, which, in turn, affect the reproductive health of the animals and hormonal equilibrium during the lactation period (Izquierdo et al. 2021; Aguilar-González et al. 2022; Dey et al. 2025). These constraints highlight the need for nutritional strategies that can simultaneously enhance feed efficiency, milk production, and physiological stability in dairy goats raised under tropical conditions.

Ruminal fermentation is the primary physiological process determining the successful utilization of nutrients in ruminants (Shen et al. 2023). Rumen microbial activity involving bacteria, protozoa, and archaea produces volatile fatty acids (VFA), namely acetate, propionate, and butyrate, which serve as the primary energy source for livestock. The volume of VFA generated is a critical criterion for determining the ratio of milk fat and lactose. Propionate is the primary contributor of glucose for

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lactogenesis, while acetate is directly involved in milk fat production (Ramírez-Restrepo et al. 2016; Danielsson et al. 2017; Shen et al. 2023). Low rumen fermentation efficiency increases methane production as a pathway for disposing of hydrogen, resulting in feed energy loss and reduced milk production efficiency. Therefore, improving rumen fermentation efficiency is a central target for enhancing productive performance while reducing energy losses in dairy goat systems (Greening et al. 2019; Ku-Vera et al. 2020).

The primary focus of research on rumen fermentation efficiency has been on altering nutritional factors through dietary additives. One quickly emerging method in this direction is the use of plant-derived bioactive compounds, particularly tannins, as natural rumen modifiers. Tannins, both condensed and hydrolysable, can bind to proteins, thereby decreasing protein degradation in the rumen and increasing undegradable protein flow to the small intestine (Gunun et al. 2015; Aboagye et al. 2018). In addition, tannins have been reported to reduce protozoa and methanogenic archaea populations, thereby directing hydrogen produced by methanogenesis toward VFA (volatile fatty acid) production, mainly propionate (Carrasco et al. 2017; Fitri et al. 2022; Pazla et al. 2025a). These functional properties make tannins a promising dietary intervention for simultaneously improving nitrogen utilization and mitigating methane emissions.

The same alternation is important when considering the variation in tannin effects on animal performance, depending on the amount fed. At moderate dosages, tannins may enhance nutrient utilization, reduce rumen ammonia levels, and increase milk production without altering feed intake (Broderick et al. 2017; Arık et al. 2024). High-dose tannin treatment, on the other hand, could negatively affect nutrient intake and digestibility by forming non-digestible tannin-protein complexes. Consequently, selecting tannin sources and identifying optimal doses are crucial factors for adopting tannins in dairy goat production systems. This dose-dependent response underscores the importance of identifying locally available tannin sources with manageable antinutritional risks (Hassanat et al. 2017; Besharati et al. 2022).

Fruits from the mangrove, particularly those from *Sonneratia alba*, are a plentiful source of natural tannins that serve as local source and are used in animal husbandry as functional feed ingredients. Multiple studies have documented that mangrove fruits are rich in tannins and phenolic compounds with biological activities that can improve feed quality and control rumen fermentation (Soenardjo and Supriyantini 2017; Elihasridas et al. 2025a). In addition, simple technological treatments of mangrove fruits increase nutrient utilization and reduce the antinutritional effects of tannins. Nonetheless, the literature on the application of mangrove fruit in dairy goats remains scarce, focusing primarily on fermentation parameters and partial digestibility. This gap indicates the need for more comprehensive evaluations that include productive performance and physiological responses in dairy goats (Jamarun et al. 2025).

In contrast, palm fatty acid distillate (PFAD), a byproduct of the palm oil industry, is very rich in fatty acids and could be a high-density energy source for ruminants. The provision of fat increases energy supply for lactation, increases milk yield, and alters ruminal conditions regarding fatty acid biohydrogenation (Vargas-Bello-Pérez et al. 2022; Fitrianggi et al. 2025). The presence of fats acts as another testosterone sink, helping minimize methane production. However, excessive fat intake reduces forage digestibility and disrupts the rumen microbiota; therefore, appropriate formulation strategies are required. Thus, PFAD supplementation requires careful balancing to maximize energy benefits without impairing rumen function (Ungerfeld 2015; Hu et al. 2023).

Feeding mangrove fruits and PFAD together creates a synergistic nutritional approach. Tannins protect proteins and, at the same time, inhibit methanogenic microbes in the rumen, while PFAD is the energy source necessary for lactation support. The bonding between the two can improve rumen fermentation productivity, providing a balanced supply of energy and protein and thereby optimizing the quantity and quality of milk produced. The improved nutrient efficiency influences lactation hormone regulation, particularly insulin and IGF-1, which are the primary regulators of milk synthesis and secretion in dairy goats (Hassanabadi et al. 2021; Izquierdo et al. 2021). Such an integrated feeding strategy may therefore link nutritional efficiency with endocrine regulation of lactation.

There have been several studies examining the separate impacts of tannins or fats. However, few have considered the combined impact of PFAD and mangrove fruit as a tannin source on feed intake, nutrient digestibility, milk production and quality, and the hormonal profile of dairy goats. Hence, this research is of great significance because it not only enhances our understanding of the topic but also, scientifically, supports the development of strategies for feed production that are both efficient and sustainable and reliant on local resources. Addressing this knowledge gap is particularly relevant for tropical production systems that depend heavily on locally available feed resources.

This study hypothesized that dietary supplementation with PFAD combined with mangrove fruit tannins would improve nutrient digestibility and milk quality, and modulate lactation- and stress-related hormonal responses, without negatively affecting feed intake or milk yield. The objective of this study was to evaluate the effects of PFAD and different inclusion levels of mangrove fruit extract on feed intake, nutrient digestibility, milk production and quality, and hormonal profiles (cortisol, oxytocin, and prolactin) in dairy goats.

MATERIALS AND METHODS

Research location and time

The study took place at Toni Farm, a dairy goat farm located in Payakumbuh City, West Sumatra Province, Indonesia (latitude: −0.2330638; longitude: 100.6268024; altitude: ±514m above sea level). The region has a tropical climate with two distinct seasons, and during the study, average temperatures ranged from 20°C to 29°C. The study period was from September to November 2025.

Research materials

The primary research materials were mangrove fruit (*Sonneratia alba*) sourced from the coastal area of Pasaman Regency, West Sumatra, which served as a natural tannin source. The mangrove fruit was dried and ground for use as a feed additive, depending on the treatment. Palm Fatty Acid Distillate (PFAD) was sourced from a palm oil processing plant in North Sumatra and used as a dietary fat energy source in the ration. The basal feed consisted of forage (grass and field shrubs) and concentrates containing tofu pulp, cassava, jackfruit peel, and a mineral mix. Table 1, 2, and 3 present the chemical composition and nutrient content of the rations.

Table 1: Chemical composition of concentrate and forage used in the experimental diets (% dry matter basis)

Chemical composition (%)	Concentrate	Forage
Dry matter	30.95	41.38
Organic matter	96.46	88.46
Crude protein	11.85	16.35
Crude fat	4.57	3.26
Crude fiber	17.53	20.83
Ash	3.54	11.54
Nitrogen-free extract	62.51	48.02
Total digestible nutrient	79.73	66.94
NDF	65.13	45.25
ADF	30.47	29.78
Cellulose	25.72	20.30
Hemicellulose	34.66	15.47
Lignin	2.98	2.81
Silica	1.77	6.67

Table 2: Chemical composition of the experimental rations (% dry matter basis)

Chemical composition	(%)
Dry matter	37.20
Organic matter	91.73
Crude protein	13.64
Crude fat	4.00
Crude fiber	18.85
Ash	8.63
Nitrogen-free extract	72.05
Total digestible nutrient	30.24
NDF	57.24
ADF	22.50
Cellulose	27.00
Hemicellulose	2.87
Lignin	4.71

Table 3: Treatment composition of palm fatty acid distillate (PFAD and mangrove fruit (*Sonneratia alba*) extract in the diets (%)

Treatments (%)	Mangrove fruit	PFAD
T1	0	6
T2	0.5	6
T3	1	6
T4	2	6

Note: T1 = Control diet; T2 = Diet + 6% PFAD + 0.5% mangrove fruit extract; T3 = Diet + 6% PFAD + 1.0% mangrove fruit extract; T4 = Diet + 6% PFAD + 2.0% mangrove fruit extract.

Experimental animals and experimental design

The study used 16 Peranakan Etawa (PE) dairy goats with an initial body weight averaging 40.5±2.37kg and aged 2.5–3years. This study considered the sample size adequate for detecting treatment effects under a randomized block design, with individual animals serving as experimental units and blocking minimizing variability. Similar nutritional and hormonal studies in dairy goats have commonly used 4 animals per treatment with comparable experimental designs and statistical power (Pazla et al. 2022; Prayitno et al. 2025; Arief et al. 2025). Therefore, the use of 16 animals (4 treatments × 4 replicates) was deemed sufficient to evaluate the effects of PFAD and mangrove fruit supplementation on intake, digestibility, milk traits, and hormonal responses. Prior to treatment, all animals underwent a 14-day acclimatization period to the basal diet. This acclimatization period ensured stable physiological conditions and rumen microbe populations. The study followed a Randomized Block Design featuring four treatments and four replicates, in which each replicate included one goat positioned as an experimental unit. The study administered the following treatments:

T1 = Control ration
T2 = Ration + 6% PFAD + 0.5% mangrove fruit extract
T3 = Ration + 6% PFAD + 1.0% mangrove fruit extract
T4 = Ration + 6% PFAD + 2.0% mangrove fruit extract

The treatment and data collection period lasted 46 days, following the adaptation period.

Nutrient consumption and digestibility

The study calculated Nutrient consumption from daily feed intake and the nutrient composition of the experimental diets. Apparent nutrient digestibility was determined using the total fecal collection method. Fecal samples were collected during the last five consecutive days of the experimental period using individual fecal collection bags. The study collected total feces excreted per animal every 24h, weighed and homogenized the samples, and took representative subsamples for chemical analysis. The study analyzed dry matter (DM), crude protein (CP), crude fat, crude fiber, and ash content according to AOAC (2016) guidelines.

Milk production and quality

The study recorded daily milk production throughout the experimental period. The milk sample collection process was done on days 25, 28, 32, 54, 57, and 60 to form a composite representing the mid- and late-phase lactation during the study. The volume of the morning and afternoon milk samples was combined daily. The study used the Lactosan SA Milk Analyzer (Milkronik Ltd., Bulgaria) to analyze milk quality, including fat, protein, lactose, and total solids.

Hormone analysis

At the end of the study, the researchers collected blood samples from the jugular vein. Serum was separated from the blood by centrifugation without an anticoagulant at 3000rpm for 10min. The study measured cortisol, prolactin, and oxytocin concentrations using a commercial ELISA kit (BT-Laboratory, China) according to the manufacturer's instructions. The study read absorbance at 450nm using a microplate reader.

Statistical Analysis

Prior to analysis, data were tested for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene’s test. All data met the assumptions required for parametric analysis. The data were analyzed using one-way ANOVA in SPSS version 21.0. When significant differences among treatments were observed ($P<0.05$), the study used Duncan's Multiple Range Test. The study treated each animal as an independent experimental unit and presented data as mean±SD.

RESULTS

Feed intake

Based on Table 4, supplementation of PFAD and mangrove fruit extract in the ration had no significant effect (P>0.05) on the dry matter, organic matter, and crude protein intake of dairy goats. Dry matter intake ranged from 2.954 to 2.993kg/head/day, organic matter intake ranged from 2.703 to 2.782kg/head/day, and crude protein intake ranged from 0.408 to 0.411kg/head/day in all treatments.

Nutrient digestibility

Ration treatment significantly influenced (P<0.05) the digestibility of dry matter, organic matter, and crude protein in dairy goats (Table 5). Dry matter digestibility in treatment T1 (62.96±0.62%) was lower than in T3 (65.25±0.80%) and T4 (65.62±0.81%), but not significantly different from T2 (64.23±1.45%). Organic matter digestibility showed a significant difference (P<0.05), with treatment T4 (66.65±0.54%) higher than T1 (63.97±0.56%) and the other treatments. Furthermore, crude protein digestibility differed significantly among treatments (P<0.05). Treatment T4 produced the highest crude protein digestibility (66.24±0.47%) and was significantly different from T1 (62.81±0.92%), T2 (63.53±0.49%), and T3 (64.20±1.12%).

Milk production and quality

Based on Table 6, milk production in dairy goats was not significantly influenced (P>0.05) by feed treatment. Milk production ranged from 0.987 to 1.003liters/head/day in all treatments. Milk fat content differed significantly among treatments (P<0.05). Treatment T2 produced the highest fat content (7.95±1.18%) and was significantly different from T1 (5.84±0.41%) and T3 (5.92±1.89%), while T4 (6.55±2.44%) was in between. Milk protein and lactose levels showed no significant differences (P>0.05) among treatments, with protein levels ranging from 3.090% to 3.363% and lactose levels ranging from 2.925% to 3.180%.

The parameters of total milk solids, namely non-fat solids and total solids, also did not differ significantly (P>0.05) among treatments. The levels of non-fat solids varied between 6.51 and 7.08%, whereas the total solids levels varied between 13.21 and 14.66%. Furthermore, the physical properties of milk (i.e., density and salt content) and the treatment feed, as shown by the high P-value (P>0.05), had no significant effect on its quality. The milk density changed very little during the experiment, ranging from 1.021 to 1.022, whereas the salt content was more variable, ranging from 0.430 to 0.463%.

Table 4: Feed Intake of dairy goats fed diets supplemented with palm fatty acid distillate (PFAD) and mangrove fruit (*Sonneratia alba*) extract

Parameter (kg/head/day)	Treatment			
	T1	T2	T3	T4
Dry matter intake	2.972±0.023^{NS}	2.983±0.043^{NS}	2.954±0.041^{NS}	2.993±0.039^{NS}
Organic matter intake	2.703±0.041^{NS}	2.734±0.033^{NS}	2.766±0.041^{NS}	2.782±0.046^{NS}
Crude protein intake	0.410±0.003^{NS}	0.408±0.002^{NS}	0.411±0.006^{NS}	0.409±0.004^{NS}

Note: T1 = Control diet; T2 = Diet + 6% PFAD + 0.5% mangrove fruit extract; T3 = Diet + 6% PFAD + 1.0% mangrove fruit extract; T4 = Diet + 6% PFAD + 2.0% mangrove fruit extract. NS = not significant (P > 0.05).

Table 5: Nutrient digestibility of dairy goats fed diets supplemented with palm fatty acid distillate (PFAD) and mangrove fruit (*Sonneratia alba*) extract

Parameter (%)	Treatment			
	T1	T2	T3	T4
Dry matter digestibility	62.96±0.62^{b}	64.23±1.45^{ab}	65.25±0.80^{a}	65.62±0.81^{a}
Organic matter digestibility	63.97±0.56^{c}	65.15 ±0.97^{b}	65.50±0.81^{b}	66.65±0.54^{a}
Crud protein digestibility	62.81±0.92^{b}	63.53±0.49^{b}	64.20±1.12^{b}	66.24±0.47^{a}

Note: T1 = Control diet; T2 = Diet + 6% PFAD + 0.5% mangrove fruit extract; T3 = Diet + 6% PFAD + 1.0% mangrove fruit extract; T4 = Diet + 6% PFAD + 2.0% mangrove fruit extract. Different superscripts on the same row indicate significant differences (P<0.05).

Table 6: Milk production and quality of dairy goats fed diets supplemented with palm fatty acid distillate (PFAD) and mangrove fruit (*Sonneratia alba*) extract

Parameter	T1	T2	T3	T4
Milk production and main components				
Milk production (L day^{-1})	0.987±0.03^{NS}	0.993±0.02^{NS}	1.002±0.04^{NS}	1.003±0.01^{NS}
Fat (%)	5.84±0.41^{c}	7.95±1.18^{a}	5.92±1.89^{c}	6.55±2.44^{b}
Protein (%)	3.260±0.45^{NS}	3.363±0.22^{NS}	3.175±0.20^{NS}	3.090±0.49^{NS}
Lactose (%)	3.088±0.43^{NS}	3.180±0.20^{NS}	3.008±0.18^{NS}	2.925±0.46^{NS}
Total milk solids				
Solid non-fat (%)	6.87±0.95^{NS}	7.08±0.46^{NS}	6.69±0.42^{NS}	6.51±1.03^{NS}
Total solid (%)	13.21±0.56^{NS}	14.66±1.51^{NS}	13.69±2.26^{NS}	14.15±1.79^{NS}
Physical properties and milk purity				
Density	1.022±0.003^{NS}	1.021±0.001^{NS}	1.021±0.001^{NS}	1.021±0.001^{NS}
Salts (%)	0.463±0.07^{NS}	0.463±0.03^{NS}	0.453±0.02^{NS}	0.430±0.09^{NS}
Freezing Points (°C)	−0.381±0.05^{NS}	−0.400±0.03^{NS}	−0.370±0.03^{NS}	−0.360±0.05^{NS}

Note: T1 = Control diet; T2 = Diet + 6% PFAD + 0.5% mangrove fruit extract; T3 = Diet + 6% PFAD + 1.0% mangrove fruit extract; T4 = Diet + 6% PFAD + 2.0% mangrove fruit extract. Different superscripts on the same row indicate significant differences (P<0.05). NS = not significant (P>0.05).

Table 7: Stress hormone and lactation profiles (cortisol, oxytocin, and prolactin) of dairy goats fed diets supplemented with palm fatty acid distillate (PFAD) and mangrove fruit (*Sonneratia alba*) extract

Parameter (ng/L)	Treatment			
	T1	T2	T3	T4
Cortisol	530.67±9.34[d]	510.60±4.85[d]	465.16±13.30[b]	407.61±16.88[a]
Oxytocin	3.05±0.64[c]	3.20 ±0.64[c]	4.42±0.56[b]	6.15±0.68[a]
Prolactin	6.32±0.61[c]	7.02±1.12[bc]	7.85±0.92[b]	11.20±0.69[a]

Note: T1 = Control diet; T2 = Diet + 6% PFAD + 0.5% mangrove fruit extract; T3 = Diet + 6% PFAD + 1.0% mangrove fruit extract; T4 = Diet + 6% PFAD + 2.0% mangrove fruit extract. Different superscripts on the same row indicate significant differences (P<0.05).

Stress hormone and lactation profile

According to Table 7, the ration treatment had a significant impact on the cortisol, oxytocin, and prolactin levels in the dairy goats at the P<0.05 level. Cortisol levels were highest in treatment T1 (530.67±9.34ng/L) and decreased significantly in treatments T2 (510.60ng/L±4.85), T3 (465.16ng/L±13.30), and T4 (407.61ng/L±16.88), with the lowest value in T4. Oxytocin levels also showed significant differences between treatments (P<0.05). Treatment T4 produced the highest oxytocin levels (6.15ng/L±0.68), followed by T3 (4.42ng/L±0.56), while T1 (3.05ng/L±0.64) and T2 (3.20ng/L±0.64) showed lower values. Furthermore, prolactin levels differed significantly (P<0.05) between treatments. Treatment T4 produced the highest prolactin levels (11.20ng/L±0.69), while T1 showed the lowest values (6.32ng/L±0.61). Treatments T2 (7.02ng/L±1.12) and T3 (7.85ng/L±0.92) were in between.

Zafar: Correct all values in the above para as shown in green.

DISCUSSION

Feed intake

The results of this study showed that feeding PFAD and mangrove fruit extract up to 2.0% did not significantly affect (P>0.05) the goats' daily intake of dry matter, organic matter, and crude protein. These findings indicate that the animals still accept the treatment ration and do not reduce consumption, as such reductions are commonly linked to low palatability or physiological disorders (Kholif et al. 2016; Cortese et al. 2019; Bedford et al. 2020).

The stable feed intake pattern across all treatments indicates that the levels of PFAD and mangrove tannin supplementation remain within the physiological tolerance limits of dairy goats. This condition is beneficial, as just-enough feed intake is one of the key factors in maintaining energy balance and, further, in regulating metabolic processes during lactation (Harjanti et al. 2017; Mariana et al. 2019). In addition, the comparable crude protein intake across treatments suggests that the inclusion of mangrove fruit extract did not block protein absorption from the diet and, consequently, the potential for nutrient utilization remained active (Kolawole et al. 2019; Braun et al. 2019; Poolthajit et al. 2021).

The effects of tannins on feed intake are known to be dependent on the amount given. Livestock tolerate tannins at low to moderate dietary levels without reductions in feed intake (Patra and Saxena 2010; Wang et al. 2022); however, intake usually decreases at higher doses (Gunun et al. 2018). The absence of differences in consumption in this study indicates that the level of mangrove fruit extract inclusion used is still safe for dairy goats.

Nutrient digestibility

The increase in dry matter, organic matter, and crude protein digestibility in treatments with higher levels of mangrove fruit extract clearly indicates that tannins significantly affect nutrient digestion in dairy goats. Tannins, as polyphenolic compounds, are known to affect the digestibility and utilization of nutrients, depending on dosage (feed, etc.); therefore, low and moderate levels can increase nutrient extraction efficiency. However, very high concentrations reduce feed digestibility, particularly of mineral- and fiber-rich components, by forming insoluble complexes (Adejoro et al. 2019; Avila et al. 2020; Besharati et al. 2022).

The high crude protein digestibility observed in the mangrove fruit supplementation treatment suggests a role for tannins in preventing complete ruminal degradation of feed protein. Tannins can initiate reversible interactions with proteins, which, in turn, result in lowering the rate of protein destruction by the microbes of the rumen; thus, more protein is allowed to pass through the rumen and be digested and absorbed in the small intestine (Gunun et al. 2016; Iswarin et al. 2016). This mechanism contributes to enhanced nitrogen use efficiency and crude protein digestibility, as reduced rumen protein degradation is associated with less ammonia production and more protein reaching the intestine (Adejoro et al. 2019; Sharifi and Chaji 2019).

Furthermore, the increase in the digestibility of dry matter and organic matter suggests that tannins are not only regulators of proper microbial activity but also stabilizers of rumen fermentation. It has been published that tannin controls protozoa numbers, does not allow mutualism to develop efficiently between nutrient and cellulose bacteria, and forms VFAs (volatile fatty acids) more efficiently, which, in the end, has a positive impact on the organic part of the ration's utilization (Perna Junior et al. 2022). The conditions thus created allow for an increase in digestibility without a decrease in feed intake that is not so great as to go unnoticed, as has been the case in the research outcomes of this study.

Relying on PFAD as a source of fat in the feed increases the nutrient digestibility of tannins. Nevertheless, fat is known to have such an effect as to interfere with the activities of the rumen microbes. However, several studies have shown that specific fatty acids can serve as energy sources for microbes, thereby indirectly supporting fermentation stability (Bhagwat et al. 2012; Pecka-Kiełb et al. 2021). Mixing tannins from mangroves with PFAD is thought to balance rumen fermentation, thereby reducing the negative impact of fat on digestibility and maintaining nutrient utilization efficiency (Guo et al. 2023; Elihasridas et al. 2025b; Pazla et al. 2025b; Zhang et al. 2025).

Milk production and quality

According to the data presented in Table 6, the addition of PFAD and mangrove fruit extract did not cause a significant change in milk production by dairy goats (P>0.05). Various physiological factors beyond nutrition, such as the lactation phase (Rahmadiati et al. 2023), hormonal status (Prihantoro et al. 2021), and genetic capacity of livestock (Widianingrum 2021), influence milk production in dairy cattle. As a result, milk production often shows a limited response to feed interventions.

Although milk production did not differ significantly, ration treatment significantly influenced milk fat content (P<0.05). The increase in milk fat content in the PFAD treatment suggests that feed fat plays a significant role in modifying milk composition. Feed fat, including PFAD and palm oil, is a high-density energy source that plays a greater role in altering milk composition, particularly the fat fraction, than in increasing milk production volume (Handojo et al. 2018).

An increase in milk fat proportion relates to the function of rumen fermentation products, especially acetate and β-hydroxybutyrate, which are considered the main precursors of milk fat production. Acetate is the primary carbon source for the formation of new fatty acids in mammary glands (Lin et al. 2019), and β-hydroxybutyrate is an energy source that helps to maintain metabolic efficiency during lactation (Lv et al. 2021). This conclusion indicates that PFAD supplementation increases energy utilization for milk fat production, but does not necessarily increase overall milk yield.

The use of mangrove fruit extract as a source of tannin did not lead to any significant increase or decrease in the levels of protein, lactose, non-fat solids (NFS) and total milk solids (P>0.05). This result means that the level of tannins used does not affect the synthesis of the main milk components. Tannins enhance nutrient utilization efficiency by protecting feed protein (Anantasook et al. 2016) and stabilizing rumen fermentation, thereby maintaining nutrient availability for milk synthesis without affecting milk quality (Yanza et al. 2021).

The current findings on milk composition stability align with reports of moderate tannin supplementation, which typically maintains milk quality without consistently increasing milk volume (Dey and De 2014). Therefore, tannins derived from mangrove fruits function as possible functional feed additives that contribute to the quality of milk without having any adverse effects on the synthesis of the major milk components.

Stress hormone and lactation profiles

PFAD supplementation and mangrove fruit extract significantly (P<0.05) modified the hormonal and lactation profiles in dairy goats as reflected by the levels of cortisol, oxytocin, and prolactin. The control treatment (T1) showed the highest cortisol values, and successive treatments with increasing levels of mangrove fruit extract resulted in a significant reduction in cortisol levels, with T4 showing the lowest values. Cortisol is a stress hormone related to nutritional status and metabolic balance; hence, its decrease indicates a more favorable physiological condition and less stress in animals as a result of better feed (DiGiacomo et al. 2018; Fazio et al. 2024).

Mangrove tannin administration significantly reduced cortisol levels, indicating that these secondary plant metabolites alleviate physiological stress associated with impaired rumen fermentation and nutrient intake. Tannins reduce protozoa numbers, thereby enabling fermentation to proceed and, consequently, reducing physiological stress reactions in livestock (Roca-Fernández et al. 2020; Antonius et al. 2023).

In line with the decrease in cortisol, oxytocin concentrations were significantly elevated (P<0.05) in response to treatment with a higher dose of mangrove fruit extract. Oxytocin is the primary hormone that plays a role in the milk let-down reflex through the contraction of myoepithelial cells around the alveoli of the mammary gland (Masedunskas et al. 2017). The increase in oxytocin in this study indicates that the animals were in a more comfortable physiological state, which supports the efficiency of the lactation process. Additionally, oxytocin improves animal welfare by promoting its release, which links to reduced stress and more favorable physiological interactions (Ziegler et al. 2015; Chen and Sato 2016).

The treatment with T3 and T4 was significantly different (P<0.05) from the control in terms of prolactin levels, which increased substantially. Prolactin is the primary hormone in the lactation process and serves as the main regulator of milk production in the mammary glands. Higher prolactin levels are suggested to indicate sufficient nutrient availability (Vailati-Riboni et al. 2016) and good metabolic status in animals (Humer et al. 2018).

The relationship between nutritional condition and hormonal response is also clear in the case of PFAD's role as an energy source and tannins as metabolic alchemists. PFAD is an energy source that maintains metabolic balance (Handojo et al. 2019). In contrast, tannins facilitate the capture of feed proteins and improve nutrient flow to the rumen (Pazla et al. 2025c), ultimately altering hormone levels during lactation (Shi et al. 2017). The upsurge in prolactin and oxytocin hormones, thus, is a better indicator of the efficiency and quality improvement of the lactation process than the simple quantitative increase in milk production.

The combination of PFAD and mangrove fruit extract in dairy goats had a positive effect on their physiological status, as summarized in Table 7, by lowering stress-related hormones and simultaneously promoting the release of lactation hormones. The presence of such a hormonal profile is an important sign that the effects of improved nutritional rations are first evident in endocrine responses and animal welfare before they are reflected in milk production parameters (Sun et al. 2015; Wang et al. 2016; Anwar et al. 2023).

The relatively small sample size and short experimental duration limit this study. Future studies with larger animal populations and more extended feeding periods are required to confirm the long-term effects of PFAD and mangrove fruit extract supplementation.

Conclusion

Dietary supplementation of 6% PFAD along with 2.0% *Sonneratia alba* (mangrove) fruit extract in the dairy goat diet did not cause any changes in feed intake and milk production. However, it did enhance nutrient digestibility and alter milk quality, especially fat content. The increase across the board in dry matter, organic matter, and crude protein digestibility has been a clear indication of improved nutrient utilization efficiency and of the animals' metabolic balance being unaffected. Additionally, this treatment combination reduced stress hormone (cortisol) levels and increased lactation hormones (oxytocin and prolactin), reflecting more stable physiological conditions in the animals and supporting the efficiency of the lactation process. Overall, the use of PFAD and mangrove fruit extract as functional feed ingredients has the potential to improve milk quality and the welfare of dairy goats through enhanced nutrient efficiency and hormonal responses. However, it does not directly increase milk production volume. Practically, PFAD and mangrove fruit extract may be used as functional feed ingredients to improve nutrient efficiency and milk quality while maintaining animal welfare and production performance.

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Author's Contribution: EE, RP: conceptualization, methodology, formal analysis, resources, investigation, writing-original draft. AA, NJ: data curation, resources, investigation, writing-original draft. YU, ZI: funding acquisition, investigation, data curation, writing-original draft, and finalizing it. GY: validation, investigation, resources, writing the original draft, and finalizing it. All authors have reviewed and given their approval for the final version of this manuscript.

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REFERENCES

Aboagye IA, Oba M, Castillo AR, Koenig KM, Iwaasa AD and Beauchemin KA, 2018. Effects of hydrolyzable tannin with or without condensed tannin on methane emissions and nitrogen use in beef cattle. Journal of Animal Science 96(12): 1–12. https://doi.org/10.1093/jas/sky352

Adejoro FA, Hassen A and Akanmu AM, 2019. Effect of lipid-encapsulated acacia tannin extract on feed intake, nutrient digestibility, and methane emission in sheep. Animal 9(11): 863. https://doi.org/10.3390/ani9110863

Aguilar-González M, Buitrón G, Shimada A, Ayala-Sumuano J, González-Dávalos L, Varela-Echavarría A and Mora O, 2022. Study on manipulation of ruminal fermentation using a bioelectrochemical system. Journal of Animal Physiology and Animal Nutrition 107(2): 357–366. https://doi.org/10.1111/jpn.13723

Anantasook N, Wanapat M, Gunun P and Cherdthong A, 2016. Reducing methane production by supplementation of *Terminalia chebula* RETZ containing tannins and saponins. Animal Science Journal 87(6): 783-790. https://doi.org/10.1111/asj.12494

Antonius A, Pazla R, Putri EM, Negara W, Laia N, Ridla M, Suharti S, Jayanegara A, Asmairicen S, Marlina L and Marta Y, 2023. Effectiveness of herbal plants on rumen fermentation, methane gas emissions, in vitro nutrient digestibility, and population of protozoa. Veterinary World 16(7): 1477-1488. https://doi.org/10.14202/vetworld.2023.1477-1488

Anwar F, Tariq H, Usman A, Mobashar M, Akram K, Yousaf M, Anwar MMJ, Manzoor A, Rahim A, Khalid A and Saleem M, 2023. Nutritional Interventions on Dairy Performance and Profitability. Biological and Clinical Sciences Research Journal 4(1): 511. https://doi.org/10.54112/bcsrj.v2023i1.511

AOAC (2016). Official Methods of Analysis of AOAC International (20th ed). AOAC International.

Arief A, Pazla R, Rizqan and Yanti G, 2025. Optimizing goat milk production and quality: evaluation of local feed sources for sustainable nutrition in the tropics. International Journal of Agriculture and Biosciences 14(6): 1465-1473. https://doi.org/10.47278/journal.ijab/2025.170

Arık H, İnanç Z, Kahraman O, Damar S and Akkaya A, 2024. Effects of quebracho tannin supplementation in early lactation dairy cow rations on milk yield parameters, rumen fermentation, digestibility and blood parameters. Journal of Animal and Feed Sciences 33(3): 321–330. https://doi.org/10.22358/jafs/183438/2024

Avila AS, Zambom MA, Faccenda A, Fischer ML, Anschau FA, Venturini T, Tinini RCR, Dessbesell JG and Faciola AP, 2020. Effects of Black Wattle (*Acacia mearnsii*) Condensed Tannins on Intake, Protozoa Population, Ruminal Fermentation, and Nutrient Digestibility in Jersey Steers. Animals 10(6): 1011. https://doi.org/10.3390/ani10061011

Bedford A, Beckett L, Harthan L, Wang C, Jiang N, Schramm H, Guan LL, Daniels KM, Hanigan MD and White RR, 2020. Ruminal volatile fatty acid absorption is affected by elevated ambient temperature. Scientific Reports 10(1): 13902. https://doi.org/10.1038/s41598-020-69915-x

Besharati M, Maggiolino A, Palangi V, Kaya A, Jabbar M, Eseceli H, De Palo P and Lorenzo JM, 2022. Tannin in Ruminant Nutrition: Review. Molecules 27(23), 8273. https://doi.org/10.3390/molecules27238273

Bhagwat AM, De Baets B, Steen A, Vlaeminck B and Fievez V, 2012. Prediction of ruminal volatile fatty acid proportions of lactating dairy cows based on milk odd- and branched-chain fatty acid profiles: New models, better predictions. Journal of Dairy Science 95(7): 3926-3937. https://doi.org/10.3168/jds.2011-4850

Braun HS, Schrapers KT, Mahlkow-Nerge K, Stumpff F and Rosendahl J, 2019. Dietary supplementation of essential oils in dairy cows: evidence for stimulatory effects on nutrient absorption. Animal 13(3): 518-523. https://doi.org/10.1017/s1751731118001696

Broderick GA, Grabber JH, Muck RE and Hymes-Fecht UC, 2017. Replacing alfalfa silage with tannin-containing birdsfoot trefoil silage in total mixed rations for lactating dairy cows. Journal of Dairy Science 100(5): 3548–3562. https://doi.org/10.3168/jds.2016-12073

Carrasco JMD, Cabral C, Redondo LM, Pin Viso ND, Colombatto D, Farber MD and Miyakawa MEF, 2017. Impact of chestnut and quebracho tannins on rumen microbiota of bovines. Biomed Research International 2017: 9610810. https://doi.org/10.1155/2017/9610810

Chen S and Sato S, 2016. Role of oxytocin in improving the welfare of farm animals — A review. Asian-Australasian Journal of Animal Sciences 30(4): 449-454. https://doi.org/10.5713/ajas.15.1058

Cortese M, Segato S, Andrighetto I, Ughelini N, Chinello M, Schiavon E and Marchesini G, 2019. The Effects of Decreasing Dietary Crude Protein on the Growth Performance, Feed Efficiency and Meat Quality of Finishing Charolais Bulls. Animals 9(11): 906. https://doi.org/10.3390/ani9110906

Danielsson R, Dicksved J, Sun L, Gonda H, Müller B, Schnürer A and Bertilsson J, 2017. Methane production in dairy cows correlates with rumen methanogenic and bacterial community structure. Frontiers in Microbiology 8: 226. https://doi.org/10.3389/fmicb.2017.00226

Dey A and De PS, 2014. Influence of condensed tannins from *Ficus bengalensis* leaves on feed utilization, milk production and antioxidant status of crossbred cows. Asian-Australasian Journal of Animal Sciences 27(3): 342-348. https://doi.org/10.5713/ajas.2013.13295

Dey M, Jairath G, Gadzama I, Alves S and Ponnampalam E, 2025. Impact of mixed rations on rumen fermentation, microbial activity and animal performance. Ruminants 5(3): 42. https://doi.org/10.3390/ruminants5030042

DiGiacomo K, Norris E, Dunshea FR, Hayes BJ, Marett LC, Wales WJ and Leury BJ, 2018. Responses of dairy cows with divergent residual feed intake as calves to metabolic challenges during midlactation and the nonlactating period. Journal of Dairy Science 101(7): 6474-6485. https://doi.org/10.3168/jds.2017-12569

Elihasridas E, Pazla R, Ikhlas Z, Yanti G, Martaguri I, Fitri Y and Sari R, 2025a. Improving feed quality through the addition of mangrove fruit (*Sonneratia alba*). Andalasian Livestock 2(1): 71–85. https://doi.org/10.25077/alive.v2.n1.p71-85.2025

Elihasridas, Pazla, R, Antonius, Yanti G, Ikhlas Z, Fitri Y, Zulfadillah J, Bariva MA, Subhi MA, Triana N and Elfindo T, 2025b. Interaction of palm fatty acid distillate (PFAD) and high-tannin mangrove fruit extract (*Sonneratia alba*) on the in vitro digestibility of fiber fractions in dairy cattle feed. Andalasian Livestock 2(2): 178–184. https://doi.org/10.25077/alive.v2.n2.p178-184.2025

Fazio E, Bionda A, Attard G, Medica P, La Fauci D, Amato A, Liotta L and Lopreiato V, 2024. Effect of the lactation phases on the amplitude of variation in blood serum steroid hormones and some hematochemical analytes in three dairy cow breeds. Animals 14(22): 3336. https://doi.org/10.3390/ani14223336

Fitrianggi EN, Zain M and Montesqrit, 2025. The oil supplementation in animal feed research across Indonesia: research method to data analysis. Andalasian Livestock 2(2): 113–125. https://doi.org/10.25077/alive.v2.n2.p113-125.2025

Fitri A, Yanza YR, Jayanegara A, Ridwan R, Astuti WD, Sarwono KA, Fidriyanto R, Rohmatussolihat R, Widyastuti Y and Obitsu T, 2022. Divergence effects between dietary acacia and quebracho tannin extracts on nutrient utilization and methane emission of ruminants. Animal Science Journal 93(1): e13765. https://doi.org/10.1111/asj.13765

Greening C, Geier R, Wang C, Woods LC, Morales SE, McDonald MJ, Rushton-Green R, Morgan XC, Koike S, Leahy SC, Kelly WJ, Cann I, Attwood GT, Cook GM and Mackie RI, 2019. Diverse hydrogen production and consumption pathways influence methane production in ruminants. The ISME Journal 13(10): 2617–2632. https://doi.org/10.1038/s41396-019-0464-2

Gunun P, Gunun N, Khejornsart P, Ouppamong T, Cherdthong A, Wanapat M, Sirilaophaisan S, Yuangklang C, Polyorach S, Kenchaiwong W and Kang S, 2018. Effects of *Antidesma thwaitesianum Muell. Arg.* Pomace as a source of plant secondary compounds on digestibility, rumen environment, hematology, and milk production in dairy cows. Animal Science Journal 90(3): 372-381. https://doi.org/10.1111/asj.13147

Gunun P, Wanapat M, Gunun N, Cherdthong A, Sirilaophaisan S and Kaewwongsa W, 2015. Effects of condensed tannins on rumen fermentation characteristics and nitrogen utilization in goats. Asian-Australasian Journal of Animal Sciences 29(8): 1111–1119. https://doi.org/10.5713/ajas.15.0552

Gunun P, Wanapat M, Gunun N, Cherdthong A, Sirilaophaisan S and Kaewwongsa W, 2016. Effects of condensed tannins in mao (*Antidesma thwaitesianum Muell. Arg*.) seed meal on rumen fermentation characteristics and nitrogen utilization in goats. Asian-Australasian Journal of Animal Sciences 29(8): 1111–1119. https://doi.org/10.5713/ajas.15.0552

Guo C, Kong F, Li S, Wang X, Sun X, Du W, Dai D, Wang S, Xie B and Xu X, 2023. Effect of alkaline mineral complex buffer supplementation on milk performance, serum variables, rumen fermentation and rumen microbiota of transition dairy cows. Fermentation 9(9): 792. https://doi.org/10.3390/fermentation9090792

Handojo L, Indarto A, Shofinita D, Meitha A, Nabila R and Triharyogi H, 2018. Calcium soap from palm fatty acid distillate (PFAD) for ruminant feed: quality of calcium source. MATEC Web of Conferences 156: 02007. https://doi.org/10.1051/matecconf/201815602007

Handojo L, Indarto A, Shofinita D, Saadi MR, Yulistia D and Hasyyati FI, 2019. Calcium soap from palm fatty acid distillate for ruminant feed: Calcium oxide particle size. MATEC Web of Conferences 268: 03001. https://doi.org/10.1051/matecconf/201926803001

Harjanti WA, Harjanti DW, Sambodho P and Santoso SAB, 2017. Pengaruh suplementasi baking soda dalam pakan terhadap urea darah dan urea susu sapi perah laktasi. Jurnal Peternakan Indonesia (Indonesian Journal of Animal Science) 19(2): 66-72. https://doi.org/10.25077/jpi.19.2.65-71.2017

Hassanabadi M, Mohri M and Seifi H, 2021. Effects of vitamin D3 injection in close-up period on insulin resistance and energy balance in transition dairy cows. Veterinary Medicine and Science 8(2): 741–751. https://doi.org/10.1002/vms3.692

Hassanat F, Gervais R and Benchaar C, 2017. Methane production, ruminal fermentation characteristics, nutrient digestibility, nitrogen excretion, and milk production of dairy cows fed conventional or brown midrib corn silage. Journal of Dairy Science 100(4): 2625–2636. https://doi.org/10.3168/jds.2016-11862

Hu F, Piao M, Yang C, Diao Q and Tu Y, 2023. Effects of coconut oil and palm oil on rumen microbiota and fatty acid profile. Microorganisms 11(3): 655. https://doi.org/10.3390/microorganisms11030655

Humer E, Gruber L and Zebeli Q, 2018. Effects of meeting the requirements in energy and protein, and of systemic inflammation on the interval from parturition to conception in dairy cows. Czech Journal of Animal Science 63(6): 201-211. https://doi.org/10.17221/13/2017-cjas

Iswarin R, Fani F and Pambudi AW, 2016. Particle size's effect of application forage processing technology on consumption efficiency, palatability and digestibility of local goat. Animal Production 18(1): 8-13. https://doi.org/10.20884/1.anprod.2016.18.1.529

Izquierdo A, Reyes A, Lang G, Oaxaca J, Liera J, Mancera A, Mosqueda M, Vázquez A, Aparicio P, Cedeño C, Pérez J and Sánchez R, 2021. Nutrition and food in the reproduction of cattle. European Journal of Agriculture and Food Sciences 3(3): 21–33. https://doi.org/10.24018/ejfood.2021.3.3.184

Jamarun N, Pazla R, Jayanegara A, Elihasridas E, Yanti G, Antonius A and Ardani LR, 2025. Evaluation of lime treatment in reducing tannin content and enhancing nutrient utilization of mangrove fruits. Emirates Journal of Food and Agriculture 37: 1–11. https://doi.org/10.3897/ejfa.2025.126901

Kholif AE, Morsy TA, Abd El Tawab AM, Anele UY and Galyean ML, 2016. Effect of supplementing diets of anglo-nubian goats with soybean and flaxseed oils on lactational performance. Journal of Agricultural and Food Chemistry 64(31): 6163-6170. https://doi.org/10.1021/acs.jafc.6b02625

Kolawole D, Esenowo E, Abu OA and Umoh JE, 2019. Growth performance, nutrient digestibility and economy of rabbits fed varying dietary levels of Cameroon pepper fruit meal. Journal of Biology, Agriculture and Healthcare 9(24): 38-43. https://doi.org/10.7176/jbah/9-24-06

Ku-Vera JC, Jiménez-Ocampo R, Valencia-Salazar SS, Montoya-Flores MD, Molina-Botero IC, Arango J, Gómez-Bravo CA, Aguilar-Pérez CF and Solorio-Sánchez FJ, 2020. Role of secondary plant metabolites on enteric methane mitigation in ruminants. Frontiers in Veterinary Science 7: 584. https://doi.org/10.3389/fvets.2020.00584

Lin Y, Lv H, Jiang M, Zhou J, Song S and Hou X, 2019. Functional analysis of the dairy cow mammary transcriptome between early lactation and mid-dry period. Journal of Dairy Research 86(1): 63-67. https://doi.org/10.1017/s0022029919000049

Lv H, Meng Q, Wang N, Duan X, Hou X and Lin Y, 2021. Cell death-inducing DNA fragmentation factor-α-like effector C (CIDEC) regulates acetate- and β-hydroxybutyrate-induced milk fat synthesis by increasing FASN expression in mammary epithelial cells of dairy cows. Journal of Dairy Science 104(5): 6212-6221. https://doi.org/10.3168/jds.2020-18975

Mariana E, Sumantri C, Astuti DA, Anggraeni A and Gunawan A, 2019. Mikroklimat, termoregulasi dan produktivitas sapi perah friesians holstein pada ketinggian tempat berbeda. Jurnal Ilmu Dan Teknologi Peternakan Tropis 6(1): 70. https://doi.org/10.33772/jitro.v6i1.5617

Masedunskas A, Chen Y, Stussman R, Weigert R and Mather IH, 2017. Kinetics of milk lipid droplet transport, growth, and secretion revealed by intravital imaging: lipid droplet release is intermittently stimulated by oxytocin. Molecular Biology of the Cell 28(7): 935-946. https://doi.org/10.1091/mbc.e16-11-0776

Patra AK and Saxena J, 2010. Exploitation of dietary tannins to improve rumen metabolism and ruminant nutrition. Journal of the Science of Food and Agriculture 91(1): 24-37. https://doi.org/10.1002/jsfa.4152

Pazla R, Jamarun N, Zain M, Arief, Yanti G, Putri EM, Candra RH, 2022. Impact of *Tithonia diversifolia* and *Pennisetum purpureum*-based ration on nutrient intake, nutrient digestibility and milk yield of Etawa crossbreed dairy goat. International Journal of Veterinary Science 11(3): 327-335. https://doi.org/10.47278/journal.ijvs/2021.119

Pazla R, Natsir A, Hidayat R, Ginting N, Jamarun N, Zain M, Antonius, Ikhlas Z, Rosani U, Sucitra LS, Utami BV and Hidayat MZ, 2025a. The role of dosage and regional origin of Gambir (*uncaria gambir*) leaf extract in enhancing rumen fermentation and suppressing methane emissions. Energy Nexus 20: 100564. https://doi.org/10.1016/j.nexus.2025.100564

Pazla R, Antonius, Jamarun N, Elihasridas, Ikhlas Z, Fitri Y, Rohaeni ES, Usman, Rostiana O, Waryat, Setyadjit, Lintang M, Yani A, Joseph GH, Marlina L and Ardinal, 2025b. Encapsulated gambir catechin–palm fatty acid distillate as an antibacterial and antioxidant feed additive and its effects on rumen fermentation products. Results in Engineering 27: 105914. https://doi.org/10.1016/j.rineng.2025.105914

Pazla R, Antonius A, Ikhlas Z, Jayanegara A, Ardani LR, Hadiatry MC, Jumjunidang J, Budiyanti T, Firsoni F, Ardinal A, Iswari K, Febrina D and Ratni E, 2025c. The potential of tannin from *Sonneratia alba* fruit in defaunation of rumen protozoa and reducing methane gas production: an approach to increase livestock digestive efficiency. Czech Journal of Animal Science 70(6): 223–233. https://doi.org/10.17221/130/2024-CJAS

Pecka-Kiełb E, Miśta D, Króliczewska B, Zachwieja A, Słupczyńska M, Król B and Sowiński J, 2021. Changes in the in vitro ruminal fermentation of diets for dairy cows based on selected sorghum cultivars compared to maize, rye and grass silage. Agriculture 11(6): 492. https://doi.org/10.3390/agriculture11060492

Perna Junior F, Galbiatti Sandoval Nogueira R, Ferreira Carvalho R, Cuellar Orlandi Cassiano E and Mazza Rodrigues PH, 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. Journal of Animal Physiology and Animal Nutrition 107(1): 89-102. https://doi.org/10.1111/jpn.13702

Poolthajit S, Srakaew W, Haitook T and Wachirapakorn C, 2021. Effects of betaine-biotin-chromium supplementation and concentrate to roughage ratio on nutrient utilization efficiency in Thai native cattle. Animals 11(9): 2747. https://doi.org/10.3390/ani11092747

Prayitno CH, Sarwanto D dan Setiadi D, 2025. Effects of seaweed and organic mineral supplementation on nutrient digestibility and milk yield in lactating Saanen crossbred goats. Buletin Peternakan 49(3): 172–179. https://doi.org/10.21059/buletinpeternak.v49i3.107899

Prihantoro YW, Muktiani A and Harjanti DW, 2021. The intake of total digestible nutrient, digestibility of dry matter and organic matter of lactating cows that get supplements of *Curcuma xanthorriza* Roxb. Jurnal Ilmiah Peternakan Terpadu 9(1): 44. https://doi.org/10.23960/jipt.v9i1.p44-52

Rahmadiati OC, Rochmi SE, Yuliani MGA, Ma'ruf A, Sofyan MS, Achmad AB and Chrismanto D, 2023. Quality and quantity of dairy cow milk production in view of differences in concentrate use at Kud Kertajaya Kandangan, Kediri regency, East Java. Journal of Applied Veterinary Science and Technology 4(1): 11-14. https://doi.org/10.20473/javest.v4.i1.2023.11-14

Ramírez-Restrepo CA, Tan C, O'Neill CJ, López-Villalobos N, Padmanabha J, Wang J and McSweeney CS, 2016. Methane production, fermentation characteristics and microbial profiles in the rumen of tropical cattle. Animal Feed Science and Technology 216: 58–67. https://doi.org/10.1016/j.anifeedsci.2016.03.005

Roca-Fernández A, Dillard SL and Soder K, 2020. Ruminal fermentation and enteric methane production of legumes containing condensed tannins fed in continuous culture. Journal of Dairy Science 103(8): 7028-7038. https://doi.org/10.3168/jds.2019-17627

Sharifi A and Chaji M, 2019. Effects of processed recycled poultry bedding with tannins extracted from pomegranate peel on the nutrient digestibility and growth performance of lambs. South African Journal of Animal Science 49(2): 290. https://doi.org/10.4314/sajas.v49i2.9

Shen J, Zheng W, Xu Y and Yu Z, 2023. The inhibition of high ammonia to in vitro rumen fermentation is pH dependent. Frontiers in Veterinary Science 10: 1163021. https://doi.org/10.3389/fvets.2023.1163021

Shi H, Zhang C, Zhao W, Luo J and Loor J, 2017. Peroxisome proliferator-activated receptor delta facilitates lipid secretion and catabolism of fatty acids in dairy goat mammary epithelial cells. Journal of Dairy Science 100(1): 797-806. https://doi.org/10.3168/jds.2016-11647

Soenardjo N and Supriyantini E, 2017. Analysis of tannin content in mangrove fruit *Avicennia marina*. Jurnal Kelautan Tropis 20(2): 90. https://doi.org/10.14710/jkt.v20i2.1701

Sun HZ, Wang DM, Wang B, Wang JK, Liu HY, Guan le L and Liu JX, 2015. Metabolomics of four biofluids from dairy cows: potential biomarkers for milk production and quality. Journal of Proteome Research 14(2): 1287-1298. https://doi.org/10.1021/pr501305g

Ungerfeld EM, 2015. Limits to dihydrogen incorporation into electron sinks alternative to methanogenesis in ruminal fermentation. Frontiers in Microbiology 6: 1272. https://doi.org/10.3389/fmicb.2015.01272

Vailati-Riboni M, Meier S, Burke CR, Kay JK, Mitchell MD, Walker CG, Crookenden MA, Heiser A, Rodriguez-Zas SL, Roche JR and Loor JJ, 2016. Prepartum body condition score and plane of nutrition affect the hepatic transcriptome during the transition period in grazing dairy cows. BMC Genomics 17(1): 854. https://doi.org/10.1186/s12864-016-3191-3

Vargas-Bello-Pérez E, Pedersen NC, Khushvakov J, Ye Y, Dhakal R, Hansen HH, Ahrné L and Khakimov B, 2022. Effect of supplementing dairy goat diets with vegetable oils. Frontiers in Veterinary Science 9: 899314. https://doi.org/10.3389/fvets.2022.899314

Wang D, Liang G, Wang B, Sun H, Liu J and Guan Le L, 2016. Systematic microRNAome profiling reveals the roles of microRNAs in milk protein metabolism and quality: insights on low-quality forage utilization. Scientific Reports 6(1): 21194. https://doi.org/10.1038/srep21194

Wang W, Patra AK, Puchala R, Ribeiro L, Gipson TA and Goetsch AL, 2022. Effects of dietary inclusion of *Sericea lespedeza* hay on feed intake, digestion, nutrient utilization, growth performance, and ruminal fermentation and methane emission of alpine doelings and katahdin ewe lambs. Animals 12(16): 2064. https://doi.org/10.3390/ani12162064

Widianingrum DC, 2021. Pengembangan budidaya azolla mycrophilla sebagai alternatif pakan ternak dan pemanfaatannya sebagai pupuk bio organik di wilayah masyarakat desa baletbaru, sukowono. Jurnal Abdimas Madani Dan Lestari (JAMALI) 3(1): 11-19. https://doi.org/10.20885/jamali.vol3.iss1.art2

Yanza YR, Fitri A, Suwignyo B, Elfahmi, Hidayatik N, Kumalasari NR, Irawan A and Jayanegara A, 2021. The utilisation of tannin extract as a dietary additive in ruminant nutrition: a meta-analysis. Animals 11(11): 3317. https://doi.org/10.3390/ani11113317

Zhang M, Hou L, Yang Y, Zhang H, Zhang Z, Li J, Xu C and Guo T, 2025. Effect of different levels of *Scutellaria baicalensis* straw on slaughter performance and rumen microorganisms of rams. PLoS One 20(6): e0325708. https://doi.org/10.1371/journal.pone.0325708

Ziegler C, Dannlowski U, Bräuer D, Stevens S, Laeger I, Wittmann H, Kugel H, Dobel C, Hurlemann R, Reif A, Lesch KP, Heindel W, Kirschbaum C, Arolt V, Gerlach AL, Hoyer J, Deckert J, Zwanzger P and Domschke K, 2015. Oxytocin receptor gene methylation: converging multilevel evidence for a role in social anxiety. Neuropsychopharmacology 40(6): 1528-1538. https://doi.org/10.1038/npp.2015.2