

Improving Goat Milk Production and Functional Quality Through Local Resource-Based Feed: A Study of *Tithonia diversifolia*, Katuk Leaves (*Sauropus androgynus*) and Palm Kernel Concentrate

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Article History: 25-228

Received: 12-Aug-25

Revised: 07-Oct-25

Accepted: 24-Oct-25

Online First: 02-Dec-25

ABSTRACT

This research aimed to assess how replacing forage with *Tithonia diversifolia* and adding katuk leaves (*Sauropus androgynus*) alongside palm kernel meal concentrate affected Peranakan Etawa goat milk intake, digestibility, production, and quality. A 60-day experimental period was conducted at Toni Farm in Payakumbuh, where researchers used 20 lactating goats distributed across 4 treatments, with 5 replicates per treatment in a completely randomized design. The treatments consisted of: A (control: 60% conventional forage + 40% concentrate), B (60% *Tithonia* + 20% concentrate + 20% palm kernel meal), C (B + 1.5% katuk leaves), and D (B + 3% katuk leaves). The parameters observed included dry matter intake and digestibility, organic matter, crude protein, milk production, and milk amino acid and fatty acid content. Compared with the control, treatments C and D significantly enhanced feed utilization and milk production ($P < 0.05$), along with notable increases in essential amino acids (lysine and leucine) and linoleic acid levels. It was concluded that the combination of *Tithonia diversifolia*, katuk leaves, and palm kernel meal is an effective local feed formulation for sustainably improving the quantity and quality of goat milk.

Keywords: *Tithonia diversifolia*, Katuk leaves, Palm kernel meal, Goat milk, Amino acids, Fatty acids

INTRODUCTION

A significant challenge in increasing dairy goat productivity in Indonesia is the fluctuating availability and quality of forage, especially during the dry season. *Tithonia diversifolia* (paitan) is a promising wild plant species for use as an alternative livestock feed (Rivera et al. 2022; Soares et al. 2024; Silva Júnior and de Andrade, 2024; Putri et al. 2024) because of its high protein levels (18–25%) and its ability to grow rapidly on marginal land (Pazla et al. 2024a; b; Febrina et al. 2025). In contrast, katuk leaves (*Sauropus androgynus*) are recognized for their bioactive constituents, including flavonoids, tannins, and high protein content, which play a beneficial role in supporting livestock metabolic functions (Purba and Paengkoum, 2022) and influence milk quality, particularly amino acid composition (Wirawati et al. 2018; Fatmawati et al. 2022; Nurdianti et al. 2023). Meanwhile, palm kernel cake (PKC), as an abundant agroindustrial waste product, has a sufficiently high protein and energy content, making it a

cheap and potential concentrate source for ruminants (Amizi et al. 2012; Santos et al. 2019; Ginting et al. 2019; Aina et al. 2021; Ferreira et al. 2022; Arief et al. 2024). The integration of these materials in feed formulations is an efficient and sustainable strategy to support livestock productivity.

However, the integration of *Tithonia diversifolia*, katuk leaves and a palm kernel meal-based concentrate into a single local dairy goat feed ration, such as Peranakan Etawa, has never been systematically studied. Previous studies have been primarily aimed at the individual effects of one of the additives on production or growth performance or digestibility (Pazla et al. 2021; Arief and Pazla, 2023) and not on the overall effects of the three additives on feed intake, digestibility, production, milk quality, fatty acid and amino acid content. This is the existing scientific gap; there is a need for real (empirical) data showing how these local ingredients can work together to improve the nutritional value of goat milk and feed efficiency.

Cite This Article as: Arief, Pazla R and Rizqan, 2026. Improving goat milk production and functional quality through local resource-based feed: a study of *Tithonia diversifolia*, katuk leaves (*Sauropus androgynus*), and palm kernel concentrate. International Journal of Veterinary Science 15(2): 418-427. <https://doi.org/10.47278/journal.ijvs/2025.150>

This study provides an integrated approach in which a feed formulation based on *Tithonia diversifolia* and katuk leaves, combined with palm kernel meal concentrate, was designed for testing in Peranakan Etawa goats. In addition, its effects on animals (physiological aspects) and on high-quality livestock products were examined to determine its impact on milk quality (bioactive components such as saturated/unsaturated fatty acids), daily production, and other nutritional properties.

This research was conducted to examine the effect of using *Tithonia diversifolia* as a substitute for forage, adding katuk leaves and feeding palm kernel meal concentrate on the consumption and digestibility of organic matter, crude protein, and dry matter, as well as the production and quality of Peranakan Etawa goat milk, mainly focusing on the profiles of fatty acids and amino acids.

MATERIALS AND METHODS

Place and time of research

The research was conducted at Toni Farm, a dairy goat facility in Payakumbuh, West Sumatra, Indonesia. It is situated at an elevation of approximately 514 meters above sea level, with average daily temperatures ranging from 20 to 29°C. The study took 2 months, beginning with a 10-day adaptation period, followed by a 45-day treatment period, and concluding with 5 days of fecal collection. Feed and feces nutritional analysis were performed in the Ruminant Nutrition Laboratory, Faculty of Animal Science, Andalas University, Padang. In contrast, analysis of fatty acids and amino acids in milk samples was performed at the Integrated Laboratory, IPB University, Bogor.

Experimental animals and experimental design

In this study, 20 lactating Peranakan Etawa goats were used, each with an average body weight of 40.5kg. The goats' ages ranged from 2.5 to 3 years. The animals were randomly assigned to 4 treatment groups of 5

replicates each, ensuring that each treatment group included one goat. It was a completely randomized design (CRD) study. The effects of treatment on chemical composition and nutrient content are shown in Table 1 and 3, respectively.

Feed treatment

The four feed treatments in this study were based on variations in the use of *Tithonia diversifolia* forage, commercial concentrate, palm kernel meal (PKM), and the addition of katuk leaves (*Sauropus androgynus*). The details of the treatments are as follows (Table 2):

Treatment A (control): 60% conventional forage (field grass/farm forage) + 40% commercial concentrate

Treatment B: 60% *Tithonia diversifolia* + 20% commercial concentrate + 20% palm kernel meal concentrate

Treatment C: Same as Treatment B, with an additional 1.5% katuk leaves as supplementary forage

Treatment D: Same as Treatment B, with the addition of 3% katuk leaves as additional forage

The ration formulation was designed to meet the daily nutritional needs of lactating goats, in accordance with NRC (2007) standards, with adjustments to ensure balanced levels of TDN (isotrophic nitrogen and isocaloric energy) across treatments. *Tithonia diversifolia* and katuk leaves were chosen as alternatives to conventional forage because of their higher protein content and, respectively, as functional forage supplements due to their higher levels of essential amino acids and bioactive compounds. Palm kernel cake, as a protein and energy source, is an alternative in animal feed concentrates.

Maintenance management

Goats are kept in individual pens with good ventilation and ad libitum access to drinking water. The feed is given twice a day, at 7 am and 5 pm. The amount of feed consumed is calculated by subtracting the feed given from the amount provided, as some feed remains at the end of each day.

Table 1: Chemical Composition (%) of goat feed prepared based on *Tithonia diversifolia*, katuk leaves, and palm kernel meal

Chemical composition (%)	<i>Tithonia</i>	Palm Concentrate	<i>Sauropus androgynus</i>	Concentrate	Forage
Dry Matter	87.88	93.06	91.88	93.98	87.33
Organic Matter	84.01	94.07	89.36	96.46	88.46
Crude protein	19.56	12.53	23.8	11.85	16.35
Crude fat	1.09	3.50	4.02	4.57	3.26
Crude fiber	17.44	19.05	12.02	17.53	20.83
Ash	13.88	5.93	10.64	3.54	11.54
Nitrogen Free Extract	48.03	58.99	49.52	62.51	48.02
Total Digestible Nutrients	64.72	77.54	74.2	79.73	66.94
Neutral Detergent Fiber	63.07	49.16	46.43	65.13	45.25
Acid Detergent Fiber	42.71	25.27	29.87	30.47	29.78
Cellulose	29.82	16.10	23.84	25.72	20.30
Hemicellulose	20.36	23.89	16.56	34.66	15.47
Lignin	9.24	5.6	3.07	2.98	2.81
Silica	3.65	3.66	2.96	1.77	6.67

Table 2: Treatment layout for goat milk production experiment

Treatment	Forage (%)		Concentrate (%)	Palm kernel meal (%)	<i>Sauropus androgynus</i> (%)
	Forage farm	<i>Tithonia</i>			
A	60	-	40	-	-
B	-	60	20	20	-
C	-	60	20	20	1.50
D	-	60	20	20	3

Table 3: Nutrient Contents of various treatments for the goat milk production experiment

Nutrient Contents	Treatment (%)			
	A	B	C	D
Dry Matter	37.00	40.77	41.67	42.57
Organic Matter	91.66	88.51	89.85	91.19
Crude protein	14.55	16.61	16.97	17.33
Crude fat	3.78	2.27	2.33	2.39
Crude fiber	19.51	17.78	17.96	18.14
Nitrogen Free Extract	53.82	53.12	53.86	54.60
Total Digestible Nutrients	72.06	70.29	71.40	72.51
Neutral Detergent Fiber	53.20	60.70	61.40	62.09
Acid Detergent Fiber	30.06	36.77	37.22	37.67
Cellulose	22.47	26.26	26.61	26.97
Hemicellulose	23.15	23.93	24.17	24.42
Lignin	2.88	7.26	7.31	7.35
Silica	4.71	3.28	3.32	3.36

A (control: 60% conventional forage + 40% concentrate), B (60% Tithonia + 20% concentrate + 20% palm kernel meal), C (B + 1.5% katuk leaves), and D (B + 3% katuk leaves).

Sample collection and laboratory analysis

Feed and fecal samples were collected during the last 5 days of the treatment period. Individual feces bags were used to collect feces, which were weighed, homogenized, and stored for analysis. Dry matter (DM), crude protein (CP), organic matter (OM), crude fat, crude fiber and ash were analyzed using the AOAC (2016) method. The Van Soest et al. (1991) method was used to analyze neutral detergent fiber (NDF) and acid detergent fiber (ADF). Milk production was recorded daily using a measuring cup over 32 days. Composite milk samples collected in the morning and evening on days 25, 28 and 32 were analyzed for quality. Milk fatty acid components were analyzed according to AOAC (2012), whereas high-performance liquid chromatography (HPLC) was used to examine amino acid profiles.

Digestibility calculation

Digestibility was calculated using the formula:

$$\text{Digestibility} = \frac{\text{Nutrient Intake} - \text{Nutrient Feces}}{\text{Nutrient Intake}} \times 100\%$$

Digestible of Nutrients

Dry Matter Digestibility

$$\frac{(\text{sample weight} \times \text{DM}) - (\text{residu weight} \times \text{DM} - \text{blank weight} \times \text{DM})}{\text{sample weight} \times \text{DM}} \times 100\%$$

Organic Matter Digestibility

$$\frac{(\text{sample weight} \times \text{OM}) - (\text{residu weight} \times \text{OM} - \text{blank weight} \times \text{OM})}{\text{sample weight} \times \text{OM}} \times 100\%$$

Digestibility of Crude Protein

$$\frac{(\text{sample weight} \times \text{sample CP} \times \text{sample DM}) - (\text{residue weight} \times \text{residue CP} \times \text{residue DM})}{(\text{sample weight} \times \text{sample CP} \times \text{sample DM})} \times 100\%$$

Statistical Analysis

Data analysis was conducted using one-way analysis of variance (ANOVA) with SPSS software version 21.0. In cases of significant differences across treatments ($P < 0.05$), a Duncan Multiple Range Test (DMRT) was conducted as a follow-up test. The experimental unit was a single goat, and all the data were represented as mean \pm SD.

RESULTS

Consumption of dry matter, organic matter and crude protein

The study finds that feed treatment significantly

affects dry matter intake (DMI), organic matter intake (OMI), and crude protein intake (CPI) in Peranakan Etawa goats (Table 4). Dry matter intake ranged from 3.17 to 3.67 kg/head/day, with the lowest being treatment A (control) and the highest for treatment D. The trend for the increase in dry matter intake followed the increase in the proportion of *Tithonia diversifolia* and katuk leaf inclusion, possibly because of the good palatability and higher concentration of nutrients of the forages.

Table 4: Consumption of Dry Matter, Organic Matter, Crude Protein (kg/day) by experimental goats

Treatment	Dry Matter Intake	Organic Matter Intake	Crude Protein Intake
A	3.17 \pm 0.033 ^a	2.90 \pm 0.031 ^a	0.60 \pm 0.006 ^a
B	3.45 \pm 0.037 ^b	3.05 \pm 0.033 ^b	0.61 \pm 0.007 ^b
C	3.57 \pm 0.036 ^c	3.22 \pm 0.032 ^c	0.64 \pm 0.006 ^c
D	3.67 \pm 0.044 ^d	3.37 \pm 0.040 ^d	0.67 \pm 0.008 ^d

Note: Different superscripts indicate significantly different effects ($P < 0.05$). A (control: 60% conventional forage + 40% concentrate), B (60% Tithonia + 20% concentrate + 20% palm kernel meal), C (B + 1.5% katuk leaves), and D (B + 3% katuk leaves).

Both OM intakes also mimicked the same pattern, with treatment D having the highest intake of 3.37kg/day, while treatment A had an intake of 2.90kg/day. The implication is that substituting conventional forage with *Tithonia diversifolia* and adding palm kernel meal and katuk leaves can increase the amount of organic material for livestock intake and utilization.

Meanwhile, crude protein consumption increased drastically from 0.60kg/day in treatment A to 0.67kg/day in treatment D. This testifies to the tremendous contribution of *Tithonia diversifolia*, palm kernel cake, and katuk leaves as good-quality protein sources. Katuk leaves, in particular, are rich in crude protein and bioactive compounds that can trigger feed intake and protein metabolism efficiency.

Overall, the present research indicated that formulation diets based on *Tithonia diversifolia* and palm kernel cake, supplemented with katuk leaves, can increase the intake of basic nutrients for milk production and the maintenance of physiological functions in dairy goats. No doubt, these findings have far-reaching implications for supporting the possibility of using local resources as strategic ingredients in the formulation of efficient and sustainable diets.

Digestibility of dry matter, organic matter and crude protein

Digestibility values showed that feed treatment significantly affected DM, OM, and CP digestibility in Peranakan Etawa goats (Table 5). The DS digestibility increased stepwise from 63.47% in treatment A (control) to 68.18% in treatment D, indicating improved feed utilization efficiency due to a better balance in the ration composition. Gradually adding *Tithonia diversifolia* and katuk leaves was found to improve fiber quality and rumen fermentation activity.

Digestibility of OM also increased from 63.06% (A) to 68.18% (D). This indicates that the proportion of digestible organic matter increased with supplementation of functional forages and other concentrates. The combination of *Tithonia diversifolia*, palm kernel cake, and katuk leaves promoted greater rumen microbial degradation of organic substrates.

Table 5: Digestibility Nutrient by Dry Matter, Organic Matter, Crude Protein (%)

Treatments	Digestibility Dry Matter	Digestibility of Organic Matter	Digestibility Crude Protein
A	63.47±0.76 ^a	63.06±0.87 ^a	66.97±2.08 ^a
B	64.15±1.24 ^a	63.68±2.28 ^a	73.08±2.26 ^b
C	66.81±0.39 ^b	66.79±1.11 ^b	75.49±0.76 ^b
D	68.18±2.11 ^b	68.96±0.95 ^c	78.17±2.29 ^c

Different superscripts indicate significantly different effects (P<0.05). A (control: 60% conventional forage + 40% concentrate), B (60% *Tithonia* + 20% concentrate + 20% palm kernel meal), C (B + 1.5% katuk leaves), and D (B + 3% katuk leaves).

The highest gain was in crude protein digestibility. The lowest value was for treatment A at 66.97%, while treatment D had the highest at 78.17%. This indicates that the feed containing good-quality protein from katuk leaves and palm kernel cake not only increases protein intake but also increases the percentage of digestible and absorbable protein. This could also be due to interactions among bioactive compounds in katuk leaves, which can boost proteolytic enzyme activity and limit excessive protein degradation in the rumen.

In general, improvements in digestibility across all parameters indicate that substituting conventional feed with high-quality local ingredients can enhance nutrient utilization efficiency in lactating goats. The current study suggests that the use of *Tithonia diversifolia* and katuk leaf-based feed may play a crucial role in preserving livestock productivity while reducing environmental degradation.

Milk production

The results revealed that feed treatment had a significant impact on milk yield of Peranakan Etawa goats (Fig. 1). Daily milk yield during the observation period increased step by step from 859.06 mL/head/day in treatment A (control) to 1061.07 mL/head/day in treatment D. This increase indicates that *Tithonia diversifolia*, palm kernel meal, along with the inclusion of katuk leaves, has a significant role to play in supporting lactation performance.

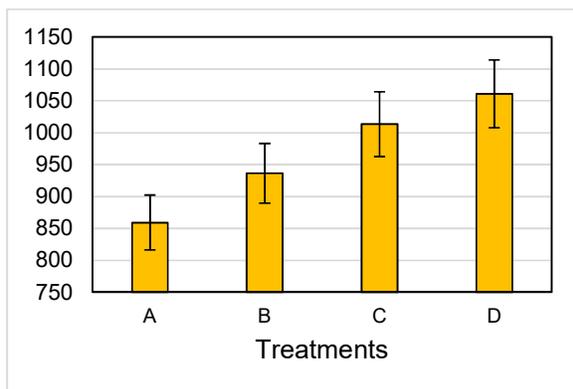


Fig. 1: Milk Production (mL/head/day) of experimental goats kept on A (control: 60% conventional forage + 40% concentrate), B (60% *Tithonia* + 20% concentrate + 20% palm kernel meal), C (B + 1.5% katuk leaves), and D (B + 3% katuk leaves).

Treatments B and C had milk yields of 936.33mL/day and 1013.63mL/day, respectively, indicating that supplementation with *Tithonia diversifolia* as a substitute

for conventional forage increased the supply of essential nutrients —energy and protein —to support milk synthesis. The extra boost in the production of treatments C and D can be attributed to the application of katuk leaves as high-quality forage, which not only contain protein but also bioactive compounds such as flavonoids and sterols that can influence lactation hormones.

The increased protein availability and improved protein digestibility in treatments C and D are also expected to increase the conversion rate of nutrients into milk. The improvement of nutrient intake and digestion observed in treatment D also contributed to increasing overall milk production. Thus, feed diets based on *Tithonia diversifolia* and katuk leaf were found to increase milk production significantly compared to the control rations. These results indicate that integrating potential local feed sources into dairy goats' feed can be a cost-saving, environmentally friendly way to improve milk productivity at the smallholder farm level.

Milk amino acid content

Analysis of the amino acid content of milk shows that differences in feed composition result in significant differences in the concentration of essential and non-essential amino acids in Peranakan Etawa goat milk (Table 6). Lysine, leucine, and glutamate are key amino acids investigated in this study and are essential and non-essential amino acids, respectively.

Table 6: Amino Acid Contents (%) of treatments of the goat milk production experiment

Parameter	Treatments			
	A	B	C	D
Amino Acid				
Aspartic acid	0.28	0.32	0.30	0.27
Threonine	0.17	0.19	0.17	0.16
Serine	0.20	0.22	0.20	0.18
Glutamate	0.83	0.95	0.86	0.78
Glycine	0.06	0.08	0.07	0.06
Alanine	0.12	0.14	0.12	0.11
Valine	0.25	0.28	0.26	0.24
Methionine	0.09	0.04	0.07	0.08
Ileucine	0.18	0.20	0.19	0.17
Leucine	0.36	0.41	0.38	0.34
Tyrosine	0.15	0.17	0.15	0.14
Phenylalanine	0.18	0.20	0.19	0.17
Histidine	0.13	0.14	0.14	0.13
Lysine	0.25	0.31	0.34	0.27
Arginine	0.17	0.17	0.17	0.18

A (control: 60% conventional forage + 40% concentrate), B (60% *Tithonia* + 20% concentrate + 20% palm kernel meal), C (B + 1.5% katuk leaves), and D (B + 3% katuk leaves).

The highest lysine concentration in milk was achieved in treatment C at 0.34%, followed by treatment B (0.31%), D (0.27%), and the lowest in the control (A) at 0.25%. Lysine is an essential amino acid for protein synthesis in the body and, as a rule, is a limiting amino acid in dairy products. Increased lysine content signals the role of katuk leaves, which were found to have high protein content with a balanced amino acid composition and increased protein digestion efficiency in *Tithonia diversifolia* and palm kernel cake diets.

Leucine concentration also increased, with the highest concentration in treatment B at 0.41%, followed by C at

0.38%, A at 0.36%, and D at 0.34%. Leucine is one of the branched-chain amino acids (BCAA) that are very important in muscle growth and energy metabolism. The increase in the leucine content in treatments B and C indicates the contribution of locally used feed materials to milk nutrient quality.

Glutamate is a non-essential amino acid that provides food with its savory flavor and assists the body in utilizing and excreting nitrogen. In a study, glutamate was found to be highest in B (0.95%), followed by C (0.86%), A (0.83%), and D (0.78%). Animals produce glutamate themselves, but the quantity in milk predominantly reflects the quality and type of food the animal consumes.

Overall, these results indicate that feeding a diet based on *Tithonia diversifolia*, palm kernel cake, and katuk leaves can increase the content of essential and non-essential amino acids in goat milk. This increase not only enhances the nutritional value of the milk but also adds functional value to local dairy products as a source of high-quality protein.

Milk fatty acid content

Examination of the fatty acid composition in Peranakan Etawa goat milk indicates that various feed compositions influence the level of monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), especially oleic acid (C18:1) and linoleic acid (C18:2) (Table 7). The two fatty acids are important for increasing the functional value of milk as a healthy food.

Table 7: Fatty Acid Content (%) of treatments of the goat milk production experiment

Parameter	Treatment			
	A	B	C	D
Monounsaturated Fatty Acid (MUFA)				
Palmitoleic acid (C16:1)	0.48	0.47	0.46	0.48
Oleic acid (C18:1 cis-9)	10.05	9.80	8.31	7.69
Elaidic acid (C18:1 trans-9)	0.38	0.36	0.35	0.35
Total	10.91	10.63	9.12	8.52
	39.18			
Saturated Fatty Acid (SFA)				
Butyric acid (C4:0)	0.60	0.60	0.67	0.68
Caproic acid (C6:0)	1.31	1.2	1.51	1.4
Caprylic acid (C8:0)	2.13	1.59	1.98	1.63
Capric acid (C10:0)	6.80	6.01	6.98	5.41
Lauric acid (C12:0)	5.12	2.31	2.81	2.73
Myristic acid (C14:0)	6.03	5.63	5.06	5.25
Pentadecanoic acid (C15:0)	0.66	0.64	0.60	0.64
Palmitic acid (C16:0)	17.74	19.2	16.58	17.88
Heptadecanoic acid (C17:0)	0.67	0.56	0.56	0.62
Stearic acid (C18:0)	8.56	8.01	7.75	9.24
Arachidic acid (C20:0)	0.14	0.17	0.15	0.17
Total	49.76	45.92	44.65	45.65
	185.98			
Polyunsaturated Fatty Acid (PUFA)				
Linoleic acid	0.19	0.29	0.20	0.27
Total	0.95			

A (control: 60% conventional forage + 40% concentrate), B (60% *Tithonia* + 20% concentrate + 20% palm kernel meal), C (B + 1.5% katuk leaves), and D (B + 3% katuk leaves).

The highest oleic acid content was found in treatment A (control) at 10.05%, followed by a sequential decrease in treatments B (9.80%), C (8.31%), and D (7.69%). This decrease is probably caused by the differences in type and composition of forages and concentrates, particularly the

use of *Tithonia diversifolia* and palm kernel meal in treatments B-D, which appear to elevate saturated fatty acid content in milk and consequently lower the proportion of MUFA. However, the oleic acid content in all treatments remains within a nutritionally beneficial range.

On the other hand, linoleic acid was higher in treatments B and D than in the control. The most successful were treatment B (0.29%), D (0.27%), C (0.20%), and A (0.19%). Linoleic acid is a fatty acid essential to the human body and one of the components of PUFAs, which are recognized for their positive effects on heart disease prevention. The increase in linoleic acid content in treatments B and D indicates that the use of katuk leaves and *Tithonia diversifolia* as forage in the diet not only supports milk production but also increases the content of polyunsaturated fatty acids in the milk produced.

These results indicate that while oleic acid concentrations tend to decrease with the addition of local forage, the proportion of PUFAs, particularly linoleic acid, can be increased through the use of feed ingredients such as katuk leaves, which are rich in essential fatty acids. Thus, feed modifications based on local resources have the potential to produce milk with higher functional value, particularly in terms of fatty acids beneficial to consumer health.

DISCUSSION

Nutrient consumption (DM, OM, dan CP)

Increased dry matter (DM), organic matter (OM), and crude protein (CP) intake among Peranakan Etawa goats fed the treatment diet of *Tithonia diversifolia*, palm kernel meal (PKM), and katuk leaves shows improved palatability and nutritional value of the treatment diet. Treatment D showed the highest intake across all three measures, indicating that a feed mix combining functional forage and non-traditional protein sources can increase daily feed intake by a large margin compared to traditional diets.

Overall, high dry matter intake indicates that the animals were susceptible to the feed mixture in terms of odor, palatability, and physical texture. Pazla et al. (2025) and Azevêdo et al. (2010) reported that fiber content, energy status, and protein balance within the diet influence dry matter intake. In this study, *Tithonia diversifolia* has moderate protein ($\pm 19.5\%$) and crude fiber ($\pm 17.4\%$) levels, thereby providing digestibility and stimulating consumption.

Katuk leaves (*Sauropus androgynus*) added to the ration also play an important function in stimulating intake. Not only does the crop have a high protein content ($\pm 23.8\%$), but it also contains bioactive metabolites, such as saponins, flavonoids, and alkaloids, with appetite-stimulating properties that increase intake by positively impacting rumen fermentation.

Other concentrates, such as palm kernel meal, also influence feed intake. Although palm kernel cake is high in crude fiber, it can, when combined with good-quality forage, provide sufficient energy and protein for the needs of lactating animals. Suhendro et al. (2018) stated that palm kernel cake can be incorporated into concentrates at levels of 20–30% without reducing feed intake, especially when compounded with easily digestible ingredients of forages.

The increased consumption of organic matter (OM) and crude protein (CP) by treatments C and D indicates that the quality of the diet from locally available feedstuffs is sufficient to meet the metabolic needs of dairy goats. The increased protein content in the diet is also known to improve the energy efficiency of rumen microbial use and activity (Akhtar et al. 2017; Dai et al. 2023), thereby indirectly enhancing the ingestion of other nutrients. Increased CP intake is also a crucial part of milk production, as the used protein provides the amino acids required for milk production and for body tissue maintenance.

Tithonia diversifolia, katuk leaves, and BIS were incorporated in the diets of Peranakan Etawa goats in one study. This enhanced the intake of essential nutrients, the goats' physical health, and their productivity.

Digestibility of dry matter, organic matter and crude protein

The enhancement of the digestibility of dry matter (DM), organic matter (OM), and crude protein (CP) in Peranakan Etawa goats indicates that the ration formulation utilizing *Tithonia diversifolia*, palm kernel meal (PKM), and katuk leaves is favorable to digestive efficiency in the gastrointestinal tract, particularly the rumen. Optimum digestibility values were recorded in treatment D, i.e., 78.69% of DM, 70.91% of OM, and 81.65% of CP, whereas the minimum was found in treatment A (control).

Greater dry matter digestibility in treatments B, C, and D compared to the control demonstrates that the feed formula provides substrates that are readily broken down by rumen microbes. Falls et al. (2017) and Chaucheyras-Durand et al. (2016) documented that the digestibility of DM is greatly influenced by the fiber structure and composition of lignocellulose in the diet. *Tithonia diversifolia*, in this case, has lower fractions of neutral detergent fiber (NDF) and acid detergent fiber (ADF) than conventional forage, hence improving enzyme access to plant cell walls.

In addition, the phytochemicals in katuk leaves, such as flavonoids, moderate tannin content, and phenolic acids, may stimulate rumen microbial activity and reduce excess protein deamination. Sayd et al. (2022) and Kalantar (2018) averred that flavonoids and low tannin levels will improve rumen fermentation and microbial nitrogen efficiency, thereby indirectly enhancing crude protein digestibility.

The increase in crude protein digestibility in treatments C and D is due to two factors: the high-quality protein found in katuk leaves and the balance between energy and protein in the BIS concentrate. Palm kernel cake has a high energy and protein content; in addition, when combined with high-quality forage in the rumen, it increases microbial efficiency in utilizing protein (Austral and Bantugan, 2016; Jiang et al. 2024). This is also consistent with Pazla et al. (2024c), who explained that the ratio of fermentable energy to protein in the diet increases the efficiency of microbial protein synthesis and the availability of amino acids to the host.

Higher digestibility of organic matter in treatments C and D also supports the hypothesis that the complementarity of forage protein sources and local concentrates promotes a favorable rumen environment for fermentation. High-value BO digestibility feed provides superior energy, which is required for necessities such as

milk production in lactating goats.

Findings from this study indicate that additional feeding of *Tithonia diversifolia*, palm kernel cake, and katuk leaves enhances the digestibility of key nutrients. Reducing congestion reduces feed consumption, potentially improving livestock performance sustainably.

Milk production

In this research, goat milk production improved significantly with a diet containing *Tithonia diversifolia*, palm kernel meal (PKM), and katuk leaves. The highest mean daily milk production was recorded in treatment D at 1061.07mL/head/day, and the lowest was in the control (treatment A) at 859.06mL/head/day. The increase indicates that the lactational capacity of dairy goats can be enhanced through dietary alterations, using locally available nutrient-dense sources.

Nutrient supply and protein-energy balance digestibility are significant factors that influence milk production. According to Goetsch (2019), the nutrient requirements of lactating goats should be adjusted to the lactation stage, and no improvement in milk production is possible unless the substrates, including glucose, amino acids, and fatty acids, are abundant. In this case, the surplus of crude protein (CP) (treatment C and D: 1.59 and 1.64 kg of CP per day, respectively) and the high CP digestibility became the probable determinants of the increased milk output.

Not only do Katuk leaves, introduced to treatments C and D, contain large amounts of protein, but they also contain bioactive substances such as steroids, polyphenols, and flavonoids. These extracts can activate the hormonal process, especially prolactin, which triggers milk secretion (Kurniati et al. 2025). The study by Intan et al. (2025) also established that taking katuk leaves can elevate lactogenic hormone levels in rats; this effect may also apply to ruminants through modulation of the endocrine system.

Moreover, the inclusion of *Tithonia diversifolia* in feed will enhance the nutritional value of rations by adding soluble fiber, high-quality protein, and secondary compounds with immunomodulatory and low antimicrobial effects. This aids in the digestive health and metabolic efficiency of livestock. A study by Pazla et al. (2022) indicates that *Tithonia*, used as a supplement, can increase goat milk production by up to 60 percent of the overall forage.

The concentrate, made from palm kernel meal, provides additional energy and protein, which also aid body metabolism and milk production. PKM has a relatively high crude fiber content; however, by mixing it with high-quality forages such as *Tithonia* and katuk leaves, the nutrient value can be maximized to benefit rumen microbes.

Therefore, the rise in milk yield in both treatments C and D is due to greater intake and digestion, as well as the biological quality of the local feed materials, which favors nutrient adequacy and hormonal activity. Such findings suggest that FFS composed of *Tithonia diversifolia*, katuk leaves, and BIS could be a future sustainable solution to improving local goat milk supplies.

Milk amino acid contents

Milk is a valuable indicator of the quality of amino acids in food in general, and of proteins in particular,

especially in terms of the protein's biological value and the availability of essential nutrients to consumers. The findings of studies reveal that the amino acid composition of Peranakan Etawa goat milk varies in the proportions and quantities of essential and non-essential amino acids, depending on the feed formulation. The three major amino acids selected for analysis in the present study are lysine, leucine, and glutamate, which represent key essential and dominant non-essential amino acids.

Treatments C (0.34%) and B (0.31%) had the highest lysine content, an essential amino acid for growth and tissue formation, compared to the control (0.25%). This shows that *Tithonia diversifolia*, palm kernel cake (BIS), and katuk leaves have synergistic effects on the feed formulation, enhancing the production of high-quality protein in milk. The main limiting amino acid in a variety of dairy foods is lysine; thus, a higher level of it will give further functional meaning to the goat milk (ALKaisy et al. 2023).

Leucine, a member of the BCAA (branched-chain amino acids) group, also rose in treatment B (0.41) and C (0.38) when compared with A (0.36) and D (0.34). Leucine plays central roles in energy production and muscle protein synthesis (Hewlings and Kalman 2020), and its milk content is highly dependent on the quality and balance of dietary protein intake (Millward, 2012; Duan et al. 2016). Greater leucine content in milk in treatment B and C shows that the optimal proportion of katuk leaves and *Tithonia* in the ration can promote the effectiveness of feed protein conversion to milk protein.

In glutamic acid, the most concentrated non-essential amino acid in milk, responsible for umami flavor and also a precursor to neurotransmitters, treatment B contained the highest (0.95%), followed by C (0.86%), and then A (0.83%). The decrease in treatment D (0.78%) shows that the excess addition of katuk leaves (>3%) is not always accompanied by an increase in amino acid content, perhaps because antinutrients such as tannins or saponins are in high concentration, which can serve as inhibitors for the absorption or metabolism of amino acids (Akande et al. 2010).

Overall, the increase in amino acid content in milk is highly correlated with high consumption and digestibility of protein from rations based on *Tithonia diversifolia* and katuk leaves. These results reinforce previous findings that feed composition can be manipulated to enrich the functional nutritional value of animal production. With the increased lysine and leucine content in Peranakan Etawa goat milk, the potential of Peranakan Etawa goat milk as a high-quality protein source can be further optimized in community nutrition improvement programs.

Milk fatty acid content

Fatty acids in milk are important not only as a source of energy but also as bioactive components that determine the health quality of milk production. In this study, two main groups of fatty acids were analyzed in depth, monounsaturated fatty acids (MUFA), represented by oleic acid (C18:1) and polyunsaturated fatty acids (PUFA), represented by linoleic acid (C18:2). The variations in the composition of these two fatty acids responded to the ratios of formulation of *Tithonia diversifolia*, palm kernel cake as well as leaves of katuk.

Treatment D showed the highest percentage of oleic acid (10.05) and treatment D showed the lowest value (7.69). Oleic acid is also recognized as the predominant MUFA in goat milk and has a protective role for human cardiovascular health (Voblikova et al. 2020; Bondoc et al. 2023). Reductions in OA in treatments C and D were possibly attributed to the higher dietary supplementation concentration, with more forage and fiber, which may influence rumen lipid metabolism and alter the biohydrogenation of unsaturated fatty acids into saturated fatty acids by rumen microbes (Lourenço et al. 2010). Moreover, excessive consumption of protein and bioactive compounds in katuk leaves may reduce the abundance of selected MUFA-producing microorganisms, thereby lowering milk oleic acid concentration.

On the other hand, one of the essential PUFA, linoleic acid, increased in treatments B (0.29%) and D (0.27%), exceeding the control (0.19%). Linoleic acid is an essential component and a precursor to any bioactive compound, which is well-known to have anticancer and immunomodulatory effects (prostaglandins, conjugated linoleic acid (CLA)) (Dey et al. 2024; Zain et al. 2025). The rise in levels of linoleic acid can perhaps be ascribed to the role played by active compounds in leaves of katuk, *Tithonia diversifolia*, which has the potential of inhibiting biohydrogenation of unsaturated fatty acids in the rumen, leading to increased absorption of PUFAs in the small intestine and their deposit into milk (Toral et al. 2011).

The milk fatty acid profile is also formed by palm kernel cake as a fat source in concentrates (Pimentel et al. 2016). Even though PKC is predominantly rich in saturated fatty acids (palmitic acid), a well-composed diet with high-quality forage can be used to balance the ratio of MUFA and PUFA content of the milk. Thus, the mixture of local feed ingredients in the study has the potential to ensure milk with a healthier lipid profile.

In general, variations in fatty acid composition reflect the complex interactions among feed types, rumen fermentation, and lipid metabolism in goats. Proper feed formulation can not only increase milk production but also improve milk nutritional quality, particularly by preventing degenerative diseases through increased consumption of unsaturated fatty acids.

Conclusion

The use of *Tithonia diversifolia* as a forage substitute, combined with palm kernel meal and katuk leaves, has been shown to increase nutrient intake and digestibility, as well as milk production, in Peranakan Etawa goats. This formulation also enriches the milk with essential amino acids and unsaturated fatty acids, indicating better nutritional and functional value for the product. Thus, the use of this local feed material is an effective and sustainable strategy for improving goat milk productivity and quality at the farmer level.

DECLARATIONS

Funding: This research was funded by the Institute of Research and Community Service, Andalas University with the support of *Skema Penelitian Unggulan Jalur Kepakaran* Batch 1, under grant number 360/UN16.19/PT.01.03/PUJK/2025.

Acknowledgement: The authors would like to acknowledge the financial support of this study by the Institute of Research and Community Service, Andalas University with the support of *Skema Penelitian Unggulan Jalur Kepakaran* Batch 1 with contract No. 360/UN16.19/PT.01.03/PUJK/2025.

Conflict of Interest: The authors state that no conflicts of interest exist in connection with this research.

Data Availability: All data examined in this research have been presented in tables in the manuscript.

Ethics Statement: This research received approval from the Ethics Commitee, Faculty of Medicine, Andalas University, under reference number 33/UN.16.2/KEP-FK/2023.

Author's Contribution: AA designed and conducted the laboratory experiments, and drafted the original manuscript. RP gathered information in laboratory, data analyzed, writing the original manuscript, and finalizing it. RR was involved in data analysis, interpretation, and manuscript revision. The final manuscript was approved by all authors.

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