

RESEARCH ARTICLE

Effects of Palm Kernel Cake Based Biosupplement Biscuits on Nutrient Utilization, Growth Performance, and Metabolic Responses in Male Ettawah Goats

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Abstract: Palm Kernel Cake (PKC), a major by-product of the palm oil industry, has considerable potential as an alternative feed ingredient for ruminants because of its wide availability, moderate protein content, and economic value. However, its utilization is often constrained by high fiber and lignocellulosic components that may limit nutrient digestibility. This study evaluated the effects of PKC-based biosupplement biscuits as an innovative feed delivery system on nutrient intake, digestibility, growth performance, feed efficiency, and metabolic responses in growing male Ettawah goats. Twenty growing male Ettawah goats, with treatment-group mean initial body weights ranging from 15.45 to 16.32 kg, were assigned to a completely randomized design consisting of four dietary treatments with PKC-based biosupplement biscuit inclusion levels of 0%, 20%, 30%, and 40%. The feeding trial was conducted for 60 days following a 14-day adaptation period. Data were analyzed using analysis of variance (ANOVA) followed by orthogonal polynomial analysis. The results showed that increasing PKC inclusion significantly decreased dry matter intake ($p < 0.05$), while crude protein, ether extract, and fiber intake increased. Dry matter and crude protein digestibility improved significantly ($p < 0.05$), reflecting better nutrient digestibility. Average daily gain increased from 43.57 g/day in the control group to 51.96 g/day in goats receiving 40% PKC supplementation, accompanied by improved feed efficiency. Hematological and biochemical parameters remained within normal physiological ranges, suggesting no adverse effects on animal health. Increased concentrations of glucose, total protein, albumin, and globulin reflected improved metabolic responses. In conclusion, PKC-based biosupplement biscuits at inclusion levels of 30–40% significantly enhanced nutrient utilization, dry matter and crude protein digestibility, average daily gain, feed efficiency, and metabolic stability without adverse effects on animal health, demonstrating their potential as a sustainable feeding strategy for tropical goat production systems.

Keywords: Agro-Industrial By-Product, Feed Efficiency, Goat Nutrition, Rumen Fermentation, Small Ruminant Nutrition

Received: 06-05-2026 | Revised: 19-06-2026 | Accepted: 15-07-2026 | DOI: 10.3844/ajavsp.2026.21.03.024

Introduction

Feed cost remains one of the largest constraints in ruminant production systems, particularly in tropical developing countries where the availability of high-quality feed ingredients fluctuates seasonally. The increasing competition between humans and livestock for conventional feed resources has encouraged the exploration of alternative feed ingredients derived from agricultural and agro-industrial by-products. Among these by-products, Palm Kernel Cake (PKC), which originates from the palm oil extraction industry, has gained considerable attention because of its year-round availability, moderate protein content, and relatively low market price [1, 2].

The use of PKC in livestock feeding may help reduce feed costs while improving the use of agro-industrial residues in ruminant production systems. Previous work in Indonesian goats has also demonstrated the practical potential of palm-oil plantation by-products and PKC-based local feeds to support nutrient utilization and productive performance [15, 23].

Despite its nutritional potential, the use of PKC in ruminant diets is often limited by its relatively high fiber content, especially lignocellulosic fractions and non-starch polysaccharides such as mannan. These components may reduce nutrient digestibility, limit ruminal degradation, and decrease feed intake when included at excessive levels [6]. High dietary fiber concentrations can increase rumen fill and reduce passage rate, ultimately lowering voluntary feed consumption and animal performance. Consequently, improving the feeding value and utilization efficiency of PKC remains an important research objective in tropical ruminant nutrition.

Several approaches have been investigated to enhance PKC utilization, including fermentation technology, enzyme supplementation, and dietary reformulation [7, 8]. Although these strategies have shown promising results, most studies have primarily focused on improving nutrient composition and digestibility. Information regarding practical feed delivery systems that can improve nutrient intake consistency, reduce feed selectivity, and enhance feeding efficiency under field conditions remains limited [9].

One potential strategy is the development of biosupplement biscuits, which combine PKC with other nutrient sources in a compact feed form. This approach may improve palatability, minimize feed wastage, and provide more uniform nutrient intake. Compact feed forms may improve feeding consistency and reduce feed selection by animals, resulting in more stable nutrient intake.

In the present study, the term biosupplement refers to a nutritionally enriched feed biscuit formulated from palm kernel cake combined with energy, protein, mineral, and forage sources. No probiotic, microbial inoculant, enzyme additive, or fermentation starter was incorporated during biscuit production. The term biosupplement is used to describe its biological function in enhancing nutrient utilization, growth performance, and metabolic responses.

Ettawah goats are widely raised by smallholder farmers in Indonesia because of their adaptability and dual-purpose production potential. However, growth performance in traditional production systems is often constrained by inadequate nutrient intake and poor feed quality. The use of PKC-based biosupplement biscuits may therefore provide a practical nutritional strategy to improve productivity while reducing feeding costs.

Previous studies evaluating PKC have mainly emphasized fermentation or enzymatic treatments, whereas information regarding PKC utilization in biosupplement biscuit form and its effects on nutrient digestibility, growth performance, and metabolic responses in Ettawah goats is still scarce.

Therefore, this study aimed to evaluate the effects of different inclusion levels of PKC-based biosupplement biscuits on nutrient intake, digestibility, growth performance, feed efficiency, and blood metabolic responses in growing male Ettawah goats. It was hypothesized that supplementation levels of 30–40% would improve nutrient utilization and growth performance without negatively affecting physiological status.

Materials and Methods

Animals, Location, and Experimental Design

This study was conducted in Banjarbaru, South Kalimantan, Indonesia. A total of 20 growing male Ettawah goats were used. At the beginning of the feeding trial, treatment-group mean initial body weights ranged from 15.45 to 16.32 kg, as presented in Table 4. All animals were clinically healthy and adapted to experimental conditions prior to data collection.

The experiment employed a Completely Randomized Design (CRD) consisting of four dietary treatments with five replicates per treatment. The treatments were defined as follows: T0 (100% conventional diet), T1 (20% palm kernel cake (PKC)-based biosupplement biscuit), T2 (30% PKC-based biosupplement biscuit), and T3 (40% PKC-based biosupplement biscuit). The experiment was conducted under tropical environmental conditions typical of South Kalimantan.

Housing and Feeding Management

Goats were individually housed in raised pens measuring 1.0×1.5 m to facilitate feed intake and fecal collection. Each pen was equipped with a feed container, a drinking bucket, and an identification label.

The feeding trial lasted for 60 days following a 14-day adaptation period. Experimental diets were offered twice daily at 08:00 and 15:00. Feed refusals were collected and weighed daily before the morning feeding to calculate feed intake. Fresh drinking water was provided ad libitum throughout the study. Body weight was recorded at the beginning and at the end of the experimental period.

Animals were fed at approximately 3–4% of body weight on a dry matter basis, and body weight was recorded weekly before morning feeding.

Diet Composition and Nutrient Analysis

The experimental diets were formulated using rice bran, ground corn, soybean meal, Palm Kernel Cake (PKC), mineral mix, *Gliricidia sepium* leaves, and field grass (*Pennisetum purpureum*). All forage materials (*Pennisetum purpureum* and *Gliricidia sepium*) were obtained from the same cultivation area and harvested at comparable stages of maturity throughout the experimental period to minimize compositional variation among treatments. This procedure was applied to ensure consistency in nutrient composition and reduce potential confounding effects associated with forage quality fluctuations. The inclusion levels of PKC-based biosupplement biscuits varied according to the treatment groups. The composition and nutritional content of the experimental diets are presented in Table 1.

Table 1: Ingredient Composition and Nutritional Content of Experimental Diets

A. Ingredient Composition (% DM basis)				
Ingredient (%)	T0 (0%)	T1 (20%)	T2 (30%)	T3 (40%)
PKC-based biosupplement biscuit	0	20	30	40
Rice bran	25	20	15	10
Ground corn	20	18	15	12
Soybean meal	15	12	10	8
Mineral mix	1	1	1	1
Gliricidia sepium leaves	19	19	19	19
Pennisetum purpureum grass	20	10	10	10
Total	100	100	100	100
B. Nutritional Composition (% DM basis)				
Dry matter (%)	92.1	92.8	93.1	93.4
Organic matter (%)	80.5	82	83.5	85
Crude protein (%)	12.7	13.2	13.8	14.2
Ether extract (%)	3.4	3.7	4.1	4.5
Crude fiber (%)	25.6	26.2	26.8	27.4
Nitrogen-free extract (%)	49.1	49.5	50	50.6
Neutral detergent fiber (NDF, %)	70.1	71.5	72.8	74
Acid detergent fiber (ADF, %)	29	29.5	30.1	30.8
Calcium (%)	0.7	0.85	0.95	1.05
Phosphorus (%)	0.44	0.45	0.46	0.47

Note: T0 = control diet; T1 = 20% PKC-based biosupplement biscuit; T2 = 30% PKC-based biosupplement biscuit; T3 = 40% PKC-based biosupplement biscuit. All values are expressed on a dry matter basis

The chemical composition of the experimental diets showed that dry matter ranged from 92.10 to 93.40%, while organic matter varied between 80.50 and 85.00%. Crude protein content increased slightly with higher inclusion levels of PKC-based biosupplement biscuits, ranging from 12.70 to 14.20%. Ether extract ranged from 3.40 to 4.50%, indicating an increase in dietary energy density associated with PKC inclusion.

Crude fiber content ranged from 25.60 to 27.40%, reflecting the fibrous nature of PKC and forage components. Nitrogen-Free Extract (NFE), representing readily available carbohydrates, ranged from 49.10 to 50.60%. Structural carbohydrate fractions, including Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF), ranged from 70.10 to 74.00% and 29.00 to 30.80%, respectively.

Mineral content analysis showed that calcium levels ranged from 0.70 to 1.05%, while phosphorus ranged from 0.44 to 0.47%, indicating a relatively balanced mineral profile across treatments.

Proximate analysis of feed samples was conducted following standard AOAC procedures [21], and fiber fractions (NDF and ADF) were determined using the Van Soest method [12].

The biosupplement biscuits were prepared by thoroughly mixing all ingredients, followed by molding into compact cylindrical forms and oven-drying at 60 °C for 24 h until a constant weight was achieved. The compact physical structure was designed to improve nutrient homogeneity, reduce feed sorting behavior, and minimize feed wastage during feeding.

Blood Sampling and Metabolic Profile Analysis

At the end of the experimental period, approximately 5 mL of blood was collected from each animal via jugular venipuncture. Blood samples were kept at room temperature for 1–2 h to allow clotting and serum separation, followed by centrifugation at 4000 rpm for 5 min.

The obtained serum was transferred into Eppendorf tubes and analyzed for metabolic parameters, including total protein, glucose, cholesterol, calcium, and phosphorus, using standard laboratory procedures.

Measured Variables

The following parameters were measured: Dry Matter Intake (DMI), Crude Protein Intake (CPI), Total Digestible Nutrients (TDN) intake, Average Daily Gain (ADG), Feed Efficiency (FE), and blood metabolic profile (total protein, glucose, cholesterol, calcium, and phosphorus).

Ethical Approval

All animal handling and experimental procedures were performed following institutional guidelines for the care and use of animals in research. The study protocol was approved by the Animal Ethics Committee of Universitas Islam Kalimantan (Approval No: 175/UNISKA-FP/A.3/V/2025).

Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) under a Completely Randomized Design (CRD) using the following model:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

Where:

Y_{ij} = Observed value

μ = Overall mean

τ_i = Treatment effect

ε_{ij} = Experimental error

Prior to ANOVA, data were tested for normality and homogeneity of variance using the Shapiro-Wilk and Levene's tests, respectively. In addition, orthogonal polynomial contrasts (linear and quadratic) were applied to evaluate responses to increasing inclusion levels of Palm Kernel Cake (PKC)-based biosupplement biscuits (0%, 20%, 30%, and 40%) [22]. Differences were considered statistically significant at $p < 0.05$. SPSS version 17 was used for the analyses.

Results and Discussion

Feed Intake and Nutrient Utilization Dynamics

Dry matter intake decreased linearly ($p < 0.05$) with increasing PKC inclusion, likely due to increased fiber content and rumen fill. In contrast, crude protein and ether extract intake increased, reflecting higher nutrient density in PKC-based diets. This pattern suggests that goats utilized dietary nutrients more efficiently despite the lower dry matter intake. Table 2 shows that increasing PKC inclusion significantly affected nutrient intake parameters.

Table 2: Average Daily Nutrient Intake of Male Ettawah Goats

Parameter (g/day)	T0	T1	T2	T3
Dry matter	843.24±10 ^b	853.54±20.5 ^b	762.3±2.2 ^a	774.62±10.0 ^a
Crude protein	62.34±2.0 ^a	65.04±2.4 ^a	68.74±4.0 ^b	70.54±3.0 ^b
Crude fiber	91.19±12.6 ^a	93.12±6.4 ^a	95.12±4.0 ^b	96.27±4.7 ^b
Ether extract	43.12±4.5 ^a	43.17±4.0 ^a	46.15±7.0 ^b	49.65±2.0 ^c
NFE	242.24±8.0 ^a	244.25±1.6 ^a	254.42±12.5 ^b	260.12±9.10 ^c
NDF	302.25±10.7 ^a	304.72 ± 9.4 ^a	310.28±1.2 ^b	316.23±10.2 ^c
ADF	189.28±8.1 ^c	184.24±9.1 ^b	166.24±10.0 ^a	167.14±2.4 ^a

Values are expressed as mean ± standard deviation. Different superscripts within rows indicate significant differences ($p < 0.05$)

Dietary inclusion of PKC-based biosupplement biscuits significantly affected nutrient intake in growing Ettawah goats. Dry matter intake declined at higher PKC inclusion levels, whereas crude protein, ether extract, and fiber intake increased. The reduction in dry matter intake was likely associated with the greater fiber concentration of PKC-based diets, which may increase rumen fill and slow digesta passage rate. Similar responses have been reported in ruminants receiving high-fiber agro-industrial by-products, where increasing dietary fiber reduced voluntary feed intake but improved nutrient synchronization and digestive efficiency [5, 10, 11].

Despite the lower dry matter intake, goats receiving higher PKC supplementation showed greater protein consumption. This result indicates that the biosupplement biscuit system increased dietary nutrient density and improved protein availability. Improved protein intake may support microbial protein synthesis in the rumen, thereby enhancing nutrient utilization efficiency and fermentation activity [4]. The compact physical form of the biscuit may also have reduced feed selection behavior, allowing more consistent nutrient intake among animals.

Ether extract intake increased progressively with PKC supplementation, reflecting the relatively higher lipid content of palm kernel cake. Increased dietary lipid supply likely contributed additional metabolizable energy without substantially increasing feed volume. In ruminants, part of the lipid fraction may bypass ruminal degradation and become available for intestinal absorption, thereby improving energy utilization efficiency [12].

Neutral detergent fiber intake also increased with increasing PKC inclusion, which was expected because PKC is naturally rich in structural carbohydrates. However, the decline in ADF intake observed at higher supplementation levels may indicate partial improvement in fiber utilization, possibly associated with microbial adaptation and feed processing effects. Previous studies suggested that physical processing of fibrous feed ingredients can improve particle accessibility for rumen microorganisms and enhance fermentation efficiency [8].

The combination of PKC and other feed ingredients appeared to support more balanced nutrient availability in the rumen. The compact biscuit form may have contributed to improved nutrient utilization by reducing selective feeding behavior and promoting a more homogeneous intake of nutrients. Compared with conventional meal-form diets, the biscuit structure ensures simultaneous consumption of fiber, protein, and energy sources, thereby enhancing nutrient synchronization within the rumen ecosystem. Improved synchronization between fermentable energy and nitrogen supply may enhance microbial growth and nutrient utilization efficiency, ultimately contributing to improved animal performance. Similar observations have been reported in studies evaluating processed agro-industrial by-products in ruminant diets [5, 10, 11].

The compact biscuit structure may also influence rumen kinetics by increasing chewing activity and saliva secretion, which contribute to rumen buffering capacity. Improved buffering conditions may help maintain a more stable ruminal environment,

thereby supporting microbial activity and nutrient fermentation. Furthermore, the uniform distribution of nutrients within the biscuit matrix may promote synchronized release of fermentable substrates, enhancing microbial efficiency and nutrient utilization.

Nutrient Digestibility and Rumen Fermentation Implications

The inclusion of PKC-based biosupplement biscuits significantly affected nutrient digestibility in growing Ettawah goats. This response is consistent with earlier work showing that processed palm-oil by-product feeds and PKC-based local rations can support digestibility and productive responses in goats [15, 23] (Table 3).

Table 3: Nutrient digestibility of goats fed PKC-based biosupplement biscuits

Parameter (%)	T0	T1	T2	T3
Dry matter	72.2±4.7 ^a	74.9±3.4 ^a	75.7±11.3 ^b	77.3±2.8 ^b
Crude protein	68.7±2.4 ^a	69.8±4.2 ^a	70.6±2.1 ^b	70.94±2.0 ^b
Crude fiber	67.7±2.3 ^a	68.2±2.3 ^a	69.2±4.2 ^b	69.8±3.2 ^b
Ether extract	64.5±2.4 ^a	67.5±4.2 ^b	68.6±2.3 ^b	69.5±2.4 ^b
NFE	66.8±10.4 ^b	66.6±2.6 ^b	65.4±2.1 ^a	65.7±4.2 ^a
NDF	72.4±5.7 ^b	73.3±4.3 ^b	64.7±3.4 ^a	63.4±1.6 ^a
ADF	70.6±2.4 ^b	71.2±1.4 ^b	60.8±1.2 ^a	61.6±4.8 ^a

Linear effects were significant ($p < 0.05$), while quadratic effects were not significant

Dry matter digestibility increased from 72.2% in the control group to 77.3% in goats receiving 40% PKC supplementation. This improvement suggests that the biscuit form may have enhanced feed utilization by improving the accessibility of nutrients to rumen microorganisms. Although PKC contains relatively high levels of fiber, part of its hemicellulose fraction remains fermentable and can still be utilized by rumen microbes [3, 6]. Feed processing may also have contributed to better particle breakdown and microbial attachment during fermentation.

Crude protein digestibility also increased with higher PKC inclusion. Efficient protein utilization in ruminants depends on balanced nitrogen and energy supply in the rumen. The combination of PKC with other ingredients in the biosupplement biscuit may have created a more balanced nutrient supply for microbial growth, which in turn improved protein utilization [13, 14]. Similar responses have been reported in goats receiving agro-industrial by-product supplementation under tropical feeding systems.

Crude fiber digestibility showed a slight increase across treatments, indicating that the animals were still able to utilize fibrous feed ingredients effectively. Goats generally possess a highly adaptive rumen microbial ecosystem, allowing them to tolerate and utilize diets with relatively high fiber concentrations more efficiently than many other ruminants [12].

In contrast, NDF and ADF digestibility declined at higher levels of PKC supplementation. This reduction was likely associated with the increasing proportion of lignified and less degradable fiber fractions present in PKC. Structural carbohydrates such as lignin and mannan are more resistant to microbial degradation and may reduce the overall digestibility of cell wall components [6]. Nevertheless, the reduction in fiber digestibility did not appear to negatively affect animal performance, suggesting that improvements in protein and energy utilization compensated for the lower degradation of structural carbohydrates.

The results indicate that PKC-based biosupplement biscuits improved nutrient utilization efficiency in growing Ettawah goats. However, the proposed effects on rumen fermentation remain speculative because ruminal pH, Ammonia-N concentration, volatile fatty acid profiles, and microbial population dynamics were not directly measured in the present study. Future studies incorporating rumen fermentation characteristics and microbial analyses are required to elucidate the biological mechanisms responsible for the observed responses.

Growth Performance and Feed Efficiency

Growth performance and feed efficiency of male Ettawah goats are presented in Table 4. Initial body weight did not differ significantly among treatments, indicating that the animals were relatively uniform at the beginning of the experiment. However, final body weight, body weight gain, Average Daily Gain (ADG), and feed efficiency were significantly affected ($p < 0.05$) by dietary inclusion of PKC-based biosupplement biscuits.

Table 4: Growth Performance and Feed Efficiency of Male Ettawah Goats

Parameter	T0	T1	T2	T3
Initial body weight (kg)	16.23±1.2	15.45±2.1	16.32±2.5	15.83±3.4
Final body weight (kg)	18.67±1.5 ^a	18.16±2.4 ^a	19.14±1.6 ^b	18.74±2.4 ^b
Body weight gain (kg)	2.44±2.1 ^a	2.71±2.2 ^b	2.82±1.6 ^b	2.91±2.2 ^b
ADG (g/day)	43.57±2.5 ^a	48.39±1.4 ^b	50.35±2.8 ^b	51.96±5.3 ^b
Feed Efficiency (FE)	0.08±0.01	0.09±0.01	0.10±0.02	0.12±0.01

Different superscripts within rows indicate significant differences ($p < 0.05$)

Goats receiving higher levels of PKC supplementation showed better growth performance than those in the control group. Average daily gain increased from 43.57 g/day in T0 to 51.96 g/day in T3, while feed efficiency improved from 0.08 to 0.12. These results indicate that goats were able to convert dietary nutrients into body weight more efficiently when PKC based biosupplement biscuits were included in the diet.

The highest ADG and feed efficiency values were observed in goats receiving 30–40% PKC supplementation. Goats receiving PKC supplementation showed more efficient nutrient use despite the lower dry matter intake observed at higher inclusion levels. Similar responses have been reported in ruminants fed agro-industrial by-products, where improved nutrient synchronization and rumen fermentation contributed to better growth performance [2].

Figure 1 shows a consistent increase in both ADG and feed efficiency as PKC inclusion increased. The improvement in animal performance was likely associated with better nutrient digestibility and more efficient ruminal fermentation. Higher crude protein intake in treatments T2 and T3 may have supported microbial protein synthesis and increased the production of volatile fatty acids, particularly propionate, which plays an important role in energy metabolism and growth [20].

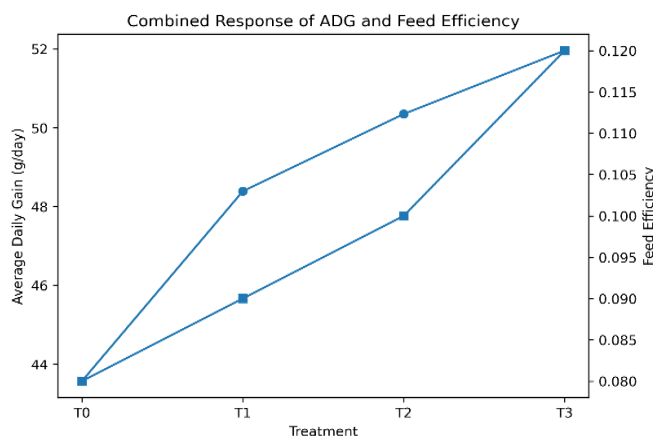


Fig. 1: Combined response of Average Daily Gain (ADG) and Feed Efficiency (FE) in male Ettawah goats fed increasing levels of PKC-based biosupplement biscuits

The higher ether extract content of PKC-based diets may also have contributed additional metabolizable energy. Part of the lipid fraction in PKC can bypass ruminal degradation and become available for digestion in the small intestine, thereby improving energy utilization efficiency without substantially increasing feed intake [12].

Improved feed efficiency further indicates that nutrients consumed by the animals were utilized more effectively for tissue growth. In addition, the compact form of the biosupplement biscuit may have reduced feed sorting and feed losses, resulting in more stable nutrient intake during the feeding period.

The improvement in growth performance and feed efficiency demonstrates the potential of PKC-based biosupplement biscuits as an alternative feeding strategy for growing Ettawah goats.

The linear increase in average daily gain and feed efficiency suggests a dose-dependent response to increasing PKC inclusion. The absence of a performance plateau at the highest supplementation level indicates that nutrient utilization remained effective up to 40% PKC inclusion. These findings suggest that the nutritional benefits of PKC-based biosupplement

biscuits were not fully exhausted at the highest inclusion level tested. Nevertheless, further studies involving higher supplementation levels are needed to determine the optimal upper threshold for PKC utilization in growing goats.

Blood Metabolic and Physiological Responses

The effects of PKC-based biosupplement biscuits on hematological and metabolic parameters of male Ettawah goats are presented in Table 5. All measured blood parameters remained within normal physiological ranges, indicating that the inclusion of PKC up to 40% did not induce any adverse health effects.

Table 5: Hematological Parameters of Male Ettawah Goats Fed PKC-Based Biosupplement Biscuits

Parameter	T0	T1	T2	T3	Normal Range
Hemoglobin (g/dL)	9.1 ± 0.5	9.8 ± 0.4	10.4 ± 0.6	10.8 ± 0.5	8–12
Hematocrit (%)	26.2 ± 1.2	28.1 ± 1.0	29.4 ± 1.3	30.1 ± 1.4	22–38
Erythrocytes (×10 ⁶ /μL)	10.1 ± 0.8	10.8 ± 0.7	11.6 ± 0.6	12.1 ± 0.5	8–18
Leukocytes (×10 ³ /μL)	9.2 ± 1.0	9.6 ± 0.9	10.2 ± 0.7	10.4 ± 0.8	4–13
Lymphocytes (%)	58.0 ± 3.1	59.4 ± 2.2	61.8 ± 2.0	62.3 ± 2.4	50–70

Neutrophils (%) ranged from 30.5±2.2 in T0 to 30.8±2.0 in T3, remaining within the normal physiological range of 20–48%. The hematological values observed throughout the study indicated that dietary supplementation with PKC-based biosupplement biscuits up to 40% did not negatively affect the health status of the animals. The increase in hemoglobin concentration, hematocrit values, and erythrocyte counts suggests improved oxygen transport capacity and better physiological condition in goats receiving higher PKC supplementation [15, 16].

The improvement in hematological status may be related to enhanced protein and energy availability, which support erythropoiesis and overall metabolic processes. Adequate amino acid supply derived from microbial protein synthesis is essential for hemoglobin formation, while sufficient dietary energy contributes to red blood cell production and metabolic activity [4, 17, 18].

Leukocyte counts remained relatively stable, while lymphocyte percentages tended to increase gradually with increasing PKC inclusion. These results indicate that PKC supplementation did not trigger stress or inflammatory responses in the animals. Instead, the observed responses may suggest improved immune function, potentially associated with the Mannan-Oligosaccharide (MOS) content of PKC, which can function as a prebiotic compound [6, 19]. MOS has been reported to improve gut microbial balance and stimulate immune responses, thereby enhancing animal health and resilience.

The stable hematological profile observed throughout the study indicates that PKC supplementation was well tolerated by the animals and did not disturb physiological homeostasis. This finding supports the practical application and sustainability of PKC supplementation in small-ruminant feeding systems.

Blood Biochemical Profile and Metabolic Implications

The effects of PKC-based biosupplement biscuits on blood biochemical parameters of male Ettawah goats are presented in Table 6. All measured variables remained within normal physiological ranges, indicating that dietary inclusion of PKC up to 40% did not negatively affect metabolic status or animal health.

Table 6: Blood Biochemical Parameters of Male Ettawah Goats Fed PKC-Based Biosupplement Biscuits

Parameter	T0	T1	T2	T3	Normal Range
Glucose (mg/dL)	56.3±3.2	58.6±3.0	61.4±2.8	64.2±2.9	45–80
Total Protein (g/dL)	6.3±0.2	6.6±0.3	6.9±0.2	7.1±0.3	6–7.5
Albumin (g/dL)	2.8±0.2	3.0±0.1	3.2±0.2	3.3±0.2	2.7–3.9
Globulin (g/dL)	3.4±0.3	3.6±0.2	3.7±0.2	3.8±0.2	2.5–4.5
Cholesterol (mg/dL)	92.1±4.5	95.6±4.0	98.4±3.8	100.5±4.1	80–130
Urea (mg/dL)	22.5±2.1	23.4±2.4	24.0±2.0	24.2±1.9	10–30
Creatinine (mg/dL)	1.1±0.07	1.12±0.05	1.13±0.04	1.15±0.06	0.5–1.5

Blood glucose concentration increased gradually with increasing PKC supplementation, from 56.3 mg/dL in the control group to 64.2 mg/dL in goats receiving 40% PKC supplementation. The increase in blood glucose reflects improved energy metabolism and greater availability of glucogenic substrates in the rumen. The increase in blood glucose was likely associated with greater propionate production during rumen fermentation [20]. The higher availability of fermentable nutrients in the PKC-based biosupplement biscuits likely contributed to increased glucose synthesis and energy supply.

Total protein, albumin, and globulin concentrations showed a gradual increase with increasing PKC supplementation while remaining within normal physiological ranges. The maintenance of these biochemical parameters within established reference values indicates that PKC-based biosupplement biscuits did not induce metabolic disturbances and were adequately utilized by the animals. Albumin plays an important role in nutrient transport and osmotic regulation, whereas globulin contributes to immune function and physiological homeostasis [18]. Similar findings have been reported in goats receiving nutritionally balanced agro-industrial by-products, where improved nutrient availability supported normal protein metabolism without adverse health effects [10, 11].

Likewise, cholesterol, urea, and creatinine concentrations remained within normal physiological ranges across treatments. The stability of these metabolites suggests that lipid metabolism, nitrogen utilization, and renal function were not negatively affected by increasing levels of PKC supplementation. These findings are consistent with previous studies demonstrating that the incorporation of palm oil by-products in ruminant diets can improve nutrient utilization while maintaining normal metabolic status and organ function [5, 10]. Collectively, the biochemical profile supports the safety and metabolic suitability of PKC-based biosupplement biscuits for growing male Ettawah goats.

Several limitations of the present study should be acknowledged. First, the relatively small sample size ($n = 20$) may limit the generalizability of the findings. Second, ruminal fermentation characteristics, including rumen pH, Ammonia-N concentration, volatile fatty acids, and microbial population dynamics, were not measured. Consequently, the biological mechanisms underlying the improvements in nutrient utilization and growth performance remain partially speculative. Future studies involving larger animal populations under different production systems are recommended to validate and extend these findings.

Conclusion

The inclusion of palm kernel cake-based biosupplement biscuits significantly improved nutrient utilization, as evidenced by higher dry matter and crude protein digestibility, increased average daily gain, and improved feed efficiency in growing male Ettawah goats. Supplementation levels of 30–40% produced the most favorable responses while maintaining hematological and biochemical parameters within normal physiological ranges. These findings demonstrate that PKC-based biosupplement biscuits represent a practical and sustainable strategy for utilizing palm oil industry by products in tropical goat production systems. Future studies should investigate rumen fermentation characteristics and microbial dynamics to clarify the biological mechanisms underlying these responses.

Practical Implications

The utilization of PKC-based biosupplement biscuits may reduce dependence on conventional feed ingredients and improve feeding efficiency in tropical small-ruminant production systems. A recent study in lactating Ettawah Crossbred goats likewise reported that PKC-based biosupplement biscuits improved nutrient utilization and milk production, supporting the broader applicability of this feeding strategy across physiological stages [24].

Acknowledgment

The authors gratefully acknowledge the financial support provided by the Ministry of Higher Education through the Fundamental Research Grant Scheme (2025).

Funding Information

This research was funded by the Ministry of Higher Education through the Fundamental Research Grant Scheme (2025).

Author's Contributions

Tintin Rostini: Conceived and designed the study, supervised the experiment, coordinated data collection and analysis, interpreted the results, and led manuscript writing and revision.

Danang Biyatmoko: Contributed to research design, data interpretation, manuscript review, and scientific revision of the article.

Achmad Jaelani: Participated in experimental design, feed formulation, laboratory supervision, and critical revision of the manuscript.

Dr Suharlina: Contributed to animal management, sample collection, statistical analysis, and manuscript edited.

Raga Samudera: Participated in field data collection, feed preparation, laboratory analysis, and data tabulation.

Fuzi Maulana Ashar: Contributed to laboratory analysis, interpretation of nutritional data, and manuscript preparation.

Ditza Pasca Irwansa: Assisted with data processing, graphical presentation, and technical editing of the manuscript.

Ethics

All experimental procedures involving animals were approved by the Institutional Animal Ethics Committee of Islamic University of Kalimantan (Approval No: 175/UNISKA-FP/A.3/V/2025).

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