



Mangostin-Rich Mangosteen Pulp Extract Improves Lipid and Protein Metabolism in Meat Goats

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ABSTRACT

The use of plant-derived bioactive compounds as natural feed supplements has gained increasing attention in ruminant production because of their potential to promote animal health and reduce the reliance on synthetic supplements and antibiotics. This study evaluated the effects of dietary supplementation with mangosteen peel powder (MPP) and mangosteen pulp extract containing 10% mangostin (MG10) on growth performance, hematological parameters, and metabolic profiles in meat goats. Overall, 25 male goats were divided into control, 1% MPP (MPP1), 2% MPP (MPP2), 1% MG10 (MG10-1), and 2% MG10 (MG10-2) groups. Hematological, serum lipid and sugar, serum protein, and liver function analyses were performed using blood samples, and feed intake and growth performance were examined. Growth performance did not differ significantly among groups; however, daily feed intake was significantly higher ($p = 0.030$) in the MG10-1 and MG10-2 groups than in the control group. Hemoglobin levels and red blood cell counts were unaffected by treatment and remained within normal ranges across all groups. MPP consumption increased aspartate aminotransferase activity and blood sugar levels. Conversely, MG10 supplementation, especially MG10-2, significantly elevated high-density lipoprotein ($p = 0.007$) and albumin levels ($p = 0.014$), whereas MG10-1 increased blood urea nitrogen and albumin levels. Low-density lipoprotein and cholesterol levels remained unchanged after supplementation. Overall, MG10 demonstrated greater potential than MPP as a functional feed additive because of its beneficial effects on lipid and protein metabolism. Thus, MG10 is a promising natural supplement for improving metabolic health and optimizing feed utilization in livestock production systems.

Keywords: *blood biochemical; feed additives; Garcinia mangostana; goat production; mangostin*

INTRODUCTION

Goats are an important small ruminant species in Thailand, with a rapidly expanding market and high consumer demand. Despite increasing demand and supportive policies, goat farming in Thailand continues to face several challenges, including persistently low productivity, recurring health problems, and rising feed costs. These constraints undermine profitability and sustainability and limit the ability of the sector to expand and meet market demand.

To address these concerns, previous studies have focused on improving goat production systems, with most research emphasizing enhanced nutrition and management to increase productivity (Mayberry *et al.*, 2018; Teixeira *et al.*, 2024; Aman *et al.*, 2025) and the

mitigation of health-related issues to reduce economic losses (Airs *et al.*, 2023; Rabee *et al.*, 2025). Recently, plant by-products and plant-derived compounds have gained considerable attention as animal feed supplements, offering potential benefits beyond basic nutrition (Wójtowski *et al.*, 2023; Bouma & Noosen, 2024; Rabee *et al.*, 2025). The use of functional animal feed supplements is increasingly being considered a promising strategy for improving animal performance efficiency while reducing the reliance on expensive traditional feeds and synthetic additives. In particular, bioactive compounds derived from plants have gained attention because of their potential to improve nutrient utilization (Faniyi *et al.*, 2021; Rabee *et al.*, 2024; Peng *et al.*, 2024), modulate metabolic processes (Tsiplakou *et al.*, 2021; Aldian *et al.*, 2025), and support animal health

without compromising its welfare (Jaber, 2025; Jia *et al.*, 2025; Asfa *et al.*, 2025).

Mangosteen (*Garcinia mangostana* L.) is a tropical fruit widely cultivated in India and Southeast Asia, especially in Thailand. Traditionally, extracts from the mangosteen peel have been used in herbal medicine due to their pharmacological properties, including anti-inflammatory, antimicrobial, and antioxidant effects (Suttirak & Manurakchinakorn, 2014). The mangosteen pericarp is particularly rich in several phenolic compounds such as xanthenes, benzophenones, flavonoids, bioflavonoids, phenols, and tannins (Manimekalai *et al.*, 2016; Rohman *et al.*, 2019). Among these, xanthenes are considered the most distinctive group of compounds, as more than 50 different xanthenes have been identified in mangosteen (Akao *et al.*, 2008; Adriani & Widjastuti, 2020). The most extensively studied xanthenes in mangosteen are α -mangostin, β -mangostin, and γ -mangostin (Zarena & Sankar, 2009; Wittenauer *et al.*, 2012; Rohman *et al.*, 2019). However, xanthenes have been reported to affect lipid metabolism, particularly suppressing *de novo* cholesterol synthesis (Adriani & Widjastuti, 2020). In addition, xanthenes present in the mangosteen peel extract can suppress the intestinal absorption of cholesterol and bile acids, thereby reducing blood cholesterol levels (Kusmayadi *et al.*, 2019). These dual effects on cholesterol synthesis and absorption suggest that mangosteen peel may have substantial potential to improve lipid metabolism and overall health in livestock.

Several *in vitro* and *in vivo* studies in ruminants have explored the functional potential of mangosteen peel supplementation. These studies demonstrated beneficial effects, such as enhanced rumen fermentation efficiency, increased nutrient digestibility, and improved antioxidant status, highlighting the potential of mangosteen peel as a sustainable feed additive in ruminant production systems (Pilajun & Wanapat, 2011; Phesatcha *et al.*, 2022). By improving nutrient utilization efficiency and reducing oxidative damage, mangosteen peel can help address two major challenges in goat production: increasing feed costs and animal health concerns. Moreover, natural feed additives can reduce the need for synthetic growth promoters and antibiotics, aligning with current trends toward safer and more environmentally sustainable livestock production.

In addition to its effects in the rumen, the biological activity of mangosteen peel has been demonstrated in various animal models. A systematic review of studies revealed that mangosteen pericarp extract can reduce oxidative stress, lipid peroxidation, and inflammation in animals exposed to toxins, unhealthy diets, and ultraviolet radiation. These protective effects are primarily mediated by increased endogenous antioxidant enzyme activity and reduced levels of oxidized low-density lipoprotein (LDL), highlighting the systemic antioxidant potential of mangosteen-derived compounds (Elmund & Hartrianti, 2020). Furthermore, mangosteen peel supplementation has been reported to improve growth performance, gastrointestinal health, nutrient efficiency, and immune responses in chickens

(Kim *et al.*, 2024). These findings suggest that the beneficial effects of mangosteen extend across animal species, highlighting its potential as a versatile feed additive.

Evidence indicates that mangosteen peel extract, rich in xanthenes and other bioactive phytochemicals, can provide a practical solution to several challenges in goat production. By improving feed efficiency, enhancing health through antioxidant and antimicrobial activities, and reducing dependency on costly or synthetic inputs, mangosteen peel can contribute to more sustainable and profitable goat farming. Despite these promising preliminary findings, further systematic investigation is needed to clarify the specific effects of mangosteen supplementation on goat performance, metabolism, and health under practical production conditions.

Therefore, this study compared the effects of mangosteen peel powder (MPP) and mangosteen pulp extract containing 10% mangostin (MG10) on growth performance, hematological parameters, and serum metabolic profiles in growing meat goats.

MATERIALS AND METHODS

Ethical Approval

The protocols for animal experimentation were approved by the Institutional Animal Care and Use Committee of Silpakorn University. All animal experiments adhered to the criteria outlined in the Ethics of Use to Animals for Scientific Work by the National Research Council of Thailand (Project ID: 19/2567).

Animals

Twenty-five young crossbred Thai-native \times Boer male goats (average body weight [BW], 14.06 ± 0.74 kg) were transported from local farms to the experimental facilities of the Faculty of Animal Sciences and Agricultural Technology, Silpakorn University (Cha-Am, Thailand). Upon arrival, all goats received a subcutaneous injection of 5 mL of 10% catosal (containing 100 mg of butaphosphan and 0.05 mg of cyanocobalamin/mL) once daily for seven consecutive days. Animals were fed a uniform basal diet for 1 month before the experimental period to allow for adaptation. All goats were healthy and free of diarrhea during this period.

Following the adaptation period, the goats were randomly assigned to five dietary treatments: a control diet, a basal diet supplemented with 1% or 2% MPP (MPP1 and MPP2, respectively), or a basal diet supplemented with 1% or 2% powdered mangosteen pulp extract containing 10% mangostin (MG10-1 and MG10-2, respectively; both supplements from AP OPERATIONS, Si Racha, Thailand). Twenty-five goats were housed in an open-pen system (five animals per pen) at a stocking density of 2.0 m² per goat under natural ventilation in a tropical environment in Thailand from December 2024 to March 2025. Each goat was fed a

basal ration equivalent to 2% of its BW per day. Acacia leaves and the basic diet were provided twice daily at 9:00 and 16:00 h during the experiment, along with unrestricted access to clean drinking water. Daily feed intake was determined by measuring feed refusals every 24 h on a pen basis, and feed intake was subsequently calculated for each animal within the same pen. Each animal was weighed every week before feeding in the morning during both the adaptation and experimental periods. The chemical composition of experimental diets is presented in Table 1.

Blood Sample Collection and Analysis

Blood samples (10 mL) were collected from the jugular vein before the morning feeding on days 0 (the initial day of the experiment) and 30 (the final day of the experiment). Blood samples were collected in evacuated tubes containing K₃EDTA for hematological analysis and into serum tubes with a clotting activator for biochemical profile assessment. All samples were analyzed within 2 h of collection.

Hematological Analysis

Hematological analysis (red blood cell [RBC] counts; hemoglobin [Hb] concentrations; white blood cell [WBC] counts; and the differential percentages of neutrophils, lymphocytes, and monocytes) was determined using an automated hematology analyzer (PENTRA 60, HORIBA Medical, Kyoto, Japan). The analyzer was calibrated according to the manufacturer's instructions, and to ensure measurement accuracy, internal quality controls were conducted daily.

The erythrocyte sedimentation rate (ESR) was determined using the Westergren method, in which anticoagulated whole blood was drawn into a Westergren tube and allowed to stand vertically at room temperature. RBC sedimentation was recorded after 1 h.

Serum Biochemical Analysis

Fasting blood sugar (FBS), cholesterol, triglyceride, high-density lipoprotein (HDL), LDL, blood urea nitrogen (BUN), aspartate aminotransferase (AST), total protein, and albumin concentrations were analyzed using an automated biochemical analyzer (ROCHE Cobas C 501, Roche, Basel, Switzerland) according to the

manufacturer's instructions. Calibration was performed using standard reference materials, and internal quality control sera were analyzed daily to ensure accuracy and reproducibility.

Statistical Analysis

All data were analyzed using analysis of variance, and differences in means were compared using Duncan's multiple range test at a 95% confidence level, performed with the R statistical package (R Core Team 2025). The results are expressed as the mean ± standard error of the mean.

RESULTS

Growth Performance

The effects of MPP and MG10 supplementation on the growth performance of growing meat goats are presented in Table 2. Initial BW, final BW, and average daily gain (ADG) were not significantly affected by dietary treatments ($p > 0.05$). The initial BW of goats ranged from 13.14 to 14.42 kg, and after the feeding trial, the final BW ranged from 16.74 to 17.88 kg among the groups. Similarly, ADG varied between 72.73 and 122.42 g/day, with no significant differences among the groups.

Daily feed intake was significantly influenced by dietary supplementation ($p = 0.030$). Goats receiving MG10-1 (381.60 g/day) and MG10-2 (383.00 g/day) consumed significantly more feed than control goats (313.30 g/day), whereas intake in the MPP1 (357.40 g/day) and MPP2 (349.10 g/day) groups was intermediate.

Erythrocyte Profile

The effects of dietary supplementation with MPP and MG10 on erythrocyte parameters in growing meat goats are presented in Table 3. RBC counts and Hb concentrations were not significantly affected by dietary treatments ($p > 0.05$). Specifically, the RBC counts ranged from $1.22 \times 10^6/\text{mm}^3$ in the MPP1 group to $2.22 \times 10^6/\text{mm}^3$ in the MG10-2 group. Hb concentrations varied between 5.55 and 7.85 g/dL, with a tendency to be higher in the MG10-2 group than in the control group. Although not significant, the ESR tended to be higher in the MG10-1 group (50 mm/h) than in the other groups (0.00 mm/h, $p = 0.072$).

Table 1. Chemical composition of the basal diet for meat goats (g/kg DM, unless otherwise stated)

Nutrients	Experimental diets				
	Control	MPP1	MPP2	MG10-1	MG10-2
OM	920.27	920.47	920.66	920.67	921.06
CP	131.09	130.38	129.67	130.18	129.27
EE	34.71	34.61	34.52	34.56	34.42
NDF	345.14	346.89	348.64	343.19	341.24
ADF	350.77	351.36	351.95	348.26	345.76
TDN	625.00	623.75	622.50	625.75	626.50
GE, MJ/kg DM	18.63	18.62	18.61	18.64	18.65

Note: OM, organic matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fiber; ADF, acid detergent fiber; TDN, total digestible nutrients (calculated according to NRC [2007]); GE, gross energy. MPP1, 1% mangosteen peel powder; MPP2, 2% mangosteen peel powder; MG10-1, 1% mangosteen pulp extract containing 10% mangostin; MG10-2, 2% mangosteen pulp extract containing 10% mangostin.

Table 2. Growth performance of growing meat goats fed diets supplemented with mangosteen

Variables	Experimental diets					SEM	P
	Control	MPP1	MPP2	MG10-1	MG10-2		
Initial BW (kg)	13.76	13.60	14.42	13.84	13.14	0.206	0.311
Final BW (kg)	17.13	16.84	16.82	17.88	16.74	0.210	0.957
Basal feed intake (g/head/day)	313.30 ^b	357.40 ^{ab}	349.10 ^{ab}	381.60 ^a	383.00 ^a	12.754	0.030
ADG (g)	102.12	98.18	72.73	122.42	109.09	8.164	0.787

Note: Different superscripts in the same row indicate significant differences ($p < 0.05$). ADG, average daily gain; BW, body weight; SEM, standard error of the mean; MPP1, 1% mangosteen peel powder; MMP2, 2% mangosteen peel powder; MG10-1, 1% mangosteen pulp extract containing 10% mangostin; MG10-2, 2% mangosteen pulp extract containing 10% mangostin; SEM, standard error of the mean.

Table 3. Erythrocyte profile of growing meat goats fed mangosteen-supplemented diets

Variables	Experimental diets					SEM	P
	Control	MPP1	MPP2	MG10-1	MG10-2		
Red blood cells ($\times 10^6/\text{mm}^3$)	1.46	1.22	1.77	1.66	2.22	0.168	0.426
Hemoglobin (g/dL)	5.95	5.55	6.85	6.45	7.85	0.397	0.330
Erythrocyte sedimentation rate (mm/h)	0.00 ^b	0.00 ^b	0.00 ^b	0.50 ^a	0.00 ^b	0.100	0.072

Note: Different superscripts in the same row indicate significant differences ($p < 0.05$). MPP1, 1% mangosteen peel powder; MMP2, 2% mangosteen peel powder; MG10-1, 1% mangosteen pulp extract containing 10% mangostin; MG10-2, 2% mangosteen pulp extract containing 10% mangostin; SEM, standard error of the mean.

Leukocyte Profile

The leukocyte profile of growing meat goats fed MPP and MG10 is presented in Table 4. The total WBC count ranged from 19.80×10^3 to $29.75 \times 10^3/\text{mm}^3$, with no significant differences among groups ($p > 0.05$). In contrast, differential leukocyte counts were significantly influenced by the dietary treatments. The neutrophil percentage was significantly lower ($p = 0.005$) in the MG10-1 and MG10-2 groups (12.00%) than in the control and MPP groups (18.50%–19.50%). Conversely, lymphocyte percentages were significantly higher ($p < 0.001$) in the MG10 groups (81.00%–83.50%) than in the control and MPP groups (72.00%–73.50%). Monocyte percentages also differed among treatments ($p = 0.023$), with lower values observed in the MG10-2 group (3.00%) than in the other groups (5.00%–6.00%).

Serum Lipid and Sugar Profiles

The effects of experimental diets on FBS and serum lipid profiles are presented in Table 5. FBS levels differed significantly among the groups ($p = 0.013$), with higher levels in the MPP1 group (42.50 mg/dL) than in the control (26.50 mg/dL) and MG10-1 groups (30.00 mg/dL). FBS levels in the MG10-2 (39.00 mg/dL) and MPP2 groups (36.50 mg/dL) did not differ significantly from those in the other groups.

Serum cholesterol concentrations were higher in the MPP1 (58.00 mg/dL) and MG10-2 groups (90.00 mg/dL) than in the control group (43.50 mg/dL); however, these differences were not significant ($p = 0.108$). Triglyceride levels were significantly influenced by diet ($p = 0.047$). MG10-2 supplementation resulted in the highest triglyceride concentration (57.50 mg/dL), which was significantly higher than those in the control (31.00 mg/dL) and MG10-1 groups (23.00 mg/dL). The MPP1 and MPP2 groups exhibited intermediate triglyceride levels (39.50–40.50 mg/dL) that did not differ significantly from those in the other groups. HDL levels differed significantly among treatment groups ($p = 0.007$), with the MG10-2 group exhibiting a significantly higher concentration (62.50 mg/dL) than the other groups, which showed comparable values (34.50–42.50 mg/dL). LDL levels did not differ significantly among treatments ($p = 0.120$); however, the MG10-1 group showed a comparatively elevated level (50.50 mg/dL).

Serum Protein and Liver Function

Dietary treatments significantly affected BUN, AST, and albumin concentrations (Table 6). BUN levels were highest in the MG10-1 group (26.50 mg/dL), significantly exceeding those in the control (22.00 mg/dL), MPP1 (20.50 mg/dL), MPP2 (20.50 mg/dL), and MG10-2 groups (18.50 mg/dL, $p = 0.006$). AST activity differed

Table 4. Leukocyte profile of growing meat goats fed mangosteen-supplemented diets

Variables	Experimental diets					SEM	P
	Control	MPP1	MPP2	MG10-1	MG10-2		
White blood cells ($\times 10^3/\text{mm}^3$)	29.75	24.45	26.10	19.80	20.05	1.883	0.230
Neutrophils (%)	19.50 ^a	18.50 ^a	19.50 ^a	12.00 ^b	12.00 ^b	1.765	0.005
Lymphocytes (%)	72.00 ^b	73.50 ^b	73.00 ^b	81.00 ^a	83.50 ^a	2.353	<0.001
Monocytes (%)	5.50 ^a	6.00 ^a	5.00 ^a	5.50 ^a	3.00 ^b	0.524	0.023

Note: Different superscripts in the same row indicate significant differences ($p < 0.05$). MPP1, 1% mangosteen peel powder; MMP2, 2% mangosteen peel powder; MG10-1, 1% mangosteen pulp extract containing 10% mangostin; MG10-2, 2% mangosteen pulp extract containing 10% mangostin; SEM, standard error of the mean.

Table 5. Serum lipid and sugar profiles of growing meat goats fed mangosteen-supplemented diets

Variables	Experimental diets					SEM	P
	Control	MPP1	MPP2	MG10-1	MG10-2		
Fasting blood sugar (mg/dL)	26.50 ^c	42.50 ^a	36.50 ^{ab}	30.00 ^{bc}	39.00 ^{ab}	2.930	0.013
Cholesterol (mg/dL)	43.50	58.00	51.00	49.50	90.00	8.230	0.108
Triglyceride (mg/dL)	31.00 ^b	39.50 ^{ab}	40.50 ^{ab}	23.00 ^b	57.50 ^a	5.755	0.047
HDL (mg/dL)	34.50 ^b	42.50 ^b	37.00 ^b	39.50 ^b	62.50 ^a	5.004	0.007
LDL (mg/dL)	3.00	7.50	6.00	50.50	16.00	8.746	0.120

Note: Different superscripts in the same row indicate significant differences ($p < 0.05$). HDL, high-density lipoprotein; LDL, low-density lipoprotein; MPP1, 1% mangosteen peel powder; MPP2, 2% mangosteen peel powder; MG10-1, 1% mangosteen pulp extract containing 10% mangostin; MG10-2, 2% mangosteen pulp extract containing 10% mangostin; SEM, standard error of the mean.

Table 6. Serum protein and liver function of growing meat goats fed mangosteen-supplemented diets

Variables	Experimental diets					SEM	P
	Control	MPP1	MPP2	MG10-1	MG10-2		
BUN (mg/dl)	22.00 ^b	20.50 ^b	20.50 ^b	26.50 ^a	18.50 ^b	1.345	0.006
AST (U/L)	17.50 ^c	22.50 ^a	16.50 ^c	21.50 ^{ab}	18.50 ^{bc}	1.158	0.011
Total protein (g/dL)	6.55	5.25	6.25	6.25	6.30	0.224	0.453
Albumin (g/dL)	2.15 ^b	3.05 ^a	2.65 ^{ab}	2.95 ^a	3.20 ^a	0.186	0.014

Note: Different superscripts in the same row indicate significant differences ($p < 0.05$). BUN, blood urea nitrogen; AST, aspartate aminotransferase; MPP1, 1% mangosteen peel powder; MPP2, 2% mangosteen peel powder; MG10-1, 1% mangosteen pulp extract containing 10% mangostin; MG10-2, 2% mangosteen pulp extract containing 10% mangostin; SEM, standard error of the mean.

significantly among groups ($p = 0.011$). The MPP1 group exhibited the highest AST level (22.50 U/L), which was significantly higher than that in the control (17.50 U/L) and MPP2 groups (16.50 U/L), whereas the MG10-1 (21.50 U/L) and MG10-2 groups (18.50 U/L) showed intermediate values. Total protein concentrations did not differ among treatments ($p = 0.453$), ranging from 5.25 to 6.55 g/dL. In contrast, albumin levels were significantly affected by diet ($p = 0.014$), with higher levels observed in the MPP1 (3.05 g/dL), MG10-1 (2.95 g/dL), and MG10-2 groups (3.20 g/dL) than the control group (2.15 g/dL), whereas albumin levels in the MPP2 group (2.65 g/dL) did not differ significantly from those in the other groups.

DISCUSSION

The present study demonstrated that dietary supplementation with MPP and MG10 did not significantly affect growth performance, as indicated by initial and final BW or ADG, in growing meat goats. These results are consistent with those of previous studies, suggesting that dietary polyphenol or plant-derived extract supplementation does not necessarily result in measurable improvements in growth performance in small ruminants fed nutritionally adequate basal diets (Poli *et al.*, 2021; Giller *et al.*, 2021; Serra *et al.*, 2021).

Interestingly, Ban *et al.* (2022) reported that MPP, which contains flavonoids and cinnamic acids, can impart a pleasant flavor, whereas its condensed tannin content can impart a bitter and tangy taste. Therefore, supplementation with these nutrients may slightly reduce feed intake in meat goats. In this study, goats supplemented with MG10 exhibited significantly higher feed intake than the control group, whereas MPP supplementation had a moderate effect on feed intake.

This suggests that mangostin-rich extracts can enhance palatability or stimulate appetite, likely by modulating taste perception or gastrointestinal microbial activity, as observed for other plant-derived bioactive compounds (Ban *et al.*, 2022; Fabela-Morón, 2024). However, the increase in voluntary feed intake did not result in substantial weight gain (Poli *et al.*, 2025), indicating that additional feed consumption did not translate into enhanced growth. This may be attributable to the relatively short duration of the feeding trial or, alternatively, to the possibility that mangosteen supplementation did not substantially influence the nutrient utilization efficiency or the metabolic conversion of the additional feed.

Hematological parameters were not significantly affected by supplementation with either MPP or MG10 in growing meat goats. These results suggest that mangosteen-derived bioactive compounds do not adversely affect erythropoiesis or hemoglobin synthesis, supporting the hematological safety of the supplements under the conditions of this study (Soosean *et al.*, 2010; Kim *et al.*, 2024). In contrast, ESR was slightly elevated in the MG10-1 group. Although significance was not reached, this finding could indicate transient, mild changes in plasma protein levels or erythrocyte aggregation (Harrison, 2015). The elevated ESR observed in the MG10-1 group may be associated with changes in plasma protein composition, particularly increases in acute-phase proteins and globulin fractions. These alterations could result from immunostimulation and modifications in hepatic protein metabolism induced by MG10-1 supplementation, thereby promoting erythrocyte aggregation and a higher sedimentation rate. Similar minor variations in the inflammatory status have been reported in ruminants supplemented with plant-derived bioactive compounds, likely reflecting short-term physiological adaptations

rather than adverse effects (Kumprechtová *et al.*, 2022). Overall, these results suggest that the dietary inclusion of MPP or MG10 is hematologically safe for growing meat goats. The slight increases in RBC count and Hb levels, along with the modest elevation in ESR observed in one group, warrant further investigation, potentially through longer-term supplementation or higher inclusion rates, to determine whether these trends have functional significance for oxygen transport or erythrocyte stability.

Notably, MG10 supplementation affected the counts of various WBC types. Mangosteen-derived products, particularly MG10, have been reported to exert immunomodulatory effects by altering the distribution of WBCs toward adaptive immunity. Bioactive compounds may enhance adaptive immunity by facilitating antigen presentation and T and B cell activation via cytokine signaling, thereby improving antigen-specific immune responses. Such modulation may strengthen the immune response, enhance disease resistance, and help maintain immune homeostasis during stress periods, such as weaning or exposure to high pathogen levels (Ban *et al.*, 2022). A lower neutrophil-to-lymphocyte ratio, as observed in MG10-supplemented groups, could indicate reduced systemic inflammation and better immune homeostasis, consistent with the anti-inflammatory properties of α -mangostin reported in previous studies (Kim *et al.*, 2017; Herrera-Aco *et al.*, 2019).

Serum biochemical indicators are critical parameters for assessing animal health, and dietary nutrient absorption and metabolism strongly influence their levels (Zaitsev *et al.*, 2021). FBS, total cholesterol, HDL, and triglyceride levels are key indicators of energy metabolism (Grauagnard *et al.*, 2012). In the present study, MPP supplementation resulted in a slight increase in FBS levels, whereas MG10-2 significantly increased HDL and triglyceride concentrations without affecting total cholesterol or LDL levels. These findings suggest that mangostin-rich extracts can improve lipid mobilization and metabolism while modulating carbohydrate utilization (Ban *et al.*, 2022). Elevated BUN, a marker of nitrogen metabolism, along with increased albumin levels, an indicator of hepatic protein synthesis, in MG10-supplemented goats, suggest enhanced hepatic protein metabolism and synthetic function (Ban *et al.*, 2022). In contrast, the modest increase in AST levels observed in the MPP1 group remained within the normal physiological range, indicating no evidence of hepatotoxicity. These results align with previous reports indicating that plant-derived bioactive compounds, including xanthenes and polyphenols, can support liver function, enhance protein synthesis, and improve metabolic efficiency in ruminants (Ban *et al.*, 2022; Kim *et al.*, 2024).

CONCLUSION

Overall, the present findings highlight the potential of mangosteen-derived bioactive compounds, particularly MG10, to enhance feed intake, modulate immune function, and improve metabolic profiles

without adversely affecting growth or hematological health. The observed immunomodulatory effects, increased HDL and triglyceride levels, and enhanced protein metabolism indicate that mangosteen supplementation may confer physiological benefits beyond basic nutrition. Future studies should investigate long-term supplementation, varying inclusion levels, and interactions with different basal diets to optimize efficacy and clarify the physiological, metabolic, and immunomodulatory roles of mangosteen bioactive compounds in small ruminants.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the manuscript.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used ChatGPT (OpenAI, USA) for preliminary language assistance. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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