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Physiological and Immunological Responses to *Moringa oleifera* and Flaxseed Supplementation in Goat Kids

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ABSTRACT

The 120-day feeding trial was executed between February and May, 2022 at the Livestock Research Farm (LRC) of the National Dairy Research Institute, Karnal, Haryana, to evaluate the effects of *Moringa oleifera* leaf meal (MOLM) and flaxseed supplementation on the hematological, biochemical, and immune indices of Alpine×Beetal crossbred goat kids. *Moringa oleifera* leaf meal and flaxseed were recognized for their nutritional and immunomodulatory properties in livestock nutrition. Thirty-two female goat kids of similar age and body weight were randomly assigned to four dietary treatments (n=8 per group) for a 120-day feeding trial. The treatments consisted of a Control (basal diet), Treatment 1 (20% MOLM), Treatment 2 (20% flaxseed), and Treatment 3 (10% MOLM+10% flaxseed). Hematological indices including hemoglobin concentration, total erythrocyte count and packed cell volume, were significantly improved following MOLM supplementation. Furthermore, plasma total protein, immunoglobulin, and total antioxidant capacity (TAC) were significantly elevated in the treatment1 group (p<0.05). The results indicated that the dietary incorporation of 20% MOLM effectively enhanced the hematological profile, biochemical status, and systemic immune function of the goat kids. Although, the Treatment 3 , group outperformed the Treatment 2 group but did not exceed the performance of the Treatment 1, group. In conclusion, incorporating 20% *Moringa oleifera* leaf meal represented a highly sustainable and effective nutritional strategy for improving hematological profiles, boosting systemic immune function, and mitigating oxidative stress in Alpine×Beetal goat kids.

KEYWORDS: Flaxseed, hematology, immunity, *Moringa oleifera*, cortisol

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1. INTRODUCTION

Small ruminant farming, particularly goat rearing, acts as a critical pillar for global food and nutritional security, especially within vulnerable and developing regions. This is largely due to the species' inherent versatility and overall suitability for small-scale operations (Navarrete-Molina et al., 2024; Airs et al., 2023). While goats exhibit exceptional environmental adaptability and can withstand intense heat and pathogenic stress (Joy et al., 2020), the sector remains heavily burdened by pre-weaning mortality. Kid mortality rates approach 34.60% (Hegde and Deo, 2020), primarily triggered by diarrheal infections and inadequate birth weights (Ramos et al., 2026). Consequently, because achieving optimal early body weight defines future growth patterns and weaning success, targeted kid nutrition is absolutely vital for survival. Economically, feed costs pose a formidable challenge, accounting for 60–75% of total production expenses, a burden heavily driven by protein sources that alone constitute 15–20% of concentrate expenditures (Badawi et al., 2019). Rising feed costs and external protein reliance increase ruminant production vulnerability, causing severe economic strain for traditional farming in areas facing pasture scarcity or climate threats (Morales-Reyes et al., 2025). Additionally, recurring feed shortages lead to poor animal growth, low milk yields, reduced reproductive performance and a decline in overall productivity (Togo et al., 2026) creating a pressing demand for innovative, sustainable and accessible feed resources. Consequently, phytogenic additives derived from bioactive plant materials have emerged as sustainable dietary interventions to naturally boost livestock health and maximize performance (Biswas and Kim, 2025). Within this context, utilizing functional leaf protein presents a promising yet underexplored alternative (Furia et al., 2026). Among available options, *Moringa oleifera* is exceptionally valued for its rapid agricultural growth, substantial biomass yield and continuous year-round availability (Abdoun et al., 2023). The nutritional density of *M. oleifera* leaves is remarkable, offering crude protein 22–30 % of dry matter (Sultana, 2020), with approximately 47% of high quality rumen-bypass protein (Leitanthem et al., 2022). Beyond macronutrients, *M. oleifera* supplies bioactive compounds essential for disease prevention (Islam et al., 2021). Rich in secondary metabolites like flavonoids and polyphenols (Chis et al., 2023; Luetragoon et al., 2020), offering nine times yogurt's protein, this leaf meal provides an excellent alternative in livestock feed (Olusanya et al., 2020). These targeted bioactive constituents are well-documented for their strong systemic anti-inflammatory, antioxidant, and immune-boosting properties (Kam et al., 2026; Kholif et al., 2021). Prior research has consistently shown that supplementing small ruminants with *M. oleifera* significantly enhances circulatory blood profiles and powerfully strengthens natural defense mechanisms against environmental stressors (Mohai-Ud Din et al., 2026; Khalid et al., 2023). Alongside leaf meals, flaxseed provides an exceptional dietary safeguard during forage shortages. When incorporated into rations, it delivers concentrated metabolic energy, beneficial dietary fiber, essential minerals and high-quality protein (Duarte et al., 2025). Flaxseed's abundant omega-3 fatty acid (Yu et al., 2022) content effectively optimizes metabolic functions, stimulating tissue growth and effectively elevating cellular immune responses across caprine species (Dong et al., 2023). In practice, moderate thermal pretreatment such as oven, sand or microwave roasting is commonly utilized to effectively degrade anti-nutritional cyanogenic glycosides and improve the overall oxidative stability of flaxseed (Hou et al., 2021). Although the isolated nutritional and health benefits of utilizing *Moringa oleifera* leaf meal (MOLM) and flaxseed are firmly established in literature, there remains a distinct lack of empirical data regarding their combined synergistic capacity in crossbred goat kids. To bridge this gap, the present study comprehensively investigated how the singular and combined dietary supplementation of MOLM and flaxseed influences the hemato-biochemical markers, plasma immunoglobulin G_1 (IgG_1) levels, systemic cortisol concentrations and total antioxidant capacity (TAC) of Alpine×Beetal goat kids.

2. MATERIALS AND METHODS

2.1. Experimental location and animals

The 120-day feeding trial was executed between February–May, 2022 at the Livestock Research Farm (LRC) of the National Dairy Research Institute, Karnal, Haryana (Latitude 29°42'N, Longitude 76°54'E). All experimental procedures were approved by the Institutional Ethical Committee (IEAC). A total of 32 female Alpine×Beetal crossbred kids, aged approximately three months with an initial body weight of 10–12 kg, were randomly allocated into four equal groups (n=8 per group). The dietary rations for all animals were formulated strictly according to the Anonymous (2013).

2.2. Experimental design

The study utilized a completely randomized design (CRD) to allocate the kids into four distinct dietary treatment groups. All groups were fed a basal diet with a roughage-to-concentrate ratio of 60:40, with the concentrate portion substituted differently for each group. The control (C) group received a basal diet with a standard concentrate mixture and no replacement. For treatment$_1$ (T_1), the basal diet included a 20% replacement of the concentrate mixture with MOLM. In treatment$_2$ (T_2), 20% of the concentrate mixture was replaced by flaxseed. Finally, for treatment$_3$ (T_3),

the basal diet featured a concentrate mixture replaced by a combination of 10% MOLM and 10% flaxseed.

2.3. Preparation of experimental feeds and chemical analysis of feed

Moringa leaves were harvested from fields of Integrated Farming System (IFS) of NDRI, Karnal and dried in shade then ground in a grinder. Flaxseed was purchased from local market of Karnal and before offering to kids it was mildly roasted at 140–145°C.

2.4. Blood and plasma samples

Blood samples were collected at 0th day and at monthly interval from jugular vein of kids using vacutainer for evaluation of total erythrocyte count, total leukocyte count, hemoglobin % and packed cell volume. Plasma was separated for the estimation of glucose, total protein, albumin, globulin and albumin: globulin ratio using Fully Automatic Biochemistry Analyzer. Immunoglobulin G_1 (IgG_1) and cortisol by using goat ELISA assay test kit and total antioxidant capacity (TAC) by FRAP assay of Benzie and Strain (1999).

2.5. Statistical analysis

Data was statistically analyzed using a one-way ANOVA and the significance of the difference between the mean values was determined by Tukey Post-hoc test (Snedecor and Cochran, 1994) through Statistical Package for Social Sciences version 22.0 software.

3. RESULTS AND DISCUSSION

3.1. Effect of dietary moringa oleifera leaf meal (MOLM) and flaxseed on hematological parameters of kids

The effects of dietary MOLM and flaxseed on the hematological profile of crossbred goat kids were summarized in Table 1. The hemoglobin (Hb) concentration, packed cell volume (PCV), and total erythrocyte count (TEC) were significantly elevated (p<0.05) in the T_1 group (20% MOLM) compared to the other dietary treatments. Furthermore, the T_3 group (10% MOLM+10% flaxseed) demonstrated significantly higher Hb and TEC values than both the T_2 group (20% flaxseed) and the Control. The Control and T_2 groups exhibited statistically similar values for Hb and TEC. The total leukocyte count (TLC) did not differ significantly across any of the treatment groups.

Table 1: Effect of dietary MOLM and flaxseed on hematological parameters of goats kids

Parameter	Treatments			
	Control	T_1	T_2	T_3
Hb %	9.65^{a}± 0.002	10.12^{c}± 0.10	9.71^{a}± 0.004	9.85^{b}± 0.002
TEC (10^6 mm^{-3})	10.60^{a}± 0.005	11.15^{c}± 0.004	10.66^{a}± 0.007	10.79^{b}± 0.003
TLC (10^3 mm^{-3})	10.68± 0.01	10.91± 0.01	10.76± 0.01	10.74± 0.01
PCV %	28.46^{a}± 0.02	29.69^{c}± 0.04	28.64^{ab}± 0.04	28.87^{b}± 0.02

Hb: Hemoglobin, TEC: Total erythrocyte count, TLC: Total leucocyte count, PCV: Packed cell volume, Mean bearing different superscripts in a row differ significantly abcd (p<0.05)

Hematological indices served as vital baseline indicators for assessing the physiological, nutritional, and health status of livestock (Daramola et al., 2005). The marked improvements in Hb, TEC, and PCV observed in the T_1 group indicated a strong hematopoietic influence of MOLM. This effect was likely mediated by the rich presence of essential amino acids, vitamins, minerals (particularly iron), and bioactive phytochemicals such as alkaloids, flavonoids, phytosterols, and saponins in *Moringa oleifera* leaves. Iron was critical for hemoglobin and myoglobin synthesis, directly enhancing erythropoiesis and the blood's oxygen-carrying capacity (Hewitt et al., 1989). Consequently, the peak TEC observed in the MOLM-supplemented group corresponded directly with the highest Hb and PCV values, underscoring the superior capability of this diet to supported robust oxygen transport.

These findings align with previous studies (Biswal, 2022; Farrag, 2024; Ukey et al., 2025) that reported significant increases in Hb and PCV among goats fed *Moringa*-based diets. Conversely, some researchers (Ali et al., 2018; Zaher et al., 2020; Wankhede et al., 2022; Perdana and Pribudi, 2026) observed no significant impact on the goat blood profile, suggesting that hematological responses might vary based on inclusion levels and experimental conditions.

However, all Hb (8–12%), TEC (8×10^6 mm^{-3}–18×10^6 mm^{-3}) and PCV (22–38 %) values recorded in this study remained entirely within standard physiological ranges for goats (Tschuor, 2008; Mohammed et al., 2016). This confirmed that the *Moringa oleifera* supplementation was highly nourishing, non-toxic and beneficial for overall blood supply. Similarly, the total leukocyte count (TLC) remained within the normal physiological range (4×10^3 mm^{-3}–13×10^3 mm^{-3}) across all groups, indicating that the kids remained healthy and free from systemic infections throughout the trial. While Biswal et al. (2022) and Ukey et al. (2025) reported significant increases in TLC suggesting immunomodulation, the stable TLC in the present study likely reflected excellent herd management and a lack of pathogenic stress. The improved hematological parameters in the T_3 group relative to the Control and T_2 indicated a positive synergistic effect of combining MOLM and flaxseed on the overall blood profile of goat kids which could likely be attributed to the highly complementary

nutritional profiles of the two feed supplements. While flaxseed provided a dense source of energy and omega-3 polyunsaturated fatty acids which were known to enhance cell membrane integrity and exert anti-inflammatory effects (Khan et al., 2020) while *Moringa oleifera* supplies the critical raw materials for hematopoiesis, such as iron, bioavailable amino acids and antioxidant vitamins (Akbar et al., 2026). The anti-inflammatory environment fostered by the flaxseed might have improved intestinal health and nutrient absorption, allowing the goat kids to more efficiently utilize the iron and proteins provided by the MOLM for red blood cell synthesis.

3.2. Effect of dietary moringa oleifera leaf meal (MOLM) and flaxseed on blood biochemical parameters of kids

The effect of dietary MOLM and flaxseed on blood biochemical parameters of goat kids was presented in Table 2. Blood biochemical indicators were essential metrics for evaluating the physiological state, nutritional level and metabolic status of livestock (Mohammed et al., 2016; Stefanska et al., 2016). In the present study, plasma glucose levels were significantly higher in the T_1 group (20% MOLM) and statistically comparable to the T_3 group (10% MOLM+10% flaxseed), while the control and T_2 groups displayed similar, lower values. This higher plasma glucose in MOLM-fed kids indicated an improved energy status, corroborating the findings of Afzal et al. (2021) and Zaher et al. (2020), who attributed elevated blood glucose in *Moringa*-fed goats to enhanced crude protein digestibility. However, blood glucose levels remained well within the normal physiological range (50–75 mg dl^{-1}) required for healthy goats (Khan et al., 2020). Conversely, Perdana and Pribudi (2026) observed no effect on serum glucose in goats, suggesting that metabolic responses might vary based on breed and specific dietary composition.

Plasma total protein (TP) was significantly elevated in the T_1 group, whereas no significant differences were observed between the T_2, T_3 and Control groups. Plasma total protein consists primarily of albumin and globulin, with albumin serving as a key marker for protein absorption, synthesis, and liver function (Wang et al., 2020). Because albumin synthesis required a balanced supply of amino acids (Hou et al., 2020), the significantly higher plasma albumin observed across all treatment groups (with T_1 being the highest) suggested that MOLM and flaxseed supplementation optimized the overall amino acid profile available to the kids. This aligned with previous research reporting significantly higher total protein and albumin levels in goats supplemented with *Moringa* (Zaher et al., 2020; Leitanthem et al., 2022; Farrag, 2024) and cattle supplemented with flaxseed (Guo et al., 2026). While, the concentrations of plasma globulin and the albumin to globulin (A:G) ratio in the current study remained non-significant (p>0.05) across all groups. This non-significant A:G ratio was consistent with the findings of Meteab et al. (2018) in Damascus goats fed flaxseed, confirming that the treatments supported homeostasis without disrupting physiological balance.

3.3. Effect of dietary moringa oleifera leaf meal (molm) and flaxseed on immunoglobulin 1 of kids

The effect of dietary MOLM and flaxseed on the immunoglobulin G_1 (IgG_1) concentrations of the experimental goat kids was detailed in Table 3. Plasma IgG_1 levels (mg dl^{-1}) were significantly elevated (p<0.05) across all treatment groups (T_1, T_2 and T_3) when compared to the

Table 2: Effect of dietary MOLM and flaxseed on blood biochemical parameters of kids

Parameter	Treatments			
	Control	T_1	T_2	T_3
Plasma glucose (mg dl-1)	60.89^{a}± 0.07	61.80^{b}± 0.02	61.03^{a}± 0.04	61.18^{ab}± 0.03
Plasma total protein (g dl^{-1})	6.45^{a}± 0.001	6.83^{c}± 0.01	6.64^{b}± 0.01	6.63^{ab}± 0.01
Plasma albumin (g dl^{-1})	3.05^{a}± 0.005	3.39^{b}± 0.003	3.27^{b}± 0.003	3.25^{b}± 0.006
Plasma globulin (g dl^{-1})	3.39± 0.01	3.43± 0.01	3.36± 0.01	3.38± 0.01
Plasma albumin: globulin	0.93± 0.006	0.99± 0.003	0.98± 0.005	0.97± 0.005

mg dl^{-1}: milligram per deciliter, g dl^{-1}: gram per deciliter; Mean bearing different superscripts in a row differ significantly ^{abcd}(p<0.05)

Table 3: Effect of dietary MOLM and flaxseed supplementation on plasma IgG1 (mg ml^{-1}) of kids

Days	Treatments			
	Control	T_1	T_2	T_3
0	8.33± 0.012	8.32± 0.012	8.35± 0.019	8.33± 0.01
30	8.75^{a}± 0.01	9.01^{c}± 0.03	8.95^{bc}± 0.04	8.82^{ab}± 0.04
60	8.89^{a}± 0.03	9.66^{b}± 0.02	9.68^{b}± 0.01	9.66^{b}± 0.01
90	9.34^{a}± 0.008	10.47^{b}± 0.01	10.48^{b}± 0.02	10.45^{b}± 0.01
120	9.91^{a}± 0.01	11.08^{b}± 0.33	11.07^{b}± 0.02	11.05^{b}± 0.02
Overall mean ±SEm	9.05^{a}± 0.004	9.70^{c}± 0.004	9.71^{c}± 0.004	9.66^{b}± 0.005

Mean bearing different superscripts in a row differ significantly abcd (p<0.05)

Control. However, the highest IgG_1 concentrations were observed in the T_1 and T_2 groups, which were statistically comparable to each other. These results clearly demonstrated that the dietary inclusion of MOLM, flaxseed and their combination exerted a strongly positive immunomodulatory effect on crossbred kids. Immunoglobulin G was recognized as the most abundant and enduring antibody in the serum, functioning as the primary driver of the secondary humoral immune response (Vidarsson et al., 2014). Consequently, an elevated IgG_1 concentration served as a reliable biological marker for enhanced systemic immunity. The immune improvements observed in the *Moringa*-fed groups aligned closely with the findings of Liu et al. (2024), who reported a significant increase in the plasma IgG_1 levels of early-weaned goat kids following MOLM supplementation. Similarly, Ojeka et al. (2016) noted enhanced serum IgG concentrations in Wistar rats administered an aqueous *Moringa oleifera* leaf extract, further validating the plant's capacity to stimulate humoral defense mechanisms. Furthermore, the robust immune response observed in the flaxseed-supplemented group (T_2) corroborates with Sun et al. (2020), who documented numerically greater plasma IgG_1 in preweaned piglets of sow fed flaxseed. This immune-boosting property could be largely attributed to the high concentration of alpha-linolenic acid (ALA) in flaxseed. ALA was a vital omega-3 polyunsaturated fatty acid (PUFA) that has been widely documented for its potent immunomodulatory and anti-inflammatory effects in livestock (Panasevich et al., 2022). Therefore, the results indicated that goats in the treatment groups possessed a superior immune status compared to the control, highlighting the efficacy of both feeds in fortifying animal health.

3.4. Effect of dietary moringa oleifera leaf meal (molm) and flaxseed on cortisol of kids

The effect of dietary MOLM and flaxseed on the plasma cortisol concentrations (ng ml^{-1}) of goat kids was presented in Table 4. The findings revealed no significant differences in plasma cortisol levels across the groups, although the control group displayed numerically higher values compared to the treatment groups. However, the cortisol concentrations for all experimental animals remained well within the normal physiological range of 3 to 15 ng ml^{-1} established for healthy goats (Montellano et al., 2007), demonstrating that the dietary interventions were highly palatable and well-tolerated, ensuring that kids remained entirely stress free throughout the trial. Similarly, Ukey et al., 2025 and Raju et al., 2024 reported reduced cortisol in *Moringa*-fed Barbari goats and lambs, respectively. Contrary to this, Girgo et al. (2020), reported a significant reduction in cortisol levels in Karan Fries (KF) cattle fed a flaxseed supplemented diet. The divergence between these studies suggested that endocrine and glucogenic responses to lipid-rich supplements like flaxseed might be highly dependent on species-specific physiological factors as well as the overarching composition of the basal diet.

Table 4: Effect of dietary MOLM and flaxseed on plasma cortisol (ng ml^{-1}) of goat kids

Days	Treatments			
	Control	T_1	T_2	T_3
0	7.80±0.12	7.84±0.14	7.80±0.14	7.80±0.14
30	7.79±0.12	7.78±0.14	7.76±0.14	7.75±0.14
60	7.78±0.13	7.72±0.15	7.69±0.14	7.71±0.14
90	7.77±0.13	7.67±0.14	7.64±0.14	7.67±0.13
120	7.78±0.17	7.61±0.14	7.59±0.14	7.63±0.13
Overall Mean± SEm	7.78±0.001	7.72±0.002	7.69±0.001	7.71±0.002

Mean bearing different superscripts in a row differ significantly abcd (p<0.05)

3.5. Effect of dietary moringa oleifera leaf meal (MOLM) and flaxseed on total antioxidant capacity (TAC) of kids

The effect of dietary MOLM and flaxseed on the TAC of the experimental kids was illustrated in Table 5. Overall, TAC (µmol ml^{-1}) was significantly enhanced by all dietary treatments compared to the Control. Specifically, the highest TAC was recorded in the T_1 group, while the T_2 and T_3 groups exhibited statistically analogous values that remained significantly superior to the Control. These results demonstrated that both supplements, individually and in

Table 5: Effect of dietary MOLM and flaxseed on TAC (µmol ml^{-1}) of goat kids

Days	Treatments			
	Control	T_1	T_2	T_3
0	33.95± 0.07	35.44± 0.58	35.32± 0.94	33.63± 4.43
30	54.99^{a}± 1.92	70.71^{c}± 1.09	64.05^{b}± 0.90	63.51^{b}± 1.42
60	72.06^{a}± 1.96	95.35^{c}± 1.77	90.46^{c}± 0.51	82.72^{b}± 1.64
90	89.16^{a}± 1.70	116.41b± 1.99	108.65^{b}± 3.92	109.24^{b}± 2.98
120	102.06^{a}± 0.34	133.05^{c}± 1.60	122.10^{b}± 0.85	121.03^{b}± 1.81
Overall mean± SEm	70.84^{a}± 0.4	90.19^{c}± 0.2	84.12^{b}± 0.6	82.03^{b}± 0.5

Mean bearing different superscripts in a row differ significantly ^{abcd}(p<0.05)

combination, were highly effective at elevating the systemic antioxidant defenses of growing kids. The pronounced antioxidant status observed in T_1 was consistent with the findings of Babiker et al. (2017), Afzal et al. (2021) in Beetal goats, and Juhaimi et al. (2020) in Aardi goat kids. This substantial improvement was primarily attributed to the rich phytochemical profile of Moringa leaves, which are abundant in potent free-radical scavengers such as ascorbic acid, flavonoids, phenolics and carotenoids (Makkar and Becker, 1996; Anwar et al., 2005). Similarly, the elevated TAC in T_2 and T_3 underscored the robust antioxidant properties of flaxseed and its by-products. Flaxseed has antioxidant-active compounds that effectively mitigated oxidative stress a physiological benefit that has been widely documented across various livestock species, including dairy cattle, sheep and broiler chickens (Kumar et al., 2021; Huang et al., 2022; Zhang et al., 2025). The marked antioxidant effect of flaxseed in goats was well supported by Cecchini et al. (2018). Furthermore, the positive response to flaxseed supplementation aligned with Jiang et al. (2015), who reported increased TAC in goslings hatched from flaxseed-fed mothers, and Guo et al. (2026), who observed enhanced TAC and corresponding immunity improvements in cattle. Ultimately, the dietary inclusion of MOLM and flaxseed optimizes the overall redox balance, alleviating potential oxidative stress and supporting the long-term health of the kids.

4. CONCLUSION

Dietary supplementation with *Moringa oleifera* leaf meal (MOLM) and flaxseed significantly enhanced the physiological and immunological status of crossbred goat kids. The inclusion of 20% MOLM maximally improved energy and protein metabolism while yielding the highest total antioxidant capacity. Furthermore, sole supplementation of 20% MOLM or 20% flaxseed profoundly boosted humoral immunity by elevating IgG_1. All treatments maintained normal cortisol levels. Thus, these ingredients served as effective additives that promoted health and fortified immunity.

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