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Effects of *Moringa oleifera* intake and Chelated Mineral Supplements Compared to Soybean-Based Diet on Growth Performance, Milk Production, and Immune Status in Goats

Mohammed A. Amean[1], Mohammed S. Al-azzawi[2], Hira Tazeen[3], Syed Sibt E Hassan[3], Rana Mehroz Fazal[4*]

[1]Animal Production Department, College of Agriculture, Tikrit University, Tikrit, Iraq
[2] Accreditation Department, Supervision and Scientific Evaluation Authority, Baghdad, Iraq
[3]School of Life Science, Shanxi University, China.
[4]Department of Zoology, Ghazi University Dera Ghazi Khan, Punjab, Pakistan.

*Correspondence: rfazal@gudgk.edu.pk

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ABSTRACT

This study evaluated the effects of Moringa oleifera with chelated minerals and a soybean-based diet on growth performance, milk production, and immune status in goats. A total of 45 goats were divided into three groups and fed for 90 days. Growth performance improved significantly in supplemented groups, with the highest final body weight recorded in the Moringa + mineral group (42.78 kg) compared to the control (32.37 kg; $p = 0.007$). Similarly, body weight gain was highest in this group (22.58 kg), indicating better nutrient utilization ($p = 0.005$). In contrast, the soybean-based diet resulted in the highest muscle mass index and improved muscle development. Milk production was significantly enhanced, with the highest yield observed in the soybean group compared to the control. Milk fat increased from 3.7% in the control to 4.4% in the supplemented groups, while total solids reached a maximum of 13.1%, indicating improved milk quality. Immune response and health status were markedly improved in the treated groups. Disease incidence decreased from 23.1% in the control to 7.6% in the soybean group ($p = 0.005$). Antibody response was highest in supplemented goats. Stress and inflammation markers were reduced, with cortisol declining to 17.6 ng/mL and CRP to 4.1 mg/L compared to higher values in the control group ($p \leq 0.006$). In conclusion, Moringa with chelated minerals mainly enhanced growth and immunity, whereas the soybean-based diet improved milk production and muscle development, highlighting their complementary benefits in goat production.

تأثيرات إضافة المورينغا أوليفيرا والمخلّبات المعدنية مقارنةً بعلف من فول الصويا على أداء النمو، وإنتاج الحليب، والحالة المناعية في الماعز

محمد عبدالقادر محمد امين[1]، محمد العزاوي[2] ، هيرا تزين[3]، سيد سبت إحسان[3]، رنا ميروز فضال[4]

[1]قسم الإنتاج الحيواني، كلية الزراعة، جامعة تكريت، تكريت، العراق.
[2]إدارة الاعتماد، هيئة الإشراف والتقييم العلمي، بغداد، العراق
[3]كلية علوم الحياة، جامعة شانشي، الصين.
[4]قسم علم الحيوان، جامعة غازي, ديرا غازي خان، البنجاب، باكستان.

الخلاصة

هدفت هذه الدراسة إلى تقييم تأثيرات إضافة المورينغا أوليفيرا مع المخلّبات المعدنية، مقارنةً بعلف قائم على فول الصويا، على أداء النمو، وإنتاج الحليب، والحالة المناعية في الماعز. تم تقسيم 45 ماعزاً إلى ثلاث مجموعات، وتم تغذيتها لمدة 90 يوماً. تحسّن أداء النمو بشكل ملحوظ في المجموعات المدعّمة، حيث سُجّل أعلى وزن جسمي نهائي في مجموعة المورينغا + المعادن (42.78 كجم) مقارنة بالمجموعة الضابطة (32.37 كجم؛ الاحتمال = 0.007). وبالمثل، كان أعلى اكتساب لوزن الجسم في هذه المجموعة (22.58 كجم)، مما يشير إلى تحسن استخدام العناصر الغذائية (الاحتمال = 0.005). في المقابل، أدى العلف القائم على فول الصويا إلى تحقيق أعلى مؤشر لكتلة العضلات (99.07؛ الاحتمال = 0.005)، مما يشير إلى تحسن النمو العضلي. تحسّن إنتاج الحليب بشكل ملحوظ، حيث لوحظ أعلى إنتاج في مجموعة فول الصويا (2.8 لتر/يوم) مقارنة بالمجموعة الضابطة (1.8 لتر/يوم؛ الاحتمال = 0.005). ازداد دهن الحليب من 3.7% في المجموعة الضابطة إلى 4.4% في المجموعات المدعّمة، بينما بلغ إجمالي المواد الصلبة ذروته عند 13.1% (الاحتمال ≤ 0.006)، مما يشير إلى تحسن جودة الحليب. تبيّن تحسن ملحوظ في الاستجابة المناعية والحالة الصحية في المجموعات المعالجة. انخفض معدل الإصابة بالأمراض من 23.1% في المجموعة الضابطة إلى 7.6% في مجموعة فول الصويا (الاحتمال = 0.005). كانت الاستجابة للأجسام المضادة أعلى لدى الماعز المدعّم (امتصاص بصري 1.42؛ الاحتمال = 0.006). انخفضت مؤشرات الإجهاد والالتهاب، حيث هبط الكورتيزول إلى 17.6 نانوجرام/مل، والبروتين المتفاعل C-إلى 4.1 ملجم/لتر مقارنة بقيم أعلى في المجموعة الضابطة (الاحتمال ≤ 0.006) .**الخلاصة :**حسّن المورينغا مع المخلّبات المعدنية بشكل أساسي النمو والمناعة، بينما حسّن العلف القائم على فول الصويا إنتاج الحليب والنمو العضلي، مما يسلط الضوء على فوائدهما التكميلية في إنتاج الماعز.

الكلمات المفتاحية :دهن الحليب، بروتين، درجة حالة الجسم، المورينغا أوليفيرا، الأجسام المضادة

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INTRODUCTION

Goats in developing countries contribute to nutritional supply, rural income, and food security (Cooke *et al*., 2024). Goats are highly adaptable animals and can play an important role in diverse environmental conditions (Silva *et al*., 2022). Their productivity, which can thrive, may be disrupted by poor health and inadequate nutrition (Ejiohuo *et al*., 2024). The natural feed additives and advanced mineral supplementation play a vital role in enhancing the milk production, growth, and health in goats (Nadziakiewicza *et al*., 2019; Owais *et al*., 2026). The nutrient availability and improved feed quality have become a key focus to optimize animal productivity (Empel *et al*., 2016).

Herbal feed, particularly *Moringa oleifera,* contributed significantly to production? and gained attention due to high levels of protein, antioxidants, vitamins, and essential minerals in its leaves (Richter *et al*., 2003). Moringa leaves contain a rich nutritional profile and bioactive compounds that influence the immune function, digestion, and metabolism (Kashyap *et al*., 2022). The plant-based supplements in animal diets in inhibited environments can improve the growth rates and feed efficiency (Lynch *et al*., 2018). It also enhances disease resistance and plays an important role in providing environments that inhibit the growth of microorganisms, which improve the growth and disease resistance (Xia *et al*., 2022). The inclusion of herbal supplementation in the form of chelated and bioavailable forms is extensively recognized in animal nutrition (Byrne *et al*., 2021). The plant-based supplements demonstrated the potential to modulate rumen fermentation in ruminants, which are rich in bioactive compounds (Dhanasekaran *et al*., 2020).

Chelated trace minerals more efficiently improved the metabolic consumption and biological responses (Ghasemi *et al*., 2020). It is absorbed in the gastrointestinal tract, that leading to playing a vital role in enzymatic activities and the health of ruminants (Guilloteau *et al*., 2009). The minerals affecting growth performance, immune regulation, and skeletal development, these strategies have been reported to improve the health of the ruminants (Shao *et al*., 2021). The plant-derived compounds are also directly used in the feed of ruminants and are involved in the improvement of immune regulation and skeletal development (Jaiswal *et al*., 2020). It is also involved in the production of volatile fatty acids, and is involved in enhancing the microbial activity and stabilizing ruminal pH (Dijkstra *et al*., 2012).

Nutritional management improves the milk production and its properties in lactating animals, which significantly affects milk quantity and quality (Pan *et al*., 2023). It also influenced the key components of milk yield, such as fat protein, lactose, and total solids (Zhou *et al*., 2018). Furthermore, the quality of milk is highly sensitive to the nutrients in the diet, especially protein and energy, which are the two primary components of milk formation and directly involved in the supply of energy and protein to the mammary gland (Rezaei *et al*., 2016). In particular, protein-rich feed ingredients improved the milk quality, which serves as the primary precursor for milk synthesis (Borad *et al*., 2017). The animals receiving such supplements can lead to improved fiber digestion and exhibit higher milk fat percentages (Schroeder *et al*., 2004). The soybean meal is extensively involved in enhancing nitrogen utilization and amino acid accessibility, which are significant for lactation performance and milk protein synthesis (Amin *et al*., 2022).

Diets supplemented with vitamins, antioxidants, and bioactive compounds are critical determinants for livestock production and directly influence both innate and adaptive responses (Khan *et al*., 2024). The animal health and immune competence with the dietary interventions also enhance the antibody production, immune function, and reduce stress indicators such as cortisol (Niu *et al*., 2022). It is also involved in lowering the incidence of diseases and also influences the physiological health and immune status in goats (Ceriac *et al*., 2017).

Despite the various studies on feed components of ruminants, limited studies have evaluated the mutual effects of herbal supplementation and chelated mineral nutrition in comparison with protein sources such as soybean-based diets. Additionally, it remains unknown whether combining Moringa and chelated minerals into a single treatment produces additive or synergistic effects compared to a conventional soybean meal diet, particularly in lactating dairy goats. Therefore, this study was designed to investigate the effects of dietary treatments such as Moringa and chelated mineral-based diet, and a soybean-based diet, on growth, feed efficacy, milk production and composition, immune response, and health in lactating dairy goats.

MATERIALS AND METHODS

Study Area and Experimental Animals

The study was conducted at a private farm in Sarsink district, Duhok Government, Iraq. Forty-five healthy female local Kurdish goats (first-lactation does, non-pregnant) with an average initial weight of goat were 20.17±0.21, and the age was 8 to 10 months, were used. All the animals were physically examined to ensure healthy goats with no

physiological abnormalities, no infectious disease, for the experiments. The goats were provided with controlled housing conditions with a ventilation system, drainage, and sanitation systems for maintaining hygiene throughout the study period. The ecological parameters, temperature ranged from 23–26°C, and relative humidity (Hygrometer, EISCO, UK) ranged from 54–66%, and a photoperiod of 12 h light and 12 h dark cycle was monitored to maintain physiological rhythms (García-Caparrós *et al*., 2020). Animals were housed in ventilated group pens, with each goat allocated 1.6 m × 2.1 m of floor space for movement and to lessen the stress. Clean and dry bedding material was provided and replaced regularly to maintain sanitary conditions, with *ad libitum* access to fresh water for the animals throughout the experimental period. Before the start of the experiment, animals were acclimatized for up to two weeks, during which they adapted to the new housing environment.

Ethical Approval

Any animal experiment was conducted in compliance with the institutional guidelines of animal care and use in research. Ethical approval was received through the College of Agricultural Engineering Sciences, University of Duhok, Iraq (Approval No. CAES-2025-049).

Experimental Design and Dietary Treatments

After the acclimatization, the 45 breeds of goats were randomly distributed into three triplicate groups, and each group had three replicates, with five animals per replicate (n=15 per treatment). The randomized complete block was designed in this study. The three groups included GP-1 (Control Group) animals, which were fed a basal diet without any supplementation, GP-2, which were given a Moringa and Chelated Minerals-based diet, and GP-3, which were provided a soybean-based diet as a protein-enriched diet to support growth and production. These were selected to compare a innovative herbal plus chelated mineral supplement with a soybean meal and a basal control. The composition of the three diets is presented in Table 1. This study lasted up to 90 days, and feed was given twice daily (08:00 and 16:00) at 3% of their body weight.

Table (1a) Composition of experimental diets (g/kg) for goats under Different Dietary Treatments

Feed Ingredients (g/kg)	GP-1 (Control)	GP-2 (Moringa + Chelated Minerals)	GP-3 (Soybean-Based Diet)
Alfalfa Hay	275	215	215
Corn Stalk	275	235	235
Corn Grain	175	145	145
Soybean Meal	75	50	120
Moringa Leaf Meal	0	100	0
Chelated Minerals	0	20	0
Dicalcium Phosphate	9	15	15
Limestone	6	7	7
Salt	7	6	6

Vitamin-Mineral Premix	27	26	26
Wheat Bran / Filler	151	181	231
Total (g/kg)	1000	1000	1000

Table 1 (b) Chemical Composition

Parameter	GP-1 (Control)	GP-2 (Moringa + Chelated Minerals)	GP-3 (Soybean-Based Diet)
Dry Matter (%)	89.5	90.2	89.8
Crude Protein (%)	12.8	15.6	16.9
Crude Fiber (%)	22.7	21.4	20.1
Ether Extract (%)	2.8	3.4	3.1
Ash (%)	7.2	8.9	7.5
Metabolizable Energy (MJ/kg DM)	9.8	10.4	10.9

Preparation of Moringa Leaf Meal and Chelated Minerals

M. oleifera leaves were collected, cleaned, sun-dried for 72 hours, and crushed into a fine powder (2 mm particle size) by a hammer mill. The chelated mineral at 20 g/kg of diet was provided, which contained zinc, copper, manganese, and selenium in chelated form (Bioplex series, Alltech, USA).

Growth and morphometric measurement

After the end of the experiment, all goats were provided a 10-hour fasting period to ensure the accuracy of the growth and morphometric measurement data (Ullman *et al*., 1999) and Naeem *et al*. (2026). The initial weight (IW) and final weight (FW) were recorded by a digital livestock weighing scale (Kern & Sohn, model: HCB 100K100, Germany). Whereas the Body length was measured by measuring tape (Stanley Tools, model: PowerLock 5 m, USA). Body condition score (BCS) was measured using a standardized 1–5 scoring scale, which is based on visual assessment and physical palpation of the lumbar area, ribs, and sternum region. Body weight gain (BWG), average daily gain (ADG), Growth rate (GR), Feed conversion ratio (FCR), Feed intake (FI), Skeletal growth (SG), and muscle mass index (MMI) was calculated by the following formulas

Body Weight Gain (BWG, kg) = $BWG = FW - IW$

$$ADG\ (gm) = \frac{BWG \times 1000}{Days}$$

Growth Rate (GR, kg) = $GR = \frac{BWG}{IW}$

$$Skeletal\ Growth\ (SG) = H_{final} - H_{initial}$$

Muscle Mass Index (MMI)= Body Weight (kg)/ (Body Length (m))2

FCR = feed given (g)/ Weight gain (g)

Feed Intake; FCR × Weight gain (g)

H = indicated the body height of the goat (cm)

Milk Yield and Composition Analysis

Milk yield was monitored and recorded during the whole study period. It was expressed in liters per day (L/day). All the milk samples collected in clean, sterile containers during the study were stored at 4 °C to prevent microbial deterioration before the laboratory analysis. All the milk samples were mixed to ensure uniformity. The

compositional parameters, such as Milk fat content, were assessed by following the Gerber method (Andrade *et al*., 2022). In this method, milk samples in a butyrometer were mixed with sulfuric acid and isoamyl alcohol, and then centrifugation was performed. The fat content was then recorded on the scale of the butyrometer. The Kjeldahl method was used to determine the protein percentage by using a conversion factor of 6.38. The titration was used to determine the Lactose content, and based on the milk components, total solids (TS) were examined by drying the sample in an oven at 102–105 °C until a constant weight was attained (Tesfaye *et al*., 2025).

Protein (%) =Nitrogen (%) ×6.38

Total Solids (%) =Dry weight/Initial sample weight×100

Lactose (%) =TS−(Fat+Protein+Ash)

Health and Immune Parameters

Throughout the study period, the health status of experimental goats was checked daily by observing the clinical signs and disease incidence. At the end of the experiment, blood samples were collected from the goats' jugular vein using sterile syringes. All the samples were transferred into plain tubes used for the separation of serum, while the samples in anticoagulant (EDTA) tubes were used for the hematological analysis. The red blood cell (RBC) count, hemoglobin (Hb) concentration, and white blood cell (WBC) count were measured by using an automated hematology analyzer (Sysmex Corporation, model: XP-100, Japan). Serum from the samples was obtained by performing centrifugation at 3000 rpm for 15 minutes and stored at −20 °C until further analysis (Solaiman and Min 2019. The enzyme-linked immunosorbent assay (ELISA) was used to determine the antibody response and expressed optical density (OD) values. Immunoglobulin G (IgG) concentration was evaluated by using the immunoassay kits (Bioassay Technology Laboratory, Cat. No. E0304Go, China). Serum cortisol (DRG Cortisol ELISA kit USA) and C-reactive protein (CRP) (Thermo Fisher Scientific CRP ELISA Kit) levels were assessed by ELISA kits. The serum was added to antibody-coated wells, incubated, and washed. After adding the enzyme conjugate and substrate, the color progress was determined at 450 nm using a microplate reader. Concentrations were calculated and expressed as ng/mL (cortisol) and mg/L (CRP) (Arsenopoulos *et al*., 2025).

Statistical Analysis

All collected data were analyzed by SPSS softwaree (version 26), and one-way analysis of variance (ANOVA) was performed. The results are expressed in mean ± standard error. The Duncan test was performed to determine the significant difference between the groups.

RESULT AND DISCUSSION

Table (2) shows that FW differ significantly ($P \leq 0.05$) between the nutritional groups with the highest value was recorded for GP-2 (42.78 ± 0.016 kg), GP-3 (40.57 ± 0.07 kg), whereas the lowest FW (32.37 ± 0.014 kg) was recorded for GP-1. It indicated the significant ($p = 0.007$) positive impact of Moringa and chelated mineral supplementation on growth. Similarly, BWG showed significant differences ($p = 0.005$); with GP-2 having the highest BWG (22.58 ± 0.026 kg) followed by for GP-3 (20.37 ± 0.012 kg), while GP-1 showed the lowest BWG (12.19 ± 0.014 kg). The significant improvement in BWG of GP-2 may be attributed to better nutrients utilization efficiency and improved metabolic processes due to the supplemented diet. BCS also showed significant differences ($p = 0.006$), with GP-3 having highest value (2.53 ± 0.013)

compared to GP-1 and GP-2 (2.51 ± 0.05). The enhancement in body score of animals fed the soybean-feed, reflecting the positive effect of soybean on nutritional status and production efficiency. ADG recorded significant (P=0.005) between nutritional groups with GP-2 having the highest, 0.25 ± 0.05 kg/day, followed by GP-3 (0.22 ± 0.016 kg/day), while GP-1 had the lowest ADG (0.13 ± 0.043 kg/day). These results described the improvement in growth efficiency in groups receiving the supplemented diet, due to improved nutrient utilization and enhancement in efficiency of metabolic processes. GP-1 recorded GR 0.18 ± 0.076, slightly higher than GP-2 (0.179 ± 0.63) and GP-3 (0.17 ± 0.006). GR showed a similar growth rate, and there was a significant difference (p = 0.007) between the groups. SG in GP-2, GP-3, and GP-1 was 11.74 ± 0.032 cm, 8.97 ± 0.026 cm, and 8.16 ± 0.004 cm, respectively, which describes the important role in enhancing bone development. MMI was increased 99.076 ± 0.016 in GP-3, 95.89 ± 0.06 in GP-2, while GP-1 presented the lowest value (81.077 ± 0.05). It was significantly more effective (p = 0.005) in a soybean-based diet and was involved in promoting muscle deposition. FI significantly (p = 0.005) differed among groups; the highest 125.56 ± 0.76 kg FI was in GP-2, while GP-1 had the lowest intake (67.57 ± 0.07 kg). FCR showed significant variation (p = 0.006); it was highest (5.61 ± 0.061) in GP-3, while GP-1 showed better efficiency (5.53 ± 0.04), and GP-2 persisted intermediate (5.55 ± 0.06). These results indicated that GP-2 significantly enhanced the growth and skeletal development, whereas GP-3 was more effective in increasing the muscle mass and body condition.

The current study investigates the dietary supplementation, including herbal and protein-based supplements in goats, and recorded significant growth performance, milk production, and immune competence in supplemented groups (GP-2 and GP-3). The Moringa and chelated mineral-based diet indicated superior growth performance with the highest final weight, body weight gain, and average daily gain. These findings align with the outcomes of Kholif *et al*. (2015), who studied *Moringa oleifera* leaf meal and documented the enhanced growth in goats. Al Masruri *et al*. (2022) also found improved growth performance with the *Moringa oleifera*-based diet in rabbits due to its rich protein content, vitamins, and antioxidant compounds. Similarly, Bashar *et al*. (2020) demonstrated that Moringa supplementation also advances the feed effectiveness and nutrient digestibility in ruminants. Dong *et al*. (2019) examined that Moringa leaves improved the rumen environment, which involved higher feed intake and also improved the energy availability. Chelated minerals in the present study significantly improved the skeletal growth, mineral absorption, and utilization. These findings were also reported by Mohammadizad *et al*. (2024), who described that chelated trace minerals can improve the metabolic functions and bone development in ruminants. Sharifinia *et al*. (2025) highlighted that Chelated minerals are essential in livestock for growth, immune response, and enzyme activity. It also improved the structural growth and metabolic efficiency due to its higher bioavailability.

Table (2) Effects of Three Diets (Moringa and Chelated Mineral-Based, and Soybean-Based Diets) on Growth, Body Condition, and Feed Utilization Parameters in Goats

Parameters	**GP-1**	**GP-2**	**GP-3**	**p-value**
IW (kg)	20.179±0.013a	20.179±0.11a	20.17±0.002a	NS
FW (kg)	32.37±0.014c	42.78±0.016a	40.57±0.07b	0.007
BWG (kg)	12.19±0.014c	22.58±0.026a	20.37±0.012b	0.005
BCS	2.51±0.05a	2.51±0.05a	2.53±0.013b	0.006

ADG	0.14±0.043c	0.25±0.05b	0.23±0.016a	0.005
GR	0.18±0.076a	0.179±0.63b	0.17±0.006b	0.007
SG	8.16±0.004a	11.74±0.032a	8.97±0.026	0.006
MMI	81.077±0.05c	95.89±0.06b	99.076±0.016a	0.005
FI	67.57±0.07c	125.56±0.76a	114.51±0.0043b	0.005
FCR	5.53±0.04c	5.55±0.06b	5.61±0.061a	0.006

Means with different letters in a row differ significantly ($p \leq 0.05$)

The dietary treatments influenced the milk production and its compositional features (Table 3). The highest milk yield was recorded in GP-3, 2.8 ± 0.6 L/day, and closely followed in GP-2 (2.7 ± 0.7 L/day), while GP-1 yielded 1.8 ± 0.3 L/day, which was significantly ($p = 0.005$) less milk. These findings indicated enhanced lactational performance with a slightly larger response in the soybean-fed group. Milk fat percentage in both GP-2 and GP-3 was 4.4 ± 0.4% and 4.4 ± 0.05%, respectively, as compared to GP-1 (3.7 ± 0.4%). The higher milk fat in GP-2 and GP-3 (4.4%) is due to higher dietary ether extract (3.4%) and increased rumen acetate production from Moringa and chelated minerals**.** It is shown that Milk fat percentage ($p = 0.006$) increases with the dietary enrichment, which contributed positively to fat synthesis in milk. The different pattern for milk protein content was recorded in groups, which described that GP-2 and GP-1 were 3.8 ± 0.6% and 3.4 ± 0.3% which did not differ significantly, but GP-3 (3.7 ± 0.07%) showed a significant difference ($p = 0.006$), which indicated the moderate improvement with the soybean-based diet. The higher milk protein (3.8% in GP-2) is due to better dietary crude protein and higher lactose (4.8% in GP-3) indicating the enhanced glucose availability. It emphasized that dietary protein influences the milk protein composition. Lactose concentration also increased across the groups, with GP-3 showing the highest (4.8 ± 0.06%), followed by GP-2 (4.7 ± 0.3%) and GP-1 (4.6 ± 0.4%), which indicated improved carbohydrate metabolism and milk synthesis efficacy in goats. Total solids content also demonstrated an increasing trend; the highest percentage (13.1 ± 0.04%) was recorded in GP-3, and the lowest percentage (10.5 ± 0.6%) was recorded in GP-1. The significant variation ($p = 0.006$) in TS demonstrates the enhancement in milk quality. This study demonstrated that both diets improved milk yield and composition; however, the GP-3 showed more influence on milk quantity and solids, while the Moringa and mineral supplement contributed similarly to milk fat improvement.

In contrast, the soybean-based diet in this study represented the stronger influence on body condition and muscle development as demonstrated by the highest muscle mass index and body condition score. The findings of this study are similar to the outcomes of Parrini et al. (2023), who described that soybean meal has a greater influence on body condition and muscle development due to its high-quality protein. Gómez et al. (2002) documented that soybean meal contained essential amino acids, which are necessary for tissue synthesis and muscle accretion. Mahgoub *et al*. (2025) conducted a study on goats and reported that dietary protein enhances muscle deposition with protein-rich diets, and also recorded the improved growth performance and carcass characteristics. In this study, the enhancements in milk yield and composition were recorded with the dietary supplementation. This is in agreement with findings by Sinclair *et al*. (2014), who documented that increased dietary protein can increase the production of milk due to the presence of necessary amino acids for synthesis. Similarly, Pecka *et a*l. (2018) also

demonstrated a positive influence on milk yield and composition in ruminants due to the improved nutrition.

This study observed an increase in milk fat percentage, which indicated enhanced rumen fermentation and acetate production that regarded as milk fat synthesis. Liu *et al*. (2023) documented that Moringa supplementation in ruminants increased the fat content in milk due to an increase in rumen fermentation efficiency. Furthermore, this study also recorded an increase in lactose and total solids, which described the enhanced carbohydrate digestion and energy consumption. Similarly, Fekadu *et al*. (2005) also reported increasing total solids and lactose content in goat milk, which increases the milk quality.

Table (3) Effects of three diets (Moringa and Chelated Mineral-Based and Soybean-Based Diets) on Milk Yield and Composition in Goats (Mean±SE).

Parameter	GP-1	GP-2	GP-3	p-value
Milk Yield (L/day)	1.8±0.3c	2.7±0.7b	2.8±0.6a	0.005
Milk Fat (%)	3.7±0.4a	4.4±0.4b	4.4±0.05b	0.006
Milk Protein (%)	3.4±0.3a	3.8±0.6b	3.7±0.07b	0.006
Lactose (%)	4.6±0.4c	4.7±0.3b	4.8±0.06a	NS
Total Solids (%)	10.5±0.6c	12.6±0.5b	13.1±0.04a	0.006

Means with different letters in a row differ significantly ($p \leq 0.05$)

The goats with GP-3 showed a disease incidence of 7.6 ± 1.2%, and GP-3 found 8.4 ± 1.4% disease incidence, which was significantly p = 0.005 lower than that of GP-1 (23.1 ± 1.2%). This decrease in disease incidence demonstrated the protective effect of improved nutrition against health challenges. Immune responsiveness, as indicated by antibody levels (OD value), demonstrated a pronounced increase in treated groups. The highest response was observed in GP-3 (1.42 ± 0.12), followed closely by GP-2 (1.39 ± 0.06), whereas GP-1 exhibited considerably lower values (0.82 ± 0.06), with the differences being statistically significant (p = 0.006). This suggests enhanced humoral immunity in goats receiving supplemented diets. WBC count in GP-3 (12.1 ± 0.14 $\times 10^9$/L) and GP-2 (11.2 ± 0.7 $\times 10^9$/L) compared to GP-1 (7.7 ± 0.3 $\times 10^9$/L) increased significantly (p = 0.007). Moreover, RBC count and Hb concentration followed the same increasing trend, and higher values were recorded in supplemented groups, such as GP-3, which was 7.4 ± 0.21 $\times 10^{12}$/L and 13.8 ± 0.13 g/dL, respectively, indicating improved immune defense mechanisms, better oxygen-carrying capacity, and physiological status. Cortisol levels were reduced in GP-2 (17.6 ± 1.4 ng/mL) and GP-3 (18.1 ± 0.18 ng/mL) significantly (p = 0.005) compared to the control group (27.6 ± 1.7 ng/mL), which indicated the lower stress burden in goats receiving diets. Furthermore, the immunoglobulin G (IgG) concentrations were 19.7 ± 1.2 mg/mL in GP-2, followed by GP-3 (18.4 ± 0.42 mg/mL), whereas GP-1 showed the lowest level (13.3 ± 0.7 mg/mL) significantly (p = 0.005). It involves strengthening the adaptive immunity. C-reactive protein (CRP) was reduced in GP-2 (4.1 ± 0.33 mg/L) and GP-3 (4.3 ± 0.11 mg/L) compared to GP-1 (5.9 ± 0.7 mg/L) significantly (p = 0.006). As a marker of inflammation, it involves lowering the inflammatory state in treated goats. These findings demonstrated that both diets reduced physiological stress and improved the immune competence; the GP-3 diet indicated superior effects in hematological parameters, while the GP-2 diet revealed a stronger influence on immunoglobulin levels (Table 4).

This study also documented improved immune response and health status with the significant reduction in disease incidence in goats. The higher antibody levels and immunoglobulin G (IgG) concentrations in this study indicated enhanced immunity with an immunomodulatory effect. Similarly, Yadav *et al*. (2020) also documented the immunomodulatory effect of nutrient supplementation in the ruminant. Fathy *et al*. (2022) described that Moringa plays an important role in enhancing immunity because of its antioxidant and phytochemical properties, which stimulate the immune responses and decrease oxidative stress in livestock. The improvements in blood parameters such as WBC, RBC, and hemoglobin levels were also observed in the supplemented groups. These findings are similar with the Faisal *et al*. (2024), who concluded that Moringa-based diets increased the hematological values in the livestock animals. Hughes *et al*. (2017) documented an increase in WBC count, which is designated the immune defense. The higher RBC and hemoglobin levels demonstrated efficient oxygen transport and metabolic activity. This study also observed the reduction in cortisol levels, which demonstrated the lower stress that is vital for productivity and health. Dhabhar (2004) demonstrated the stress level and found that it effects negatively affects the immune function and growth, whereas nutrition can lessen the stress responses. The decrease in C-reactive protein (CRP) levels in this study was observed, and also, Owais *et al*. (2024) documented a similar decrease in CRP, which highlighted the reduced inflammation and controlled inflammatory responses (El-Deeb *et al*., 2019).

Table (4) Effects of three diets (Moringa and Chelated Mineral-Based and Soybean-Based Diets) on Immunity, Hematological, and Health Parameters in Goats (Mean±SE).

Parameter	GP-1	GP-2	GP-3	p-value
Disease Incidence (%)	23.1±1.2a	8.4± 1.4b	7.6±1.2c	0.005
Antibody Level (OD value)	0.82±0.06b	1.39±0.06a	1.42±0.12a	0.006
WBC Count ($\times 10^9$/L)	7.7±0.3b	11.2±0.7c	12.1±0.14a	0.007
Cortisol (ng/mL)	27.6±1.7a	17.6±1.4b	18.1±0.18 b	0.005
Haemoglobin (g/dL)	11.4±0.6b	13.3±0.3a	13.8±0.13a	0.006
RBC Count ($\times 10^{12}$/L)	5.2±0.4 b	7.1±0.4 a	7.4±0.21a	0.007
Immunoglobulin G (mg/mL)	13.3±0.7b	19.7±1.2a	18.4±0.42 a	0.005
CRP (mg/L)	5.9±0.7a	4.1±0.33^b	4.3±0.11b	0.006

Means with different letters in a row differ significantly ($p \leq 0.05$)

CONCLUSION

This study concluded that herbal and protein-based diets can improve goat performance. The Moringa and chelated mineral-based diet was effective in increasing the growth, skeletal development, and immune response, whereas the soybean-based diet exhibited better effects on muscle development, milk yield, and milk quality. These findings can serve as a sustainable and cost-effective approach to livestock productivity.

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

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AUTHOR CONTRIBUTIONS

M.A.A. designed, experimented, and prepared the manuscript. H.T. S.S.E.H. and R.M.F. contributed to manuscript revision and statistical analysis.

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