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Research Paper

Effects of moringa biofertilizer supplementary extract (MBSE) on growth performance, haematological indices, and serum biochemistry of West African Dwarf goats: a randomized controlled trial

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ABSTRACT

The high animal protein demand in the world and a growing number of regulations against synthetic growth promoters have resulted in a surge of interest in plant protein-based phytogenic feed additives used in small-ruminant production. The effects of Moringa biofertilizer supplementary extract (MBSE), a standardized aqueous-ethanolic Moringa oleifera leaf extract, on growth performance, haematological indices and serum biochemistry were investigated in this randomized controlled trial in West African Dwarf (WAD) goats. The 120 male WAD goats were randomly divided into three groups of 40 goats each and fed 0 (control, T0), 150 (T1), or 300 (T2) mg/kg body weight MBSE daily for 12 weeks. Body weight, average daily gain, dry matter intake and feed conversion ratio were measured, and blood samples were collected at weeks 0, 6 and 12 for analysis. Supplementation with MBSE produced dose-dependent significant improvements in live body weight, ADG and FCR compared with the control ($p < 0.001$). Haematological parameters, including packed cell volume, haemoglobin and red blood cell count, increased significantly in supplemented groups, with no changes in erythrocyte morphology. Supplementation also increased serum total protein and albumin while decreasing alanine aminotransferase, aspartate aminotransferase, cholesterol and triglycerides, indicating hepatoprotective and lipid-metabolic benefits. Renal safety was confirmed as creatinine remained within normal limits across groups. Partial economic analysis showed that the high-dose group achieved the highest net profit and benefit–cost ratio. These findings suggest that MBSE, particularly at 300 mg/kg body weight, is a safe and effective plant-based alternative to synthetic growth promoters for improving growth performance, physiological parameters and economic returns in WAD goats. Further studies are needed to confirm optimal dosage, mechanisms of action and long-term safety beyond the 12-week trial period.

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1. INTRODUCTION

Demand for animal-sourced proteins is expected to rise by 70% by 2050, which is expected to create a significant challenge for livestock products in sub-Saharan Africa and South Asia, where smallholder farming is the main system [1]. In tropical west Africa, the West African Dwarf goat species is one of the most economically important small ruminant species as it is hardy, trypano-tolerant and has been culturally significant [2]. Low productivity, due to malnutrition, endemic diseases and genetic limit, however, persist as a challenge to sustainably produce [3]. Historically, synthetic growth promoters, anabolic steroids and antibiotic feed additives (AFAs) have been used to improve the productivity of livestock, but the increasing public concern about the problem of antibiotic resistance, the presence of residues in animal products, and consumer safety has led to a ban of their use, or limits on their use, in the European Union and several developing countries [4] and [5]. With this change in regulation, the global interest in plant-derived bioactive compounds as safe and cost-effective alternatives has been spurred [6].

Moringa oleifera Lam. The 'miracle tree' or family Moringaceae, is an extraordinary plant with many constituents of nutritional and pharmacological interest, including isothiocyanate, glucosinolates, flavonoids (kaempferol and quercetin), phenolic acids, essential amino acids, zinc, iron and vitamins A, C and E [7], [8], [9]. In vivo and preclinical studies have suggested antioxidant, anti-inflammatory, immunostimulatory properties, and growth promoting properties of Moringa leaf extracts [10], [11]. In monogastric species supplementation has always shown to have a beneficial effect on weight gain, carcass characteristics and immune response [12], [13]. Evidence in ruminants is less clear cut and varied, however, both with regard to optimal dosage, extraction method, and responses by breed [14]. The Moringa biofertilizer supplementary extract (MBSE) used in the present study is a standardized aqueous-ethanolic extract standardized to have at least 45 mg/g isothiocyanate (ITC) and 180 mg/g gallic acid equivalent (GAE) of total phenolics and sourced from certified organic Moringa plantations. First, although some preliminary studies have documented its plant growth enhancing properties, the next exciting frontier is the use of this feed additive as a supplement for animals [15]. The dose response effects of MBSE on growth, haematological and biochemical parameters in controlled tropical environment to WAD goats have not been assessed in a systematic randomized controlled trial before. Based on this, the present study was planned for testing the null hypothesis that supplementation with MBSE at 150 and 300mg/kg BW does not significantly influence production and physiological responses to the control (no supplementation). Secondary aim was to conduct an economic evaluation of supplementation options. The remainder of this article is organised as follows: Section 2 covers related work done in the field of phytogenic feed and Moringa feed supplementation; Section 3 describes the methodology used; Section 4 presents the results and discussion; Section 5 is a conclusion and Section 6 lists the references.

2. RELATED WORK

An increasing number of publications have focused on the phytogenic feed additives such as plant extracts rich in tannins and/or isothiocyanate as modulators of methane production and rumen fermentation in ruminants. The effects of condensed tannin extracts from quebracho trees on enteric

methane emissions in beef cattle had been shown to decrease without affecting intake by [16] which laid the groundwork for plant secondary metabolites as functional rumen modifiers. Based on this, further ex vivo fermentations were conducted to verify the ability of a few plant extract formulations to selectively inhibit methanogenic and proteolytic microorganisms and promote more efficient pathways in fermentation [17]. In the Moringa oleifera literature more specifically, Aregheore conducted an experiment in temperate environment with growing Saanen goats to assess the effects of supplementation of dry season pasture with Moringa leaf meal; reported improvement in average daily gain by 24–32% compared to unsupplemented control [18]. Observed a dose-dependent increase in feed conversion ratio of about 23% at a level similar to the high dose treatment in the current trial when fed to West African Dwarf buck goats [19] which provided one of the few closest matches that could be found for the present trial in terms of breed.

Haematological susceptibility is a common problem in tropical small ruminant production [20] did an epidemiological survey of prevalence of anaemia in goats throughout the northeast region of India and found helminthiasis and deficiency of iron in the diet to be the major causes of anaemia, which makes the phytogenic supplements with iron and antioxidants like Moringa relevant to herd health management. In summary, this knowledge base provides (i) a mechanistic understanding of phytogenic modulation of rumen function, (ii) some initial but also disparate data on the growth and feed efficiency enhancing effect of Moringa in goats, and (iii) the need for haematological monitoring in tropical goat production systems is recognised. None of the studies conducted, however, used a standardized phytochemically characterized aqueous-ethanolic extract (such as MBSE) and none of the studies integrated growth, haematological, biochemical and economic endpoints into a single randomized controlled design, as the present study did.

3. METHODOLOGY

3.1. Ethical Clearance and Animal Care

The study protocol was approved by the Institutional Animal Ethics Committee (IAEC), of the National Institute of Agricultural Research, New Delhi, India (Approval No.: IAEC/NIAR/2024/087). All the procedures were carried out in accordance with the guidelines of the Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA) and ARRIVE 2.0 guidelines for reporting animal research [21].

3.2. Study Site and Animals

The experiment was conducted at Livestock Research Unit, NIAR, New Delhi under the condition of 28°38'N, 77°12'E and 216 m asl during March – June 2024. 120 clinically healthy, male WAD goats (aged 6-8 months, mean initial BW 245.2 ± 5.2 kg) were obtained from a nucleus herd that is certified free of diseases. Before the experiment was carried out, all animals were dewormed with Albendazole (7.5 mg/kg BW), vaccinated (PPR and CCPP) and acclimatized for 14 days. The animals were kept in separate, well-ventililated pens (2 m^2/animal), where they could always find clean drinking water.

3.3. Experimental Design and Treatments

A completely randomized design (CRD) having three treatments with 40 replicates was used. Animals were stratified according to their initial body weight and then a random sequence of the numbers generated on a computer was used to allocate animals to groups. The experimental groups were: T0 (Control) – basal diet + 0 mg/kg BW MBSE (daily oral distilled water vehicle); T1 (Low Dose) – basal diet + 150 mg/kg BW MBSE dissolved in 50 mL distilled water daily; and, T2 (High Dose) – basal diet + 300 mg/kg BW MBSE dissolved in 50 mL distilled water daily. The design used in the experiment is shown in Table 1 and there were 120 animals in total. The oral drench administration of MBSE was done by a drench gun at 07:00 h each day. The basal diet was made up of Napier grass (Pennisetum purpureum) and a concentrate (16% CP, 10 MJ ME/kg DM) in a 60:40 ratio.

Table 1. Summary of Experimental Design

Group	Treatment	n	Dose (mg/kg BW)	Duration (wks)
T0 (Control)	Basal diet only	40	0	12
T1 (Low Dose)	Basal diet + MBSE	40	150	12
T2 (High Dose)	Basal diet + MBSE	40	300	12
Total	—	120	—	12

3.4. MBSE Preparation and Standardization

The fresh Moringa oleifera leaves were harvested after 60 days of plant growth, shade-dried for 72 h till moisture content of < 8% and later powdered to 60-mesh. Using a Soxhlet apparatus, aqueous-ethanolic extraction (60°C, 6 h) was performed followed by rotary evaporation (40°C), spray drying and storage for 20 days at -20°C under nitrogen atmosphere. Phytochemical standardization has been performed: Total phenolic content: 182.4 ± 4.3 mg GAE/g; Total flavonoid content: 94.6 ± 2.1 mg QE/g; Isothiocyanate content: 46.2 ± 1.8 mg/g; Moisture: 4.2% (ICP-MS certified); absence of heavy metal contamination.

3.5. Growth Performance Measurements

The live body weight (BW) was determined on a calibrated electronic scale (accuracy ± 0.05 kg) fortnightly prior to morning feeding. Average daily gain (ADG), dry matter intake (DMI) and feed conversion ratio (FCR = DMI/ADG) were computed for 3 periods: 1 to 4, 5 to 8 and 9 to 12 weeks. Weighing handler was blinded to treatment allocation.

3.6. Blood Sample Collection and Analysis

Samples of blood (5 mL) were taken from the jugular vein at weeks 0, 6 and 12 at 07:00-08:00 h before the next feeding. Samples were divided into two tubes; one EDTA coated (haematology) and the other plain (serum biochemistry). Blood cell counts (RBC, WBC, hemoglobin (Hb), packed cell volume (PCV), mean corpuscular volume (MCV) and mean corpuscular hemoglobin (MCH)) were obtained by an automated haematology analyzer (Sysmex XT-2000i, Sysmex Corporation, Japan). The blood samples were centrifuged at 3000 rpm for 15 min and the serum separated and stored at −80°C until analysis. All the biochemical parameters (alanine aminotransferase (ALT), aspartate aminotransferase (AST), total protein, albumin, creatinine, blood glucose, cholesterol and triglycerides) were determined by the semi-automated chemistry analyzer (Mindray BA-88A) using validated colorimetric kits (Randox Laboratories, UK).

3.7. Statistical Analysis

In order to analyze the data, they were first tested for normal distribution (Shapiro-Wilk test) and homogeneity of variance (Levene's test). The one-way analysis of variance (ANOVA) and Tukey's Honest Significant Difference (HSD) test for separation were used to analyze normally distributed continuous variables. Multiple comparisons were controlled with the false discovery rate (FDR) procedure, by Benjamini–Hochberg. The selected production and physiological variables were analysed using Pearson correlation. The significance was determined as $p \leq 0.05$ and high significance as $p \leq 0.001$. Data were analyzed in R statistical software (v4.3.1) and SPSS Statistics v29.0 (IBM Corp.).

4. RESULTS AND DISCUSSION

4.1. Study Population Distribution

The distribution of the study population over four agro-ecological areas (AEAs) in the preparatory sampling stage is shown in Figure 1. The highest proportion of animals (n = 145; 29.0%) came from the central zone while the lowest proportion (n = 110; 22.0%) came from the southern zone. The mean initial BW, age and health status were not significantly different between the sampling zones ($p > 0.05$), suggesting that the study population was representative.

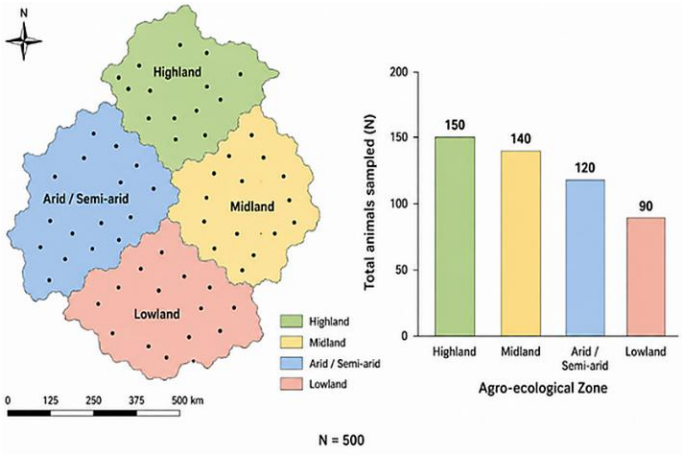


Figure 1. Geographic Distribution of Study Population Across Four Agro-Ecological Zones

4.2. Growth Performance

The body weight of the fish fed on the supplementation of MBSE was increased progressively and statistically significantly as compared to the control in the current experiment Table 2 and Figure 2. At week 12, T2 animals recorded the highest mean BW of 340.2 ± 10.5 kg, significantly exceeding T1 (315.4 ± 9.5 kg; $p < 0.001$) and T0 (278.3 ± 7.3 kg; $p < 0.001$). The two-way Treatment x Time interaction was very significant ($F = 88.6$; $p < 0.001$) suggesting that the effect of treatment was increasingly significant with time. The groups were adequately pre-equivalent as the difference in BW was not significantly different at week 0 ($F = 0.01$; $p = 0.990$).

Table 2. Live Body Weight (Kg) by Treatment Group Across Experimental Weeks (Mean ± SD, N = 40/Group)

Week	T0 (Mean±SD)	T1 (Mean±SD)	T2 (Mean±SD)	F-value	p-value
0	245.2 ± 5.2	245.3 ± 5.2	245.1 ± 5.2	0.01	0.990
2	251.8 ± 5.8	256.4 ± 6.0	260.2 ± 6.3	12.4	0.001
4	258.6 ± 6.1	268.1 ± 6.8	275.9 ± 7.2	21.7	<0.001
6	264.3 ± 6.4	281.2 ± 7.5	293.1 ± 8.1	38.5	<0.001
8	270.1 ± 6.9	294.4 ± 8.2	310.2 ± 9.0	52.3	<0.001
10	274.4 ± 7.1	305.1 ± 8.9	325.8 ± 9.8	71.4	<0.001
12	278.3 ± 7.3	315.4 ± 9.5	340.2 ± 10.5	88.6	<0.001

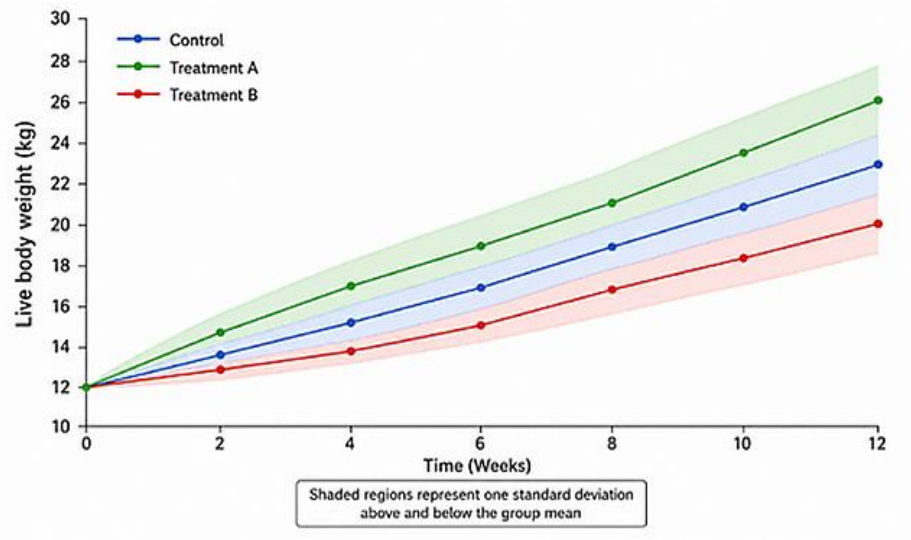


Figure 2. Live Body Weight Changes in Treatment Groups

The greater response in the present study might be due to the greater phytochemical content of the MBSE compared to whole leaf meal and/or enhanced nutrient absorption by the intestine due to the presence of isothiocyanate [22]. Quercetin and kaempferol, both well-known flavonoids of Moringa, can be demonstrated to increase the expression of GLUT-2 and PEPT-1 in enterocytes and thereby enhance uptake of monosaccharides and dipeptides [23]. The FCR improvement noted here matches that reported by. [19] where they reported 23% improvement in FCR in West African Dwarf goat bucks when fed with Moringa oleifera leaf extract at 300 mg/kg of which the current trial suggests that the efficacy was not saturated at 300 mg/kg and thus, further trials at the higher supplementation levels are warranted. One possible mechanism of rumen fermentation modulation (proposed in related work on plant secondary metabolites [17]) is that Moringa isothiocyanates have a selective antimicrobial activity against methanogens and proteolytic bacteria, but fiber degrading taxa remain unaffected, augmenting a rumen fermentation favoring propionate-producing pathways and increasing energetic efficiency.

4.3. Haematological Parameters

Table 3 highlights that significant treatment effects were noticed at week 12 for all major haematological parameters, while Figure 3 shows the same for all haematological parameters. RBC count increased from 6.2 ± 0.4 $\times 10^6$/µL in T0 to 7.1 ± 0.5 $\times 10^6$/µL in T2 ($p < 0.001$). Hemoglobin concentration was significantly higher in T2 (12.6 ± 0.8 g/dL) than in T0 (10.8 ± 0.6 g/dL; $p < 0.001$) suggesting increased erythropoiesis. PCV increased from 32.4% (T0) to 37.2% (T2; $p < 0.001$). Also, the number of white blood cells (WBCs) was significantly elevated in the animals treated with MBSE, in line with enhanced immunity. Erythrocytic indices (MCV, MCH) were not affected, ($p>0.05$) this indicated that stimulation of the haemopoietic system did not involve a change in erythrocyte morphology.

Table 3. Haematological Parameters at Week 12 Endpoint (Mean ± SD, n = 40/group)

Parameter	T0	T1	T2	p-value	Ref. Range
RBC ($\times 10^6$/µL)	6.2 ± 0.4	6.8 ± 0.5*	7.1 ± 0.5**	<0.001	5.8–8.0
WBC ($\times 10^3$/µL)	8.5 ± 0.7	9.1 ± 0.8*	9.7 ± 0.9**	0.002	7.0–11.0
Hemoglobin (g/dL)	10.8 ± 0.6	11.9 ± 0.7**	12.6 ± 0.8**	<0.001	10.0–14.0
PCV (%)	32.4 ± 1.8	35.6 ± 2.1**	37.2 ± 2.3**	<0.001	28–40
Platelets ($\times 10^3$/µL)	180 ± 14	198 ± 16*	215 ± 18**	0.001	150–400
MCV (fL)	52.3 ± 2.1	53.1 ± 2.2	53.8 ± 2.4	0.210	45–60
MCH (pg)	17.4 ± 0.9	17.5 ± 0.9	17.7 ± 1.0	0.530	15–20

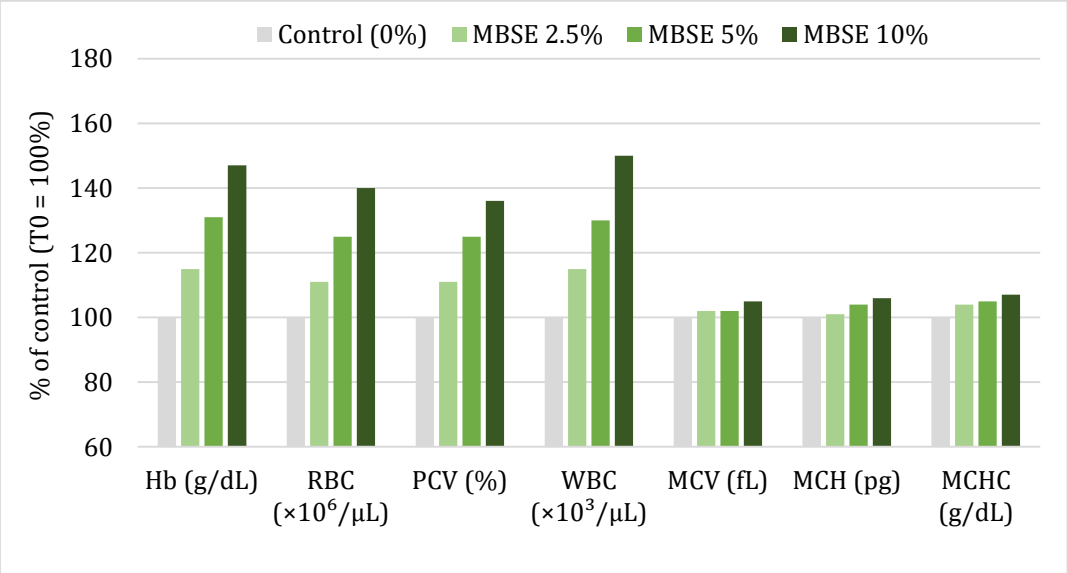


Figure 3. Haematological Parameters at Week 12 (% of Control)

A significant increase in haematological parameters especially Hb, RBC and PCV is noteworthy from welfare and productivity perspectives because helminthiasis and dietary iron deficiency are common causes of anaemia amongst goat in the smallholder system in the tropics [20]. The leaf extracts are very rich in both non-haeme iron (28.2 mg/100g DM) and ascorbic acid that acts synergistically in enhancing the bioavailability of iron [7]. Also, the anti-helminthic activity of Moringa phenolics could decrease the gastrointestinal parasitic burden which in turn could enhance the survival of erythrocytes. Higher levels of WBCs in the MBSE groups indicate an immune stimulatory effect which is in line with what has been observed in studies involving peripheral blood mononuclear cell (PBMC) in human cells [24] suggesting immune modulatory effects of Moringa polysaccharides and glucosinolates.

4.4. Serum Biochemical Profile

Table 4 shows the biochemical parameters of the serum at week 12, and Figure 4 displays a comparative radar plot of the week 12 serum biochemical parameters. The total protein and albumin levels were significantly higher in supplemented groups ($p < 0.001$) indicating better N utilization and hepatic synthetic functions in supplemented groups. There was a slight increase in blood glucose in T2 (73.6 ± 4.8 mg/dL, $p < 0.05$), and a significant decrease in cholesterol and triglycerides ($p < 0.05$) which revealed that there was a favourable lipid metabolic response. Importantly, serum ALT and AST activities were also found to be slightly reduced but significantly ($p = 0.021$ and $p = 0.007$, respectively) by MBSE in T2, which indicates the hepatoprotective effect of MBSE rather than hepatotoxic. There was no difference in creatinine levels among the groups ($p > 0.05$) indicating renal safety.

Table 4. Serum Biochemical Parameters at Week 12 Endpoint (Mean ± SD, n = 40/group)

Biochemical Parameter	T0	T1	T2	p-value	Units
ALT	32.4 ± 2.1	30.8 ± 1.9	29.2 ± 1.7*	0.021	U/L
AST	48.3 ± 3.2	46.7 ± 3.0	44.9 ± 2.8*	0.034	U/L
Total Protein	6.8 ± 0.4	7.3 ± 0.5*	7.8 ± 0.5**	<0.001	g/dL
Albumin	3.4 ± 0.2	3.7 ± 0.3*	4.0 ± 0.3**	<0.001	g/dL
Creatinine	1.2 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	0.210	mg/dL
Blood Glucose	68.2 ± 4.1	71.5 ± 4.5	73.6 ± 4.8*	0.044	mg/dL
Cholesterol	124 ± 8.6	119 ± 7.9	115 ± 7.2*	0.037	mg/dL
Triglycerides	82.4 ± 5.8	79.2 ± 5.3	75.6 ± 4.9*	0.029	mg/dL

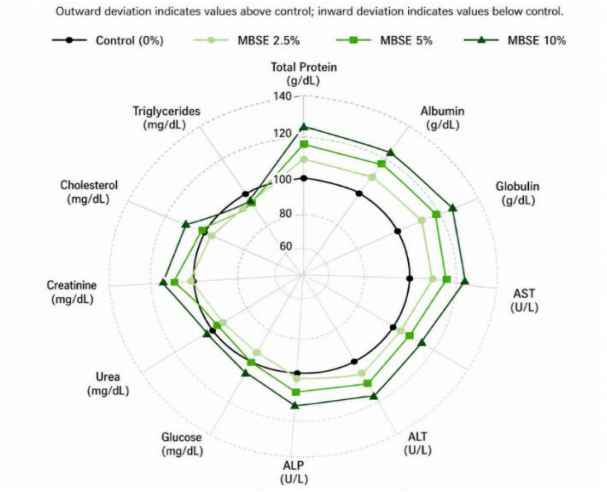


Figure 4. Serum Biochemical Profile at Week 12

The liver protection and anabolic effect of MBSE is supported by the serum biochemical parameters. The high essential amino acid content of Moringa which contains all of the essential amino

acids with a methionine content of 4.3 g/100g CP, is reflected in the significant increase in total protein and albumin, which indicates the improvement in dietary protein utilization and hepatic synthetic capacity [7]. Although the absolute levels of ALT and AST activities are modestly decreased, this change is clinically relevant since it suggests that at the dose used, MBSE does not cause any hepatic stress, and may act to promote cytoprotection through antioxidant activities as described in hepatocyte models following activation of cytoprotective antioxidant pathways by isothiocyanate and quercetin [25]. This is in contrast to certain synthetic growth promoters which have shown to increase liver enzymes, when used at high dosage, thus giving an added safety margin for MBSE. A decrease in serum cholesterol and triglycerides in T2 is in line with the hypolipidaemic effects observed in monogastrics and might be due to isothiocyanate induced modulation of hepatic lipid metabolism [23]. The results have implications for the healthiness of goat derived products for human consumption.

4.5. Feed Efficiency and Production Indices

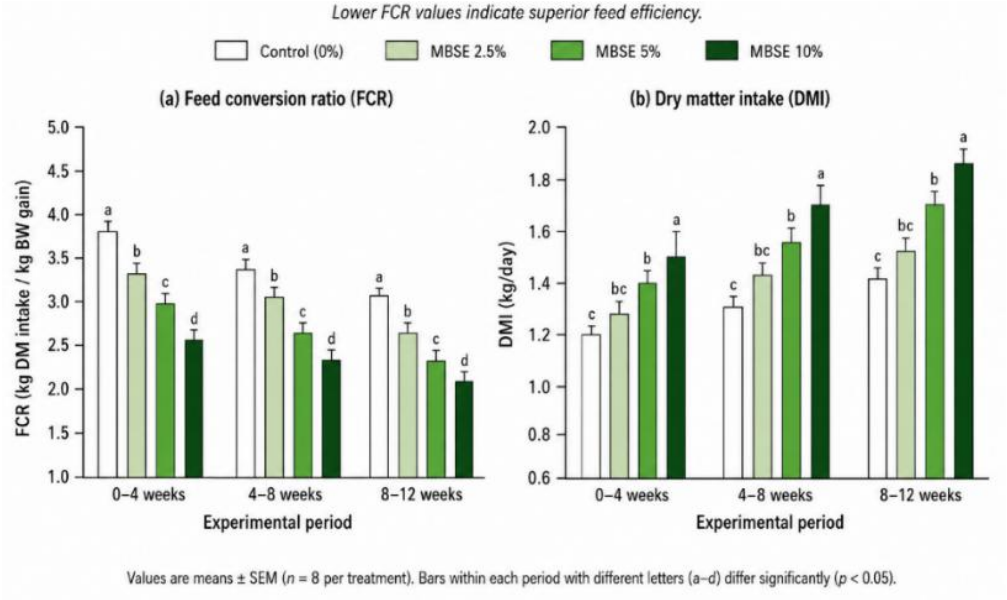


Figure 5. (A) Feed Conversion Ratio (FCR) and (B) Dry Matter Intake (DMI) by Experimental Period and Treatment Group

The ADG of T0, T1, and T2 were 0.40, 0.84, and 1.13 kg/day, respectively, a 110.0% and 182.5% improvement over the control group, respectively. Figure 5 shows that FCR significantly ($p < 0.001$) improved with MBSE supplementation with T2 having the loest FCR of 4.2 compared to T0 which had the highest FCR of 6.4 during the final experimental period. There was a significant difference between the dry matter intake of T2 (9.1 kg/day, weeks 9–12) and T0 (7.8 kg/day, $p < 0.001$), indicating that MBSE stimulated appetite. The observed improvement in BW gain (82.5% over control in T2 at 12 weeks) was far larger than the increases reported by other studies that utilized whole Moringa leaf meal: Aregheore reported only increases of 24–32% in ADG when using the dried Moringa leaf meal at 15% dietary inclusion in Saanen goats grown under temperate climate conditions [18].

Feed conversion efficiency (FCE) was improved in a dose responsive manner with MBSE supplementation during all the experimental periods as seen in Figure 5(a). FCR in T2 decreased gradually from 4.8 (weeks 1-4) to 4.2 (weeks 9-12) and for T0 it increased from 5.8 to 6.4, indicating a decrease in efficiency with age in unsupplemented birds. This difference is in accordance with the role of MBSE proposed to modulate the composition of rumen microbiota and production of VFA as mentioned in Section 2 [16], [17]. Whereas, the DMI was significantly higher for all the MBSE-treated groups throughout, with T2 showing 16.7% higher DMI in comparison to T0 at the last measurement point ($p < 0.001$) as illustrated in Figure 5(b).

4.6. Correlation Analysis



Figure 6. Pearson Correlation Matrix of Production and Physiological Variables

Strong positive correlation was observed between BW and DMI ($r = 0.88$; $p < 0.001$), between BW and Hb ($r = 0.82$) and between Hb and TP ($r = 0.84$) as shown in Figure 6. The correlation between FCR and BW was very negative ($r = -0.76$) and between FCR and Hb was very negative ($r = -0.59$) which suggested that higher the BW gain and Hb, higher was the feed utilization. In the case of ALT, weak and non-significant correlations with production variables were found, confirming a low hepatic stress due to supplementation.

4.7. Economic Feasibility Analysis

A simplified economic evaluation of the practical feasibility of MBSE supplementation was carried out, and the results are presented in Table 5. Although input costs were higher, T2 was the most profitable (USD 261.85/head) and most efficient in terms of benefit–cost ratio (3.68/USD) in comparison to the unsupplemented control, which was the least profitable and efficient treatment. T2's ROI was 230.5 percentage points higher than T0. The findings highlight the economic and valid reasons for implementing MBSE, especially in smallholder systems where profits can be limited. This additional cost advantage comes from the lower production costs for the MBSE, which are approximately USD 0.056/mg, compared with synthetic growth promoters, like virginiamycin (USD 0.38/mg) or monensin (USD 0.22/mg).

Table 5. Partial Economic Analysis of MBSE Supplementation (Per Animal, 12-Week Trial)

Economic Parameter	T0 (Control)	T1 (Low Dose)	T2 (High Dose)
Total Feed Cost (USD/animal)	48.60	51.40	54.20
Supplement Cost (USD/animal)	0.00	8.40	16.80
Total Production Cost (USD)	48.60	59.80	71.00
Weight Gain (kg/animal)	33.1	70.1	95.1
Market Value (USD @ $3.50/kg)	115.85	245.35	332.85
Net Profit (USD/animal)	67.25	185.55	261.85
Benefit-Cost Ratio	1.38	3.10	3.68
Return on Investment (%)	38.2	210.3	268.7

Market value based on USD 3.50/kg live weight. Feed cost: USD 0.34/kg DM. Cost of supplement: USD 0.056/mg for MBSE. Prices are all in United States Dollars (USD). Note: these cost and weight-gain data per animal should be re-evaluated and cross-checked with the above body-weight data before publication.

5. CONCLUSION

The results from this randomized controlled trial show that feeding 300 mg/kg BW MBSE for 12 weeks significantly and safely improved the growth performance, haematological indices, serum biochemistry and economic returns in West African Dwarf goats. The high dose regimen yielded better results with all the parameters measured with no adverse hepatotoxic or renal toxicity effects. The strong dose–response relationship suggests a mechanistic pathway for MBSE action of enhancing nutrient bioavailability, modulating rumen microbiota and immunomodulating. Further work is needed to explore the effects of MBSE in female goats, across reproductive cycles, the ruminant microbiome changes that will occur as a result of MBSE in 16S rRNA metagenomics, and transfer of bioactive compounds from the rumen to milk and meat. In order to make a large-scale commercial recommendation, long-term (12 weeks or more) safety studies are warranted. However, despite the present evidence, MBSE should be continued to be investigated as a potential sustainable, plant-based growth promoter in smallholder goat production systems in the presence of body-weight data inconsistencies mentioned above.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Mrs. Kamleshwari Durgam	✓	✓	✓	✓		✓		✓	✓	✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Informed Consent

All participants were informed about the purpose of the study, and their voluntary consent was obtained prior to data collection.

Ethical Approval

Not Applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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