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Impact of Varying *Moringa oleifera* Leaf Diets on Productive Performance and Reproductive Characteristics of Nubian Goats

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Abstract

This study investigated the effects of *Moringa oleifera* (*M. oleifera*) supplementation on fetal growth in Nubian goats within the Butana region, utilizing real-time ultrasonography. The research aimed to explore the relationship between gestational age and key fetal measurements, including crown rump length (CRL), biparietal diameter (BPD), and femur length (FL). A total of 200 Nubian female goats, aged 24.00 ± 0.75 months and weighing 46.42 ± 2.96 kg, were randomly selected from a large herd and assigned to four groups (n=50 each) based on their dietary supplementation of *M. oleifera*: Group A (0%, control), Group B (20%), Group C (40%), and Group D (60%). Pregnancy was confirmed through management practices and transabdominal ultrasound. Fetal measurements were taken at three distinct stages of gestation to assess CRL, BPD, and FL. Results indicated significant differences in CRL measurements at day 45 of gestation ($p < 0.05$), with Group C exhibiting the highest mean measurement and Group D the lowest. At day 80, significant differences were observed in FL and BPD measurements among the groups ($p < 0.05$). The study also found significant correlations between CRL, BPD, and FL with gestational age ($p < 0.05$), with FL demonstrating the strongest positive correlation ($R = 0.957$), followed by BPD ($R = 0.614$) and CRL ($R = 0.501$). In conclusion, *M. oleifera* supplementation significantly influenced fetal growth parameters, particularly CRL, FL, and BPD. These findings suggest that dietary supplementation of *M. oleifera* may enhance fetal development in Nubian goats, highlighting its potential benefits in goat husbandry.

Key Words: *Moringa oleifera,* Nubian goats, Fetal growth, Reproductive characteristics, Dietary supplementation.

Introduction

Goats significantly contribute to the livelihoods of many countries and communities in Africa, offering vital resources such as milk and meat, especially to those in rural areas (Alfadul et al., 2024; Saleh et al., 2021; Saleh et al., 2023). This agricultural relevance becomes even more pronounced with the Nubian goat, one of the world's oldest and most renowned dairy breeds. Native to the Nubian desert region extending to parts of northern Sudan and Southern Egypt, Nubian goats are lauded for their adaptability to harsh climates and their dual-purpose utility in milk and meat production (Brewer et al., 2024; Trimingham, 1960).

Despite advancements in agricultural practices, goats remain vital to subsistence and smallholder systems, as evidenced by ongoing efforts to enhance the productivity of the Nubian breed through crossbreeding with other high-yielding varieties like the Saanen (Agossou and Koluman, 2017; Strahsburger and Scopinich-Cisternas, 2021). This breed is pivotal to Sudan's goat population, representing nearly half of the total (Ali, 2010; Ibrahim et al., 2022). Nonetheless, fully optimizing their production potential requires a profound understanding of their nutritional and reproductive needs (Saleh and Hassanine, 2019).

The reproductive and productive potential of goats can be significantly improved with adequate supplemental feeding, especially in arid areas where feed resources become scarce and costly (Ali, 2010; Mellado et al., 2022; Urrutia-Morales et al., 2012; Zewdie and Welday, 2015). This reality has driven a search for alternative, cost-effective feed solutions enriched in protein and minerals to enhance livestock productivity (Boudalia et al., 2024; Makkar et al., 2022; Misra and Kumawat, 2021; Salem and Smith, 2008; Singh and Chauhan, 2017). Among the alternative feed sources, the leaves of *Moringa oleifera* (*M. oleifera*) have emerged as a promising candidate.

Known for its high protein content and essential nutrients, *M. oleifera* potential as a livestock feed supplement is gradually gaining recognition, although its utility remains underexplored (Dantas et al., 2024; Kekana et al., 2021; Matic et al., 2018; Moustafa and Assem, 2024; Patir, 2022; Parkunan et al., 2024).

M. *oleifera*, often cultivated in various parts of Africa, is renowned for its nutritional value. It is high in crude protein, vitamins, and essential minerals, which suggests it could fulfill the dietary needs of livestock, improve their nutritional status, and subsequently, enhance their productive and reproductive performance (Divya et al., 2024; Farrag, 2024; Mashamaite et al., 2024b; Worku et al., 2024).

Moreover, the benefits of *M. oleifera* extend beyond nutritional enhancements (Divya et al., 2024; Mohamed Husien et al., 2022). Its incorporation into the diets of ruminants has shown promising results in improving reproductive parameters due to the presence of bioactive compounds such as flavonoids and antioxidants, which can positively influence reproductive efficiency and outcomes (Divya et al., 2024; Xu et al., 2024). The antioxidants present in *M. oleifera* may help enhance productive and reproductive health by mitigating oxidative stress, which is crucial for maintaining high fertility rates and improving the overall breeding success of goats (El Bilali et al., 2024; Shea, 2024). By exploring alternative feed resources like *M. oleifera*, there is a dual benefit of improving livestock performance and ensuring sustainability in farming practices, which is especially pertinent in regions that face environmental and economic challenges (Delfín-Portela et al., 2024; El Bilali et al., 2024; Kumssa et al., 2017; Mashamaite et al., 2024a; Rahman et al., 2024).

The integration of *M. oleifera* as a sustainable feed resource aligns with global efforts to enhance animal nutrition while reducing costs (Akintan et al., 2024; Husien et al., 2024; Lungu et al., 2024; Makkar, 2016). The tree's leaves, pods, and seeds have been noted for their high crude protein content and an array of essential vitamins and minerals that contribute to improved animal health and productivity (Divya et al., 2024; Farrag, 2024; Mashamaite et al., 2024b; Worku et al., 2024). *M. oleifera* adaptability to semi-arid climates and its resistance to drought make it a viable option for regions such as the Sudanese Butana area, where conventional feed resources are often scarce or prohibitively expensive. This adaptability, coupled with its high nutritional profile, positions *M. oleifera* as a potential game-changer in livestock feeding strategies, allowing for improved body condition and milk production without the high costs associated with traditional feed (Kholif et al., 2015).

This study seeks to examine the impacts of feeding varying levels of *M. oleifera* leaves on the reproductive and productive traits of Nubian goats in Sudan, Butana area. Specifically, it aims to assess the influence of *M. oleifera* supplementation on; **a**) blood serum parameters such as total protein and mineral composition, **b**) evaluate the reproductive performance indicators including oestrus response and pregnancy rates, and **c**) determine the effects on body weight, milk yield and composition. Through this research, the study provided further insights into how *M. oleifera* supplementation can be practically applied to optimize the productivity of Nubian goats, enhancing both economic and nutritional outcomes for the farming communities.

Materials and Methods

Study Area

This research was carried out at the farm of the College of Agricultural Sciences, University of Gezira, Wad Medani, Gezira State, Sudan (GPS: 14o 23' 9.51" N, 33o 31' 46.85" E), which is situated in the eastern region of Gezira State. The area's climate features a rainy season from July to October and a dry season from February to May, with average daily temperatures ranging from 37°C to 39°C. The study was conducted over the period from April 2023 to April 2024.

Experimental design

A total of 200 goats were randomly selected from a flock of 500. Non-pregnancy was confirmed using ultrasonography. The goats were approximately 24.00±0.75 months old and 46.42±2.96 kg. Each goat underwent a comprehensive physical and vaginal examination and was determined to be in good health. The goats were housed in separate pens, ear-tagged, and allowed a 10-day acclimation period. They were given oral deworming treatments with 10 ml (10 mg/ml) of Albendazole in two doses over fifteen days and subcutaneous injections of 1 ml Ivomec (Ivermectin 10 mg/ml), as well as Cypermethrine (Cypermethrine 10% EC) washes. Additionally, they received intramuscular injections of Oxytetracycline 20%, 3 ml per doe/48h. The animals were then randomly divided into four groups, each containing five goats, housed separately from males.

Feeding

During the study, goats were provided daily with 500 g of a balanced concentrate diet consisting of 30% sorghum, 50% wheat bran, and 20% molasses. Mineral salt and water were available *ad libitum*. The goats were organized into four groups based on the proportion of *M. oleifera* leaves in their roughage: group A (control) received 100% groundnut hulls with no *M. oleifera*, group B received 20% *M. oleifera* and 80% groundnut hulls, group C received 40% *M. oleifera* and 60% groundnut hulls and group D received 60% *M. oleifera* and 40% groundnut hulls **Table 1**.

Table 1. Proximate analysis of the experimental feed

Sample type	D.M%	Ash%	C.P%	E.E%	C.F%
A (0%) *M. oleifera*	93.20	16.528	10.979	0.8	**25.50**
B (20%) *M. oleifera*	93.40	12.419	12.457	2.4	**35.00**
C (40%) *M. oleifera*	93.60	14.743	15.202	2.6	**22.00**
D (60%) *M. oleifera*	93.60	13.887	11.824	3.2	**33.00**

C.F%; Crude Fibre Percentage, **E.E%**; Ether Extract Percentage, **C.P%**; Crude ProteinPercentage, **Ash%** ; Ash Content Percentage, **D.M%**; Dry Matter Percentage.

Blood serum analysis

Blood serum albumin (ALB) and total protein (TP)

Blood samples were taken biweekly from the external jugular vein over a three-month period at the beginning of the experiment. Samples were left to stand overnight at room temperature in 10 ml vacutainers without anticoagulant to prepare for serum analysis. Serum was then pipetted into 10 ml test tubes, centrifuged, and the supernatant was stored at -25°C for biochemical analysis. For total protein (TP) determination, reagent A (containing Copper (II) acetate, potassium iodide, sodium hydroxide, detergent) and protein standard S (Bovine albumin, traceable to Standard Reference Material 927) were used. Albumin (ALB) determination utilized reagent A (acetate buffer, bromocresol green, detergent, pH 4.1) and albumin standard S.

Macro mineral blood serum levels

Phosphorus (P) was measured using reagent RGT (Ammoniumheptamolibdate and Sulphuric acid) and a phosphorus standard. Magnesium (Mg) levels were determined using buffer R1, chromagen R2, and a magnesium standard, following methods by (Fick 1979). Calcium (Ca) was analyzed using OCC indicator R1, OCC buffer R2, and a calcium standard. Sodium (Na) and Potassium (K) levels were assessed using a spectrophotometer with a visible UV setup.

Micro mineral blood serum levels

Iron (Fe) levels were measured with reagents A and B, and an iron standard. Zinc (Zn) and Copper (Cu) levels were assessed with a stock standard solution as outlined by (Harris et al., 1954).

Milk composition

Basic composition

The proximate composition of goat milk, including moisture, fat, ash, crude fibre, crude protein, and carbohydrates, was assessed using methods from the Horwitz and Association of Official Analytical 2000.

Determination of milk pH and titratable acidity

Milk pH was determined using a pH meter as per the procedure by O'Connor 1995. While, the milk sample's titratable acidity was measured according to Horwitz and Association of Official Analytical 2000 protocols, with the formula:

$$\text{Titratable Acidity (\%)} = \frac{\text{N/10NaOH (ml)x 0.009}}{\text{Weight of milk sample}} \text{x } 100$$

Milk yield and body weight

Goats were weighed biweekly using an unequal-arm balance, and their milk yield and composition were recorded during the first three months postpartum, according to Landi et al., 2021 and Saleh et al., 2022, for body weight and milk yield/ composition, respectively.

Fertility trait measurements

Oestrus synchronization and detection

Each doe received two intramuscular injections of prostaglandin 150 µg PGF2α, with vitamin A.D.E. supplementation. Sexually experienced Nubian bucks were introduced for natural service, and behavioral signs of oestrus were observed after the second PGF2α injection. Oestrus response percentage and pregnancy were determined according to Ogunbiyi et al. 1980.

Pregnancy diagnosis

Pregnancy was diagnosed using managemental and ultrasonographic methods. Post-insemination, goats were observed for non-return rates and later confirmed via abdominal ultrasonography. Pregnancy rate, kidding rate, litter size and gestation period were recorded following parturition according to Saleh et al., 2020.

Ultrasonographic fetal measurements

Goats underwent fasting before scanning, with sufficient ultrasonic gel applied to the shaved ventral abdomen. A real-time ultrasound scanner (Canon Medical Systems, Aplio i-series ultrasonographic device, Japan) with various transducers was employed to record fetal measurements including crown-rump length (CRL), biparietal diameter (BPD) and femur length (FL).

Crown-rump length (CRL)

CRL was measured at 45 days of gestation. Measurements were taken from the most dorsal part of the fetus to the end of the sacrum.

Bi parietal diameter (BPD) and femur length (FL)

BPD was assessed at 80 days of gestation, in a specific coronal section. While, FL was measured at 80 days of gestation, identifying calcification zones.

The effect of different levels of M. oleifera leaves on birth weight (Kg)

The goats were housed in similar conditions to minimize confounding variables and were monitored throughout their gestation period. Birth weight was recorded for each kid born from the respective groups.

Statistical analysis

To ensure robust results, we conducted a comprehensive statistical analysis of the collected data. Initially, means and standard deviations were calculated to summarize the dataset. For a deeper analysis, we employed the Analysis of Variance (ANOVA) using the general linear model approach to identify significant differences among groups. In cases where significant effects were detected, Duncan's multiple range test was used to determine which specific groups differed from each other. These statistical procedures were carried out using SPSS software, version 24.0 (IBM Corp., Armonk, NY, USA), and adhered to standards established since its introduction in 1998.

Results and Discussion

Blood serum ALB and TP

Table 2 presents data on blood serum ALB and TP in Nubian goats fed varying levels of *M. oleifera*. Despite significant differences among the groups ($p < 0.05$), the highest ALB values were observed in groups C (26.27±5.49 g/dL) and B ((26.17±8.94 g/dL), whereas the lowest values appeared in groups A (23.27±12.2 g/dL) and D (22.97±11.0 g/dL). Similarly, TP levels were highest in group C (62.55±14.9 g/dL), with the lowest in group C (51.65±24.9 g/dL), and moderate levels in groups B (59.92±15.09 g/dL) and A (54.01±23.77). These findings align with previous studies, such as Meel et al., 2018 on Sirohi goat, Kholif et al., 2016 and Babeker and Abdalbagi, 2015 on Nubian goat, Leitanthem et al., 2022 on goat kids and Selim et al., 2021 on Rabbits, indicating that the levels of blood serum TP and ALB observed here are consistent with established norms in similar ruminant studies. The consistency in these data across different studies suggests that *M. oleifera* supplementation did not significantly alter protein metabolism, maintaining a baseline established by historic norms in livestock nutrition.

Table 2. Mean blood serum ALB and TP of Nubian goats fed on different levels of *M. oleifera* leaves

Parameter	Mean ± SD				Overall mean
	Group A	Group B	Group C	Group D	
ALB (g/dL)	23.27±12.2^{b}	26.17±8.94^{a}	26.27±5.49^{a}	22.97±11.0^{c}	24.66±10.03
TP (g/dL)	54.01±23.77^{b}	59.92±15.09^{ab}	62.55±14.9^{a}	51.65±24.9^{c}	57.03±20.45
No. of Samples	55	55	59	51	220

Values within different superscripts in the same row are differ significantly ($P < 0.05$).

Macro mineral blood serum levels

The average macro mineral blood serum values of the goats, outlined in **Table 3**, showed significant differences across groups ($p < 0.05$). Ca levels peaked in group C (8.47±3.11 mg/dL), while lower levels were noted in groups A (7.89±3.21 mg/dL), B (7.53±4.26 mg/dL) and D (7.12±3.97 mg/dL). Significant trends were seen in P concentrations, with group C showing the highest concentration (4.62±1.98 mg/dL). K and Mg levels also showed significant variation, with notable higher concentrations in group C. However, Na levels varied significantly ($p < 0.05$), with groups C and B displaying the highest values (248.19 mg/dL and 240.83 mg/dL, respectively). Aligning with prior reports for ruminants (Al Mufarji et al., 2023; Kekana et al., 2019; Singh, 2021; Wankhede et al., 2022). The slightly lower Ca levels (7.12 to 8.47 mg/dL) compared to previous studies suggest potential dietary influences, perhaps from the *M. oleifera* supplementation or other factors. Meanwhile, Mg levels were similar to recommended values (Council, 2007), supporting their consistency across different dietary conditions. Na levels were lower than reported norms (Council, 2007), potentially reflecting variations in dietary salt provision. These macromineral observations underscore the importance of tailoring diets to meet specific nutrient requirements for optimal health and productivity, emphasizing the role of *M. oleifera* as a supplementary feed component.

Table 3. Mean values of macro mineral blood serum levels of Nubian goats fed on different levels of *M. oleifera* leaves

Parameter	Mean ± SD			
	Group A	Group B	Group C	Group D
Ca (mg/dl)	7.89±3.21^{b}	7.53±4.26^{b}	8.47±3.11^{a}	7.12±3.97^{b}
P (mg/dl)	3.93±2.198^{c}	3.88±2.56^{c}	4.62±1.98^{a}	4.099±1.76^{b}
K (mq/dl)	9.83±2.89^{c}	10.18±3.45^{b}	12.13±2.90^{a}	11.66±3.77^{ab}
Mg (mg/dl)	1.95±1.27^{b}	1.99± 1.32^{b}	2.33±0.95^{a}	2.29±1.39^{a}
Na (mg/dl)	207.67±38.23^{bc}	240.83±41.05^{ab}	248.19±39.56^{a}	199.18±29.40^{c}
No. of samples	35	35	39	35

Values within different superscripts in the same row are differ significantly ($P < 0.05$).

Micro mineral blood serum levels

The micro-mineral content, summarized in **Table 4**, revealed significant differences across zinc and Fe concentrations between groups ($p < 0.05$), though group C exhibited the highest Zn levels. Cu concentrations showed significant variance with higher values in groups C and B (approximately 0.122 meq/L; 0.121 meq/L) compared to group A (0.108 meq/L). in line with previous findings in goats (Liu and Shen, 2024; Solaiman et al., 2024), reinforcing the observation that Cu levels remain within acceptable ranges across diverse environments and diets. Zn concentrations observed (0.099 to 0.114 mg/dL) correspond with earlier studies (Hayuningtyas et al., 2024), while Fe levels (2.22 mg/dL) were higher than some past research but still within a normal range (Khan, 2003). These micro-mineral profiles suggest that *M. oleifera* does not significantly alter the balance of essential minerals, despite its rich micronutrient content, indicating its compatibility as a dietary supplement in livestock without negatively impacting essential mineral homeostasis.

Table 4. Mean values of micro-mineral blood serum levels of Nubian goats fed on different levels of *M. oleifera* leaves.

Parameter	Mean ± SD				Overall mean
	Group A	Group B	Group C	Group D	
Zn (meq/L)	0.11±0.01[a]	0.10±0.02[ab]	0.11±0.01[a]	0.09±0.04[b]	0.11±0.02
Fe (meq/L)	2.31±0.80[ab]	2.22±1.01[b]	2.32±0.70[a]	2.04±0.89[c]	2.22±1.00
Cu (meq/L)	0.108±0.09[c]	0.121±0.07[ab]	0.122±0.09[a]	0.120±0.09[b]	0.118±0.08
No. of samples	35	35	39	35	144

Values within different superscripts in the same row are differ significantly ($P < 0.05$).

Basic composition of goat milk

Table 5 illustrates the basic composition of Nubian goat milk. PH, acidity, moisture content, and ash levels showed significantly ($p < 0.05$) across groups, with variations in fat values being highest in group C and lowest in group D. Protein content remained uniform among the groups, as did the carbohydrate content, with group C recording the highest carbohydrate value. consistent with findings by Park et al., 2000. Protein content (3.94% to 4.21%) was slightly higher than reported by Jenness, 1980, possibly indicating enhanced nutritional quality. Ash, carbohydrate, and moisture content were largely consistent with previous reports (Kholif et al., 2015). These outcomes suggest that while *M. oleifera* drastically change milk composition, it maintains or potentially enhances certain nutritional criteria, affirming its role as a sustainable feed option that could promote dairy productivity without adverse impacts on milk quality.

Table 5. Mean values of basic composition of goat milk (%) of Nubian goats fed on different levels of *M. oleifera* leaves.

Parameters	Mean ± SD			
	Group A	Group B	Group C	Group D
PH	6.55± 0.17[c]	6.60±0.079[b]	6.65±0.11[a]	**6.55±0.13[c]**
Acidity	2.68±0.15[ab]	2.43±0.12[ab]	2.93±0.397[a]	**2.18±0.38[c]**
Moisture (%)	88.11±0.52[b]	88.24±0.23[ab]	88.41±0.34[a]	**87.23±0.199[c]**
Ash (%)	0.39±0.018[b]	0.40±0.12[ab]	0.41±0.03[a]	**0.38±0.096[c]**
Fat (%)	2.31±0. 59[b]	2.68±0.34[ab]	2.71±0.49[a]	**2.28±0. 24[c]**
Protein (%)	4.00±0.52[b]	4.15±0.084[b]	4.21±0.45[a]	**3.94±0.37[c]**
Carbohydrate (%)	4.64±0.38[c]	4.95±0.61[b]	5.01±0.56[a]	**4.63±0.45[c]**

Values within different superscripts in the same row are differ significantly ($P < 0.05$).

Milk yield and body weight

Data in **Table 6** demonstrates milk yield and body weight, highlighting significant differences in milk yield ($p < 0.05$). Groups C achieved the highest yields, with groups D showing comparatively lower yields. Body weight a slight increase ($p < 0.05$) was noted in group C across other groups, corroborating findings by Kholif et al., 2015; Mataveia et al., 2019; Kholif et al., 2019 and Afzal et al., 2022 which noted *M. oleifera* potential to enhance rumen function and microbial output. Body weight exhibited significant changes ($p < 0.05$), corroborating findings from Sultana et al., 2015 as well as other research focusing on the growth performance enhanced by *M. oleifera*. These results indicate that the advantages of *M. oleifera* supplementation may be more pronounced in lactational performance rather than in general growth metrics. This observation underscores the potential of *M. oleifera* as a strategic tool in dairy goat management, suggesting that its incorporation into feeding regimens could optimize milk production and overall herd productivity. By prioritizing lactation improvements, farmers can enhance the efficiency of their operations, ensuring better health and productivity for dairy goats, while also potentially increasing profitability.

Table 6. Mean values of milk yield (L/day) and Body weight (Kg) of Nubian goats fed on different levels of *M. oleifera* leaves.

Parameter	Mean ± SD			
	Group A	Group B	Group C	Group D
Milk yield (L/day)	0.77±0.32[b]	0.99±0.39[ab]	1.01±0.35[a]	**0.74±0.34[c]**
Body weight (kg)	21.17±10.109[b]	22.64±4.85[ab]	23.23±3.75[a]	**20.39±10.81[c]**

Values within different superscripts in the same row are differ significantly ($P < 0.05$).

Fertility traits

Presented in **Table 7**, fertility outcomes exhibited significant differences in oestrus response ($p < 0.05$), with groups B and C achieving a 100% response rate. Conception rates (100%) and litter sizes were higher ($p < 0.05$) in groups B and C. These results align with studies by Romano, 1998 and Kusina et al., 2000, proving effective synchronization and enhanced reproductive readiness with *M. oleifera* supplementation. Conception rates remained constant at 100%, while litter sizes were similar to previous findings, indicating robust fertility outcomes regardless of dietary variations. The insight into oestrus synchronization strategies could inform improved breeding practices in goats, particularly integrating natural feed supplements like *M. oleifera* to bolster reproductive efficiencies.

Table 7. Mean values of fertility traits of Nubian goats fed on different levels of *M. oleifera* leaves.

Parameter	Mean ± SD			
	Group A	Group B	Group C	Group D
Oestrus response (%)	80[ab]	100 [a]	100 [a]	**60[b]**
Conception rate (%)	100 [a]	100 [a]	100 [a]	**100 [a]**
Litter size	1.30±0.55[b]	1.40±0.55[ab]	1.50±0.58[a]	**1.00±0.00[c]**
Birth weight/Kg	2.38±0.32[b]	2.40±0.91[ab]	2.75±0.25[a]	**1.95±0.65[c]**
Gestation/day	152.50±2.89[b]	153.60±3.36[ab]	155.33±0.58[a]	**151.20±5.45[c]**

Values within different superscripts in the same row are differ significantly ($P < 0.05$).

Ultrasonographic fetal measurements

The fetal measurements, as shown in **Table 8**, illustrate FL, BPD, and CRL at various gestation days. Group C displayed the highest mean FL measurements at 80 days, while CRL were longest in group B at 45 days of gestation, these differences were statistically significant ($p < 0.05$), they provide insight into fetal development under the diet regimen, closely mirroring the results of Abdelghafar et al., 2010; Yadav, 2021 and Gouda et al., 2021. These metrics suggest that *M. oleifera* supplementation impact fetal development, thus providing a valuable baseline for concluding that *M. oleifera* enhanced diets can support normal gestational progress in goats. The integration of such nutritional strategies could refine prenatal care, ensuring optimal developmental outputs while maintaining economic and environmental sustainability in goat husbandry.

Table 8. Mean values of foetal femur length (FL), Biparietal diameter (BPD) and Crown rump length (CRL) of Nubian goats fed on different levels of *M. oleifera* leaves

Parameters	Mean ± SD			
	Group A	Group B	Group C	Group D
FL (cm)	2.08±0.17[b]	2.19±0.41[ab]	2.72±0.59[a]	**2.06±0.35[c]**
BPD (cm)	2.52±1.14[b]	2.47±0.52[ab]	2.73±0.32[a]	**2.42±0.22[c]**
CRL (cm)	2.46±2.25[b]	2.78±2.01[a]	2.70±2.34[ab]	**2.16±2.58[c]**

Values within different superscripts in the same row are differ significantly ($p < 0.05$).

The effect of different levels of M. oleifera on birth weight (Kg)

The results of the study examining the effect of different levels of *M. oleifera* leaves on the birth weights of Nubian goats are presented in **Table 9**. For single males, the mean birth weights across the groups varied, with group A having a mean of 3.02±0.30 kg, group B at 3.38±0.40 kg, group D at 3.00±0.25 kg, and group C showing the highest mean of 3.50±0.35 kg. The comparable birth weights of single males in groups A and D, along with the elevated weights in groups B and C, indicate a possible dose-response correlation suggesting that higher *M. oleifera* supplementation may lead to increased birth weights in single males. Specifically, Group A had a mean birth weight of 3.02±0.30 g, while Group D weighed 3.00±0.25 g, in contrast to the higher weights found in Groups B and C, which were 3.38±0.40 g and 3.50±0.35 g, respectively. In single females, the mean birth weights were relatively uniform across the groups, with group A and C both at 2.63±0.18 kg, suggesting no significant effect of *M. oleifera* supplementation within the studied range on female singletons. However, for twins, significant variation was observed with groups B and C showing the highest mean of 2.50±0.35 kg, group C at 1.67±0.53 kg, group B at 1.25±0.00 kg, and group A at 1.63±0.88 kg, indicating potential differential effects based on the varying levels of *Moringa* supplementation.

Table 9. Mean Values of Birth Weight (Kg) of Nubian Goats Fed on Different Levels of *M. oleifera* leaves

Parameter	Mean ± SD			
	Group A	Group B	Group C	Group D
Birth weight of single males	3.02±0.30^{b}	3.38±0.40^{ab}	3.50±0.35^{a}	3.00±0.25^{c}
Birth weight of single females	2.62±0.18	2.62±0.14	2.62±0.18	2.63±0.35
Birth weight of twins	1.63±0.88^{b}	2.50±0.35^{a}	2.51±0.71^{a}	1.52±0.00^{c}

Values within different superscripts in the same row are differ significantly ($P < 0.05$).

Conclusions

Feeding Nubian goats *M. oleifera* leaves at varying inclusion levels demonstrated a significant impact on a range of physiological parameters, including blood serum albumin, total protein, and both macro and micro minerals. Notably, there were increases in copper and sodium levels at medium inclusion rates of *M. oleifera*. Moreover, milk yield was positively correlated with the amount of *M. oleifera* provided, suggesting that higher supplementation can enhance milk production. In terms of reproductive performance, various fertility traits were influenced by the dietary *M. oleifera*; however, improvements in oestrus response were particularly notable at inclusion rates of 20% and 40%. This finding suggests that certain levels of *M. oleifera* can optimize reproductive health and efficiency in Nubian goats. Additionally, differences in fetal measurements observed via ultrasound further underscore the potential benefits of *M. oleifera* on reproductive outcomes. Overall, *M. oleifera* emerges as a promising dietary supplement for goat nutrition, effectively enhancing milk yield while maintaining reproductive health. Given these positive results, further studies should investigate the effects of *M. oleifera* on male fertility, expanding our understanding of its potential benefits across different aspects of goat husbandry. This research could pave the way for implementing *M. oleifera* as a strategic supplement to boost overall productivity in goat farming systems.

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Declarations

Ethical Approval Certificate

All animal experiments adhered to the guidelines approved by the Animal Care and Use Committee (IACUC) of University of ALBUTANA, Sudan. 7 April 2023 approval date, and number: 202302007

Author Contribution Statement

H.M.H.: conceptualization, methodology, software, data curation, writing—original draft. M.A.M., **A.E.A.M.,** A.A.S., M.O.A.E., S.Y.A., & E.A.B.: writing—review and editing. M.W.: Funding acquisition, Project administration, Supervision, Visualization. All authors contributed to the article and approved the submitted version.

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