



Research Article

Impacts of Wild Olive (*Olea europaea*) Leaf Supplementation on Milk Yield and Composition in Beetal Goats

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ABSTRACT

Introduction: Sustainable feeding strategies are critical for improving small ruminant productivity in regions facing forage scarcity. Wild olive (*Olea europaea*) foliage, is rich in protein, minerals, and bioactive compounds, making it a potential unconventional feed resource. This study aimed to evaluate the impact of wild olive leaf supplementation on nutrient intake, digestibility, milk yield and composition, and blood biochemical parameters in lactating Beetal goats.

Methods and materials: Sixteen lactating Beetal goats with average age of 3 years and body weight of 35–40 kg were randomly assigned to four dietary treatments containing 0% (Control), 5%, 10%, or 15% wild olive leaves on a dry matter (DM) basis. Wild olive leaves were chopped and incorporated directly into the basal feed ration, offered twice daily with free access to clean drinking water. Feed intake, digestibility, milk yield and composition, blood biochemistry, and mineral concentrations were measured over a six-week trial.

Results: Compared to the control group (0% wild olive leaves), goats fed 15% wild olive leaves showed the highest nutrient intake and digestibility values. Milk yield increased significantly in the group fed 15% olive leaves (2.08 L/day) compared to the control group (1.46 L/day), with corresponding improvements in fat, protein, lactose, and mineral fractions. Blood biochemical indices remained within physiological ranges across all groups, but goats fed 15% wild olive leaves exhibited higher total protein and albumin levels and lower cholesterol concentrations compared to group control.

Conclusion: Wild olive leaves can be effectively included in goat diets at up to 15% dry matter. The inclusion of 15% level of Wild olive to the goat's diet yielded the highest nutrient intake, digestibility, and milk yield compared to the control group.

1. Introduction

Agriculture remains the backbone of Pakistan's economy, contributing approximately 23.5% to gross domestic product, of which livestock accounts for about 63.6%¹. Livestock herds supply the majority of milk and meat in Pakistan; however, limited feed resources and the growing markets demand for animal-source foods are placing increasing pressure on conventional forages and feed. Identifying locally abundant, low-cost feed resources that can be integrated into crop–

livestock systems is therefore a priority for food security and rural livelihoods in Pakistan.

Olive (*Olea europaea* L.) is a seasonally abundant biomass in many production areas and has long been used in traditional medicine and as farm fodder. Olive leaves are rich in phenolic compounds, principally oleuropein and hydroxytyrosol, that exhibit strong antioxidant activity and documented bioactivity in multiple studies ^{2,3}. Global olive cultivation produces large

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volumes of pruning residues (leaves and twigs), especially in Mediterranean countries, representing an underexploited feed resource if its nutritive and safety profile for ruminants can be established².

Nutritionally, olive leaves show potential and constraints. Reported crude protein (CP) contents typically range from about 9.5% to 12.9% (DM basis), and leaves provide several amino acids (arginine, leucine, proline, glycine, valine, alanine) though they are relatively low in sulfur amino acids and lysine^{3,4}. The structural carbohydrate fraction is high (hemicelluloses and cellulose dominate) so raw leaves can limit ruminal fermentability and digestibility if used at high inclusion rates; composition also varies with leaf age, cultivar, harvest stage, and post-harvest handling, mandating local compositional analysis prior to feeding recommendations^{5,6}.

Beyond proximate composition, olive leaf polyphenols and flavonoids can modulate rumen ecology and product quality². Feeding olive by-products to ruminants has been linked to shifts in protozoal populations and changes in volatile fatty acid profiles. Some studies also report improvements in milk fat composition and oxidative stability. However, excessive fiber content or imbalanced phenolic concentrations may reduce feed intake and digestibility, leading to variable outcomes across experiments^{7,8}. Processing methods such as urea treatment or ensiling have been used successfully to increase nitrogen availability and reduce fiber constraints in olive residues, often improving rumen ammonia, total volatile fatty acids and microbial protein markers, and thereby enhancing their nutritive value for ruminants when properly applied⁷. Safety evaluations of olive-derived antioxidants indicate acceptable toxicological profiles for many extracts at appropriate doses, supporting cautious feed applications of leaf extracts or processed residues⁸.

Goat milk is a growth commodity in many regions, with global consumption and demand for goat-milk products (cheese, yogurt, fermented milks) rising steadily; this trend increases interest in dietary strategies that raise milk yield and improve milk composition in small ruminants^{9,10}. Nutritionally, goat milk often contains higher proportions of certain solids and protein relative to cow's milk, making improvements in milk composition via diet an important avenue for value addition on smallholder farms⁹.

In Pakistan, farmers sometimes use olive leaves informally as fodder, but pruning residues are largely underutilized at scale and often left to biodegrade, representing a wasted biomass and a missed opportunity for sustainable feed sourcing¹¹. Region-specific data on the nutritive composition, *in vivo* digestibility, production responses and mineral/blood-biochemical impacts of graded wild olive leaf inclusion in lactating Beetal goats are scarce. Existing studies of olive by-products vary in species, processing method and inclusion rate, leaving unresolved questions about optimal doses, effects on milk yield/ composition, and animal health indicators under local conditions^{7,12,13}.

This study aimed to evaluate the effects of graded wild olive leaf inclusion (0, 5, 10, and 15% DM) on feed intake, *in*

vivo nutrient digestibility, milk yield and composition, and macro- and micro-mineral plus selected blood biochemical indices.

2. Material and Methods

2.1. Ethical approval

All experimental procedures involving animals were conducted in accordance with institutional ethical standards and approved by the Animal Ethics Committee of the University of Agriculture, Peshawar, Pakistan. Routine animal welfare practices were strictly followed throughout the trial.

2.2. Study area and climatic conditions

The experiment was conducted at the Livestock Development and Research Station, Charbagh, District Swat, Khyber Pakhtunkhwa, Pakistan. The station is located in a semi-temperate zone characterized by moderate summers and cold winters, with average annual rainfall of approximately 1,200 mm. The climatic conditions of Swat valley are favorable for small ruminant production, and olive trees are widely available as a local resource.

2.3. Experimental animals and management

Sixteen lactating Beetal goats were selected for the trial. Goats were chosen based on uniform physiological parameters including body weight (35–40 kg), age (3 years), parity (second to third), and stage of lactation (early to mid). Goats were housed in well-ventilated pens under semi-intensive management, with each pen measuring approximately 3 × 4 m (12 m²) and accommodating four animals. Routine health care and hygiene practices were maintained throughout the study by an expert vet. All goats were vaccinated against peste des petits ruminants (PPR; manufactured in Pakistan, 1 mL subcutaneously) and clostridial diseases (*Clostridium perfringens* type C and D toxoid; imported from the UK, 2 mL subcutaneously). Antiparasitic treatment was administered prior to the trial using albendazole (produced in Pakistan, 7.5 mg/kg orally) to ensure freedom from internal parasites¹³.

2.4. Experimental design and diets

The goats were randomly allocated into four treatment groups (A–D) following a completely randomized design (CRD). Each group consisted of four goats. The basal diet was formulated according to NRC (2007) requirements using conventional feed ingredients and gradually replaced with chopped wild olive tree leaves at different inclusion levels¹⁴. Four treatment groups were established as follow, Diet A (control, 0% olive leaves), Diet B (5% olive leaves), Diet C (10% olive leaves), and Diet D (15% olive leaves on a DM basis). The feeding trial lasted six weeks, including a 10-day adaptation period followed by the experimental phase. Feed was offered twice daily (morning and evening), and refusals were weighed to calculate daily feed intake. The chemical composition of table is given in Table 1.

Table 1. Ingredient composition of experimental diets (% DM basis) formulated for lactating Beetal goats with graded wild olive leaf inclusion

Ingredient (% DM basis)	Diet A (0%)	Diet B (5%)	Diet C (10%)	Diet D (15%)
Wheat straw	40	35	30	25
Wild olive leaves	0.00	5	10	15
Total roughage	40	40	40	40
CONCENTRATE				
Maize grain	28	28	28	28
Wheat bran	18	18	18	18
Cottonseed cake	10	10	10	10
Total concentrate	56	56	56	56
SUPPLEMENTS				
Molasses	2	2	2	2
Mineral-vitamin premix	1.50	1.50	1.50	1.50
Salt (NaCl)	0.50	0.50	0.50	0.50
Total	100	100	100	100
CALCULATED NUTRIENT DENSITY				
ME (Mcal/kg DM)	2.21	2.31	2.40	2.48
NE _l (Mcal/kg DM)	1.24	1.29	1.35	1.40

DM: Dry matter; ME: Metabolizable energy; NE_l: Net energy for lactation; Mineral-vitamin premix provided per kg DM including vitamin A 10,000 IU, vitamin D 2,000 IU, vitamin E 25 IU, Fe 50 mg, Zn 40 mg, Cu 8 mg, Mn 25 mg, I 0.5 mg, Se 0.15 mg, Co 0.1 mg. ME and NE_l calculated from AOAC (2000) proximate data using NRC (2007) equations; Diet A: Control, Diet B: Control + 5% WOL (wild olive leaves), Diet C: Control + 10% WOL, Diet D: Control + 15% WOL

2.5. Sample collection

Feed samples (approximately 200 g per diet) were collected weekly, dried at 60 °C, ground to pass through a 1-mm sieve, and stored for chemical analysis. Milk samples (50 mL per goat per week) were collected after four successive milking; morning and evening milk was pooled at a 1:1 ratio to obtain representative samples, and stored at 4 °C until analysis. Blood samples (5 mL per goat per week) were collected from the jugular vein using sterile syringes into heparinized tubes, centrifuged at 3,000 rpm for 15 minutes, and plasma was stored at –20 °C until biochemical analysis.

2.6. Laboratory analysis

2.6.1. Feed analysis

Nutritional composition was determined on a dry matter basis. Dry matter (DM), crude protein (CP), crude fiber (CF), ether extract (EE), and ash were analyzed according to AOAC (2000) procedures¹⁵. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined following Van Soest et al. (1991)¹⁶.

2.6.2. Milk analysis

Fat content was measured using the Gerber method (IDF 1A:1969), protein by Kjeldahl (AOAC, 2000), lactose by enzymatic assay, and total solids (TS) and solids-not-fat (SNF) by gravimetric methods. Macro-minerals (Ca, P, K, Na, Mg) and micro-minerals (Fe, Zn, Cu) were quantified using atomic absorption spectrophotometry¹⁶.

2.6.3. Blood biochemistry

Plasma samples were analyzed for albumin, total protein,

glucose, cholesterol, urea, creatinine, hemoglobin (Hb), packed cell volume (PCV), alanine aminotransferase (ALT), and aspartate aminotransferase (AST) using automated biochemical analyzers (Hitachi 902, Japan).

2.7. Statistical analysis

Data were analyzed using a randomized complete block design (RCBD). Analysis of variance (ANOVA) was performed to test treatment effects. When significant differences were detected, means were separated using Duncan's multiple range test. Statistical significance was declared at $p < 0.05$. All analyses were performed using SPSS software (Version 20.0).

3. Results

3.1. Nutritional composition of experimental diets

The chemical composition of the experimental diets varied significantly with increasing inclusion of wild olive tree leaves (Table 2). Dry matter (DM) content showed a slight decline from 92.10% in Diet A to 89.80% in Diet D, likely due to the inherent moisture content of fresh olive foliage ($p > 0.05$). Crude protein (CP) increased progressively, reaching 13.97% in Diet D, which reflects the nitrogen-rich profile of olive leaves and their potential to enhance microbial protein synthesis in the rumen. Ether extract (EE) rose from 21.00% to 24.00%, indicating a higher lipid contribution, possibly from oleic and linolenic acids known to improve milk fat quality in group D ($p < 0.05$). Ash content also increased from group A to group D, suggesting enhanced mineral availability ($p < 0.05$). Meanwhile, fiber fractions (NDF and ADF) declined from group A to group D, which may improve digestibility by reducing indigestible structural carbohydrates ($p < 0.05$).

Table 2. Nutritional composition of experimental diets (DM basis) offered to lactating Beetal goats during a six-week feeding trial with graded wild olive leaf inclusion

Nutrient (%)	Diet A	Diet B	Diet C	Diet D	P-value
DM	92.10 ± 1.51	91.30 ± 1.43	91.00 ± 0.34	89.80 ± 1.65	0.062
CP	12.21 ± 0.34	12.43 ± 1.24	12.76 ± 1.23	13.97 ± 1.54	0.071
CF	6.33 ± 0.53 ^b	7.43 ± 0.54 ^a	7.45 ± 0.65 ^a	7.63 ± 0.43 ^a	0.05
EE	21.00 ± 0.24 ^c	21.91 ± 1.52 ^c	23.12 ± 1.25 ^b	24.00 ± 1.3 ^a	0.019
Ash	4.61 ± 0.22 ^c	5.13 ± 1.42 ^b	5.82 ± 0.54 ^b	6.50 ± 1.25 ^a	0.037
NDF	60.49 ± 0.35 ^a	59.38 ± 0.12 ^a	57.04 ± 1.42 ^b	54.98 ± 1.24 ^c	0.024
ADF	40.63 ± 0.14 ^a	39.36 ± 0.31 ^{ab}	37.08 ± 1.34 ^c	36.43 ± 1.14 ^d	0.033

^{Abcd} superscripts showed a significant difference in the rows ($p < 0.05$). Diet A: Control, Diet B: Control + 5% wild olive leaves, Diet C: Control + 10% wild olive leaves, Diet D: Control + 15% wild olive leaves, DM: Dry matter, CP: Crude protein, EE: Ether extract, NDF: Neutral detergent fiber, ADF: Acid detergent fiber

3.2. Feed intake performance

Daily feed intake parameters improved significantly with increasing olive leaf inclusion (Table 3, $p < 0.05$). Dry matter intake (DMI) rose from 751.86 g/goat/day in Diet A to 832.77 g/goat/day in Diet D, indicating enhanced palatability and voluntary intake ($p < 0.05$). Organic matter intake (OMI), crude

protein intake (CPI), and ether extract intake (EEI) followed similar trends, reflecting the nutrient density and digestibility of olive leaves ($p < 0.05$). The increase in ash intake (ASHI) suggests higher mineral availability, which is critical for metabolic functions and milk mineral content. Notably, the rise in nitrogen-free extract intake (NFEI) implies better energy supply, supporting lactation performance.

Table 3. Daily feed intake (g/goat/day) of lactating Beetal goats over a six-week feeding trial with graded wild olive leaf inclusion

Parameter	Diet A	Diet B	Diet C	Diet D	P-value
DMI	751.86 ^d ± 0.09	790.04 ^c ± 0.04	821.68 ^b ± 0.04	832.77 ^a ± 0.05	0.007
OMI	591.97 ^d ± 3.21	633.17 ^c ± 3.53	722.43 ^b ± 3.12	765.74 ^a ± 3.63	0.009
CPI	119.20 ^d ± 1.03	120.01 ^c ± 1.44	121.03 ^b ± 1.90	123.30 ^a ± 1.54	0.019
EEI	85.32 ^d ± 1.65	99.65 ^c ± 1.65	100.20 ^b ± 1.32	104.00 ^a ± 1.51	0.016
NFEI	381.50 ^d ± 2.98	421.40 ^c ± 2.89	425.23 ^b ± 2.59	428.00 ^a ± 2.34	0.009
NDFI	54.11 ^d ± 2.78	55.37 ^c ± 2.76	56.87 ^b ± 2.75	58.96 ^a ± 2.10	0.016
ADFI	47.02 ^d ± 0.87	49.82 ^c ± 0.67	51.53 ^b ± 0.10	53.01 ^a ± 0.22	0.019
ASHI	123.70 ^d ± 2.92	133.45 ^c ± 2.89	136.46 ^b ± 2.31	142.45 ^a ± 2.65	0.006

^{Abcd} superscripts showed a significant difference in the rows ($p < 0.05$). Diet A: Control, Diet B: Control + 5% wild olive leaves, Diet C: Control + 10% wild olive leaves, Diet D: Control + 15% wild olive leaves, DMI: Dry matter intake, OMI: Organic matter intake, CPI: Crude protein intake, EEI: Ether extract intake, NFEI: Nitrogen-free extract intake, NDFI: Neutral detergent fiber intake, ADFI: Acid detergent fiber intake; ASHI: Ash intake

3.3. Apparent Nutrient Digestibility

In vivo digestibility coefficients improved significantly with olive leaf supplementation (Table 4; $p < 0.05$). Dry matter digestibility (DMD) increased from 51.86% in Diet A to 64.77% in Diet D, indicating enhanced ruminal degradation and microbial activity ($p < 0.05$). Crude protein digestibility (CPD)

and ether extract digestibility (EED) also rose, suggesting better nitrogen and lipid utilization, which are essential for tissue synthesis and energy metabolism ($p < 0.05$). The improvement in ash digestibility (AshD) reflects increased mineral bioavailability, while reductions in fiber fractions (NDFD, ADFD) suggest reduced lignification and improved fermentability, enhancing rumen efficiency.

Table 4. Apparent nutrient digestibility (%) in lactating Beetal goats during a six-week feeding trial with graded wild olive leaf inclusion

Parameter	Diet A	Diet B	Diet C	Diet D	P-value
DMD	51.86 ^d ± 0.09	57.04 ^c ± 0.06	59.68 ^b ± 0.07	64.77 ^a ± 0.04	0.006
OMD	61.79 ^d ± 3.12	64.23 ^c ± 3.35	67.34 ^b ± 3.21	75.47 ^a ± 3.39	0.006
CPD	48.70 ^d ± 1.30	51.19 ^c ± 1.44	58.06 ^b ± 1.09	63.03 ^a ± 1.45	0.007
EED	57.23 ^d ± 1.65	64.41 ^c ± 1.56	69.23 ^b ± 1.32	74.56 ^a ± 1.15	0.019
NFED	71.84 ^d ± 2.89	76.42 ^c ± 2.87	80.23 ^b ± 2.95	86.65 ^a ± 2.43	0.019
NDFD	49.11 ^d ± 2.78	53.37 ^c ± 2.76	54.87 ^b ± 2.75	55.96 ^a ± 2.10	0.017
ADFD	39.02 ^d ± 0.87	41.82 ^c ± 0.67	41.53 ^b ± 0.10	42.00 ^a ± 0.22	0.017
AshD	33.05 ^d ± 2.29	39.54 ^c ± 2.31	45.43 ^b ± 2.13	54.32 ^a ± 2.56	0.019

^{Abcd} superscripts showed a significant difference in the rows ($p < 0.05$). Diet A: Control, Diet B: Control + 5% wild olive leaves, Diet C: Control + 10% wild olive leaves, Diet D: Control + 15% wild olive leaves, DMD: Dry matter digestibility, OMD: Organic matter digestibility, CPD: Crude protein digestibility, EED: Ether extract digestibility, NFED: Nitrogen-free extract digestibility, NDFD: Neutral detergent fiber digestibility, ADFD: Acid detergent fiber digestibility, AshD: Ash digestibility

3.4. Milk yield and composition

Milk yield and composition of lactating Beetal goats during a six-week feeding trial with graded wild olive leaf inclusion improved significantly with increasing levels of wild olive tree leaves in the diet (Table 5). Goats fed Diet D (15% olive leaves) produced the highest milk yield (2.085 L/day), compared to 1.46 L/day in the control group (Diet A; $p < 0.05$). This increase is likely due to enhanced nutrient intake and digestibility, particularly of crude protein and energy fractions, which support mammary gland function and milk synthesis.

Total solids, fat, protein, and lactose percentages also

increased progressively across treatments. Fat content rose from 4.12% in Diet A to 4.37% in Diet D ($p < 0.05$), suggesting improved energy partitioning and possibly the influence of olive leaf lipids such as oleic acid. Protein content increased from 3.52% to 3.65% ($p < 0.05$), reflecting better amino acid availability and rumen microbial efficiency. Lactose, a key osmotic regulator of milk volume, increased from 4.22% to 4.37% ($p < 0.05$), supporting the observed rise in milk yield. Mineral content also showed a modest increase, indicating enhanced mineral transfer into milk, though the difference was not statistically significant ($p > 0.05$).

Table 5. Milk yield and composition of lactating Beetal goats during a six-week feeding trial with graded wild olive leaf inclusion

Parameter (%)	Diet A	Diet B	Diet C	Diet D	P-value
Milk Yield (L/day)	1.46 ^d ± 0.03	1.66 ^c ± 0.03	1.94 ^b ± 0.03	2.085 ^a ± 0.04	0.006
Total Solids	13.07 ^d ± 0.08	13.28 ^c ± 0.10	13.47 ^b ± 0.10	13.59 ^a ± 0.09	0.006
Fat	4.12 ^d ± 0.02	4.27 ^c ± 0.02	4.33 ^b ± 0.00	4.37 ^a ± 0.01	0.007
Protein	3.52 ^d ± 0.01	3.58 ^c ± 0.02	3.62 ^b ± 0.03	3.65 ^a ± 0.04	0.019
Lactose	4.22 ^d ± 0.00	4.30 ^c ± 0.01	4.35 ^b ± 0.02	4.37 ^a ± 0.01	0.019
Minerals	0.82 ^d ± 0.01	0.85 ^c ± 0.04	0.87 ^b ± 0.01	0.88 ^a ± 0.01	0.061

^{Abcd} superscripts showed a significant difference in the rows ($p < 0.05$). Diet A: control, Diet B: control + 5% wild olive leaves, Diet C: control + 10% wild olive leaves, Diet D: control + 15% wild olive leaves

3.5. Blood biochemical and hematological parameters

Blood analysis revealed significant improvements in key biochemical markers with increasing olive leaf inclusion (Table 6). Albumin and total protein levels rose from 36.3 g/L and 68 g/L in Diet A to 39.5 g/L and 71.4 g/L in Diet D, respectively, indicating enhanced protein metabolism and liver function ($p < 0.05$). Alanine aminotransferase (ALT) and aspartate aminotransferase (AST) remained within physiological ranges, with slight increases in Diet B and C,

suggesting no hepatic stress ($p > 0.05$). Urea and glucose levels increased modestly, reflecting improved nitrogen utilization and energy status ($p > 0.05$). Cholesterol levels decreased significantly from 50.2 mg/dL in Diet A to 42.3 mg/dL in Diet D ($p < 0.05$), possibly due to the hypocholesterolemic effects of olive leaf polyphenols. Creatinine levels rose slightly, remaining within normal limits ($p > 0.05$). Hematological indices (PCV and hemoglobin) showed no adverse changes, confirming the safety of olive leaf inclusion ($p > 0.05$).

Table 6. Blood biochemical and hematological parameters of lactating Beetal goats during a six-week feeding trial with graded wild olive leaf inclusion

Parameter	Diet A	Diet B	Diet C	Diet D	P-value
Albumin (g/L)	36.3 ^d ± 0.3	38.4 ^c ± 0.5	39.2 ^b ± 0.6	39.5 ^a ± 0.1	0.006
Total Protein (g/L)	68.0 ^c ± 0.6	70.0 ^b ± 0.4	71.2 ^a ± 0.3	71.4 ^a ± 0.1	0.007
ALT (IU/L)	15.5 ± 1.5	15.6 ± 1.4	15.8 ± 0.2	15.9 ± 1.3	0.7
AST (IU/L)	64.5 ± 1.0	75.1 ± 1.3	75.9 ± 0.6	73.1 ± 0.7	0.19
Urea (mg/dL)	53.6 ± 2.0	56.6 ± 2.3	56.7 ± 2.1	56.6 ± 2.1	0.31
Glucose (mg/dL)	72.5 ± 0.5	75.5 ± 0.3	75.6 ± 0.4	75.9 ± 0.1	0.33
Cholesterol (mg/dL)	50.2 ^c ± 0.6	42.6 ^a ± 0.3	42.6 ^a ± 0.4	42.3 ^a ± 0.3	0.039
Creatinine (mg/dL)	1.42 ± 0.9	1.66 ± 0.6	1.74 ± 0.6	1.84 ± 0.1	0.47
Packed Cell Volume (%)	29.0 ± 1.2	30.1 ± 1.5	28.5 ± 1.8	29.2 ± 1.5	0.61
Hemoglobin (g/dL)	11.3 ± 0.4	12.1 ± 0.6	11.5 ± 0.6	12.3 ± 0.4	0.61

^{Abcd} superscripts showed a significant difference in the rows ($p < 0.05$). Diet A: Control, Diet B: control + 5% wild olive leaves, Diet C: control + 10% wild olive leaves, Diet D: control + 15% wild olive leaves, ALT: Alanine aminotransferase, AST: Aspartate aminotransferase

3.6. Milk macro-mineral profile

Milk macro-mineral concentrations increased significantly with olive leaf supplementation (Table 7). Calcium (Ca) rose from 1951.0 mmol/L in Diet A to 1954.7 mmol/L in Diet D, supporting bone health and milk coagulation ($p < 0.05$).

Phosphorus (P), potassium (K), sodium (Na), and magnesium (Mg) also increased, reflecting improved mineral absorption and transfer into milk ($p < 0.05$). These minerals are essential for cellular function, osmotic balance, and enzymatic activity, and their elevation suggests enhanced nutritional quality of milk.

Table 7. Milk macro-mineral concentrations (mmol/L) of lactating Beetal goats during a six-week feeding trial with graded wild olive leaf inclusion

Mineral (mmol/L)	Diet A	Diet B	Diet C	Diet D	P-value
Ca	1951.0 ^d ± 0.32	1951.3 ^c ± 0.06	1953.6 ^b ± 0.07	1954.7 ^a ± 0.04	0.0001
P	1251.9 ^d ± 0.12	1252.0 ^c ± 0.35	1253.3 ^b ± 0.21	1255.7 ^a ± 0.30	0.0001
K	1362.0 ^d ± 0.30	1363.5 ^c ± 0.44	1364.1 ^b ± 0.09	1366.0 ^a ± 0.45	0.0001
Na	441.3 ^c ± 0.65	442.4 ^b ± 0.56	442.7 ^b ± 0.32	444.6 ^a ± 0.15	0.0001
Mg	53.4 ^d ± 0.89	54.4 ^c ± 0.87	55.2 ^b ± 0.95	56.7 ^a ± 0.43	0.0001

^{Abcd} superscripts showed a significant difference in the rows ($p < 0.05$). Diet A: control, Diet B: control + 5% wild olive leaves, Diet C: control + 10% wild olive leaves, Diet D: control + 15% wild olive leaves, Ca: Calcium; P: Phosphorus, K: Potassium, Na: Sodium, Mg: Magnesium

3.7. Milk micro-mineral profile

Milk micro-mineral concentrations also improved with olive leaf inclusion (Table 8). Iron (Fe), zinc (Zn), and copper (Cu) levels were significantly higher in Diet D compared to Diet A

($p < 0.05$). These trace minerals play vital roles in immune function, antioxidant defense, and enzymatic reactions ($p < 0.05$). The increase in Zn and Cu may be attributed to the mineral-rich nature of olive leaves and their influence on rumen microbial activity and absorption efficiency ($p < 0.05$).

Table 8. Milk micro-mineral concentrations (mmol/L) of lactating Beetal goats during a six-week feeding trial with graded wild olive leaf inclusion

Mineral	Diet A	Diet B	Diet C	Diet D	P-value
Fe	719.7 ^c ± 0.10	721.0 ^b ± 0.04	723.5 ^a ± 0.05	723.8 ^a ± 0.07	0.0001
Zn	5198.6 ^c ± 0.12	5201.2 ^b ± 0.35	5202.3 ^b ± 0.21	5203.5 ^a ± 0.39	0.0001
Cu	400.2 ^d ± 0.30	401.2 ^c ± 0.44	403.1 ^b ± 0.09	404.0 ^a ± 1.45	0.0001

^{Abcd} superscripts showed a significant difference in the rows ($p < 0.05$). Diet A: Control; Diet B: Control + 5% wild olive leaves; Diet C: Control + 10% wild olive leaves; Diet D: Control + 15% wild olive leaves, Fe: Iron; Zn: Zinc; Cu: Copper

4. Discussion

The present study demonstrated that supplementation of wild olive tree leaves in the diets of Beetal goats exerted a positive influence on nutrient intake, digestibility, milk yield, and blood biochemical parameters. Incremental inclusion of olive leaves (5–15%) progressively enhanced DMI, CPI, EEI, and overall nutrient utilization, with diet D (15% olive leaves) consistently outperforming the control diet. These findings align

with earlier reports that olive leaves are rich in crude protein (9.5–12.9%) and can serve as valuable unconventional forages⁷.

Nutrient digestibility indices, including DMD, OMD, and CPD, were significantly improved in goats fed higher levels of olive leaves. This enhancement may be attributed to the structural breakdown of lignocellulose and improved rumen microbial activity, as previously explained by urea treatment studies^{17,18}. Although untreated olive leaves are generally characterized by low CP and high lignin¹⁹, the present results

confirm that even without chemical treatment, moderate inclusion levels can improve nutrient utilization, possibly due to the synergistic effect of basal diet composition and adaptation of rumen microbiota.

Milk yield and composition were positively affected by olive leaf supplementation. Goats receiving Diet D (15% olive leaf inclusion, DM basis) produced the highest milk yield (2.08 L/day), with incremental improvements in fat, protein, lactose, and mineral fractions. These results corroborate the findings of a study, who reported significant increases in milk production and compositional quality in goats fed olive leaf diets. The observed rise in macro- and micro-minerals (Ca, P, K, Na, Mg, Fe, Zn, Cu) in milk further supports the hypothesis that olive leaves contribute to mineral enrichment²⁰.

Blood biochemical analysis revealed improved albumin, total protein, glucose, and hemoglobin levels in goats fed olive leaves, while cholesterol levels declined, suggesting a potential hypocholesterolemic effect. These outcomes are in agreement with previous findings¹⁹, who highlighted the beneficial role of olive by-products in enhancing ruminant health and performance¹⁸.

Overall, the study confirms that olive leaves, even in untreated form, can be strategically utilized as a sustainable feed resource for small ruminants at inclusion levels up to 15% DM. Their inclusion not only improves feed intake and nutrient digestibility but also enhances productive and metabolic responses without adverse health effects. Variability in chemical composition²⁰, underscores the importance of considering factors such as tree age, pruning type, and seasonal variation when formulating diets.

5. Conclusion

This study confirms that wild olive leaves are a viable, sustainable feed supplement for Beetal goats, with the 15% dry-matter inclusion level yielding the greatest improvements in feed intake, nutrient digestibility, milk yield, and milk composition (including fat, protein, lactose, and minerals), alongside beneficial blood biochemical changes such as enhanced protein metabolism and reduced cholesterol. These findings support olive leaf utilization as a cost-effective feeding strategy that boosts productivity and metabolic health without adverse effects, while also aligning with circular bioeconomy goals by repurposing agricultural by-products. Long-term studies is recommended to further evaluate reproductive, growth, and immune outcomes, as well as the role of bioactive compounds in olive leaves.

Declarations

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

Ijazul Haq conceptualized the study, designed the methodology, and performed data collection; Arshad Zahoor supervised the project, handled administration, and reviewed the manuscript; Qurat ul Ain Badhana conducted laboratory analyses, interpreted the data, and drafted the manuscript;

Emaan Showkat carried out statistical analysis and literature review; and Muhammad Tahir managed fieldwork, sample handling, and data validation. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Ethical considerations

This manuscript represents an original study submitted for the first time to this journal. The authors have ensured compliance with ethical standards, including the avoidance of duplication and plagiarism. No artificial intelligence tools were used in the conduct or completion of this study. The authors take full responsibility for the originality of the work prior to submission and throughout the publication process.

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