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Effects of Concentrate-to-Peanut Hay Ratio on Growth, Rumen Fermentation, Blood Metabolites, Behaviour and Economic Return of Kooka Lambs

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ABSTRACT

This study evaluated the effects of concentrate-to-peanut-hay ratios (C:F) on growth performance, rumen fermentation, blood biochemistry, immunoglobulins, behaviour and economics of Kooka lambs. Twenty-one male Kooka lambs (18 ± 1 kg; 4 months old) were randomly allocated to diets containing 20:80, 40:60 or 60:40 C:F (DM basis) for 75 days, including 15 days of adaptation. Lambs fed 60:40 C:F had higher dry matter intake (0.76 kg/day) and final body weight (21.92 kg) than those fed 20:80 C:F ($p < 0.05$), whereas total weight gain was greater with 40:60 (3.54 kg) and 60:40 (3.72 kg) than with 20:80 C:F (2.94 kg) ($p < 0.05$). 40:60 C:F gave the best feed conversion ratio (11.52; $p < 0.05$). Increasing concentrate decreased rumen pH (6.66 to 6.12) and increased NH_3-N (11.0 to 18.3 mg/dL) ($p < 0.05$). Plasma immunoglobulins G and A were highest with 20:80 C:F and declined with increasing concentrate ($p < 0.05$). Serum total protein and cortisol increased with concentrate inclusion ($p < 0.05$), while glucose, cholesterol, creatinine, blood urea nitrogen and white blood cells were unaffected ($p > 0.05$). Lambs fed 60:40 C:F showed more feeding activity and less standing, locomotion and oral manipulation ($p < 0.05$). The 40:60 C:F diet yielded the highest estimated margin over feed cost (PKR 1,990.80/lamb) and net return (PKR 2,564.80/lamb), whereas 60:40 C:F had the highest production cost and lowest margin. Overall, 60:40 C:F maximised intake and final body weight, whereas 40:60 C:F gave the best feed conversion and economic return; no single ratio was superior for all responses.

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INTRODUCTION

Small-ruminant production plays a crucial role in livelihoods and food security in developing countries, where lamb production

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is favoured because lambs adapt to a wide range of agro-ecological environments and can use poor-quality forage (Aksel et al., 2024; Demir, 2024; Subhopoto et al., 2024; Qi et al., 2024). In parts of Asia and Africa, lamb production has increased household income and employment and provides high-quality animal protein, as lamb meat is a good source of essential amino acids, vitamins and minerals (Devendra, 2016; Gifford, 2016; Nel et al., 2023; Samad et al., 2025).

Forages comprise a major proportion of the diet in lamb production systems (Ramírez-Restrepo & Barry, 2005); however, in the arid and semi-arid tropical regions of many developing countries, there is a severe shortage of good-quality forage (Balehegn et al., 2022). Lambs are predominantly reared by grazing low-quality natural pastures and are stall-fed crop residues, such as wheat straw, that have low crude protein content and limited ruminal degradability (Chishti et al., 2022; Chishti et al., 2024; Khan & Habib, 2012), which directly limits lamb performance. Recent research has therefore focused on alternatives to low-quality crop residues and the efficient utilisation of non-conventional and agro-industrial feed resources (Boudalia et al., 2024; Dzulqaidah et al., 2026; Khan et al., 2009), including alternative forages such as industrial hemp silage and hay (Shah et al., 2024), and on balancing forage sources with legumes and concentrates to improve feed intake and nutrient digestibility in small ruminants (Ramadani et al., 2025).

Peanut, or groundnut (*Arachis hypogaea* L.), is one of the main oilseed crops of developing countries. Most of it is grown by smallholders under both rain-fed and irrigated conditions, and both the kernels and the by-products have a market (Asuquo et al., 2024). Pakistan grew groundnut on roughly 142,900 ha in 2023-24, and about 137,800 ha of this area was in Punjab (Government of Pakistan, 2025). The kernels are used for food, confectionery and oil extraction. The haulms left after the pods are harvested are sun-dried and stored as peanut hay, so the material is available locally and at low cost. Peanut hay is also a legume forage, which sets it apart from cereal straws: it contains about 105 g/kg dry matter (DM) crude protein and about 466 g/kg DM neutral detergent fiber (NDF), carries useful amounts of minerals and is well digested by sheep (Khan et al., 2013; Song et al., 2023). For these reasons, it could replace low-quality crop residues in lamb diets.

The concentrate-to-forage (C:F) ratio is a major dietary factor determining nutrient intake, rumen fermentation and growth in small ruminants (Boudalia et al., 2024; Ramadani et al., 2025). An appropriate C:F ratio may reduce nutrient waste, improve feed efficiency, and support animal health and productivity, whereas excessive concentrate can lower ruminal pH and increase feed cost (Haddad & Ata, 2009; Plaizier et al., 2008). However, the response to concentrate depends on the quality of the basal forage, and no information is available on the appropriate level of concentrate inclusion when peanut hay is the sole forage for growing lambs.

Kooka is a thin-tailed, medium-sized sheep breed found mainly in Sindh province, Pakistan. The average live weight of adult males reaches up to 52 kg, and the breed is an important source of income for rural households; even so, very limited research has been conducted on its nutrition (Barham et al., 2013). Peanut haulms have been fed to sheep, cattle and beef heifers (Hill, 2002; Khan et al., 2013; Waters et al., 2015), but we found no study that tested peanut hay with different amounts of concentrate in indigenous lambs such as Kooka. Breed, sex and age all influence the body weight and growth of indigenous small ruminants (Moaeen-ud-Din et al., 2024), and their response to concentrate-rich feeding is not the same as that of improved breeds (Akbar et al., 2024). Breed-specific data are therefore needed.

We chose the three C:F ratios to cover the feeding conditions that Kooka lambs actually meet in practice. A 20:80 ratio is close to the forage-based feeding of smallholders, who give little concentrate; 40:60 matches the moderate supplementation of semi-intensive fattening; and 60:40 matches the concentrate-rich diets of commercial fattening units. Immune and stress indicators were measured alongside growth and rumen fermentation because a change in dietary energy and fibre shifts ruminal pH and the gut environment, and this may in turn affect systemic immunity and stress responses in growing ruminants (Plaizier et al., 2017; Sordillo & Aitken, 2009). Plasma immunoglobulin G (IgG), immunoglobulin M (IgM) and immunoglobulin A (IgA) served as indicators of circulating humoral immunity, with IgA also reflecting mucosal immunity. White blood cell count was used as a broad indicator of cellular immune status, and cortisol as a marker of hypothalamic-pituitary-adrenal axis activity (Calder, 2013; Moberg, 2000).

Our hypothesis was that more concentrate would raise dry matter intake (DMI) and live-weight gain because the diet would be more energy-dense, and would lower rumen pH while raising ruminal NH_3-N, because starch ferments quickly and the supply of degradable nitrogen would be larger. These changes can act on physiological status in opposite directions, so we did not expect immune, blood and behavioural indicators to follow the same pattern as growth. We also expected the 40:60 ratio to give a better balance between feed efficiency and economic return than either extreme ratio. The study therefore aimed to compare the three C:F ratios for intake, growth performance, rumen pH and NH_3-N, blood biochemistry and immune indicators, behaviour and economic return in Kooka lambs.

MATERIALS AND METHODS

Location

The experiment was conducted during the winter season (November to December, 2025) at the Raja Muhammad Akram Animal Nutrition Research Centre, Directorate of Farms, University of Agriculture, Faisalabad. The average ambient temperature and relative humidity during this time period were about 17 °C and 50%, respectively. The experimental

protocol was reviewed and approved by the Directorate of Graduate Studies, University of Agriculture Faisalabad, Pakistan, under approval/reference No. DGS 5189-92. All animal handling procedures were carried out in accordance with institutional animal welfare guidelines.

Experimental Phases

The study evaluated the effects of different ratios of concentrate to peanut hay on growth performance, ruminal characteristics, blood and immune parameters, behaviour and economic return. A total of 21 healthy male indigenous Kooka lambs, 4 months of age with an initial body weight of 18 ± 1 kg, were used. Lambs were randomly allocated to the three dietary treatments (seven lambs per treatment) by lottery method, and initial body weight was balanced among treatments (18.10, 17.90 and 18.20 kg for the 20:80, 40:60 and 60:40 C:F diets, respectively). The experiment lasted 75 days and comprised a 15-day adaptation period followed by a 60-day data-collection period.

Animal Selection and Management

Each dietary treatment group was housed in a separate group pen measuring 3.0 × 2.5 m (7.5 m^2), with seven lambs per pen, under similar environmental conditions. Each lamb was individually identified, and individual feed intake was recorded while the lambs were temporarily tethered during feeding. One hour of play time was provided every day before sunset, during which the lambs of each treatment group were released together into an adjacent open yard without access to feed; all groups had the same duration and conditions. Clean bedding and free access to clean drinking water were provided throughout the experiment, and animal welfare was ensured by regular health checks, careful handling and clean housing conditions.

Feeding Strategies

To compare the effects of different C:F ratios, the lambs were allocated to one of three dietary treatments: 20% concentrate and 80% forage (low-concentrate diet), 40% concentrate and 60% forage (moderate-concentrate diet), and 60% concentrate and 40% forage (high-concentrate diet). The C:F ratios were formulated and expressed on a DM basis. The same concentrate mixture was used in all three treatments, and peanut hay was the sole forage source; only the proportions of concentrate and peanut hay differed among the diets.

Experimental Diet

The three diets were formulated with different proportions of concentrate and peanut hay to meet the nutrient requirements of growing lambs (National Research Council, 2007;

Ward & Gifford, 2017). Peanut hay (*Arachis hypogaea* L.) was bought ready to use in dried form and kept in a dry, clean, covered store until feeding so that it was not exposed to humidity. Peanut hay and concentrate ingredients are often contaminated by aflatoxin-producing *Aspergillus* species (Sarwar et al., 2024), so a commercial toxin binder was added to the concentrate at 0.10% as a precaution; such binders can reduce aflatoxin B1 toxicity in contaminated concentrate feed (Rivera et al., 2025). The feeds were not tested for aflatoxins before feeding; however, we cannot confirm that they were free of mycotoxins. Table 1 gives the ingredient composition of the concentrate, the nutrient composition of the concentrate and of peanut hay, and the calculated composition of the three complete diets. Because one concentrate was mixed with peanut hay in different proportions, the diets differed in nutrient composition: crude protein (CP) and total digestible nutrients (TDN) rose, and NDF and acid detergent fiber (ADF) fell, as concentrate inclusion increased.

Table 1
Ingredient and nutrient composition of experimental diets

Ingredient (%)	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet
	20:80	**40:60**	**60:40**
Forage (Peanut hay)	80	60	40
Concentrate	20	40	60
Ingredient Composition of Concentrate			
Corn grain ground	27.17	27.17	27.17
Wheat bran	20	20	20
Canola meal	15	15	15
Rice bran	14	14	14
Molasses	7	7	7
Corn gluten 30%	6	6	6
Soybean meal, 44% CP	3.94	3.94	3.94
Rapeseed meal	3	3	3
Limestone, ground	1.65	1.65	1.65
Sodium bicarbonate	0.80	0.80	0.80
Urea	0.75	0.75	0.75
[1]NaCl	0.59	0.59	0.59
Toxin binder	0.10	0.10	0.10
Total	100	100	100
Nutrient Composition of Concentrate			
Dry matter	88.52	88.52	88.52
Crude protein	20	20	20
[2]TDN	76.11	76.11	76.11
Crude fat	5.38	5.38	5.38

Table 1 (*continued*)

Ingredient (%)	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet
	20:80	40:60	60:40
Nutrient Composition of Concentrate			
Ash	7.62	7.62	7.62
[3]ADF	10.68	10.68	10.68
[4]NDF	22.85	22.85	22.85
Lignin	3.35	3.35	3.35
Calcium	0.85	0.85	0.85
Chloride	0.45	0.45	0.45
Potassium	1.30	1.30	1.30
Magnesium	0.43	0.43	0.43
Sodium	0.50	0.50	0.50
Phosphorus	0.84	0.84	0.84
Sulphur	0.30	0.30	0.30
Nutrient Composition of Peanut Hay			
Dry matter	90	90	90
Crude protein	11.2	11.2	11.2
Crude fibre	32.3	32.3	32.3
Ether extract	1.4	1.4	1.4
NDF	50.4	50.4	50.4
ADF	38.2	38.2	38.2
Ash	8.1	8.1	8.1
Calculated Nutrient Composition of Total Experimental Diet (%)			
Crude protein	13.00	14.72	16.48
NDF	44.89	39.38	33.87
ADF	32.70	27.19	21.69
Dry matter	89.70	89.41	89.11
TDN	53.62	59.24	64.87
Ether extract	2.20	2.99	3.79
Ash	8.00	7.91	7.81
[5]ME (MJ/kg DM)	8.11	8.96	9.81

Note. All ingredient and nutrient values are expressed on a dry matter basis. C:F = concentrate-to-forage ratio; [1]NaCl = sodium chloride; [2]TDN = total digestible nutrients; [3]ADF = acid detergent fibre; [4]NDF = neutral detergent fibre; [5]ME = metabolisable energy. Mineral values are expressed as a percentage of DM. The DM, CP, crude fat (ether extract) and ash of the concentrate and peanut hay, and the fibre fractions of peanut hay, were determined by laboratory analysis (Latimer, 2019), whereas TDN, fibre fractions and mineral contents of the concentrate were calculated from the formulation. The nutrient composition of the complete diets was calculated as the weighted mean of the concentrate and peanut hay values, based on their proportions in each diet, and was not analysed. The TDN content of the diets was estimated from the TDN of the concentrate (76.11%) and peanut hay (48.00%), with the latter adopted from the feed composition data reported by Myer and Hersom (2011). The ME was estimated as ME (Mcal/kg DM) = 0.04409 × TDN (%) × 0.82 (National Research Council, 2007) and converted to MJ/kg DM (1 Mcal = 4.184 MJ). These values are estimates and were not measured experimentally

Data Collection

The following parameters were measured: growth performance, ruminal fermentation characteristics (pH and NH_3-N), immune parameters (IgG, IgM, IgA and white blood cell counts), blood biochemistry (glucose, total protein, cholesterol, creatinine, blood urea nitrogen and plasma cortisol), behaviour and economic return.

Growth Performance

To determine the effects of various feeding strategies, the growth performance of lambs was assessed by observing the body weight, average daily gain, feed intake, and feed conversion ratio.

Feed Intake

Feed offered and refused (orts) were recorded daily for each lamb over 24-h intervals, and daily feed intake was calculated as the difference between the amounts offered and refused. The concentrate was mixed with peanut hay in the specified C:F ratios and fed as a complete mixed ration once daily at 08:00 h on an ad libitum basis. Dry matter intake was calculated from the DM content of the feed offered and refused. The proximate composition of the feed ingredients (DM, CP, ether extract, crude fibre and ash) was determined at the start of the trial according to Latimer (2019) and the laboratory feed evaluation procedures described by Rehman and Zulfiqar (2024).

Average Daily Gain

Using an electronic scale (XK3188-T20 Weighing Indicator, Master scales, Faisalabad, Pakistan), the body weights of the lambs were measured on the first day of the experiment and then every week after that. Weekly body weight measurements were recorded throughout the experimental period to monitor changes in growth performance over time. Lambs were kept off feed for eight hours in accordance with Herath et al. (2021) before every weighing. These body weights were used to compute average daily growth (ADG) using the following formula as in Equation 1:

$$\text{ADG (g/day)} = \frac{\text{Final body weight} - \text{Initial body weight}}{\text{Number of days}} \quad [1]$$

Feed Conversion Ratio

The feed conversion ratio (FCR) was determined every week following the method of Gjorgjievski et al. (2022) using the formula as in Equation 2:

FCR = Total dry matter intake (kg) / Total weight gain (kg) [2]

Rumen Fluid Collection

Following the protocol outlined by Ramos-Morales et al. (2014), rumen fluid was collected at the end of the experimental trial by stomach tube, as a non-invasive alternative to rumen cannulation, from three lambs per treatment. These lambs were selected at random, and the same three lambs per treatment were used for both rumen fluid and blood sampling. Sampling was limited to three lambs per treatment because of the cost of the analytical kits and to minimise handling and restraint stress in the remaining animals; this small sample size is acknowledged as a limitation when interpreting ruminal and blood parameters. A flexible plastic stomach tube (about 10 mm inner diameter and 100 cm long) was inserted orally and guided into the rumen while each lamb was carefully restrained in an upright position. The first 10 mL of aspirated fluid was discarded to reduce saliva contamination, and about 15-20 mL of rumen fluid was then collected; nevertheless, some contamination with saliva was still possible with this method. Sampling was performed once, 2-3 h after the morning meal. The rumen fluid was filtered through four layers of cheesecloth, and samples for NH_3-N determination were stored at -20 °C and analysed within seven days of collection.

Sample Handling and pH Estimation

The pH value was measured as soon as the rumen fluid had been collected using a digital pH meter that had been calibrated with standard pH buffer solutions of pH 4.0 and 7.0. The pH probe was washed with distilled water and then put in the rumen fluid sample. The value was noted when a stable reading was obtained, usually after 30 to 60 seconds, as in the case of Duffield et al. (2004).

Ammonia Nitrogen Estimation

The Kjeldahl distillation method, as outlined by Fenner (1965), was used to measure the content of ammonia nitrogen (NH_3-N) in rumen fluid. To release ammonia, a 5 mL aliquot of rumen fluid was put into a Kjeldahl distillation tube and combined with a potassium hydroxide solution (2 mol/L). The combination was then steam-distilled in a Kjeldahl distillation device. The liberated ammonia was distilled into a receiving flask that held a 40 g/L boric acid solution along with a mixture of indicators (bromocresol green and methyl red). The distillate was gathered until a sufficient volume (about 100 mL) was reached. Titration against standard hydrochloric acid (0.005 N) was then used to quantify the trapped ammonia until the endpoint was attained, as evidenced by a colour shift. The NH_3-N concentration was calculated using the following Equation 3:

$$NH_3\text{-N (mg/dL)} = \frac{(V-B)\times N \times 14\times 100}{A} \quad [3]$$

Where:
V = volume of HCl used for sample titration (mL)
B = volume of HCl used for blank titration (mL)
N = normality of HCl
14 = atomic weight of nitrogen
A = volume of sample aliquot (mL)

In this equation, (V - B) × N gives the millimoles of ammonia nitrogen in the aliquot, multiplication by 14 converts this to milligrams of nitrogen, and multiplication by 100/A expresses the result per 100 mL of rumen fluid; NH_3-N concentration is therefore reported in mg/dL throughout the manuscript. All analyses were performed in duplicate, and results were expressed as mean values (Fenner, 1965; Souza et al., 2013).

Blood Sampling

Following the procedures outlined by Zhong et al. (2012) blood samples (10 mL) were collected from the jugular vein of the same three lambs per treatment at approximately 11:00 AM at the end of the experiment. Blood was collected into three types of vacutainer tubes: EDTA-coated tubes for haematology (white blood cell counts), lithium heparin-coated tubes for plasma, and plain tubes for serum. Plasma was used for the determination of IgG, IgM and IgA; serum was used for the blood biochemistry parameters (glucose, total protein, cholesterol, creatinine and blood urea nitrogen); and plasma was used for cortisol. Serum was obtained by allowing blood in plain tubes to clot at room temperature and centrifuging at 1,500 × g for 10 min at 4 °C, and plasma was obtained by centrifuging blood in lithium heparin tubes at 2,500 × g for 15 min at 4 °C. Serum and plasma were stored at -20 °C and -80 °C, respectively, until analysis.

Immune Parameters

Plasma IgG, IgM and IgA concentrations were determined using sheep-specific commercial ELISA kits (Cat. Nos. 7620, 7630 and 7640, respectively; Alpha Diagnostic International, San Antonio, TX, USA) according to the manufacturer's instructions, with absorbance read at 450 nm using a microplate reader. The analytical sensitivities of the IgG, IgM and IgA kits were 5 ng/mL, 2.5 ng/mL and 0.1 µg/mL, respectively. Cortisol was quantified using a sheep-specific competitive ELISA kit (Cat. No. CSB-E17045Sh; Cusabio, Wuhan, China) with a sensitivity of 0.047 ng/mL and a detection range of 0.047-200 ng/mL. Total white blood cell counts were determined in EDTA-treated blood using an automated haematology

analyser (BC-2300, Shenzhen Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China). According to the manufacturer, the intra- and inter-assay coefficients of variation were 2.5-6.2% and 1.1-2.4% for IgG, 4.98% and 5.86% for IgM, 5% and 9% for IgA, and less than 8% and 10% for cortisol, respectively.

Blood Biochemistry

Blood biochemistry parameters (glucose, total protein, total cholesterol, blood urea nitrogen and creatinine) were determined in serum from the same lambs using an automated clinical chemistry analyser (QCA Diagnostics, USA) with commercial diagnostic kits, according to the manufacturer's protocols (Chen et al., 2021).

Behavioural Observations

Feeding, rumination, resting, standing, locomotion and abnormal (non-nutritive oral manipulation) behaviours were monitored to describe how the behavioural patterns of the lambs changed with diet. Behaviour was recorded once a week during the 60-day data-collection period, giving 8 observation days, and the same schedule was used for every lamb and treatment. Each observation day had two 2-h sessions, one from 08:00 to 10:00 h after the morning feeding and one from 14:00 to 16:00 h. Within a session, the behaviour of each lamb was recorded by instantaneous scan sampling every 10 min, which gave 12 intervals per session, 24 per day and 192 per lamb over the experiment. At every scan, a lamb was placed in one of the six mutually exclusive categories defined in Table 2, so the six percentages add up to 100% for each lamb. Continuous recording of the video was used only to confirm short-duration activities, mainly oral manipulation, and did not enter the percentages in Table 7. For each lamb, the percentage of each behaviour was calculated from the scan data as: Behaviour (%) = (number of intervals in which the behaviour was observed / total number of observation intervals) × 100 (Cartoni Mancinelli et al., 2023). These percentages describe the observation sessions only, not the full 24-h day. Behaviour was recorded both by direct observation and on video. Three infrared night-vision cameras (DH-CA-FW48J; Zhejiang Dahua Technology, Hangzhou, China), mounted about 6 m above the pens, covered all lambs, allowing recording to take place without observers standing near the pens. The same trained observers reviewed all recordings and were blinded to treatment through coded video files. Each lamb was identified within its group pen by body marks. The individual lamb was the observational unit, and the weekly observations of each lamb were averaged over all observation days to give one value per lamb for statistical analysis. Behaviour was classed as abnormal when a lamb performed non-nutritive oral manipulation, either of pen fixtures (bar, crib or bucket biting and chain chewing) or of pen-mates (wool or ear biting), that was not linked to feeding, drinking or rumination.

These behaviours were scored only as present or absent at each scan. Their repetitiveness and invariance were not assessed, so they were not classed as stereotypies. They were recorded on all observation days throughout the experimental period. The ethogram (Table 2) was adapted from previously published work (Aziz ur Rahman et al., 2017).

Table 2
Behavioural definitions for the lambs monitored during the trial

Behaviour	Explanations
Rumination	The act of rechewing the cud regurgitated from the rumen for additional digestion while the animal is either lying down or standing up.
Feeding	The animal's tendency to bite, eat, and chew the concentrate and forage.
Resting	The posture where animals lie down without doing other activities.
Standing	The posture when the animal is standing without doing any other activity.
Locomotion	The animal's activity of walking and moving in the pen.
Abnormal behaviour	Non-nutritive oral manipulation directed at pen fixtures (bar, crib or bucket biting, chain chewing) or at pen-mates (wool or ear biting), not associated with feeding, drinking or rumination.

Note. Behavioural definitions adapted from Aziz ur Rahman et al. (2017)

Economic Analysis

An economic evaluation was made per lamb to compare the cost-effectiveness of the dietary treatments. Feed prices were the average prices in the local feed market of Faisalabad during the experimental period (November-December 2025): PKR 100/kg DM for concentrate and PKR 40/kg DM for peanut hay. Feed costs were based on the DM intake of concentrate and peanut hay during the 60-day data-collection period; the 15-day adaptation period was not included. Purchasing cost was the price paid for each lamb at the start of the experiment, calculated as initial body weight × PKR 1,250/kg live weight, and it differed slightly among treatments only because mean initial body weights differed slightly. Miscellaneous costs per lamb covered veterinary care, bedding and utilities. The following indicators were calculated as in Equations 4 to 11 (Akram et al., 2024; Chase & Fortina, 2023):

$$\text{Total feed cost (PKR/lamb)} = \text{concentrate DMI (kg)} \times \text{concentrate price} + \text{peanut hay DMI (kg)} \times \text{peanut hay price} \quad [4]$$

$$\text{Total production cost (PKR/lamb)} = \text{purchasing cost} + \text{total feed cost} + \text{miscellaneous costs} \quad [5]$$

$$\text{Feed cost per kg weight gain (PKR/kg)} = \text{total feed cost} / \text{total weight gain} \quad [6]$$

$$\text{Estimated value of weight gain (PKR/lamb)} = \text{total weight gain} \times \text{PKR 1,300/kg} \quad [7]$$

$$\text{Estimated margin over feed cost (PKR/lamb)} = \text{estimated value of weight gain} - \text{total feed cost} \quad [8]$$

$$\text{Estimated value of final live weight (PKR/lamb)} = \text{final body weight} \times \text{PKR 1,300/kg} \quad [9]$$

$$\text{Estimated net return (PKR/lamb)} = \text{estimated value of final live weight} - \text{total production cost} \quad [10]$$

$$\text{Benefit: cost ratio} = \text{estimated value of final live weight} / \text{total production cost} \quad [11]$$

Because the lambs were retained for a further research trial and were not sold, revenue was estimated from an assumed live-weight market price of PKR 1,300/kg rather than from actual sale values.

Statistical Analysis

The individual lamb was the experimental unit for all variables. For growth performance, total DMI, final body weight, total weight gain, ADG and FCR were calculated per lamb over the 60-day data-collection period (n = 7 per treatment). Weekly body weights served to monitor growth and were not analysed as repeated measures. Ruminal (pH and NH_3-N), immune and blood biochemical parameters were measured once, at the end of the experiment, in three lambs per treatment (n = 3). For behaviour, the weekly percentages of each lamb were averaged over all observation days to give one value per lamb (n = 7), so repeated observations on the same animal were not treated as independent replicates. On this basis, all variables were analysed by one-way ANOVA in a completely randomised design with the model $Yij = \mu + Ti + eij$, where Yij is the observation on lamb j receiving treatment i, μ is the overall mean, Ti is the fixed effect of dietary treatment (i = 1-3), and eij is the random residual error. Normality of the residuals was checked with the Shapiro-Wilk test and homogeneity of variances with Levene's test. Where the treatment effect was significant ($p < 0.05$), means were separated by Tukey's HSD test. Results are given as treatment means with the pooled standard error of the mean (SEM), calculated from the residual mean square of the ANOVA and the number of lambs per treatment for each parameter (n = 7 or n = 3). Significance was declared at $p < 0.05$; p-values between 0.05 and 0.10 are reported but were not interpreted as treatment effects. Statistical analyses were carried out in SPSS (version 22; IBM Corp., Armonk, NY, USA) (Montgomery, 2017).

RESULTS AND DISCUSSIONS

Growth Performance Parameters

Growth performance of Kooka lambs fed different C:F ratios is presented in Table 3. The DMI was highest in lambs fed the 60:40 C:F diet and lowest in those fed the 20:80 C:F diet, with the 40:60 C:F diet intermediate ($p < 0.05$). Final body weight was higher in lambs fed the 60:40 C:F diet than in those fed the 20:80 C:F diet ($p < 0.05$), whereas the 40:60 C:F diet did not differ from either.

Total weight gain and ADG were higher in lambs fed the 40:60 and 60:40 C:F diets than in those fed the 20:80 C:F diet ($p < 0.05$), and the two higher-concentrate diets did not differ from each other. ADG was calculated by dividing total weight gain by the 60-day data-collection period, so both variables have the same p-value. Feed conversion was best (lowest FCR) in lambs fed the 40:60 C:F diet (11.52), which differed from the 20:80 C:F diet (12.65; $p < 0.05$); the 60:40 C:F diet (12.25) was intermediate and did not differ from either.

Table 3
Effects of peanut hay inclusion at different concentrate to forage ratios on growth performance of Kooka lambs

Parameters	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet	SEM	p-value
	20:80	40:60	60:40		
[1]DMI (kg/day)	0.62[b]	0.68[ab]	0.76[a]	0.021	0.001
[2]Final BW (kg)	21.04[b]	21.44[ab]	21.92[a]	0.210	0.028
Total weight gain (kg)	2.94[b]	3.54[a]	3.72[a]	0.094	< 0.001
[3]ADG (kg/day)	0.049[b]	0.059[a]	0.062[a]	0.002	< 0.001
[4]FCR	12.65[a]	11.52[b]	12.25[ab]	0.267	0.024

Note. Means within a row with different superscript letters indicate significant differences among treatments ($p < 0.05$; Tukey's HSD test); SEM = pooled standard error of the mean ($n = 7$ lambs per treatment); [1]DMI = dry matter intake; [2]BW = body weight; [3]ADG = average daily gain; [4]FCR = feed conversion ratio

Ruminal Parameters

The effects of C:F ratio on ruminal fermentation characteristics are presented in Table 4. Rumen pH decreased with increasing concentrate inclusion and was highest in the 20:80, intermediate in the 40:60 and lowest in the 60:40 C:F diet ($p < 0.05$). Ruminal NH_3-N concentration was higher in lambs fed the 60:40 C:F diet (18.3 mg/dL) than in those fed the 20:80 C:F diet (11.0 mg/dL) ($p < 0.05$), with the 40:60 C:F diet (14.3 mg/dL) intermediate.

Table 4
Effects of peanut hay inclusion at different concentrate to forage ratios on rumen pH and ammonia nitrogen of Kooka lambs

Parameters	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet	SEM	p-value
	20:80	40:60	60:40		
Rumen pH	6.66[a]	6.37[b]	6.12[c]	0.064	0.003
Rumen NH_3-N (mg/dL)	11.0[b]	14.3[ab]	18.3[a]	1.225	0.016

Note. Means within a row with different superscript letters indicate significant differences among treatments ($p < 0.05$; Tukey's HSD test); SEM = pooled standard error of the mean (n = 3 lambs per treatment); NH_3-N = ammonia nitrogen

Immune Parameters

Plasma immunoglobulin concentrations are presented in Table 5. IgG concentration was lower in lambs fed the 60:40 C:F diet than in those fed the 20:80 and 40:60 C:F diets ($p < 0.05$), which did not differ from each other. IgA concentration decreased with increasing concentrate inclusion and was highest in the 20:80, intermediate in the 40:60 and lowest in the 60:40 C:F diet ($p < 0.05$).

IgM concentration was not significantly affected by dietary treatment ($p = 0.062$); the lower numerical value in the 60:40 C:F diet (1.6 vs. 1.9 g/L) was not statistically significant and is not interpreted as a treatment effect.

Table 5
Effects of peanut hay inclusion at different concentrate to forage ratios on immunity parameters of Kooka lambs

Immunoglobulin (g/L)	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet	SEM	p-value
	20:80	40:60	60:40		
IgG	18.5[a]	17.8[ab]	14.5[b]	0.581	0.006
IgM	1.9	1.9	1.6	0.081	0.062
IgA	3.0[a]	2.8[b]	2.4[c]	0.067	0.002

Note. Means within a row with different superscript letters indicate significant differences among treatments ($p < 0.05$; Tukey's HSD test); means without superscripts did not differ ($p > 0.05$); SEM = pooled standard error of the mean (n = 3 lambs per treatment); immunoglobulins were determined in plasma

Blood Biochemistry

Blood biochemistry parameters are presented in Table 6. Serum total protein was higher in lambs fed the 60:40 C:F diet (7.4 g/dL) than in those fed the 20:80 C:F diet (6.5 g/dL)

($p < 0.05$), with the 40:60 C:F diet (7.0 g/dL) intermediate. Cortisol concentration was higher in the 60:40 C:F diet (1.10 µg/dL) than in the 20:80 (1.05 µg/dL) and 40:60 (1.07 µg/dL) C:F diets ($p < 0.05$). Glucose ($p = 0.065$), cholesterol ($p = 0.098$), creatinine ($p = 0.073$), BUN ($p = 0.067$) and WBC counts ($p = 0.079$) did not differ significantly among treatments, and the numerical differences in these variables are not interpreted as treatment effects.

Table 6
Effects of peanut hay inclusion at different concentrate to forage ratios on blood biochemistry of Kooka lambs

Parameters	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet	SEM	p-value
	20:80	40:60	60:40		
Glucose (mg/dL)	63	59	65	1.446	0.065
Total Protein (g/dL)	6.5^{b}	7.0^{ab}	7.4^{a}	0.153	0.017
Cholesterol (mg/dL)	75	71	77	1.631	0.098
Creatinine (mg/dL)	1.6	1.5	1.4	0.049	0.073
[1]BUN (mg/dL)	15.9	16.1	16.4	0.120	0.067
[2]WBC ($\times 10^3/\mu L$)	7.9	8.3	8.5	0.153	0.079
Cortisol (µg/dL)	1.05^{b}	1.07^{ab}	1.10^{a}	0.010	0.033

Note. Means within a row with different superscript letters indicate significant differences among treatments ($p < 0.05$; Tukey's HSD test); means without superscripts did not differ ($p > 0.05$); SEM = pooled standard error of the mean ($n = 3$ lambs per treatment); [1]BUN = blood urea nitrogen; [2]WBC = white blood cells (determined in EDTA blood); other parameters were determined in serum

Behavioural Responses

Behavioural percentages are presented in Table 7. Values represent the percentage of scan-sampling intervals within the observation sessions in which each behaviour was recorded; the six categories are mutually exclusive and sum to 100% for each treatment. The proportion of intervals spent feeding was higher in lambs fed the 60:40 C:F diet (27.22%) than in those fed the 20:80 C:F diet (14.09%) ($p < 0.05$), with the 40:60 C:F diet intermediate. Standing was lower in the 60:40 C:F diet than in the 20:80 and 40:60 C:F diets, and locomotion and abnormal behaviour were lower in the 60:40 than in the 20:80 C:F diet ($p < 0.05$), with the 40:60 C:F diet intermediate. Rumination ($p = 0.061$) and resting ($p = 0.712$) did not differ significantly among treatments.

Table 7
Effects of peanut hay inclusion at different concentrate to forage ratios on behavioural parameters of the Kooka lambs

Behaviour (%)	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet	SEM	p-value
	20:80	40:60	60:40		
Rumination	18.13	15.32	13.75	1.225	0.061
Feeding	14.09[b]	20.31[ab]	27.22[a]	2.553	0.007
Resting	51.73	49.68	47.28	3.786	0.712
Standing	9.97[a]	9.21[a]	7.19[b]	0.446	0.001
Locomotion	2.93[a]	2.56[ab]	2.01[b]	0.180	0.007
Abnormal behaviour	3.15[a]	2.92[ab]	2.55[b]	0.106	0.003

Note. Means within a row with different superscript letters indicate significant differences among treatments ($p < 0.05$; Tukey's HSD test); means without superscripts did not differ ($p > 0.05$); SEM = pooled standard error of the mean (n = 7 lambs per treatment). Values are percentages of scan-sampling intervals within the observation sessions; the six behavioural categories are mutually exclusive and sum to 100%

Economic Analysis

The economic evaluation is presented in Table 8. The economic analysis showed that concentrate cost per lamb increased from PKR 744 in the 20:80 C:F diet to PKR 1,632 in the 40:60 and PKR 2,736 in the 60:40 C:F diet, whereas peanut hay cost decreased from PKR 1,190 to PKR 979.20 and PKR 729.60, respectively. Miscellaneous costs were similar among treatments (PKR 321-340). Consequently, total feed cost increased from PKR 1,934 (20:80) to PKR 2,611.20 (40:60) and PKR 3,465.60 (60:40), and total production cost increased from PKR 24,899 to PKR 25,307.20 and PKR 26,548.60, respectively. Feed cost per kg of weight gain was lowest in the 20:80 C:F diet (PKR 657.82) and highest in the 60:40 C:F diet (PKR 931.61). The estimated margin over feed cost was highest in the 40:60 C:F diet (PKR 1,990.80), followed by the 20:80 (PKR 1,888) and 60:40 (PKR 1,370.40) C:F diets. Similarly, the estimated net return over total production cost was highest in the 40:60 C:F diet (PKR 2,564.80), followed by the 20:80 (PKR 2,453) and 60:40 (PKR 1,947.40) C:F diets, and the benefit:cost ratios were 1.10, 1.10 and 1.07, respectively. Economic values were calculated from treatment means and were not analysed statistically.

Table 8
Economic evaluation of Kooka lambs fed different concentrate to forage ratios

Parameter (per lamb, PKR)	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet
	20:80	40:60	60:40
Production cost			
Purchasing cost of lamb[1]	22625	22375	22750

Table 8 (*continued*)

Parameter (per lamb, PKR)	Low-Concentrate Diet	Moderate Diet	High-Concentrate Diet
	20:80	**40:60**	**60:40**
Cost of concentrate	744	1632	2736
Cost of hay	1190	979.20	729.60
Miscellaneous	340	321	333
Total production cost	24899	25307.20	26548.60
Economic evaluation			
Total weight gain (kg)	2.94	3.54	3.72
Assumed live-weight price (PKR/kg)	1300	1300	1300
Estimated price of weight gain	3822	4602	4836
Total feed cost	1934	2611.20	3465.60
Feed cost per kg weight gain	657.82	737.63	931.61
Estimated margin over feed cost	1888	1990.80	1370.40
Final body weight (kg)	21.04	21.44	21.92
Estimated value of final live weight	27352	27872	28496
Estimated net return over total production cost	2453	2564.80	1947.40
Benefit:cost ratio	1.10	1.10	1.07

Note. Values are per lamb for the whole experimental period and are expressed in Pakistani rupees (PKR) unless otherwise stated. [1]Purchase price of the lamb at the start of the experiment (initial body weight × PKR 1,250/kg). Feed costs were calculated from the recorded DM intake of concentrate (PKR 100/kg DM) and peanut hay (PKR 40/kg DM) during the 60-day data-collection period, using average local market prices in Faisalabad during the study. Miscellaneous costs include veterinary care, bedding and utilities. Estimated value of weight gain = total weight gain × assumed live-weight price (PKR 1,300/kg); estimated margin over feed cost = estimated value of weight gain - total feed cost; estimated value of final live weight = final body weight × PKR 1,300/kg; estimated net return = estimated value of final live weight - total production cost; benefit:cost ratio = estimated value of final live weight / total production cost. Margin and net return exclude labour, housing and other fixed costs and are estimates, because the lambs were retained for further research and were not sold

DISCUSSION

Raising the proportion of concentrate in peanut hay-based diets increased DMI and final body weight in this study, and lambs on the 40:60 and 60:40 C:F diets gained more weight in total than those on the 20:80 C:F diet. Feed conversion was best on the 40:60 C:F diet. With more concentrate, rumen pH fell, and ruminal NH_3-N rose; plasma IgG and IgA declined, whereas serum total protein and cortisol increased. Lambs on the 60:40 C:F diet were seen feeding more often and standing, moving and performing oral manipulation less often. Under the assumed prices, the 40:60 C:F diet returned the highest estimated margin over feed cost.

Intake probably rose with concentrate inclusion because the concentrate-rich diets supplied more digestible energy and non-structural carbohydrate and less fibre (Haddad, 2005; Haddad & Ata, 2009). Calculated dietary NDF fell from 44.89% in the 20:80 C:F diet to 33.87% in the 60:40 C:F diet (Table 1). A high NDF content increases rumen fill and slows the passage of digesta, both of which limit voluntary intake (Allen, 2000), and this may account for the lower DMI on the 20:80 C:F diet.

Lambs fed the 60:40 C:F diet reached the highest final body weight, and total weight gain on both the 40:60 and 60:40 C:F diets exceeded that on the 20:80 C:F diet. Concentrate-rich diets supply more energy and more fermentable substrate for rumen microbes, which usually improves nutrient digestibility and growth (Liu et al., 2019b; Suárez et al., 2006). The extra gain cannot, however, be credited to energy or non-structural carbohydrate alone. The complete diets were not analysed, and dietary CP also rose from 13.00% to 16.48% as concentrate increased (Table 1), so the response more likely reflects the combined change in energy, protein and fibre that came with the change in C:F ratio. Indigenous goats reared under a high-input, concentrate-rich system have likewise grown faster (Akbar et al., 2024), and similar concentrate-based regimes are used in lamb fattening (Şengül, 2024). Daily gains of 49-62 g/day and FCR values of 11.52-12.65 are moderate. This fits the modest growth potential of indigenous small ruminants, whose body weight depends on breed, sex and age (Moaeen-ud-Din et al., 2024), and it also reflects the young age of the lambs and the low CP (13.00%) and TDN (53.62%) of the 20:80 C:F diet.

Feed conversion followed a different pattern from intake. FCR was lowest on the 40:60 C:F diet, and adding more concentrate did not improve it further. Haddad et al. (2001) similarly found that lambs used nutrients more efficiently with moderate than with high concentrate inclusion, which is in line with the diminishing returns expected from additional dietary energy (Tedeschi et al., 2015). The 40:60 C:F diet may have offered a better balance between fermentable energy and fibre. We did not measure physically effective fibre or ruminal nutrient degradability, though, so this explanation remains to be confirmed.

Rumen pH and NH_3-N concentration are the main indicators of the fermentation environment in the rumen (Liu et al., 2019a). Rumen pH fell from 6.66 to 6.12 as concentrate increased. This agrees with the rapid fermentation of non-fibre carbohydrates and the build-up of volatile fatty acids on high-grain diets (Plaizier et al., 2008), and with the shift towards amylolytic bacteria at the expense of fibrolytic microorganisms (Russell & Rychlik, 2001). Ruminal pH between 6.2 and 7.0 is generally regarded as favourable for normal fermentation (Zhang et al., 2013). All treatment means stayed above 6.0, the threshold commonly used to define subacute ruminal acidosis (Nocek, 1997). Rumen fluid was, however, collected by stomach tube only once, 2-3 h after the morning meal at the end of the experiment. Ruminal pH varies considerably through the day, and stomach-tube samples can be diluted by saliva. One measurement therefore cannot rule out subacute

ruminal acidosis during the trial, and a mean pH of 6.12 on the 60:40 C:F diet shows that the rumen was approaching the range in which fibre digestion may be impaired.

Ruminal NH_3-N comes from the breakdown of dietary protein and non-protein nitrogen and is the main nitrogen source for microbial protein synthesis (Van Soest, 1994). The rise in NH_3-N from 11.0 to 18.3 mg/dL with more concentrate is best explained by a larger supply of rumen-degradable nitrogen. Dietary CP increased from 13.00% to 16.48% (Table 1), and because the concentrate contained 0.75% urea, the intake of rapidly degradable non-protein nitrogen rose in step with concentrate inclusion. Work in goats has shown that energy supply needs to be matched with non-protein nitrogen and rumen-degradable protein to support intake, digestibility and performance (Ikram et al., 2025; Nghiep & Truong, 2024). Microbial protein synthesis and nitrogen use efficiency were not measured here, so the NH_3-N data cannot show whether microbial protein production increased or decreased.

Plasma IgG and IgA were highest on the 20:80 C:F diet and declined with increasing dietary concentrate inclusion, whereas IgM was not significantly affected ($p = 0.062$). These results show that circulating immunoglobulin concentrations differed among diets. On their own, they do not show a difference in overall immune competence, because the lambs were not given an immune challenge such as vaccination and we did not measure inflammatory markers or acute-phase proteins. Concentrate-rich feeding and the lower ruminal pH that accompanies it can change rumen and hindgut microbial communities and may promote inflammatory and immune-related responses (Yu et al., 2024; Plaizier et al., 2017). Metabolic imbalance and oxidative stress can also impair immune function in ruminants (Sordillo & Aitken, 2009). We cannot tell whether either mechanism operated here, since rumen pH was measured once and oxidative and inflammatory status were not assessed. The link between concentrate inclusion and lower IgG and IgA is therefore best seen as a possible relationship rather than an established mechanism. Immune function depends on a balanced nutrient supply (Calder, 2013), and because only three lambs per treatment were sampled at one time point, the immunoglobulin data need cautious interpretation.

Serum total protein increased with concentrate inclusion. The larger dietary protein supply and altered protein metabolism on the concentrate-rich diets (Van Soest, 1994) are a more likely cause than better immune status, especially as IgG and IgA, which belong to the serum globulin fraction, fell over the same range. Because albumin and globulin were not determined separately, we cannot say which fraction drove the change.

Cortisol is commonly used as a physiological indicator of stress in animals; however, its concentration may be influenced by several physiological and environmental factors (Baboo et al., 2024; Cuan et al., 2024; Ertaş Oğuz et al., 2024; Khan et al., 2024; Moberg, 2000). Lambs on the 60:40 C:F diet had higher cortisol than those on the 20:80 C:F diet, but the difference was small (1.10 vs. 1.05 µg/dL). Cortisol was measured only once, in three lambs per treatment, and it is also affected by handling, restraint, time of day and

the sampling procedure. This result is therefore not firm evidence of dietary stress, and its biological significance is uncertain.

Glucose, cholesterol, creatinine, BUN, and WBC counts did not differ significantly among treatments ($p > 0.05$), indicating that the diets did not affect these indicators. Sampelayo et al. (2007) likewise reported that dietary energy sources can alter metabolic profiles while values generally stay within physiological limits in healthy animals.

The C:F ratio changed some of the behavioural patterns of the lambs. The share of observation intervals spent ruminating fell from 18.13% to 13.75% as concentrate increased, but the difference was not significant ($p > 0.05$). Dietary fibre is the main stimulus for chewing and rumination (Beauchemin, 2018), and less fibre in the diet usually means less rumination (Allen, 2000; Dado & Allen, 1994; Zebeli et al., 2012). Calculated NDF dropped from 44.89% to 33.87% across the diets, but physically effective fibre and particle size were not measured, so rumination could not be related directly to effective fibre supply. Rumination percentages were also fairly low because behaviour was recorded only in two 2-h daytime sessions rather than over 24 h; they describe the activity budget during those sessions, not total daily rumination time.

Lambs on the 60:40 C:F diet were seen feeding in more of the observation intervals. We did not expect this, as forage-based diets normally take longer to eat. The timing of the sessions relative to feed delivery, or differences in meal patterns that we did not assess, may explain it. Diet composition and nutrient density are known to shape feeding patterns and daily activity budgets (Bikker et al., 2014; Phillips, 2008). The same lambs also stood and moved in fewer intervals; since foraging motivation and energy balance were not measured, no specific cause can be assigned to the lower locomotion. Non-nutritive oral manipulation was likewise recorded in fewer intervals on the 60:40 C:F diet. These findings describe changes in selected behaviours during the observation periods. They are not a full welfare assessment, which would require further behavioural, physiological and health-based indicators.

Total production cost per lamb rose from PKR 24,899 on the 20:80 C:F diet to PKR 26,548.60 on the 60:40 C:F diet, mainly because the extra concentrate cost more than was saved on hay. Feed makes up a large part of livestock production costs, and feeding more concentrate pays only if performance improves enough (Upton, 2004). A higher production cost is therefore not the same as lower profitability; what matters is whether the extra weight gain brings in enough revenue to cover the extra feed (Akram et al., 2024; Yimenu & Letta, 2024). Here, the 20:80 C:F diet had the lowest feed cost per kg of gain (PKR 657.82), but its smaller weight gain held back the estimated value of gain. The 40:60 C:F diet gave the highest estimated margin over feed cost (PKR 1,990.80) and the highest estimated net return over total production cost (PKR 2,564.80 per lamb). The 60:40 C:F diet produced the heaviest lambs but had the highest feed cost per kg of gain (PKR 931.61)

and the lowest estimated margin and net return. Earlier lamb studies report the same trade-off between growth and feed cost as concentrate inclusion increases (Haddad et al., 2001; Mahgoub et al., 2000). These economic figures are estimates. The lambs were kept for further research and not sold, so revenue was based on an assumed live-weight price of PKR 1,300/kg; feed prices were those of the local market at the time; and the margin over feed cost leaves out labour, housing and other fixed costs. Different live-weight or feed prices could change how the treatments rank.

Overall, no single C:F ratio was best for every response. Raising concentrate to 60% maximised intake and final body weight but lowered rumen pH, increased feed cost per kg of gain and gave the lowest estimated return. The 40:60 C:F ratio gave the best feed conversion and the highest estimated margin under the assumed prices, while the 20:80 C:F ratio gave the lowest feed cost per kg of gain and the highest IgG and IgA but the poorest growth. Some limitations should be kept in mind. Ruminal and blood parameters came from only three lambs per treatment at one time point. The treatments changed CP, NDF and energy concentration as well as the C:F ratio, and the composition of the complete diets was calculated rather than analysed. Physically effective fibre was not measured. Each treatment group was housed in a single pen, so pen and treatment effects cannot be separated. Finally, peanut hay was bought ready to use, so its stage of harvest was unknown, and the feeds were not analysed for aflatoxins.

CONCLUSION

In Kooka lambs fed peanut hay-based diets, raising the concentrate proportion from 20% to 60% of dietary dry matter increased DMI and final body weight, lowered rumen pH and raised ruminal NH_3-N. The 60:40 C:F ratio gave the highest final body weight but also the highest feed cost per kg of gain and the lowest estimated economic return, whereas the 40:60 C:F ratio gave the best feed conversion ratio and the highest estimated margin over feed cost under the assumed prices. Plasma IgG and IgA were highest with the 20:80 C:F ratio, IgM was unaffected, and serum total protein and cortisol increased with concentrate inclusion; the dietary treatments also altered selected behavioural patterns, including feeding, standing, locomotion and oral manipulation behaviours. Because different variables favoured different ratios, the choice of C:F ratio should depend on the production goal and on current feed and live-weight prices. Under the conditions of this study, a 40:60 C:F ratio may be a practical compromise between feed efficiency and economic return. Potential implications for animal welfare and for the sustainability of lamb production were not evaluated and require further investigation, and the physiological and immunological findings should be confirmed in larger studies with repeated sampling.

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INSTITUTIONAL REVIEW BOARD STATEMENT

The experimental protocol was reviewed and approved by the Directorate of Graduate Studies, University of Agriculture Faisalabad, Pakistan, under approval/reference No. DGS 5189-92.

DATA AVAILABILITY STATEMENT

Data can be obtained from the corresponding author upon request.

CONFLICTS OF INTEREST

The authors have declared no conflict of interest. Support for the research was provided by Sind Feed and Allied Products (Pvt.) Ltd., which had no role in the design of the study, data collection, analysis, data interpretation, and decision to publish the manuscript.

REFERENCES

Akbar, J., Ishaq, K., Ahmed, T., Yousaf, A., Shaiq, P. A., Abdullah, S. S., & Javed, I. (2024). Influence of castration age and various ear implants on growth performance of Beetal goats reared under high input feeding system. *Pakistan Journal of Agricultural Sciences, 61*(1), 223-231. https://doi.org/10.53555/v64xts83

Akram, A., Mehmood, S., Manzoor, S., Bölükbaş, B., & Qaisrani, S. N. (2024). Comparative efficacy and economic appraisal of different feeds in sexed broilers. *Applied Animal Science Bulletin, 1*(1), 23-28. https://doi.org/10.22194/AASB/24.1003

Aksel, E., Çelik Gürbulak, E., Abay, M., & Demiral, Ö. O. (2024). Determination of the effect of GDF9, BMP15, BMPR1B gene polymorphism, and environmental factors for fecundity by logistic regression analysis in Kangal Akkaraman sheep. *Kafkas Universitesi Veteriner Fakultesi Dergisi, 30*(4), 497-506. https://doi.org/10.9775/kvfd.2024.31761

Allen, M. S. (2000). Effects of diet on short-term regulation of feed intake by lactating dairy cattle. *Journal of Dairy Science, 83*(7), 1598-1624. https://doi.org/10.3168/jds.S0022-0302(00)75030-2

Asuquo, I., Agbachom, E., & Ettah, O. (2024). Analyzing the dynamics of groundnut production and marketing in Cross River State, Nigeria. *Journal of Global Innovations in Agricultural Sciences, 12*, 411-416. https://doi.org/10.22194/JGIAS/24.1208

Aziz ur Rahman, M., Chuanqi, X., Huawei, S., & Binghai, C. (2017). Effects of hay grass level and its physical form (full length vs. chopped) on standing time, drinking time, and social behaviour of calves. *Journal of Veterinary Behavior, 21*, 7-12. https://doi.org/10.1016/j.jveb.2017.06.004

Baboo, A. S. A., Naeem, M., Behan, A. A., & Rajput, N. (2024). Serum cortisol concentration is a reliable tool to assess stress level among stereotypic and non-stereotypic Thoroughbred horses. *Pakistan Veterinary Journal, 44*(1), 155-161. https://doi.org/10.29261/pakvetj/2023.115

Balehegn, M., Ayantunde, A., Amole, T., Njarui, D., Nkosi, B. D., Müller, F. L., Meeske, R., Tjelele, T. J., Malebana, I. M., Madibela, O. R., & Boitumelo, W. S. (2022). Forage conservation in sub-Saharan Africa: Review of experiences, challenges, and opportunities. *Agronomy Journal, 114*(1), 75-99. https://doi.org/10.1002/agj2.20954

Barham, G. S., Baloch, M. H., Nizamani, A. H., Khaskheli, M., Khaskheli, G., Pirzado, S. A., Magsi, A. S., Soomro, H., & Fazilani, S. (2013). Effect of management systems on growth and conformation of male lambs of Kachhi and Kooka sheep. *International Journal of Plant and Animal Sciences, 1*(6), 64-69.

Beauchemin, K. A. (2018). Invited review: Current perspectives on eating and rumination activity in dairy cows. *Journal of Dairy Science, 101*(6), 4762-4784. https://doi.org/10.3168/jds.2017-13706

Bikker, J. P., van Laar, H., Rump, P., Doorenbos, J., van Meurs, K., Griffioen, G. M., & Dijkstra, J. (2014). Evaluation of an ear-attached movement sensor to record cow feeding behaviour and activity. *Journal of Dairy Science, 97*(5), 2974-2979. https://doi.org/10.3168/jds.2013-7560

Boudalia, S., Smeti, S., Dawit, M., Senbeta, E. K., Gueroui, Y., Dotas, V., Bousbia, A., & Symeon, G. K. (2024). Alternative approaches to feeding small ruminants and their potential benefits. *Animals, 14*(6), Article 904. https://doi.org/10.3390/ani14060904

Calder, P. C. (2013). Feeding the immune system. *Proceedings of the Nutrition Society, 72*(3), 299-309. https://doi.org/10.1017/S0029665113001286

Cartoni Mancinelli, A., Trocino, A., Menchetti, L., Chiattelli, D., Ciarelli, C., & Castellini, C. (2023). New approaches to selecting a scan-sampling method for chicken behavioural observations and their practical implications. *Scientific Reports, 13*(1), Article 17177. https://doi.org/10.1038/s41598-023-44126-2

Chase, L. E., & Fortina, R. (2023). Environmental and economic responses to precision feed management in dairy cattle diets. *Agriculture, 13*(5), Article 1032. https://doi.org/10.3390/agriculture13051032

Chen, H., Wang, C., Huasai, S., & Chen, A. (2021). Effects of dietary forage to concentrate ratio on nutrient digestibility, ruminal fermentation and rumen bacterial composition in Angus cows. *Scientific Reports, 11*(1), Article 17023. https://doi.org/10.1038/s41598-021-96580-5

Chishti, M. F. A., Rahman, M. A. U., Jatta, K., Khan, S., Riaz, M., Bilal, Q., Anwar, U., Ahmad, S., Bajwa, H. M., & Rasul, F. (2022). Effect of forage to concentrate ratio on growth performance and feeding behaviour of Thalli lambs. *Tropical Animal Health and Production, 54*(4), Article 236. https://doi.org/10.1007/s11250-022-03226-3

Chishti, M. F. A., Rahman, M. A. U., Rehman, M. S. U., & Bilal, M. Q. (2024). Chemical composition and *in-situ* digestion kinetics of nutritionally enriched straw from genetically improved wheat varieties. *Pakistan Journal of Agricultural Sciences, 61*(2), 671-684. https://psa.pastic.gov.pk/article/179183/chemical-composition-and-in-situ-digestion-kinetics-of-nutritionally-enriched

Cuan, J., Wu, C., Zheng, F., Lu, X., & Waqas, M. U. (2024). Sevoflurane pretreatment enhances myocardial ischemia-reperfusion injury via activating HIF-1α/iNOS/cGMP to inhibit endoplasmic reticulum stress. *Pakistan Veterinary Journal, 44*, 785-793. https://doi.org/10.29261/pakvetj/2024.257

Dado, R. G., & Allen, M. S. (1994). Variation in and relationships among feeding, chewing, and drinking variables for lactating dairy cows. *Journal of Dairy Science, 77*(1), 132-144. https://doi.org/10.3168/jds.S0022-0302(94)76936-8

Demir, E. (2024). Genomic diversity and autozygosity-based signatures of selection in Kangal Akkaraman sheep via genotyping-by-sequencing. *Kafkas Universitesi Veteriner Fakultesi Dergisi, 30*(5), 669-675. https://doi.org/10.9775/kvfd.2024.32339

Devendra, C. (2016). Animal-agricultural systems in Asia: Enhanced impacts and rural prosperity. *International Journal of Dairy Processing & Research, 3*(3), 47-65. https://doi.org/10.19070/2379-1578-1600012

Duffield, T., Plaizier, J. C., Fairfield, A., Bagg, R., Vessie, G., Dick, P., Wilson, J., Aramini, J., & McBride, B. (2004). Comparison of techniques for measurement of rumen pH in lactating dairy cows. *Journal of Dairy Science, 87*(1), 59-66. https://doi.org/10.3168/jds.S0022-0302(04)73142-2

Dzulqaidah, A. M. A., Islamiyati, R., & Nadir, M. (2026). Impact of eco-enzyme application on nutrient intake, fiber composition, and feed digestibility in PE goats using agro-industrial waste-based complementary feed. *Journal of Global Innovations in Agricultural Sciences, 14*, 169-174. https://doi.org/10.22194/JGIAS/26.1691

Ertaş Oğuz, F., Babaoğlu, A., Türkan, F., Oğuz, E., Demirel, A., & Paçal, N. (2024). Investigation of interleukins and oxidative stress parameters in cows naturally infected with bovine viral diarrhea virus. *Pakistan Veterinary Journal, 44*(3), 924-930. https://doi.org/10.29261/pakvetj/2024.256

Fenner, H. (1965). Method for determining total volatile bases in rumen fluid by steam distillation. *Journal of Dairy Science, 48*, 249-251. https://doi.org/10.3168/jds.S0022-0302(65)88206-6

Gifford, C. L. (2016). *Complete nutrient analysis of grain-finished and grass-finished lamb cuts* [Master's thesis, Colorado State University]. Mountain Scholar. https://mountainscholar.org/handle/10217/173540

Gjorgjievski, S., Nakov, D., Kuzelov, A., Todorovska, T., Ilieva, F., & Vanevska, K. (2022). Feeding of lambs with improved pelleted feed. *Journal of Agriculture and Plant Sciences, 20*(2), 23-29. https://doi.org/10.46763/JAPS22202023gj

Government of Pakistan. (2025). *Agricultural statistics of Pakistan 2023-24*. Economic Wing, Ministry of National Food Security and Research. https://mnfsr.gov.pk/SiteImage/Publication/ASP%20for%20Web%202024.pdf

Haddad, S. G. (2005). Effect of dietary forage: Concentrate ratio on growth performance and carcass characteristics of growing Baladi kids. *Small Ruminant Research, 57*(1), 43-49. https://doi.org/10.1016/j.smallrumres.2004.05.001

Haddad, S. G., & Ata, M. (2009). Growth performance of lambs fed on diets varying in concentrate and wheat straw. *Small Ruminant Research, 81*, 96-99. https://doi.org/10.1016/j.smallrumres.2008.11.015

Haddad, S. G., Nasr, R. E., & Muwalla, M. M. (2001). Optimum dietary crude protein level for finishing Awassi lambs. *Small Ruminant Research, 39*(1), 41-46. https://doi.org/10.1016/S0921-4488(00)00172-3

Herath, H. M., Pain, S. J., Kenyon, P. R., Blair, H. T., & Morel, P. C. (2021). Growth and body composition of artificially reared lambs exposed to three different rearing regimens. *Animals, 11*(12), Article 3370. https://doi.org/10.3390/ani11123370

Hill, G. M. (2002). Peanut by-products fed to cattle. *Veterinary Clinics of North America: Food Animal Practice, 18*(2), 295-315. https://doi.org/10.1016/S0749-0720(02)00019-1

Ikram, M., Sharif, M., Nawaz, H., & Bilal, M. Q. (2025). Effects of rumen-degradable protein concentrations on blood haematology, meat composition, and organoleptic properties in male Beetal kids. *Applied Animal Science Bulletin, 2*(2), 67-73. https://doi.org/10.22194/AASB/25.1014

Khan, M. T., Khan, N. A., Bezabih, M., Qureshi, M. S., & Rahman, A. (2013). The nutritional value of peanut hay (*Arachis hypogaea* L.) as an alternate forage source for sheep. *Tropical Animal Health and Production, 45*(3), 849-853. https://doi.org/10.1007/s11250-012-0297-8

Khan, N., Habib, G., & Ullah, G. (2009). Chemical composition, rumen degradability, protein utilisation and lactation response to selected tree leaves as substitute of cottonseed cake in the diet of dairy goats. *Animal Feed Science and Technology, 154*(3-4), 160-168. https://doi.org/10.1016/j.anifeedsci.2009.08.011

Khan, N. A., & Habib, G. (2012). Assessment of *Grewia oppositifolia* leaves as crude protein supplement to low-quality forage diets of sheep. *Tropical Animal Health and Production, 44*(7), 1375-1381. https://doi.org/10.1007/s11250-012-0074-8

Khan, S. R., Iqbal, R., Hussain, R., Ali, M., Khalid, M., Nazish, N., & Naqvi, S. S. (2024). Broccoli partially lowers oxidative stress, histopathological lesions and enhances antioxidant profile of mono sex tilapia exposed to zinc oxide nanoparticles. *Pakistan Veterinary Journal, 44*(2), 306-313. https://doi.org/10.29261/pakvetj/2024.159

Latimer, G. W., Jr. (Ed.). (2019). *Official methods of analysis of AOAC INTERNATIONAL* (21st ed.). AOAC International.

Liu, H., Xu, T., Xu, S., Ma, L., Han, X., Wang, X., Zhang, X., Hu, L., Zhao, N., Chen, Y., & Pi, L. (2019a). Effect of dietary concentrate to forage ratio on growth performance, rumen fermentation and bacterial diversity of Tibetan sheep under barn feeding on the Qinghai-Tibetan plateau. *PeerJ, 7*, Article e7462. https://doi.org/10.7717/peerj.7462

Liu, C., Wu, H., Liu, S., Chai, S., Meng, Q., & Zhou, Z. (2019b). Dynamic alterations in yak rumen bacteria community and metabolome characteristics in response to feed type. *Frontiers in Microbiology, 10*, Article 1116. https://doi.org/10.3389/fmicb.2019.01116

Mahgoub, O., Lu, C. D., & Early, R. J. (2000). Effects of dietary energy density on feed intake, body weight gain and carcass chemical composition of Omani growing lambs. *Small Ruminant Research, 37*(1-2), 35-42. https://doi.org/10.1016/S0921-4488(99)00132-7

Moaeen-ud-Din, M., Muner, R. D., Khan, M. S., & Reecy, J. M. (2024). Effect of breed, sex and age on body weight and linear body measurements in Punjab goat breeds. *Pakistan Journal of Agricultural Sciences, 61*(1), 243-250. https://share.google/oXaq9ENSZuhumObPT

Moberg, G. P. (2000). Biological response to stress: Implications for animal welfare. In G. P. Moberg & J. A. Mench (Eds.), *The biology of animal stress: Basic principles and implications for animal welfare* (pp. 1-21). CABI Publishing. https://doi.org/10.1079/9780851993591.0001

Montgomery, D. C. (2017). *Design and analysis of experiments* (9th ed.). John Wiley & Sons.

Myer, R. O., & Hersom, M. (2011). *Alternative feeds for beef cattle* (AN128). UF/IFAS Extension, University of Florida. https://edis.ifas.ufl.edu/publication/AN128

National Research Council. (2007). *Nutrient requirements of small ruminants: Sheep, goats, cervids, and New World camelids*. National Academies Press.

Nel, C. L., van der Werf, J. H., Rauw, W. M., & Cloete, S. W. (2023). Challenges and strategies for genetic selection of sheep better adapted to harsh environments. *Animal Frontiers, 13*(5), 43-52. https://doi.org/10.1093/af/vfad055

Nghiep, H. X., & Truong, N. B. (2024). Effects of energy feed combinations and non-protein nitrogen on feed intake and nutrient digestibility in Saanen crossbred goats. *Journal of Global Innovations in Agricultural Sciences, 12*, 1171-1177. https://doi.org/10.22194/JGIAS/24.1535

Nocek, J. E. (1997). Bovine acidosis: Implications on laminitis. *Journal of Dairy Science, 80*(5), 1005-1028. https://doi.org/10.3168/jds.S0022-0302(97)76026-0

Phillips, C. (2008). *Cattle behaviour and welfare*. John Wiley & Sons. https://doi.org/10.1002/9780470752418

Plaizier, J. C., Krause, D. O., Gozho, G. N., & McBride, B. W. (2008). Subacute ruminal acidosis in dairy cows: The physiological causes, incidence and consequences. *The Veterinary Journal, 176*(1), 21-31. https://doi.org/10.1016/j.tvjl.2007.12.016

Plaizier, J. C., Li, S., Tun, H. M., & Khafipour, E. (2017). Nutritional models of experimentally induced subacute ruminal acidosis differ in their impact on rumen and hindgut bacterial communities in dairy cows. *Frontiers in Microbiology, 7*, Article 2128. https://doi.org/10.3389/fmicb.2016.02128

Qi, H. D., Ye, C. F., Nan, Y., Xie, M. T., Jiang, B. H., Abulizi, N., & Zhao, Z. S. (2024). Effect of dietary glycerol addition on growth performance, serum biochemical indexes, carcass traits, fat deposition, and meat quality in fattening period Kazakh sheep. *Kafkas Üniversitesi Veteriner Fakültesi Dergisi, 30*(2), 275-282. https://doi.org/10.9775/kvfd.2023.31020

Ramadani, R. A., Natsir, A., Ismartoyo, Syahrir, S., Islamiyati, R., & Rinduwati. (2025). Balancing forage and legumes: Impact on goat feed intake and nutrient digestibility. *Journal of Global Innovations in Agricultural Sciences, 13*, 965-973. https://doi.org/10.22194/JGIAS/25.1641

Ramírez-Restrepo, C., & Barry, T. N. (2005). Alternative temperate forages containing secondary compounds for improving sustainable productivity in grazing ruminants. *Animal Feed Science and Technology, 120*(3-4), 179-201. https://doi.org/10.1016/j.anifeedsci.2005.01.010

Ramos-Morales, E., Arco-Pérez, A., Martín-García, A. I., Yáñez-Ruiz, D. R., Frutos, P., & Hervás, G. (2014). Use of stomach tubing as an alternative to rumen cannulation to study ruminal fermentation and microbiota in sheep and goats. *Animal Feed Science and Technology, 198*, 57-66. https://doi.org/10.1016/j.anifeedsci.2014.09.016

Rehman, M. A. U., & Zulfiqar, Z. (2024). Techniques for evaluating the nutritional profile and digestibility of animal feedstuffs by different laboratory methods. *Applied Animal Science Bulletin, 1*(1), 1-10. https://doi.org/10.22194/AASB/24.1001

Rivera, S. A. G., Salinas, K. F. G., Guaraca, A. C. G., Herrera, T. E. S., Cevallos, M. A. R., Lliquin, J. D. C., Guadalupe, C. S. A., & Mancero, F. J. O. (2025). Effect of diatomaceous earth supplementation and *Curcuma longa* as toxin binder on mitigating aflatoxin B1 toxicity in concentrate feed. *Journal of Global Innovations in Agricultural Sciences, 13*, 1237-1243. https://doi.org/10.22194/JGIAS/25.1804

Russell, J. B., & Rychlik, J. L. (2001). Factors that alter rumen microbial ecology. *Science, 292*(5519), 1119-1122. https://doi.org/10.1126/science.1058830

Samad, A., Muazzam, A., Alam, A. N., Hwang, Y. H., & Joo, S. T. (2025). Comprehensive review on tackling antibiotic resistance in traditional meat via innovative alternative meat solutions. *Pakistan Veterinary Journal, 45*(3), 1020-1028. https://doi.org/10.29261/pakvetj/2025.222

Sampelayo, M. S., Chilliard, Y., Schmidely, P., & Boza, J. (2007). Influence of type of diet on the fat constituents of goat and sheep milk. *Small Ruminant Research, 68*(1-2), 42-63. https://doi.org/10.1016/j.smallrumres.2006.09.017

Sarwar, M. K., Haq, I. U., Ijaz, S., Javed, N., & Akbar, N. (2024). Molecular and analytical approaches based characterization of aflatoxins producing *Aspergillus* species affecting groundnut. *Pakistan Journal of Agricultural Sciences, 61*(3), 931-940. https://psa.pastic.gov.pk/article/179208/molecular-and-analytical-approaches-based-characterization-of-aflatoxins

Şengül, Ö. (2024). The effects of apple cider vinegar given with drinking water to fattening lambs on carcass characteristics. *Pakistan Journal of Agricultural Sciences, 61*(3), 715-723.

Shah, M. H., Chishti, M. F. A., Anwar, U., Abbas, W., Mustafa, R., Farooq, U., Ramzan, F., Khalid, M. F., Rahman, M. A. U., Riaz, M., & Bilal, M. Q. (2024). Evaluation of chemical composition and in-situ digestion kinetics of industrial hemp silage and hay. *Pakistan Journal of Agricultural Sciences, 61*(3), 941-946. https://share.google/GHr0ZVXyX4TIxr30Z

Song, H., Huang, Y., Ding, L., Duan, Z., & Zhang, J. (2023). *Arachis* species: High-quality forage crops—Nutritional properties and breeding strategies to expand their utilisation and feeding value. *Grassland Research, 2*(3), 212-219. https://doi.org/10.1002/glr2.12059

Sordillo, L. M., & Aitken, S. L. (2009). Impact of oxidative stress on the health and immune function of dairy cattle. *Veterinary Immunology and Immunopathology, 128*(1-3), 104-109. https://doi.org/10.1016/j.vetimm.2008.10.305

Souza, N. K. P., Detmann, E., Valadares Filho, S. C., Costa, V. A. C., Pina, D. S., Gomes, D. I., Queiroz, A. C., & Mantovani, H. C. (2013). Accuracy of the estimates of ammonia concentration in rumen fluid using different analytical methods. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 65*(6), 1752-1758. https://doi.org/10.1590/S0102-09352013000600024

Subhopoto, M., Naeem, M., Behan, A. A., Tunio, S. A., Rajput, N., Shahani, F., & Subhopoto, A. (2024). Effects of probiotic supplementation on growth and body conformation of goat kids raised under different management systems. *Applied Animal Science Bulletin, 1*(2), 83-88. https://doi.org/10.22194/AASB/24.2006

Tedeschi, L. O., Muir, J. P., Riley, D. G., & Fox, D. G. (2015). The role of ruminant animals in sustainable livestock intensification programs. *International Journal of Sustainable Development & World Ecology, 22*(5), 452-465. https://doi.org/10.1080/13504509.2015.1075441

Upton, M. (2004). *The role of livestock in economic development and poverty reduction*. Food and Agriculture Organization of the United Nations.

Van Soest, P. J. (1994). *Nutritional ecology of the ruminant* (2nd ed.). Cornell University Press. https://doi.org/10.7591/9781501732355

Ward, M., & Gifford, C. (2017). *Sheep nutrition*. New Mexico State University.

Waters, K. M., Black, T. E., Mercadante, V. R. G., Marquezini, G. H. L., DiLorenzo, N., Myer, R. O., Adesogan, A. T., & Lamb, G. C. (2015). Effects of feeding perennial peanut hay on growth, development, attainment of puberty, and fertility in beef replacement heifers. *The Professional Animal Scientist, 31*(1), 40-49. https://doi.org/10.15232/pas.2014-01332

Yimenu, S. A., & Letta, M. U. (2024). The effects of concentrate supplement levels on feed utilisation and red meat production of Blackhead Somali sheep fed natural pasture grass hay as a basal diet. *Veterinary Medicine and Science, 10*(6), Article e70073. https://doi.org/10.1002/vms3.70073

Yu, H. Y., Gao, D. M., Du, J., Su, Y., & Zhao, J. (2024). Recombinant porcine interferon alpha enhances the humoral and cellular immune responses to porcine transmissible gastroenteritis virus inactivated vaccine in piglets. *Kafkas Universitesi Veteriner Fakultesi Dergisi, 30*(5), 641-651. https://doi.org/10.9775/kvfd.2024.32122

Zebeli, Q., Aschenbach, J. R., Tafaj, M., Boguhn, J., Ametaj, B. N., & Drochner, W. (2012). Invited review: Role of physically effective fiber and estimation of dietary fiber adequacy in high-producing dairy cattle. *Journal of Dairy Science, 95*(3), 1041-1056. https://doi.org/10.3168/jds.2011-4421

Zhang, T., Zhuang, S., Dong, W. C., Chang, G. J., Yan, R., & Wang, T. (2013). Effects of different dietary concentrate to forage ratios on rumen fluid pH and VFA levels and blood VFA levels in dairy goats. *Animal Husbandry and Veterinary Medicine, 4*, 5-10.

Zhong, R. Z., Yu, M., Liu, H. W., Sun, H. X., Cao, Y., & Zhou, D. W. (2012). Effects of dietary *Astragalus* polysaccharide and *Astragalus membranaceus* root supplementation on growth performance, rumen fermentation, immune responses, and antioxidant status of lambs. *Animal Feed Science and Technology, 174*(1-2), 60-67. https://doi.org/10.1016/j.anifeedsci.2012.02.013