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OPTIMIZING LOW-QUALITY FORAGES WITH BARLEY GRAIN OR SOYBEAN MEAL FOR LAMBS: IMPLICATIONS FOR GROWTH PERFORMANCE

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ABSTRACT

This study aimed to assess the impact of supplementing Awassi lambs fed low-quality forage with barley grain (BAR) or soybean meal (SBM) on growth performance. Twenty-four lambs were randomly assigned to the three different diets: 0 g BAR or SBM (CON; n=8), 300 g BAR /head /day (BAR; n=8), or 300 g SBM/head/day (SBM; n=8) of the basal diet. The experiment included a 70-day growth period (10 days of pen adaptation and 60 days of feeding), followed by a 10-day digestibility period (5 days of metabolic cage acclimatization and 5 days of data collection). Forage intake was greater (P<0.002) in the group supplemented with SBM than in the other diets. The SBM-containing diets had the highest dry matter (DM) and crude protein (CP) intake and digestibility, followed by the BAR-containing diet, then the CON diet. Lambs fed the SBM diet had higher intake and digestibility of neutral detergent fiber (NDF) and acid detergent fiber (ADF) than those fed BAR or CON diets. SBM supplementation significantly improved nitrogen balance. Lambs fed the SBM diet showed the greatest growth performance, followed by those fed the BAR diet, whereas the CON diet resulted in the lowest growth performance (P<0.0001). The interaction between diet and sampling time significantly affected rumen fluid pH (P<0.0001). In conclusion, supplementing low-quality forage with barley grain or soybean meal improved nutrient intake, digestibility, and growth performance, with soybean meal producing greater responses than barley grain under the conditions of this experiment.

***Keywords*:** Barley grain, Growth performance, Digestibility, Intake, Soybean meal.

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1. INTRODUCTION

In Jordan, sheep farming is a paramount activity because it helps safeguard the livelihoods and food security of rural households (Al-Barakeh et al., 2024). Jordan's predominant sheep breed, Awassi, is an important genetic resource for the country's small-ruminant industry (Al-Atiyat et al., 2026). It is well-recognized for its capacity to adapt to harsh environmental conditions. However, sheep farming grapples with severe challenges, including feed and range limitations (Al-Khaza'leh et al., 2015). In Jordan, natural rangelands and pastures, especially in the arid and semi-arid regions, have been degraded due to harsh climate conditions that are exacerbated by climate change, resulting in a persistent forage shortage, decline in forage quality throughout the year, and consequently leading to an animal nutritional imbalance (Al-Tabini et al., 2012; Abdul-Jalil et al., 2024).

Forages are the most common type of feed used in most ruminant livestock operations. In the tropics, during dry seasons, ruminants are fed forages with low feeding value, which consequently leads to low productivity and loss of liveweight (Mwangi et al., 2024). Forages low in crude protein and energy, such as wheat straw, need protein- and energy-rich supplement feedstuffs to improve nitrogen efficiency, optimize nutrient intake, and increase ration digestibility. Therefore, supplementing with energy and/or protein, the two major nutrients in animal feeding, has become necessary to sustain these animals and maintain a desired level of performance. A higher, synchronized release of energy and nitrogen in the rumen promotes the synthesis of microbial proteins and fatty acids, improving microbial nutrient assimilation and increasing feed intake, digestibility, and N utilization (Bošnjak et al., 2025). Plant type, maturation stage, and management techniques all affect forages' quality parameters, including DM digestibility, CP, and palatability (Bohnert et al., 2011). Low-quality forages are characterized by low crude protein content (< %7-8%) (Bohnert et al., 2011; Obeidat et al., 2020), high concentrations of fibre and lignin (Mwangi et al., 2024), low digestibility, low content of soluble sugars and starch, and large contents of crop residues or natural pastures (Obeidat et al., 2020). Because they are less expensive, low-

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quality forages could be used as an alternate feed source. Predicting performance responses to supplementary protein requires accounting for the forage's CP concentration, digestibility, stage- and production-specific requirements, and other limiting nutrients (DelCurto et al., 2000). Ramos et al. (2019)reported that the productive potential of lambs fed only on native pastures was not expressed, while supplementation of energy and protein improved growth performance.

Diet primarily influences the composition and functional characteristics of the ruminal microbiome (Carberry et al., 2012). Protein and energy levels are the main dietary factors influencing ruminant growth, rumen development, and ruminal microbiota fermentation (Li et al., 2019; Lv et al., 2020). Soybean meal is commonly used as a protein-rich supplement, whereas barley grain is primarily used as an energy-rich, starch-containing supplement in ruminant diets. Because of its high availability, amino acid balance, palatability, nutritional value (energy and crude protein content), and digestibility, soybean meal is regarded as the primary protein source used by livestock worldwide (Obeidat et al., 2010; Obeidat et al., 2019; Hassan et al., 2024). Soybean variety, origin, growing conditions, year of harvest, amino acid profile, and processing conditions are major factors affecting SBM composition and nutritional value (Grieshop et al., 2003; Aguirre et al., 2024; Oviedo-Rondón et al., 2024). According to Chegini et al. (2019), SBM is an efficient dietary protein source for lambs fed low-quality forage such as wheat straw. Nevertheless, using large amounts of SBM in ruminant diets is not economical. Hassan et al. (2024) found that a small supplementation of SBM (33-66g/kg DM) can still improve the economic return of growing lambs. Obeidat et al. (2020) reported that supplementing lambs with a small amount of soybean meal (125-250g/head/day) improved the utilization of low-quality forages, nutrient digestibility, and growth performance. Soybean meal usually degrades rapidly in the rumen, and its degradability is influenced by feed processing, dietary ingredients, and animal variation (Dabiri & Thonney, 2004). According to Ross et al. (2024), body weight, average daily gain, feed efficiency, and protein deposition improved in finishing beef steers when dietary rumen-degradable protein was increased with soybean meal supplementation. A study by Hassan et al. (2024), reported that the diet containing soybean meal had a greater percentage of crude protein (CP) than the alternative protein source, which helped growing lambs utilize nutrients more effectively and maintain normal rumen fermentation processes.

Due to their high energy content, which promotes high milk production or rapid growth rates, cereal grains (e.g., barley) have constituted a significant part of ruminant diets in many countries (Ahmadi et al., 2022). For ruminants, barley grains (barley) are efficient energy supplements that have highly digestible protein and readily available starch, which accelerates fermentation rate, resulting in high ruminal starch digestibility (Nikkhah, 2012; Bošnjak et al., 2025). A study by Al-Lataifeh et al. (2024) found that the feed intake, average daily gain, nutrient digestibility, and N retention were improved in lambs when fed a diet containing ground Barley grain. According to the study by Bošnjak et al. (2025), supplementing barley to an alfalfa-based diet is more beneficial in improving crude protein digestibility, nitrogen retention, and nutrient utilization and, in turn, sustainability in sheep nutrition than supplementing corn.

The hypothesis was that supplementing low-quality forages with SBM or BAR would improve forage intake and utilization, nutrient digestibility, and N balance, as well as growth performance in lambs, compared with non-supplemented low-quality forages. Despite research evaluating the effects of supplementing diets with protein or energy sources, information on the comparative supplementation of low-quality forages with barley grain or soybean meal in small ruminants is limited. Therefore, this study aimed to compare the effects of supplementing low-quality forage with 300 g/head/day of soybean meal or barley grain on performance, nutrient intake and digestibility, nitrogen balance, and rumen pH in Awassi lambs. The results are expected to highlight the importance of implementing strategic supplementation with protein and energy sources to promote sustainable feeding practices in resource-limited settings.

2. MATERIALS AND METHODS

Study procedures and animal care methods followed the guidelines of the Institutional Animal Care and Use Committee at Jordan University of Science and Technology (JUST). The experimental period was divided into trial 1 (growth period) and trial 2 (digestible period).

2.1. Growth Period

Twenty-four male Awassi lambs (29.3 ± 1.17 kg of body weight; 5-6 months of age) were used in a completely randomized design. All lambs were fed low-quality forage consisting of a mix of 70% wheat straw and 30% Alfalfa hay and were supplemented with the basal diet per head. The lambs were randomly assigned to three dietary treatments: (1) control with no supplemental barley grain or soybean meal (CON; n = 8), (2) 300 g barley grain per head per day (BAR; n = 8), and (3) 300 g soybean meal per head per day (SBM; n = 8). The inclusion rate was chosen to provide sufficient quantities of the test ingredient to assess its nutritional, biological, and economic effects while maintaining the diet's nutritional balance. The composition of the forage mix was 931, 65.5, 620.1, and 319.3 g/kg of

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dietary dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF), respectively. Following AOAC (1990) procedures, dry matter (DM) was determined by oven drying at 100°C, and crude protein (CP) was measured using the Kjeldahl method (N × 6.25). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were assessed using the Van Soest (1991) ANKOM 2000 procedure.

The growth study consisted of a 10-day adaptation period followed by a 60-day experimental feeding period. Lambs were housed individually in separate pens (1.5 x 0.75 m) and were adapted to the pens for 10 days before the study began. The test feeding period lasted 60 days. The lambs were fed *ad libitum* daily at 8:30 a.m. to assess nutrient intake. Fresh water was available *ad libitum* throughout the study period. Refusals were recorded daily. To record average daily gain (ADG), lambs' body weights were measured before feeding at the start of the study and biweekly thereafter until the end of the experimental period.

2.2. Digestible Period

A 10-day digestible period (5 days for adaptation and 5 days for data collection) started at the end of the growth period (after the 60-day growth period). Twelve of the 24 lambs from the growth trial (four per dietary treatment) were selected for the digestibility and nitrogen-balance trial and remained on their respective dietary treatments before being housed individually in metabolic cages (0.8 × 1.05 m) to evaluate nutrient digestibility and nitrogen balance. Each lamb's feces (about 10%) were collected daily and pooled for subsequent chemical analysis. and stored at -20°C. Thereafter, each lamb's fecal samples were dried at 55ºC in an oven, crushed, and stored for additional chemical analysis. Using methods developed by AOAC International (1990), fecal and feed samples were examined for DM (100°C in an oven for 24 hours), CP (Kjeldahl process; 6.25 × N), and EE (Soxtec method). Van Soest (1991) ANKOM 2000 method was used to assess the fiber contents (NDF and ADF). The detailed methods used to determine DM, CP, EE, ADF, and NDF contents were as described by Obeidat (2023).

Urine samples were obtained from each lamb using a urine collection vessel containing 50 mL of 1 N HCL. The samples were measured and documented, and a 5% aliquot of the urine was taken as a subsample for nitrogen analysis. The subsamples were then combined, and nitrogen content was determined using the Kjeldahl method. On the last day of the study, 5 mL of rumen fluid at 0, 2, and 4 h following morning feeding were sampled using a syringe fitted with a G14 needle to determine rumen fluid pH.

2.3. Statistical Procedures

The experiment was carried out using a completely randomized design. All data were analyzed using SAS version 8.1 (SAS Institute, 2000). Treatment diet was considered a fixed effect, and lamb was considered a random effect. The experimental unit was a lamb. Ruminal pH collected at the fixed times after feeding was analyzed as a repeated measure. The model included treatment, time, and the treatment-by-time interaction. Data are presented as the mean and standard error of the mean across treatments. Differences were declared to be significant at P≤0.05.

3. RESULTS

Forage intake was greater (P<0.002) in the group supplemented with SBM than in those on the BAR and CON diets (Table 1). The SBM diet had the highest DM and CP intake (g/day) (P<0.0001), followed by the BAR diet, and the CON diet had the lowest. Lambs fed the SBM diet had greater (P<0.003) intake of NDF and ADF compared to the lambs fed the BAR and CON diets.

Table 1: Effect of barley grain (BAR) or soybean meal (SBM) supplementation on nutrient intake of Awassi lambs fed low-quality forages

Item/	Diets*				
Nutrient intake	CON	BAR	SBM	SEM	P-value
Hay intake, g/d	682.9a	603.9a	829.3b	49.37	0.0015
Dry matter, g/d	682.9a	875.4b	1099.3c	55.75	<0.0001
Crude protein, g/d	44.7a	72.4b	179.9c	3.23	<0.0001
Neutral detergent fiber, g/d	424.1a	434.7a	544.7b	30.66	0.0025
Acid detergent fiber, g/d	218.1a	207.7a	276.7b	15.77	0.0013

*Diets: 0 g BAR or SBM supplementation (CON; n=8), 300 g BAR per head per day (BAR; n=8) or 300 g SBM per head per day (SBM; n=8). SEM: Standard error of the mean. Within a row, means without a common alphabet differ (P<0.05).

The SBM diet had the highest digestibility of DM (P=0.0004) and CP (P<0.0001), followed by the BAR diet, while the CON diet had the lowest (Table 2). The digestibility of NDF and ADF was higher (P<0.0001) in the SBM diet than in those on the BAR and CON diets. EE digestibility was similar among dietary treatments. Nitrogen intake and nitrogen excreted in feces and urine (g/day) were highest (P≤0.0012) in the SBM diet, followed by the BAR diet, and were lowest with the CON diet. Nitrogen retention (g/100g) and retained (g/day) were higher (P<0.0001) in the SBM diet than in those on the BAR and CON diets. The lambs' initial body weight was comparable among dietary treatments (Table 3). The SBM diet had the highest final BW, TG, and ADG (P<0.0001), followed by the BAR diet,

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while the CON diet had the lowest.

Rumen fluid pH among the diets showed a treatment × time period interaction (P<0.0001) (Fig. 1). After two and four hours of feeding, lambs fed the BAR diet had the lowest rumen pH, followed by those fed the SBM diet, and those fed the CON diet had the highest.

Table 2: Effect of barley grain (BAR) or soybean meal (SBM) supplementation on nutrient digestibility and N balance of Awassi lambs fed low-quality forages

Item	Diets*				
Digestibility coefficients	CON	BAR	SBM	SEM	P - value
Dry matter	56.3a	63.3b	68.8c	1.78	0.0004
Crude protein	58.5a	64.4b	76.8c	1.67	<0.0001
Neutral detergent fiber	53.2a	54.9a	65.6b	1.34	<0.0001
Acid detergent fiber	48.8a	49.9a	57.4b	0.72	<0.0001
Ether extract	69.9	65.0	72.3	2.66	0.0667
N Balance					
N intake, g/d	6.9a	11.9b	28.6c	0.80	<0.0001
N feces, g/d	3.0a	4.5b	6.7c	0.63	0.0012
N urine, g/d	2.6a	5.2b	7.8c	0.42	<0.0001
N retained, g/d	1.3a	2.2a	14.1b	0.41	<0.0001
N retention, g/100 g	19.9a	18.4a	49.3b	3.73	<0.0001

*Diets: 0 g BAR or SBM supplementation (CON; n=4), 300 g BAR per head per day (BAR; n=4) or 300 g SBM per head per day (SBM; n=4). SEM: Standard error of the mean. Within a row, means without a common alphabet differ (P<0.05).

Table 3: Effect of barley grain (BAR) or soybean meal (SBM) supplementation on growth performance of Awassi lambs fed low-quality forages

Item	Diets*				
	CON	BAR	SBM	SEM	P - value
Initial body weight (kg)	29.1	29.3	29.4	1.23	0.9793
Final body weight (kg)	24.3a	31.6b	34.4c	1.42	<0.0001
Total gain (kg)	-4.8a	2.3b	5.0c	0.77	<0.0001
Average daily gain (g)	-80.2a	38.8b	83.3c	12.81	<0.0001

*Diets: 0 g BAR or SBM supplementation (CON; n=8), 300 g BAR per head per day (BAR; n=8) or 300 g SBM per head per day (SBM; n=8). SEM: Standard error of the mean. Within a row, means without a common alphabet differ (P<0.05).

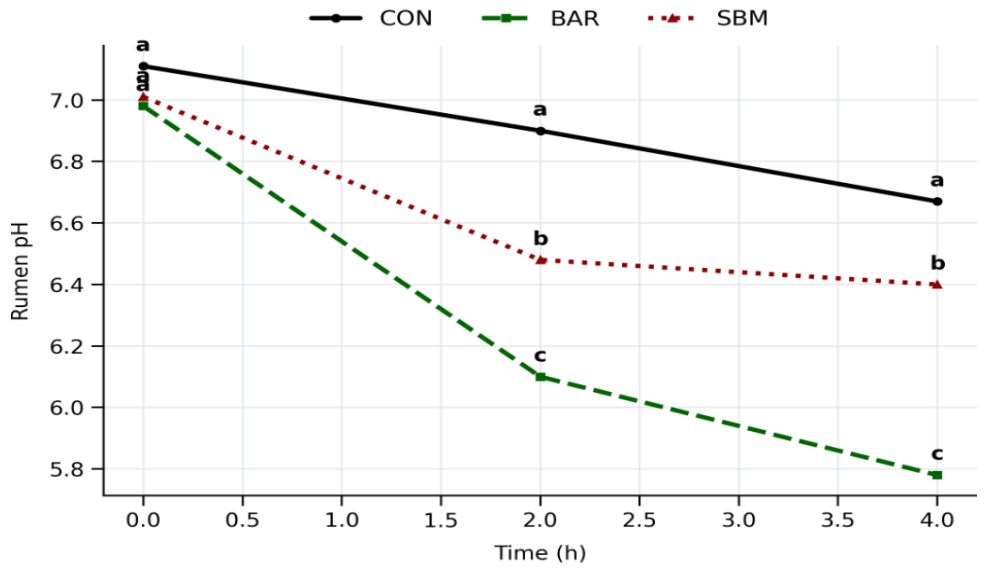

Fig. 1: Effect of barley grain (BAR) or soybean meal (SBM) supplementation on rumen fluid pH over time of Awassi lambs fed low-quality forage diets. pH values at the same time period (0, 2, 4 h) with different letters differ significantly (P<0.05).

4. DISCUSSION

Forages are essential for meeting the nutrient needs in ruminant production worldwide (Wróbel et al., 2025; Vastolo & Cutrignelli, 2025). The nutritional content of these forages varies throughout the year and can sometimes be less optimal, which could detrimentally affect overall ruminant productivity. Strategies to improve utilization of low-quality forages include protein supplementation (Shreck et al., 2021) and energy supplementation (Ponnampalam et al., 2004; Mahgoub et al., 2025). Accordingly, the hypothesis of the present study was supported by differential improvements with SBM or BAR supplementation. In the current study, forage intake significantly improved in the SBM diet (+21.4%) but numerically decreased in the BAR diet (−11.6%) compared to the control diet. Additionally,

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compared to the control diet, SBM supplementation significantly increased dry matter intake by 61% and crude protein intake 4.0-fold, while BAR supplementation significantly increased these intakes by 28.2% and 62.0%, respectively. Higher dry matter and higher hay (forage) intakes are the main causes of the notable increase in NDF and ADF intake in diet SBM compared to diet CON and BAR. Similarly, Sanson et al. (2003) reported greater hay intake and DMI in lambs and steers supplemented with SBM compared with those receiving no supplements. A previous study by Mathis et al. (1999) reported that when beef cattle are fed low-quality forages, supplementary SBM is an efficient way to improve their intake, digestion, and performance. According to Cappellozza et al. (2021) forage and total DM, organic matter intake increased with protein supplementation in ruminants consuming low-quality forages. Other researchers, such as Haddad et al. (2001), reported that as dietary CP levels increase, dry matter and CP intakes significantly increase in Awassi lambs. Bohnert et al. (2011), Cox & Wickersham (2023), and Cox & Wickersham (2024) reported that forage and total DM and OM intake, N intake, and NDF intake were affected in steers when low-quality forage was supplemented with protein. In contrast, a study by Ponnampalam et al. (2004) shows that when barley grain was provided for lambs as an energy supplement, CP intakes and estimated ME and DM digestibility increased while Hay DMI was reduced compared with the lambs fed a basal diet containing a low-quality forage. Furthermore, Moura et al. (2015) reported that when sheep were fed diets containing varying amounts of supplemental proteins, there were no variations in the intake and digestibility of nutrients including dry matter, organic matter, crude protein, and neutral detergent fiber. According to a study by Boyles et al. (1998), when steers are fed forage deficient in CP, forage consumption is increased by SBM supplementation and decreased by increasing levels of barley supplementation.

Compared with the CON diet, SBM supplementation increased DM digestibility from 56.3% to 68.8%, whereas BAR supplementation increased it to 63.3%. In the present study, soybean and barley supplementation increased dry matter and crude protein digestibility, potentially by providing additional nitrogen and fermentable nutrients that support ruminal microbial activity. The digestibility of fibers in the SBM diet was improved due to increasing CP consumption by lambs. This led to improved rumen activity for fiber fermentation. Such findings are consistent with previously reported results by Sanson et al. (2003), who reported that apparent DM digestibility was greater for supplemented lambs and steers with SBM than for nonsupplemented counterparts. Moreover, compared with corn, sheep fed the barley-only supplement showed higher CP digestibility (Bošnjak et al., 2025). However, Boyles et al. (1998) found that digestibility was comparable among treatments (no supplement, soybean meal-based supplement, barley-based supplements) for steers fed forage low in CP. McGuire et al. (2013) found that lambs and steers consuming low-quality forage can use supplements containing SBM as an additional N source without negatively affecting N efficiency, nutritional intake, or nutrient digestibility.

In the present study, compared to the control diet, SBM supplementation significantly improved nitrogen utilization efficiency (approximately 7-fold), mostly due to greater absolute nitrogen retention, while BAR supplementation improved nitrogen utilization (30.9%). The significant differences in CP intake and digestibility among treatments led to differences in total N intake. These notable variations led to varying amounts of total nitrogen excretion (fecal and urine) among treatments, indicating that total N intake is more important in determining loss levels. The greater nitrogen retention observed with SBM supplementation may reflect improved synchronization between available nitrogen and fermentable energy; however, this mechanism was not directly evaluated in the present study. This aligns with prior studies' findings (Ferrell et al., 1999; Bohnert et al., 2002; Rauch et al., 2025; Zhao et al., 2026). According to Bošnjak et al. (2025), barley inclusion in the wether sheep diet can improve nitrogen efficiency and aid in lowering environmental nitrogen losses without compromising intake or digestibility.

In this study, supplementation improves animal performance when ruminants consume low-quality forage. The addition of BAR enhanced overall growth performance by increasing final body weight by about 30% and resulting in an approximately 2.5-fold increase in total gain and average daily gain compared with the control. In contrast, SBM elicited greater responses, increasing final body weight by about 42% and improving total gain and ADG by about 3-fold, suggesting a significantly superior growth-promoting effect. These findings are consistent with other studies (Chegini et al., 2019; Obeidat et al., 2020) that found SBM supplementation increased ADG and BW gain in growing lambs. This may result from increased energy intake when a high-concentrate supplement is consumed; from the protein fraction supplying the ruminal microflora with additional amino acids and ammonia N; or from a portion of the protein bypassing ruminal degradation and providing the small intestine with more amino acids (Ferrell et al., 1999; Mirzaei-Alamouti et al., 2025). According to Wang et al. (2024), sheep's growth performance, nutrient digestibility, rumen fermentation, and microbiota are all impacted by dietary energy levels. Rapidly growing ruminants have high amino acid requirements. Feeds with low protein degradability are crucial because diets designed solely to meet the nitrogen requirements of rumen bacteria cannot support animals' growth potential (Manso et al., 1998; Jan et al., 2026; Tian et al., 2026). However, Hill et al. (1995) showed that supplementing late Gestation and lactating ewes fed low-protein grass hay with either barley or soybean meal resulted in comparable performance. A study by Ata and Obeidat (2021) showed that barley-based diets did not affect average daily gain and total weight gain of growing lambs compared to corn- based diets. Furthermore, including up to 30% of forages in concentrate-

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based diets maintained lamb growth performance under tropical conditions (Escalante Raz et al., 2026). Rumen pH is a crucial indicator of the state of rumen fermentation and is influenced by several factors (Chen et al., 2025). In the current study, increasing rumen fermentation time from 0 to 2 and 4 hours caused a decline in ruminal fluid pH across the dietary treatments evaluated. Obeidat et al. (2020) reported a similar pattern of pH reduction when low-quality forage supplemented with soybean meal was fed to lambs. The range of ruminal pH values for all treatments and sampling periods was 5.78 to 7.11. Lambs fed the BAR diet had the lowest rumen pH at two and four hours of feeding; this is likely due to the fact that barley has easily accessible starch, which accelerates fermentation rate (Moura et al., 2015; Bošnjak et al., 2025). Our findings show that the barley grain inclusion level was appropriate for the forage type and animal needs and helped avoid detrimental ruminal pH effects on fiber digestion and cellulolytic bacterial growth. A study by Al-Lataifeh et al. (2024) showed that the inclusion level of barley in the diet, regardless of the processing method, was critical in the drop in rumen pH. However, Boyles et al. (1998) found no differences in ruminal pH across treatments, including soybean meal and all levels of barley supplementation (low, moderate, and high) in steers.

5. CONCLUSION

The results showed that supplementing low-quality forages with barley grain or soybean meal improved forage intake, nutrient digestibility, and growth performance in lambs. However, soybean meal supplementation resulted in more pronounced improvements than barley grain. Strategic supplementation of protein and energy sources can support sustainable livestock production in resource-limited settings without compromising animal health and performance.

Because adding protein sources to a low-quality forage diet is more expensive, farmers will likely continue to use grain as a readily available and inexpensive energy supplement. Future studies are recommended to evaluate the effects of supplementing low-quality forage with specified rates of soybean meal or barley grain on production costs.

Declarations

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Data Availability: Data will be available upon request.

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Author's Contributions: Ja'far Al-Khaza'leh: Writing - review & editing, Writing - original draft, Formal analysis. Belal Obeidat: Funding acquisition, Conceptualization, Supervision, Software, Formal analysis, Data curation, Methodology, Writing - review & editing.

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