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Effect of Oscillating Protein Feeding on Feed Intake, Digestibility, and Nitrogen Balance in Moghani Male Lambs

Research Article

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ABSTRACT

This study aimed to investigate the effect of oscillating crude protein (CP) levels in the diet, combined with a reduction in protein levels, on feed intake, nutrient digestibility, and nitrogen balance in Moghani lambs. A total of eight male lambs were used in a 4 × 4 Latin square design. The experimental treatments included: 1) a diet containing 15% CP with a constant intake (control); 2) diets containing 13% and 17% CP; 3) diets containing 12% and 16% CP and 4) diets containing 11% and 15% CP with a 48-hour oscillating intake cycle. Feed intake, daily weight gain, and feed conversion ratio showed no significant differences among the experimental treatments. Linear comparisons of the treatments with reduced CP levels also revealed no significant differences in feed conversion ratio. Dry matter and organic matter digestibility did not differ significantly between treatments; however, the treatment with oscillating CP levels of 13% and 17% exhibited the highest crude protein digestibility. Fecal and urinary nitrogen excretion did not significantly differ among treatments, but linear comparison of the oscillating CP treatments indicated that decreasing dietary CP levels significantly reduced nitrogen excretion via feces and urine. The highest retained nitrogen and nitrogen efficiency were observed in the treatment with oscillating CP levels of 13% and 17%, which showed a significant difference compared to the constant 15% CP diet. Overall, the results indicated that oscillating CP levels in the diet improved crude protein digestibility and increased nitrogen retention and efficiency in male lambs, while having no significant effect on feed intake, feed conversion ratio, or daily weight gain. Additionally, the absence of significant differences in performance traits among treatments with reduced CP levels highlights the beneficial effects of oscillating protein feeding.

KEY WORDS daily weight gain, feed conversion ratio, nitrogen efficiency, nitrogen retention, sheep.

INTRODUCTION

The nitrogen utilization efficiency in ruminants typically ranges between 10% and 40% (Calsamiglia *et al.* 2010). Protein is the most expensive component of feed and serves as a key element in formulating ruminant diets (Khattab and Abdel-Wahed, 2018). Compared to non-ruminants, ruminants utilize dietary nitrogen with lower efficiency, leading to negative consequences such as reduced performance, lower economic returns, and excessive nitrogen excretion (de Souza *et al.* 2021). Concerns regarding high nitrogen excretion from ruminants and its environmental impact have prompted researchers to explore strategies for improving nitrogen utilization efficiency in livestock (Reynolds and Kristensen, 2008). Enhancing nitrogen utilization efficiency in animal nutrition optimizes dietary nitrogen use, providing economic benefits while reducing nitrogen excretion into the environment in the form of ammonia, nitrate, and nitrous oxide (Dijkstra *et al.* 2013; Rauch *et al.* 2021). Efforts have been made to optimize livestock production performance by reducing crude protein (CP) levels in the diet. However, adequate protein, amino acids, nutrients, and energy intake are essential for optimal animal productivity (Erickson *et al.* 2024). Studies have shown that reducing dietary CP levels increases urea recycling to the gastrointestinal tract, decreases renal urea clearance, and improves post-absorption nitrogen efficiency by altering the affinity of amino acids for various tissues (Lapierre and Lobley, 2001; Rius *et al.* 2010; Sinclair *et al.* 2014). Another approach to optimizing nitrogen utilization involves formulating diets with synchronized nutrient supply or matching the fermentation rates of protein and energy sources. While this strategy has shown some benefits, its overall success has been limited (Richardson *et al.* 2003; Yalchi *et al.* 2020). An alternative strategy is oscillating dietary protein feeding, in which animals receive diets with alternating high and low CP levels at intervals of 24, 48, or 72 hours (or longer), while maintaining an overall average target protein concentration. Studies have shown that oscillating dietary CP levels, compared to a constant CP supply, enhance nitrogen retention and utilization in sheep and cattle (Rauch *et al.* 2021). Several studies have confirmed that oscillating dietary CP levels at 48-hour intervals can increase nitrogen retention in lambs (Archibeque *et al.* 2007; Doranalli *et al.* 2011) and feedlot calves (Cole *et al.* 2003) compared to constant CP feeding at the same total protein level. In male calves, feeding an oscillating diet with 10.5% and 14.5% CP compared to a constant 12.5% CP diet at 48-hour intervals did not affect dry matter intake, crude protein digestibility, or growth performance (Menezes *et al.* 2019). Some researchers reported that oscillating dietary CP in lambs improved neutral and acid detergent fiber digestibility without affecting dry matter intake (Kiran and Mutsvangwa, 2009). In dairy cows, an increase in crude fat and starch digestibility, as well as a slight increase in dry matter digestibility, was observed, while dry matter intake and the digestibility of other nutrients remained unaffected by oscillating protein feeding (Rauch *et al.* 2023).

Given the limited studies and conflicting results regarding the effects of oscillating dietary CP in sheep, this study was designed to evaluate the impact of oscillating protein feeding combined with reduced dietary CP levels in growing male lambs. Our hypothesis is that oscillating dietary CP, compared to a constant CP diet, will enhance dry matter intake, nutrient digestibility, and nitrogen retention by increasing urea recycling to the rumen and altering absorption and post-absorption patterns during low-protein intake phases. In addition, the negative effects of reducing dietary CP on animal performance may be mitigated by oscillating protein feeding.

MATERIALS AND METHODS

Animals and experimental diets

Six experimental diets were formulated for fattening lambs with an average body weight of 30 kg and an expected daily weight gain of 250 g, based on the NRC (2007) nutrient requirements. Diets were formulated using the SRNS software with six different crude protein (CP) levels (17%, 16%, 15%, 13%, 12%, and 11%) while maintaining equal energy content (Table 1). The experimental treatments included:

Treatment 1 (Control): a diet containing 15% CP with a constant intake.

Treatment 2: diets alternating between 13% and 17% CP, (avg=15%).

Treatment 3: diets alternating between 12% and 16% CP, (avg=14%).

Treatment 4: diets alternating between 11% and 15% CP, (avg=13%).

The treatments with two CP levels followed a 48-hour oscillating feeding schedule.

Animal management and sampling

A total of eight male Moghani lambs (average initial body weight 26.63±1.32 kg) were used in a 4 × 4 Latin square design (with two merged squares, forming a rectangular Latin square). Each treatment was assigned to two lambs per period, resulting in four treatments, two squares, and a total of eight replicates. Lambs were randomly allocated to the experimental treatments. Each lamb was housed in an individual metabolic cage, allowing for separate measurement of feed intake and collection of feces and urine. Routine health procedures, including general health monitoring, vaccination against enterotoxemia, and administration of anthelmintic drugs, were performed. The lambs had free access to water, and all animals were kept under identical environmental conditions.

The entire experiment lasted four 14-day periods, consisting of 10 days of adaptation and 4 days of data collection. Lambs were fed the experimental diets at approximately 4% of their body weight, divided into two daily meals at 08:00 a.m. and 05:00 p.m. Each morning, before feeding, the remaining feed and water from the previous day were collected and weighed. The remaining feed was about 5 to 10 percent of the feed given. From day 10 of each period, feces and urine were collected separately for four consecutive days. Samples were stored at -18 °C until laboratory analysis.

Table 1 Ingredients (in percentage) and chemical composition of experimental diets

Ingredients	Experimental diets with crude protein (CP) content (%)					
	Diet 1, CP=11	Diet 2, CP=12	Diet 3, CP=13	Diet 4, CP=15	Diet 5, CP=16	Diet 6, CP=17
Alfalfa hay	25	25	25	25	25	25
Wheat straw	10	10	10	10	10	10
Barley grain	28	32	34	30	30	27.8
Corn grain	34	27.5	23	20.7	17.9	17
Soybean meal	1	3.5	6	12.3	15.1	18.2
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Sodium bicarbonate	0.75	0.75	0.75	0.75	0.75	0.75
Mineral and vitamin supplement[1]	1	1	1	1	1	1
Chemical compositions						
Crude protein (%)	10.99	12.03	12.98	15.03	16.01	17.00
Metabolizable protein (g/d)	87	93	100	108	112	115
Metabolizable energy (Mcal/kg)	2.77	2.77	2.77	2.77	2.77	2.77
Neutral detergent fiber (%)	33.03	33.72	34.12	33.88	34.02	33.86
Acid detergent fiber (%)	17.14	17.48	17.73	18.01	18.21	18.34
Crude fat (%)	2.20	2.23	2.19	2.25	2.34	2.38
Ash (%)	6.84	6.79	6.69	6.84	6.81	6.69

[1] Mineral and Vitamin supplement, each kilogram contains vitamin A: 500000 IU; vitamin D_3: 100000 IU; vitamin E: 100 mg; Phosphorous: 20 g; Sodium: 50 g; Magnesium: 20 g; Iron: 3 g; Manganese: 2 g; Zinc: 3 g; Cooper: 280 mg; Cobalt: 100 mg; Iodine: 100 mg and Selenium: 4 mg.

All experiments were conducted in accordance with internationally recognized ethical principles for working with laboratory animals and in accordance with National Institutes of Health guidelines (FASS, 2010).

Measurements and chemical analysis

For urine collection, 100 mL of 10% sulfuric acid was added to the collection buckets to prevent nitrogen loss. The recorded daily urine volume was adjusted by subtracting the acid volume. Approximately 70 mL of urine was collected daily and stored in 90 mL of plastic containers at -20 °C. Chemical composition analysis, including dry matter (DM), crude protein (CP), ether extract (EE), and ash, was conducted following AOAC (2012) methods. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using the method of Van Soest *et al.* (1991). Metabolizable protein (g/d) and metabolizable energy (Mcal/kg) estimated from SRNS software.

For urinary nitrogen analysis, 5 mL of urine was transferred to Kjeldahl digestion flasks, and total nitrogen content was determined according to Association of Official Analytical Chemists (AOAC) (2012). Total urinary nitrogen excretion was calculated based on urinary nitrogen concentration and total urine volume. For fecal nitrogen analysis, 1 g of dried fecal sample was analyzed using the Kjeldahl method (AOAC, 2012). Total fecal nitrogen excretion was determined from nitrogen concentration and the total collected dry feces weight. Nitrogen balance was calculated by subtracting the sum of urinary and fecal nitrogen excretion from the total dietary nitrogen intake.

Growth performance measurements

The lambs were weighed at the beginning and end of each period after a 12-hour fasting period (without feed and water). Daily weight gain was calculated as the difference between the initial and final weight divided by the number of days. Feed conversion ratio (FCR) was determined as feed intake per unit of weight gain. Apparent digestibility of nutrients was calculated using the total fecal collection method (McDonald *et al.* 2010). At the end of each period, blood samples were collected from the jugular vein before the morning feeding. Blood samples were centrifuged in 3500 rpm for 15 minutes (Model HB207, Behsan Company, Made in Iran) to separate serum, which was stored at -20 °C for further analysis. They were analyzed after two weeks. Blood metabolites, including glucose, urea, total protein, and albumin, were measured using an autoanalyzer (Roche Cobas, Germany) with kits from Pars Azmun Company.

Statistical analysis

Data were analyzed using a repeated Latin square design (merged or rectangular Latin square) (Cue, 2006) with the General Linear Model (GLM) procedure in SAS software, version 9.1 (SAS, 2004). The following statistical model was used:

$$Y_{lik(j)} = \mu + R_j + C_{ik} + T_l + E_{lik(j)}$$

Where:

$Y_{lik(j)}$: general observation.

μ: overall mean.
R_j: row effect.
C_{ik}: column effect within the square.
T_l: treatment effect.
$E_{lik(j)}$: experimental error.

Mean comparisons were conducted using Duncan's test, and significance was considered at $P < 0.05$.

RESULTS AND DISCUSSION

The effects of oscillating crude protein (CP) feeding on feed intake, nitrogen balance, and performance of the experimental lambs are presented in Table 2. Feed intake did not show a significant difference among treatments. The linear comparison of treatments with oscillating CP levels also did not reveal a significant difference in feed intake when the overall CP level was reduced. Nitrogen intake varied significantly among treatments, with the highest nitrogen intake observed in the 13% and 17% CP oscillating treatment and the lowest nitrogen intake in the 11% and 15% CP oscillating treatment. The linear comparison of oscillating CP treatments also showed a significant reduction in nitrogen intake as the overall CP level decreased. Fecal and urinary nitrogen excretion did not differ significantly among treatments. However, a linear comparison of oscillating CP treatments indicated a significant reduction in nitrogen excretion via both feces and urine as dietary CP levels decreased. Total nitrogen excretion (fecal+urinary) did not show a significant difference among treatments or in the linear comparison of oscillating CP treatments. Retained nitrogen was highest in the 13% and 17% CP oscillating treatment, which was significantly different from the constant 15% CP treatment. The lowest nitrogen retention was observed in the 11% and 15% CP oscillating treatment. A linear comparison of oscillating CP treatments indicated that nitrogen retention significantly decreased as dietary CP levels were reduced. Nitrogen efficiency was highest in the 13% and 17% CP oscillating treatment, which was significantly different from the constant 15% CP treatment. The linear comparison of oscillating CP treatments also showed that nitrogen efficiency significantly decreased as dietary CP levels were reduced.

Daily weight gain ranged from 226 to 251 g/day, with no significant differences among treatments. The linear comparison of oscillating CP treatments also showed no significant effect on weight gain. Feed conversion ratio (FCR) ranged from 5.11 (13% and 17% CP oscillation) to 5.11 (11% and 15% CP oscillation)**,** with no significant differences among experimental treatments. The linear comparison of oscillating CP treatments also showed no significant differences in FCR.

The effects of oscillating crude protein (CP) feeding on nutrient digestibility are presented in Table 3. Dry matter and organic matter digestibility did not show significant differences among experimental treatments. The linear comparison of oscillating CP treatments also showed no significant effect on the digestibility of dry matter and organic matter as the CP level decreased. Crude protein digestibility was significantly different among treatments. The 13% and 17% CP oscillating treatment had the highest crude protein digestibility. The linear comparison of oscillating CP treatments also showed a significant reduction in crude protein digestibility as dietary CP level decreased. Crude fat digestibility was not significantly different among treatments. The linear comparison of oscillating CP treatments also showed no significant effect on fat digestibility. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) digestibility did not show significant differences among treatments. The linear comparison of oscillating CP treatments also showed no significant effect on fiber digestibility as dietary CP levels decreased.

The effects of oscillating crude protein (CP) feeding on blood parameters in male lambs are presented in Table 4. Blood glucose concentration showed no significant differences among experimental treatments. Blood urea concentration was significantly affected by dietary treatments. The lowest urea concentration was observed in the 11% and 15% CP oscillating treatment.

However, there was no significant difference between the constant 15% CP treatment and the 13% and 17% CP oscillating treatment. The linear comparison of oscillating CP treatments showed that as dietary CP levels decreased, blood urea concentration significantly decreased. Total protein and albumin concentrations showed no significant differences among experimental treatments. The linear comparison of oscillating CP treatments also showed no significant effect on these parameters as dietary CP levels decreased.

The importance of evaluating dry matter intake in livestock is to measure the amount of available nutrients for production and animal health. The absence of significant effects on dry matter and nitrogen intake (comparing fixed feeding with oscillating feeding of 13% and 17% crude protein) aligns with previous research findings (Rauch *et al*. 2021; Rauch *et al*. 2023) that used 48-hour feeding fluctuation phases. However, these results contrast with the report by Tebbe and Weiss (2020), which stated that oscillating diet intake in cattle led to reduced feed intake (119 and 162 grams of crude protein per kg of dry matter with 24-hour fluctuation) compared to a fixed diet (141 grams of crude protein per kg of dry matter). These differences may be due to the duration of fluctuation phases, diet type, and animal species.

Table 2 Effect of oscillating crude protein feeding on feed intake, nitrogen balance and performance in experimental male lambs

Parameters	Experimental treatments				SEM	P-value	
	T1	T2	T3	T4		Model	Linear[1]
Initial weight (kg)	25.50	25.50	27.50	28.00	-	-	-
Daily feed intake (g)	1166	1219	1243	1219	27.41	0.063	0.879
Nitrogen intake (g/d)	27.98[ab]	29.24[a]	27.85[b]	25.34[c]	0.42	<0.001	0.005
Nitrogen excreted from feces (g/d)	6.16	5.77	6.24	6.21	0.14	0.084	0.044
Nitrogen excreted from urine (g/d)	13.20	13.36	12.84	11.87	0.33	0.221	0.049
Total nitrogen excreted[2] (g/d)	19.36	19.13	19.08	18.08	0.38	0.232	0.166
Nitrogen retention (g/d)	8.62[bc]	10.11[a]	8.77[ab]	7.26[c]	0.45	0.024	0.010
Nitrogen retention efficiency (%)	30.39[b]	34.45[a]	31.40[ab]	28.63[b]	1.05	0.048	0.041
Average daily gain (g/d)	239	251	249	226	24.43	0.278	0.699
Feed conversion ratio	5.20	5.11	5.68	6.11	0.69	0.629	0.583

[1] Linear comparison of treatments 2 to 4.
[2] Not counting wool shedding and layers separated from the skin.
T1: diet containing 15% CP with a constant intake; T2: diets oscillating 13% and 17% CP; T3: diets oscillating 12% and 16% CP and T4: diets oscillating 11% and 15% CP.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 3 Effect of oscillating crude protein feeding on digestibility in experimental male lambs

Digestibility (%)	Experimental treatments				SEM	P-value	
	T1	T2	T3	T4		Model	Linear[1]
Dry matter	77.96	79.11	76.41	75.48	0.91	0.145	0.055
Organic matter	79.73	81.36	78.59	77.68	0.89	0.154	0.103
Crude protein	77.43[b]	80.14[a]	77.39[b]	76.54[b]	0.51	0.003	0.014
Crude fat	78.61	78.06	77.75	76.18	2.14	0.354	0.138
Neutral detergent fiber	54.18	55.99	53.08	52.84	1.49	0.436	0.172
Acid detergent fiber	42.54	45.22	43.19	42.52	1.13	0.064	0.107

[1] Linear comparison of treatments 2 to 4.
T1: diet containing 15% CP with a constant intake; T2: diets oscillating 13% and 17% CP; T3: diets oscillating 12% and 16% CP and T4: diets oscillating 11% and 15% CP.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 4 Effect of oscillating crude protein feeding on some blood parameters in experimental male lambs

Item	Experimental treatments				SEM	P-value	
	T1	T2	T3	T4		Model	Linear[1]
Glucose (mg/dL)	74.50	75.25	73.25	68.75	4.08	0.690	0.443
Urea (mg/dL)	31.70[a]	25.50[a]	23.50[ab]	15.75[b]	2.54	0.024	0.049
Total protein (g/dL)	6.83	6.68	6.53	6.43	0.14	0.275	0.316
Albumin (g/dL)	3.37	3.35	3.42	3.44	0.06	0.637	0.321

[1] Linear comparison of treatments 2 to 4.
T1: diet containing 15% CP with a constant intake; T2: diets oscillating 13% and 17% CP; T3: diets oscillating 12% and 16% CP and T4: diets oscillating 11% and 15% CP.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Reduced nitrogen intake with decreasing dietary protein levels is consistent with previous research indicating a dependency between dry matter intake and dietary protein levels (Tian *et al*. 2019). Given the similar dry matter intake among experimental treatments, diets with lower protein levels also resulted in lower nitrogen intake.

The primary determinant of total nitrogen excretion in ruminants is the total nitrogen intake from the diet (Reynolds and Kristensen, 2008). In ruminants receiving high-concentrate diets with oscillating protein levels every 48 hours, nitrogen retention was higher in fattening calves (Ludden *et al*. 2002; Cole *et al*. 2003) and sheep (Cole, 1999; Kiran and Mutsvangwa, 2009), which matches the findings of this study. However, when male lambs were fed diets with oscillating crude protein levels every 48 hours compared to fixed crude protein diets, no significant increase in nitrogen retention was reported (Ludden *et al*. 2002).

In this study, although nitrogen intake was similar between the fixed feeding treatment (15% crude protein) and the oscillating feeding treatment (13% and 17% crude protein), nitrogen retention and efficiency improved under oscillating feeding conditions. In the oscillating feeding treatment (12% and 16% crude protein), nitrogen intake was lower than in the 13% and 17% crude protein treatments, but nitrogen retention and utilization efficiency were not significantly different. Furthermore, the lack of significant differences in nitrogen retention and utilization efficiency between the fixed feeding treatment (15% crude protein) and the oscillating feeding treatment (11% and 15% crude protein) suggests that oscillating feeding can partially compensate for dietary nitrogen deficiencies. Although nitrogen intake and retention were lower in lambs receiving the oscillating 11% and 15% crude protein diet, daily weight gain and feed conversion ratio were unaffected, consistent with previous findings (Kiran and Mutsvangwa, 2009; Ludden *et al*. 2002). However, some earlier studies reported improved daily weight gain with oscillating crude protein intake compared to fixed crude protein intake (Cole *et al*. 2003; Doranalli *et al*. 2011). Increased nitrogen retention in ruminants receiving diets with oscillating crude protein levels has been attributed to enhanced urea recycling in the rumen (Cole, 1999). It appears that the transfer of urea from blood to the rumen increases during periods of low crude protein intake, compensating for nitrogen deficiency in the rumen. In these conditions, urinary nitrogen excretion decreases, leading to higher nitrogen efficiency.

The lack of significant differences among experimental treatments in dry matter digestibility is consistent with previous research findings (Cole, 1999; Ludden *et al*. 2002; Kiran and Mutsvangwa, 2009; Khattab and Abdel-Wahed, 2018). However, some researchers have reported a significant or marginal increase in dry matter digestibility in diets with 48-hour crude protein fluctuations (Rauch *et al*. 2021; Yalchi, 2022; Rauch *et al*. 2023). Consistent with this study, feeding lactating ewes diets with oscillating crude protein levels (11.2% and 17.3%) every 72 hours did not affect dry matter and organic matter digestibility compared to fixed crude protein diets (14.1%) (Khattab and Abdel-Wahed, 2018). Crude fat digestibility was unaffected by oscillating feeding in this study, though some previous studies reported increased crude fat digestibility (Rauch *et al*. 2021; Rauch *et al*. 2023). Neutral detergent fiber digestibility in this study, as reported in previous research, was not affected by fixed or oscillating crude protein levels (Ludden *et al*. 2002). However, some studies have shown that oscillating crude protein levels in the diet, compared to fixed feeding, increase neutral detergent fiber digestibility (Khattab and Abdel-Wahed, 2018). Feeding male calves diets with oscillating crude protein levels (10.5% and 14.5%) every 48 hours, compared to fixed crude protein diets (12.5%), did not affect dry matter, organic matter, or neutral detergent fiber digestibility (Menezes *et al*. 2019), aligning with the findings of this study. Differences in digestibility may result from the duration of oscillating feeding phases (24, 48, or 72 hours), diet composition (crude protein, fiber, and starch concentration), and animal characteristics. Our results indicate that oscillating crude protein levels in the diet did not affect nutrient digestibility except for crude protein. When rumen fermentation is limited due to nitrogen deficiency (during low-protein phases), increasing dietary protein (during high-protein phases) improves rumen fermentation (Ma *et al*. 2021), compensating for reduced digestibility in low-nitrogen conditions. Although increased digestibility is desirable, the absence of significant digestibility reductions in oscillating protein diets (treatments 3 and 4) suggests that digestibility was maintained, which is a positive outcome. Also the fiber digestibility has not changed, which is a positive aspect, while dietary crude protein levels have decreased.

Blood glucose concentration is influenced by the amount of dry matter intake. In this study, dry matter intake was similar across the experimental treatments; thus, blood glucose was not affected by the experimental treatments. Researchers have indicated that blood glucose concentration can be influenced by the protein level in the diet (Rusche *et al*. 1993). In other words, a decrease in dietary protein level leads to a reduction in blood glucose concentration. In the experimental treatments where protein levels were reduced (treatments 3 and 4), blood glucose concentration did not decrease, suggesting that under oscillating feeding conditions, urea recycling to the rumen and absorption and post-absorption mechanisms could compensate for nitrogen deficiency and prevent a decrease in blood glucose. Consistent with these results, oscillating protein feeding at 48-hour intervals in lambs, compared to constant feeding, had no effect on blood glucose concentration (Yalchi, 2022). Blood urea can also be linked to the absorption and utilization of nitrogenous compounds in the diet (Hristov *et al*. 2019) and is dependent on the crude protein level in the diet. Therefore, in the low-protein diets (11% and 15%), blood urea concentration was at its lowest. However, comparison between fixed protein diets (15% crude protein) and oscillating diets (13% and 17% crude protein) showed no significant differences. In line with these results, previous researchers reported that the blood urea nitrogen concentration in lambs fed diets containing 9.5% and 15.5% crude protein with 48-hour oscillation did not differ significantly from diets with a fixed crude protein level of 12.5% (Kiran and Mutsvangwa, 2009). Similarly, no significant differences were found in blood urea nitrogen levels in lactating ewes (Khattab and Abdel-Wahed, 2018) and male calves (Menezes *et al*. 2019). However, oscillating feeding of male lambs at 48-hour intervals did increase blood urea nitrogen concentration (Yalchi, 2022). Blood protein concentration is an indicator of protein availability. Increased amino acid absorption from the diet into the bloodstream may improve blood protein value. A significant index in evaluating protein status is the total blood protein assessment (Piccione *et al*. 2011). Albumin, produced in the liver, serves as an amino acid source in peripheral tissues and functions as a transporter in the body's metabolic processes (Macrae, 2017). It can also be used for diagnosing certain diseases. In this study, no significant differences were found in the albumin concentration across the experimental treatments, indicating the health of the lambs fed with varying protein levels.

CONCLUSION

Overall, the results showed that the use of oscillating crude protein feeding strategy in the diets of growing male lambs led to an increase in crude protein digestibility, nitrogen retention, and efficiency. However, it had little effect on the digestibility of dry matter, organic matter, and fiber, feed intake, feed conversion ratio, and daily weight gain. The lack of significant differences in performance indices, such as daily weight gain, feed conversion ratio, and nitrogen efficiency, among treatments with lower crude protein levels indicates that the oscillating feeding strategy was able to mitigate or neutralize the negative impact of reduced crude protein intake in the diet. This should be considered a positive aspect of this research. Therefore, it is recommended to use the oscillating protein feeding method in the diets of fattening lambs.

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