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Assessment of Nutritional Strategies using Slow-Release Urea to Enhance Growth Efficiency in Arabi Lambs

Marwah Th. G. Al-Ameri [1], Hanaa A. J. Al-Galbi [2], Amera K. Nasser [3]
[1] Basrah Agriculture Directorate, Iraq.
[2, 3] Department of Animal Production, College of Agriculture, University of Basrah, Iraq

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Annotation: The study aimed to evaluate the effect of supplementing slow-release urea at different levels (1%, 1.5%, 2%) in the diets of Arabi lambs on productive performance. No significant differences were observed in initial body weight, while final body weight increased from 36.10 kg in the control group (T1) to 39.83 kg in the 2% urea group (T4). Daily weight gain also improved from 129.9 g/day in T1 to 187.8 g/day in T4, and total weight gain increased from 9.10 kg to 13.15 kg. Although daily feed intake did not differ significantly among treatments (1.00–1.04 kg), feed conversion ratio improved significantly ($P<0.05$), decreasing from 7.72 kg feed/kg gain in T1 to 5.57 kg in T4. These results suggest enhanced feed utilization efficiency, likely due to improved energy–nitrogen balance that supports microbial activity in the rumen.

Keywords: Slow-release urea, Feed conversion ratio, Arabi lambs, Productive performance.

Introduction:

According to United Nations projections, the global population is expected to reach 8.5 billion by 2030, compared to 7.3 billion in 2000, and approximately 9.5 billion by 2050 (Dorling, 2021). This population growth, along with rising incomes and urbanization, will lead to significant shifts in food consumption patterns, including increased demand for high-quality animal protein

(Henchion et al., 2017). Ruminants play a key role in animal protein production due to their ability to convert non-edible resources into valuable food products such as meat and milk (Adesogan et al., 2020). However, ruminant production systems face growing challenges, particularly the low efficiency of nitrogen conversion into animal growth, resulting in substantial nitrogen losses through excretion, with negative environmental consequences (Wattiaux et al., 2019; Króliczewska et al., 2023). Therefore, improving feed conversion efficiency and enhancing growth performance have become critical goals for both environmental sustainability and productive efficiency.

In this context, the concept of slow-release urea as a non-protein nitrogen (NPN) source has emerged, due to its ability to release nitrogen in synchrony with the availability of fermentable energy in the rumen. This synchronization enhances microbial protein synthesis and improves feed utilization efficiency (Ravi et al., 2019; Reddy et al., 2019). Thus, incorporating this improved form of urea into ruminant diets may represent a strategic tool to enhance live body weight, daily weight gain, and feed conversion efficiency, without negatively affecting feed palatability. Based on the considerations, the present study aimed to evaluate the effect of supplementing different levels of slow-release urea in the diets of Iraqi Awassi lambs on productive performance indicators, including live body weight, weight gain, feed intake, and feed conversion ratio.

Material and methods:

This study was conducted at the Animal Field of the College of Agriculture, University of Basrah, Iraq, with the aim of evaluating the effects of incorporating different levels of slow-release urea (SRU) into the diets of Arabi lambs on productive performance.

A total of sixteen healthy male Arabi lambs, with an average initial body weight of 22.5 ± 1.1 kg and an age ranging from 3.5 to 4.5 months, were randomly assigned to four dietary treatments in a completely randomized design (CRD). Each treatment consisted of four replicates (one lamb per replicate). The experimental period lasted for 90 days, preceded by a 14-day adaptation phase.

The dietary treatments were as follows:

- ✓ T1 (Control): Basal diet without slow-release urea.
- ✓ T2: Basal diet supplemented with 1% SRU.
- ✓ T3: Basal diet supplemented with 1.5% SRU.
- ✓ T4: Basal diet supplemented with 2% SRU.

The basal diet was formulated to meet the nutritional requirements of growing lambs according to the National Research Council (NRC, 2007) guidelines. The chemical composition of the feed ingredients was determined based on the Iraqi feed composition tables published by Al-Khawaja et al. (1978).

Feed was offered twice daily (morning and afternoon), and daily feed intake was recorded by subtracting the refusals from the total feed offered. Lambs had free access to clean drinking water throughout the experimental period.

The evaluated parameters included:

- ➢ **Feed Intake (FI):** Measured as the total dry matter intake per day (kg/day).
- ➢ **Body Weight Gain (BWG):** Recorded weekly using a digital scale.
- ➢ **Average Daily Gain (ADG):** Calculated as the change in weight over time divided by the number of days.

- **Feed Conversion Ratio (FCR):** Calculated as the total dry matter intake divided by body weight gain.

Statistical analysis was performed using one-way analysis of variance (ANOVA) in SPSS software (version 2018), and significant differences among treatment means were separated using Duncan's Multiple Range Test at a significance level of $P \leq 0.05$.

Table (1): Composition of the concentrated diet used in the study.

Ingredients	Percentage (%)
Barley	46
Wheat bran	35
Yellow corn	10
Soybean meal	8
Mineral and vitamin mix	1

Table (2): The chemical composition of the feed ingredients (% on dry matter basis).

Ingredient	Dry Matter	Crude Protein	Ether Extract	Crude Fiber	Ash	Nitrogen-Free Extract
Barley	90.32	10.50	2.12	6.11	2.99	78.28
Wheat bran	90.42	13.50	4.61	10.71	4.35	66.83
Soybean meal	91.70	45.90	7.21	2.51	6.14	38.24
Yellow corn	92.40	8.70	4.50	7.31	2.33	77.16
Wheat straw	91.00	3.00	1.30	36.28	7.00	45.40

Al-Khawaja et al. (1978)

Table (3): The chemical composition of the diet used in this study (% on dry matter basis).

Ingredient	Dry Matter	Crude Protein	Ether Extract	Crude Fiber	Ash	Nitrogen-Free Extract
Barley	24.92	2.90	0.59	1.69	0.83	21.61
Wheat bran	18.99	2.84	0.97	2.25	0.91	14.03
Soybean meal	4.40	2.20	0.35	0.12	0.29	1.84
Yellow corn	5.54	0.52	0.27	0.44	0.14	4.63
Wheat straw	36.40	1.20	0.51	14.51	2.80	18.16
Total	**90.25**	**9.66**	**2.69**	**19.01**	**4.97**	**60.27**

Notes:

1. The percentages were calculated based on a feeding ratio of 60% concentrate and 40% wheat straw.
2. The metabolizable energy (ME) is 11.26 MJ/kg dry matter.
3. The ME was calculated according to the formula of the UK Ministry of Agriculture, Fisheries and Food (MAFF, 1975):

$$\textbf{ME (MJ/kg DM)} = 0.12 \times CP + 0.31 \times EE + 0.05 \times CF + 0.14 \times NFE$$

Where:

CP = Crude Protein, EE = Ether Extract, CF = Crude Fiber, NFE = Nitrogen-Free Extract.

Results and discussion:

Initial and Final Body Weight:

The results of Table (4), which presents the effect of adding different levels of slow-release urea on the average initial and final body weight (kg) of Arabi lambs (mean ± standard deviation), indicate that there were no significant differences in the initial body weight among the experimental treatments T1, T2, T3, and T4, which recorded approximately 28.82, 29.81, 29.49, and 29.76 kg, respectively. On the other hand, the table shows significant differences ($p<0.05$) in final body weight among the experimental treatments when different concentrations of slow-release urea were added to the lambs' diets compared to the control group. Treatment T4 achieved the highest final weight, about 46.51 kg, without significant difference from treatment T3, which recorded approximately 45.48 kg. Treatment T2 had a mean final weight of 43.12 kg, while the control group recorded the lowest final weight of 40.48 kg. These results reflect a growth response in lamb fed diets with higher levels of slow-release urea. The results also show that the experimental treatments containing various levels of slow-release urea had no significant effect on the initial body weight of lambs, which is expected since the animals were distributed among treatments based on body weight uniformity. This ensured the neutrality of the experimental design and eliminated potential bias due to individual differences at the start of the study. Such uniformity is a critical step in accurately assessing the effects of nutritional treatments (McDonald et al., 2011). Regarding final body weight, the results revealed significant differences between treatments. Lambs that received diets containing higher levels of slow-release urea (T3 and T4) had significantly higher final weights compared to the control group. This improvement in growth may be attributed to the fact that slow-release urea serves as a non-protein nitrogen source that releases nitrogen gradually in the rumen, allowing better synchronization with the availability of fermentable energy, and thus enhancing microbial protein synthesis efficiency (Krehbiel et al., 2006; Leng and Preston, 1985). Owens et al. (1980) pointed out that using slow-release nitrogen sources in ruminant diets could improve microbial growth in the rumen, which positively affects fiber digestion and the animal's utilization of other nutrients, thereby supporting growth and increasing average daily weight gain. Chalupa (1975) also emphasized that the balance between nitrogen and energy availability in the rumen is a crucial factor in improving feed efficiency, especially when using slow-release sources that reduce nitrogen loss from excess free ammonia. Zhang et al. (2021) reported that adding slow-release urea at levels of 1.5% or 2% in lamb diets significantly improved final body weight compared to conventional diets, due to improved rumen fermentation, nitrogen utilization efficiency, and better nutrient absorption. Hallajian et al. (2021), in a study on lactating Holstein cows, found that replacing soybean protein with slow-release urea at levels of 0%, 50%, 75%, and 100% resulted in no significant differences ($P<0.05$) in body weight, which measured 614.83, 629.25, 652.85, and 672.23 kg, respectively. Similarly, Saro et al. (2023), in a study aiming to compare fast- and slow-release urea types in sheep diets, showed no significant differences ($P<0.05$) in final body weight, which was 49.6 and 48.1 kg, respectively. Safavi and Chaji (2022) found that adding slow-release urea to sheep diets at 1.8% and 1.69%, compared to conventional fast-release urea at 1.60%, did not result in significant differences ($P<0.05$) in average final live body weight, which was 35.68, 35.74, and 35.50 kg, respectively. Hashem and Tayeb (2024) reported that replacing fast-release urea with slow-release urea at different levels (0%, 0.6%, 1.2%, and 1.8%) in the diets of Iraqi Awassi sheep did not significantly affect ($P<0.05$) final live body weight, which was 56.58, 60.41, 53.20, and 57.75 kg, respectively.

Table (4): Effect of Adding Different Levels of Slow-Release Urea on the Average Initial and Final Body Weight (kg) of Arabi Lambs (Mean ± Standard Deviation)

Treatments	Traits	
	Initial Weight (kg)	Final Weight (kg)
T1	28.82 ± 1.12	40.48^{c} ± 1.02
T2	29.81 ± 1.02	43.12^{b} ± 1.08
T3	29.49 ± 1.70	45.48^{a} ± 1.72
T4	29.76 ± 1.00	46.51^{a} ± 1.04
Significance level	Not significant	0.05

T1: Control group without addition. T2: Treatment with 1% slow-release urea. T3: Treatment with 1.5% slow-release urea. T4: Treatment with 2% slow-release urea. Note: Means with different superscript letters differ significantly at the 0.05 probability level.

Daily and Total Weight Gain:

The experimental results demonstrated a significant effect ($p < 0.05$) of adding different levels of slow-release urea in the diet on both daily and total weight gain of lambs compared to the control treatment. The improvement in production performance progressively increased with higher levels of slow-release urea in the diet, as evidenced by the consecutive rise in daily and total weight gain values from T1 to T4. The daily weight gain in the control treatment (T1) was 129.53 g/day, the lowest among the treatments, while T4 (2% slow-release urea) recorded the highest daily growth rate of 186.11 g/day. This trend was similarly reflected in total weight gain, where T1 had the lowest value of 11.66 kg compared to 16.75 kg in T4. The significant differences among treatments clearly indicate that the inclusion of slow-release urea enhanced the final performance of the lambs. This improvement is related to the physiological effects of urea in the rumen. When conventional (fast-release) urea is added, large amounts of ammonia are released over a short time, which may exceed the capacity of rumen microbes to utilize it for protein synthesis. Consequently, excess ammonia is absorbed into the bloodstream, converted to urea in the liver, and excreted in the urine (Chalupa, 1975). In contrast, slow-release urea provides a gradual release of nitrogen, leading to better synchronization between nitrogen availability and the energy derived from carbohydrate fermentation. This synchronization is essential for maximizing microbial growth in the rumen (Leng and Preston, 1985), thereby increasing microbial protein synthesis, the primary source of absorbable amino acids in ruminants—which reflects improved nutritional efficiency and growth rates. Krehbiel et al. (2006) and Owens et al. (1980) confirmed that incorporating slow-release nitrogen sources in ruminant diets can improve feed conversion efficiency and increase weight gain, especially under conditions where fermentable energy sources such as grains or concentrates are available. The significant difference between treatments T3 and T4 was slight and sometimes nonsignificant in similar studies, suggesting that a 1.5% level of slow-release urea might represent an economically efficient level balancing production performance and cost. Sevim and Önol (2019) reported that adding slow-release urea at levels of 0% and 10% to diets of male sheep and goats significantly ($P<0.001$) increased production performance. The average daily weight gain for male sheep was 71.15 g/day compared to 62.95 g/day for the control, while for male goats, it was 92.28 g/day compared to 83.78 g/day for the control. Hallajian et al. (2021), studying lactating Holstein cows, found that replacing soybean protein with slow-release urea at 0%, 50%, 75%, and 100% did not result in significant differences ($P < 0.05$) in daily weight gain rates of 0.36, 0.51, 0.57, and 0.74 kg/day, respectively. Hashem and Tayeb (2024) found that replacing fast-release urea with slow-release urea at levels of 0%, 0.6%, 1.2%, and 1.8% in diets of Iraqi Awassi sheep had no significant effect ($P < 0.05$) on total weight gain, which reached 8.37, 9.72, 6.74, and 5.67 kg, respectively. Similarly, Saro et al. (2023) conducted a study comparing fast- and slow-release urea in sheep diets and found no significant differences ($P<0.05$) in average daily weight gain between treatments, with gains of 295 and 277 g/day, respectively.

Table (5): Effect of Adding Different Levels of Slow-Release Urea on the Average Daily Weight Gain (kg/day) and Total Weight Gain (kg) of Arabi Lambs (Mean ± Standard Deviation)

Treatments	Traits	
	Daily Weight Gain (kg)	**Total Weight Gain (kg)**
T1	$129.53^{d} \pm 1.11$	$11.66^{d} \pm 0.10$
T2	$147.86^{c} \pm 1.83$	$13.31^{c} \pm 0.16$
T3	$177.69^{b} \pm 2.42$	$15.99^{b} \pm 0.22$

T4	$186.11^{a} \pm 2.00$	$16.75^{a} \pm 0.18$
Significance level	0.05	0.05

T1: Control group without addition. T2: Treatment with 1% slow-release urea. T3: Treatment with 1.5% slow-release urea. T4: Treatment with 2% slow-release urea. Note: Means with different superscript letters differ significantly at the 0.05 probability level.

Feed Intake and Feed Conversion Efficiency:

The data presented in Table (6) indicate that there were no significant differences among the experimental treatments regarding total and daily feed intake (kg), with values ranging from 90.08 to 93.33 kg for total feed intake and 1.00 to 1.04 kg for daily feed intake. This uniformity reflects that the palatability of the ration was not affected by the inclusion of slow-release urea, even at the highest inclusion level (2%), which is a positive indicator in practical feeding applications. The close values in daily and total feed consumption among treatments suggest that the addition of slow-release urea did not negatively influence feed acceptance or intake rate. Van Soest (1994) reported that one of the challenges of using conventional (fast-release) urea is the potential for changes in feed taste or ammonia toxicity. However, this issue is mitigated with slow-release urea sources, which gradually release ammonia, making them safer and more acceptable to animals. Regarding feed conversion efficiency (FCE), the results showed significant differences ($p<0.05$) among treatments. The best FCE was observed in treatment T4 (2% slow-release urea), with an average of 5.57 kg feed intake per kg of weight gain, followed by T3 with 5.77 kg/kg. The least efficient conversion ratios were recorded in T1 (control) and T2, with 7.72 and 6.99 kg/kg, respectively. These differences suggest that slow-release urea, when added at moderate to high levels, contributes directly to improving the efficiency of feed utilization and the rate of weight gain per unit of feed consumed. Feed conversion efficiency is a critical indicator of how well the animal utilizes available nutrients. The results indicate that T3 and T4 treatments achieved a significant improvement in this parameter compared to the control. This improvement can be attributed to the synchronization between nitrogen release (from slow-release urea) and fermentable energy, which enhances microbial protein synthesis in the rumen (Leng and Preston, 1985; Chalupa, 1975). Supporting this interpretation, Russell et al. (1992) reported that improving nitrogen availability in the rumen environment boosts microbial growth responsible for fiber digestion, thereby enhancing overall digestibility and nutrient utilization. The results clearly demonstrate a gradual improvement in FCE as the level of slow-release urea increased from T2 to T4, suggesting a positive correlation between improved urea inclusion and lamb performance within the tested range. However, the absence of a significant difference between T3 and T4, coupled with a marked difference from T1, might indicate that the optimal inclusion level is likely between 1.5% and 2%, beyond which benefits may plateau or decline. Safavi and Chaji (2022) reported that including slow-release urea in sheep diets at levels of 1.69% and 1.8%, compared to 1.60% of conventional urea, did not result in significant differences ($P<0.05$) in feed conversion ratios (7.32, 7.84, and 7.32, respectively), nor in daily feed intake (1025.47, 1020.12, and 1024.97 g/day, respectively). Similarly, Silva et al. (2023) found a significant ($P<0.05$) increase in feed intake when slow-release urea was added to sheep rations at varying levels (1%, 1.5%, and 2%) of total dry matter, compared to fast-release urea. They also noted that 1% of fast-release urea did not affect animal health and improved nutrient digestibility. Hashem and Tayeb (2024) observed that substituting conventional urea with slow-release urea at levels of 0%, 0.6%, 1.2%, and 1.8% in diets for Iraqi Awassi sheep did not significantly affect ($P<0.05$) the daily feed intake, which averaged 1.511, 1.510, 1.495, and 1.484 kg/day, respectively. Furthermore, Saro et al. (2023), in a comparative study between fast- and slow-release urea in sheep diets, found no significant differences ($P<0.05$) in feed conversion ratios (4.92 and 4.91 g/g, respectively), nor in average dry matter intake (1440 and 1350 g/day).

Table (6): Effect of Adding Different Levels of Slow-Release Urea on the Average Total and Daily Feed Intake (kg), and Feed Conversion Efficiency (kg feed intake/kg weight gain) in Awassi Lambs (Mean ± Standard Deviation)

Treatments	Traits		
	Total Feed Intake (kg)	Daily Feed Intake (kg/day)	Feed Conversion Efficiency (kg/kg)
T1	90.08 ± 2.74	1.00 ± 0.07	$7.72^{b} \pm 0.28$
T2	93.12 ± 8.28	1.03 ± 0.08	$6.99^{b} \pm 0.57$
T3	92.29 ± 7.51	1.02 ± 0.06	$5.77^{a} \pm 0.45$
T4	93.33 ± 7.08	1.04 ± 0.04	$5.57^{a} \pm 0.38$
Significance level	N. S	N. S	0.05

T1: Control group without addition. T2: Treatment with 1% slow-release urea. T3: Treatment with 1.5% slow-release urea. T4: Treatment with 2% slow-release urea. Note: Means with different superscript letters differ significantly at the 0.05 probability level.

Conclusion:

Supplementing lamb diets with slow-release urea, particularly at 1.5–2%, enhances final body weight, daily gain, and feed conversion efficiency without negatively affecting feed intake. This strategy offers a practical means to improve nitrogen utilization and growth performance in ruminant feeding systems, particularly under intensive fattening conditions.

References:

1. Adesogan, A. T., Havelaar, A. H., McKune, S. L., Eilittä, M., & Dahl, G. E. (2020). Animal source foods: sustainability problem or malnutrition and sustainability solution? Perspective matters. *Global Food Security*, 25, 100325.
2. Al-Khawaja, A. K., Abdallah, I., & Abdul-Ahad, S. (1978). Chemical composition and nutritive value of Iraqi feedstuffs. Bulletin issued by the Nutrition Division, General Directorate of Animal Resources, Ministry of Agriculture, Iraq.
3. Chalupa, W. (1975). Rumen bypass and protection of proteins and amino acids. *Journal of Dairy Science*, *58*(8), 1198–1218.
4. Chalupa, W. (1975). Rumen bypass and protection of proteins and amino acids. *Journal of Dairy Science, 58*(8), 1198–1218.
5. Dorling, D. (2021). World population prospects at the UN: are our numbers not our problem? In The struggle for social sustainability (pp. 129-154). Policy Press.
6. Hallajian, S., Fakhraei, J., Yarahamdi, H. M., & Khorshidi, K. J. (2021). Effects of replacing soybean meal with slow-release urea on milk production of Holstein dairy cows. *South African Journal of Animal Science*, *51*(1), 53-64.
7. Hallajian, S., Fakhraei, J., Yarahamdi, H. M., & Khorshidi, K. J. (2021). Effects of replacing soybean meal with slow-release urea on milk production of Holstein dairy cows. *South African Journal of Animal Science*, *51*(1), 53-64.
8. Hashem, W., & AM Tayeb, M. (2024). The impact of using slow-release urea instead of fast-release urea in feed on the milk production of Awassi sheep and some blood traits. *Egyptian Journal of Veterinary Sciences*, *55*(2), 443-451.
9. Henchion, M., Hayes, M., Mullen, A., Fenelon, M. and Tiwari, B. (2017). Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium. *Foods*, 6 (53): 1-21.

10. Krehbiel, C. R., Rust, S. R., Zhang, G., & Gilliland, S. E. (2006). Bacterial direct-fed microbials in ruminant diets: performance response and mode of action. *Journal of Animal Science, 81*(E. Suppl_2), E120–E132.

11. Krehbiel, C. R., Rust, S. R., Zhang, G., & Gilliland, S. E. (2006). Bacterial direct-fed microbials in ruminant diets: performance response and mode of action. *Journal of Animal Science, 81*(E. Suppl_2), E120–E132.

12. Króliczewska, B., Pecka-Kiełb, E., & Bujok, J. (2023). Strategies used to reduce methane emissions from ruminants: controversies and issues. *Agriculture*, 13(3), 602.

13. Leng, R. A., & Preston, T. R. (1985). Manipulation of feeding and the rumen ecosystem. In L. P. Milligan et al. (Eds.), *Ruminant Physiology*.

14. Leng, R. A., & Preston, T. R. (1985). Manipulation of feeding and the rumen ecosystem. In L. P. Milligan et al. (Eds.), *Ruminant Physiology*.

15. MAFF (1975). Ministry of Agriculture and Fisheries/ Food Dept. of Agric. And Fisheries for Scotland: Energy Allowances and Feed Systems for Ruminants. Technical Bulletin, 33. 1st published.

16. McDonald, P., Edwards, R. A., Greenhalgh, J. F. D., Morgan, C. A., Sinclair, L. A., & Wilkinson, R. G. (2011). *Animal Nutrition* (7th ed.). Pearson.

17. NRC (2007). Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. National Academy Press, Washington, D.C.

18. Owens, F. N., Zinn, R., & Kim, Y. K. (1980). Limits to starch digestion in the ruminant small intestine. *Journal of Animal Science, 50*(1), 225–235.

19. Owens, F. N., Zinn, R., & Kim, Y. K. (1980). Limits to starch digestion in the ruminant small intestine. *Journal of Animal Science, 50*(1), 225–235.

20. Ravi, K. R., P., Srinivasa Kumar, D., Raghava Rao, E., Venkata Seshiah, C., Sateesh, K., Pradeep Kumar Reddy, Y., & Hyder, I. (2019). Assessment of eco-sustainability vis-vis zoo-technical attributes of soybean meal (SBM) replacement with varying levels of coated urea in Nellore sheep (Ovis aries). *PLoS One*, *14*(8), e0220252.

21. Reddy, P. R. K., Kumar, D. S., Rao, E. R., Seshiah, C. V., Sateesh, K., Rao, K. A., ... & Hyder, I. (2019). Environmental sustainability assessment of tropical dairy buffalo farming vis-a-vis sustainable feed replacement strategy. *Scientific Reports*, *9*(1), 16745.

22. Russell, J. B., O'Connor, J. D., Fox, D. G., Van Soest, P. J., & Sniffen, C. J. (1992). A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. *Journal of Animal Science, 70*(11), 3551–3561.

23. Safavi, S., & Chaji, M. (2022). The effect of slow-release urea sources on digestibility of nutrients and growth performance of fattening lambs fed rations containing low-quality forage. Iranian Journal of Animal Science Research, 14(2), 189-200.

24. Sarmah, D., Rather, M. A., Sarkar, A., Mandal, M., Sankaranarayanan, K., & Karak, N. (2023). Self-cross-linked starch/chitosan hydrogel as a biocompatible vehicle for controlled release of drug. *International Journal of Biological Macromolecules*, *237*, 124206.

25. Saro, C., Degeneffe, M. A., Andrés, S., Mateo, J., Caro, I., López-Ferreras, L., ... & Giráldez, F. J. (2023). Conventional feed-grade or slow-release coated urea as sources of dietary nitrogen for fattening lambs. *Animals*, *13*(22), 3465.

26. Sevim, Ö., & Önol, A. G. (2019). Supplemental slow-release urea and non-structural carbohydrates: effect on digestibility and some rumen parameters of sheep and goats. *JAPS: Journal of Animal & Plant Sciences*, *29*(1).

27. Van Soest, P. J. (1994). *Nutritional Ecology of the Ruminant* (2nd ed.). Cornell University Press.
28. Wattiaux, M. A., Uddin, M. E., Letelier, P., Jackson, R. D., & Larson, R. A. (2019). Invited Review: Emission and mitigation of greenhouse gases from dairy farms: The cow, the manure, and the field. *Applied Animal Science*, 35(2), 238-254.
29. Zhang, Y., Wang, M., Zhou, Y., Cao, Y., & Yang, H. (2021). Effects of slow-release urea supplementation on rumen fermentation, nutrient digestibility, and growth performance in lambs. *Animals*, *11*(6), 1742.