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DEVELOPMENT OF DIET FORMULATIONS FOR LINDA BREED GEESE OF DIFFERENT AGE GROUPS TO IMPROVE FEEDING EFFICIENCY AND METABOLIC PROCESSES

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ABSTRACT

Goose production requires nutritionally balanced diets that support rapid growth, efficient nutrient utilization, and stable metabolic processes during early development. For Linda Goslings, optimizing feed mixtures with locally available ingredients and high-quality protein sources is important for improving feeding efficiency under farm conditions. The aim of this study was to investigate the effect of diet composition on nutrient digestibility and metabolic processes in Linda goslings. The experiment was conducted at the West Kazakhstan Agrarian and Technical University named after Zhangir Khan, where one control and two experimental groups were formed. The control group received the basic feed mixture, while the diets of experimental groups II and III were supplemented with fish meal at levels of 3% and 6%, respectively. The chemical composition of the feeds and the digestibility coefficients of dry matter, crude protein, fat, fiber, and nitrogen-free extractives were evaluated. In addition, nitrogen and calcium balance, as well as energy metabolism, were assessed. The inclusion of fish meal increased the digestibility of the main nutrients, with the highest values generally observed in experimental group III. At 35–42 days of age, males in group III showed dry matter digestibility of 77.9%, crude protein 87.7%, crude fat 61.8%, crude fiber 38.7%, and nitrogen-free extractives 81.3%. By 63 days of age, nitrogen utilization reached 53.3%, calcium utilization 53.7%, metabolizable energy 3.37 MJ, and net energy gain 1.18 MJ per head. The obtained results indicate that the developed feed mixtures with fish meal improve nutrient utilization and metabolic processes in Linda goslings, with the most pronounced effect observed at the 6% inclusion level. The high biological efficiency of the developed diets can enhance feeding quality and increase productivity in goose production.

***Keywords*:** Chemical composition, Digestibility, Nutrients, Energy metabolism, Feed efficiency.

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1. INTRODUCTION

In recent decades, goose breeding has become one of the most demanded branches of agriculture, especially in countries with developed agricultural traditions (Qi et al., 2025). Despite its popularity, successfully breeding geese requires careful attention to nutrition and proper conditions to meet their physiological needs. Geese are herbivorous birds for which proper diet and grazing space are key factors in health and productivity (El Sabry & Almasri, 2023; Nugmanova et al., 2024a).

One of the main feed features for geese is the need for high-quality grasses, which form the basis of their diet (Nigusse & Birhane, 2024). In addition to grasses, geese also need cereals, such as wheat, barley, and maize, and root crops, which serve as sources of carbohydrates and vitamins (Ali et al., 2026; Chen et al., 2026). The diet of geese should be varied and balanced to ensure that they receive adequate levels of proteins, fats, and carbohydrates (Doğan, 2024). Furthermore, it is important to account for seasonal changes in the diet, especially in winter when access to fresh grass is limited and special feeds or supplements need to be used to compensate for nutrient deficiencies (Mukherjee et al., 2021; Wang et al., 2023; Reda et al., 2025; Bachinskaya, 2026).

A crucial aspect of feeding waterfowl is to achieve the right balance of nutrients required for growth, reproduction, and health. Important findings on the effects of feed additives have been reported (Islam et al., 2025). A 2023 study showed that adding fermented feeds can significantly improve growth, antioxidant activity, and gut health in geese (Nekrasov et al., 2019; Nugmanova et al., 2024b). This underscores the importance of developing breed-specific diets to meet the needs of individual breeds.

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Similar results were obtained in a study in which ducks were fed bee honeycomb extracts. Adding these extracts to feed improved egg quality, increased antioxidant levels, and boosted immune functions in laying hens (Zhu et al., 2024). These results show the great promise of natural additives in improving the productivity and health of poultry. Feed additives are gaining importance in the poultry industry due to their wide range of benefits, including stimulating growth, increasing productivity, enhancing immunity, and protecting health (Semenov et al., 2021; Du et al., 2023; Shevchenko, 2024).

Biologically active substances in compound feeds for goslings improve nutrient digestibility and increase productivity. Research shows that these substances benefit poultry growth and safety and reduce feed costs per unit of weight gain. In addition, fixed feeding frequency has no negative effect on growth performance and carcass characteristics compared to free-ranging (Cui et al., 2014; Liu et al., 2020; Zhang et al., 2024).

Thus, incorporating biologically active additives and fermented feed into the goose diet positively affects nutrient digestibility, productivity, and feed efficiency. Further research in this area will help to develop optimal feeding schemes to maximize the productivity of geese.

Recent studies have greatly contributed to our understanding of the nutritional and housing needs of waterfowl. Findings demonstrate that properly selected diets and optimal housing conditions can significantly increase productivity and improve poultry health. Introducing the latest feed additives and improved housing conditions should be a priority for waterfowl breeding in the coming years.

2. MATERIALS AND METHODS

Farm experiments were conducted at West Kazakhstan Agrarian and Technical University named after Zhangir Khan to study the digestibility of feeds in Linda goslings. As part of this research, we analyzed the nutritional value of feeds, developed optimal diets using locally sourced feed resources, and assessed their impact on poultry productivity.

To achieve the set objectives, we conducted a comprehensive assessment of the composition of feeds and feed additives selected from available local sources. Based on the obtained data, mixed feed recipes were developed for each sex and age group of goslings, accounting for the physiological needs of poultry at different growth stages.

The analyzed feeds included basic cereals (barley, wheat, millet), legumes (soybean, peas), and processing by-products (wheat bran, sunflower cake). Seashells and fish meal were added to the diet to ensure a complete amino acid composition. The nutritional value of the feeds was determined at the zootechnical laboratory of the Experimental Center of West Kazakhstan Agrarian and Technical University named after Zhangir Khan.

During the research, we developed and tested different feed mixture recipes adapted to each growing period. The components were selected to increase nutrient digestibility, improve metabolism, and minimize nitrogen and calcium losses. Our findings will provide grounds for optimizing gosling feeding systems, increasing the efficiency of local resource use, and improving poultry productivity in the West Kazakhstan Region.

According to established rearing practices, young goslings were kept in battery cages for the first 14 days of their lives to ensure optimal microclimate conditions and ease of care. From day 14 to day 63, the goslings were kept on deep bedding to promote the development of natural behavior and strengthen the musculoskeletal system.

As part of the study, specialized diets were created for different sexes and age groups, considering the physiological needs of poultry to ensure balanced nutrition at all rearing stages. To conduct the study, one control group and two experimental groups were formed. Each group included 50 male and 50 female goslings selected by the analogous-group method based on live weight and general development (Table 1). The experiment covered the period from 1 to 63 days of age.

Table 1: Experimental design.

Age, weeks	Group	Total number, n	Feeding scheme
1–63 days	Control 1	50/50	Basic feed mix recipe
	Experimental 2	50/50	Basic feed mix recipe + 3% Fish meal
	Experimental 3	50/50	Basic feed mix recipe + 6% Fish meal

The division into groups was performed based on individual homogeneity, which is an important factor for the accuracy of subsequent calculations and data analysis. This approach allowed us to evaluate the effect of experimental feed mixtures on growth, development, and metabolic processes in goslings under the conditions of this study as accurately as possible.

All groups had the same housing conditions, which excluded the influence of external factors on the results. The control group 1 received a standard diet without additional components. The diets of goslings in experimental group 2 included 3% fish meal, and experimental group 3 additionally received 6% fish meal.

This approach allowed us to test the effect of different levels of this protein supplement on growth, development, and nutrient digestibility in young geese. The goal of adding fish meal to feed mixtures was to

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increase the biological value of the diet by providing additional intake of easily digestible proteins, essential amino acids, and minerals.

Clinical examinations of goslings were performed at all stages of the experiment to assess their general condition, detect potential pathologies, and assess the effects of experimental diets on physiological parameters. Examinations were conducted daily, and more detailed examinations were performed once a week. The parameters considered during clinical examinations were appearance, activity, behavior, and the condition of the plumage, eyes, beak, feet, and skin.

Nutrient digestibility was analyzed using the classical method of balance studies. During the control period, bedding and droppings were sampled to quantify undigested feed components. The digestibility coefficient was calculated as:

$$DC = \frac{(Nf - Ne)}{Nf} \times 100 \quad (1)$$

where:
DC — digestibility coefficient, %;
Nf — nutrient content of the feed;
Ne — nutrient content of excrement.

The poultry were housed in accordance with sanitary and hygienic requirements and had free access to water and food. All birds were managed under the same sanitary and hygienic conditions, with identical access to feed and water. The experimental design, therefore, minimized the influence of housing-related factors and allowed the effect of diet composition to be evaluated more clearly.

The balance trial lasted 5–7 days. During this period, feed intake was recorded daily, feed residues were weighed, and excreta were collected for each experimental subgroup. Feed and excreta samples were analyzed for dry matter, crude protein, crude fat, crude fiber, nitrogen-free extract, nitrogen, and calcium. Digestibility coefficients were calculated by comparing nutrient intake with nutrient excretion.

Nitrogen and calcium balance were also determined by collecting all excreted material. First, the intake of nitrogen and calcium was determined by analyzing the chemical composition of the consumed feed. Then the excretion of nitrogen and calcium with droppings was determined. Balance was calculated as the difference between intake and excretion, and the efficiency of use was calculated as a percentage of total intake.

The results were subjected to statistical analysis using variation statistics. Mean values (M), standard error (Sx), standard deviation (σ), and coefficient of variation (CV) were calculated in MS Excel and Statistica 10.0. Inter-group differences were assessed using Student's t-test at $P<0.05$. The values presented in the tables should be interpreted as mean ± Sx; statistically significant differences should be marked in the final version after verification of the primary dataset.

This comprehensive approach enabled us to objectively evaluate the effects of varying levels of fish meal in the diet on the growth, productivity, and physiological development of goslings. The results will be used to optimize nutrition and increase waterfowl productivity in the West Kazakhstan Region.

3. RESULTS

The analysis of the chemical composition and nutritional value of feeds presented in Table 2 provides information on their energy and biological value. These data were then used to formulate feed mixtures adapted to the physiological needs of poultry, considering the stage of growth and productivity.

We found that metabolic energy content ranges from 7.3 to 11.6 MJ. The highest levels are found in soybean meal (11.6 MJ) and soy (11.7 MJ), indicating a high energy value of these components. The highest content of crude protein per 1 kg of dry matter is observed in feeds classified as technical wastes, including sunflower cake and fish meal, where it ranges from 118.6 to 616.9 g.

The comparative analysis of grain feeds shows that soy contains more protein compared to traditional cereals, outperforming barley by 67.8 g (31.0%), wheat by 100.0 g (45.7%), millet by 112.9 g (51.6%), and maize by 122.1 g (55.9%). Essential amino acids, such as lysine, methionine+cystine, and tryptophan, are particularly important in the diet and have a significant effect on poultry productivity and healthy development. The highest content of these amino acids was found in soy and fish meal, ranging within 41.7–44.6 g for lysine and 7.6–20.7 g for methionine+cystine.

Based on data on the chemical composition of feeds used on farms in West Kazakhstan, we developed optimal feed mixture recipes. These mixes are distinguished by high nutritional value and balanced compositions, which help to maximize the productive potential of poultry.

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Table 2: Chemical composition of feeds on the farm in the West Kazakhstan Region.

Parameters	Feed type												
	Sudan grain	Crushed maize	Millet	Rye	Sorghum	Barley	Wheat bran	Soy	Sunflower cake	Soybean meal	Wheat bran	Sunflower meal	Fish meal
ME, MJ	9.2	10.1	9.5	9.7	9.8	10.9	11.2	11.5	10.7	11.6	7.3	10.8	11.1
Dry matter, g	850	847.3	846.2	860.7	848.7	886.8	837.5	843.8	908	893.8	839.7	890	880.9
Crude protein, g	108	96.5	105.7	109	101.2	150.8	118.6	218.6	356.4	387.6	149.6	361.5	616.9
Digestible protein (DP), g	81.6	65.4	67	72.6	69.2	107.8	78.9	138.3	213.7	231.7	83.6	208.4	413.7
Lysine, g	3.6	2.9	2.1	3.8	2.6	5	3.1	41.7	12.6	22.5	3.4	12.1	44.6
Methionine+cystine, g	3.2	2.6	4.5	3.3	2.3	2.3	4.6	7.6	14.3	11.3	3.8	9.8	20.7
Tryptophan, g	1.1	0.9	1.6	0.9	0.6	0.8	1.2	2.7	4.7	2.3	0.6	4.6	6.1
Crude fat, g	16.1	33.6	32	17	26.9	25.4	23.9	36.8	56.3	24.4	28.4	32.3	87
Crude fiber, g	37	28.2	37	19.7	29.8	27.4	17.6	37.9	98.2	59.4	79.1	106.7	0
NFE, g	573	663	562	664.4	649	870.4	672	0	224.5	308.4	511	201.3	46
Sugar, g	15	22	13	12	39	12.4	18.6	0	56.4	86.4	33	51.4	0
Calcium, g	1.5	0.4	0.8	0.6	0.9	0.8	0.5	3.9	6.3	1.9	1.1	2.7	30.1
Phosphorus, g	3.4	3.8	5.3	2.3	3.2	2.8	3.2	6.8	15.1	9.8	9.8	10.8	22.4
Magnesium, g	1.2	2.8	0.8	0.6	0.8	1.9	1.6	2.1	3.7	2.7	3.3	2.60	3.4
Potassium, g	5.4	4.2	3.6	4.3	2.7	4.7	5	19.7	8.4	16.9	7.8	5.6	12.5
Sulfur, g	1.4	1.1	0.2	0.2	0.2	0	0.1	0.1	4.7	2.5	1.1	1.9	3.8
Iron, mg	31.8	7.6	33.7	62.5	45.1	1.1	43.9	112	118	203.4	131	282.5	81.5
Copper, mg	4.9	6	13.4	6.2	8.6	7.5	6.2	13.1	15.1	14.1	8.5	21.5	11.1
Zinc, mg	22.5	24.2	27.8	18.9	11.6	28.7	22.6	26	46.6	37.4	53	37.4	76.4
Manganese, mg	20.5	10.7	15.7	29.6	14.5	36.8	47.6	18.6	40.1	31	101.2	16.8	8.6
Cobalt, mg	0.07	0.4	0.01	0.05	0.1	0.4	0.3	0.02	0.14	0.09	0.3	0.21	0.3
Carotene, mg	1.3	2.1	1.2	0.3	0.9	0	2.4	1.1	2.4	0.08	1.7	0	0

A key factor determining the efficiency of waterfowl breeding is complete and balanced feeding. The diets were formulated to meet physiological nutrient needs, allowing for high productivity. Based on our research, we developed specialized recipes of feed mixtures for different sex and age groups of Linda geese bred on farms in the West Kazakhstan Region. Experimental groups with different feed variants were formed for the rearing periods of 1–14 days and 14–63 days (Table 3).

The developed feed mixture recipe provides an optimal nutrient ratio, promoting easy digestion in young goslings during the first days of life. The composition of the control group's feed mixture included 13 components, whereas the diet of the experimental group contained 14 ingredients.

A significant difference is the amount of Sudan grass: its content in the feed mixes was lowered by 3–6% in the experimental groups compared to the control. This absence, however, was compensated for by the introduction of fish meal, which increases the overall nutritional value of the feed and provides goslings with the amino acids vital for their proper growth and development. This approach improved the digestibility of the feed and increased its biological effectiveness, thus supporting the health and stable immunity of goslings.

In the second rearing period, the developed diet provided 1.00–1.02 MJ of metabolizable energy (ME) and 16.93–19.67% of crude protein (Table 4). In the feed mixture designed for the experimental group, the crude protein content was 8.24–15.27% higher than in the control group, promoting more intensive growth of goslings.

In addition, mineral composition analysis shows that the feed for the experimental groups contained more micro- and macroelements compared to the control diet. In particular, the level of phosphorus was higher by 6.29–11.84%, and magnesium content exceeded the control by 8.33–16.67%.

The analysis of the amino acid profile reveals a similar trend: lysine content in the formulation for experimental group 3 is higher by 23.3%, and methionine+cystine levels exceed those in the control group by 17.74%. The diet developed for goslings in the experimental group has a small but significant advantage in nutrient and mineral content, which could favorably affect their digestion and overall physiological development.

The study of nutrient digestibility plays a key role in improving the efficiency of poultry feed, including for geese. Determination of the digestibility of key nutrients, such as proteins, fats, carbohydrates, minerals, and vitamins, enables diet adjustments to minimize nutrient losses and maximize bioavailability (Sukhanova & Grishin, 2021; Sukhanova & Yaroslavtsev, 2022; Alabi & Adedokun, 2025; Goksen et al., 2025).

Digestibility analysis helps to assess how efficiently the bird's body utilizes different feed ingredients and to identify the effects of new ingredients or feed additives on digestive processes. This is particularly important when developing feed mixtures based on locally sourced resources, as the digestive systems of waterfowl differ from those of other farm animal species.

The digestibility of dry matter is higher in the experimental groups compared to the control. In the male geese of experimental group 3, this parameter reaches 77.4%, surpassing the control by 2.6%. Females also show certain improvement, although less pronounced.

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Table 3: Diets of young geese at the age of 1–14 days by experimental groups

Parameters		Introduction %		
		Experimental group		
		Control 1	Experimental 2	Experimental 3
Sudan grain		16	13	10
Crushed maize		5	5	5
Millet		2	2	2
Rye		2	2	2
Sorghum		2	2	2
Barley		10	10	10
Crushed wheat		20	20	20
Soy		7	7	7
Cake		10	10	10
Soybean meal		9	9	9
Wheat bran		5	5	5
Sunflower meal		10	10	10
Fish meal		–	3	6
Seashell		2	2	2
Feed mix recipe content:				
Metabolizable energy	MJ	1.03	1.03	1.03
	Kcal	243.62	246.01	248.40
Dry matter, g		84.70	84.79	84.88
Crude protein, g		19.67	21.19	22.72
Digestible protein, g		12.40	13.39	14.39
Lysine, g		0.96	1.08	1.21
Methionine+cystine, g		0.61	0.67	0.72
Tryptophan, g		0.20	0.21	0.23
Crude fat, g		2.81	3.03	3.24
Crude fiber, g		4.78	4.67	4.55
NFE, g		47.97	46.39	44.80
Sugar, g		2.99	2.95	2.90
Phosphorus, g		0.63	0.69	0.74
Magnesium, g		0.29	0.29	0.30
Potassium, g		0.74	0.77	0.79
Sulfur, g		0.13	0.13	0.14
Iron, mg		8.99	9.14	9.29
Copper, mg		0.99	1.01	1.03
Zinc, mg		2.96	3.12	3.28
Manganese, mg		3.31	3.27	3.23
Cobalt, mg		0.02	0.02	0.02
Carotene, mg		0.13	0.12	0.12

The digestibility of crude protein varies only slightly, although the experimental groups show a stable upward trend. The greatest digestibility is observed in males in experimental group 3 – 84.7%, or 2.1% higher than in the control group. An increase in digestibility is also found in females, particularly in both experimental groups.

The digestibility of crude fat also increased in both experimental groups, especially in males in experimental group 3 (53.5%), surpassing the control by 3.7%. Increased digestibility is also observed in females in the two experimental groups, although the differences are less pronounced. Crude fiber digestibility also varies by group, increasing in both experimental groups. In experimental group 3, it reaches 35.6% among males and 34.1% among females, which is higher than that observed among their peers by 1.8–3.5% and 1.9–4.9%, respectively. Experimental group 2 also shows an increase, but less pronounced.

The digestibility of nitrogen-free extractives (NFE) increased in all birds in both experimental groups. In group 2, this indicator is 78.2% in males and 77.3% in females, indicating more efficient carbohydrate digestion than in the control group. At the later stage (35–42 days), the digestibility of dry matter in the experimental groups remained higher than in the control group, with the highest value observed in males in experimental group 2 (77.9%) (Table 5). The digestibility of crude protein also continued to grow, reaching its peak in the males of experimental group 3 – 87.7%, or 4% higher than the control. NFE digestibility increased significantly in the two experimental groups, with the greatest value observed in males in experimental group 3 (81.3%).

Nitrogen and calcium balance play a critical role in the nutrition and productivity of waterfowl. Nitrogen is an essential element in proteins required for growth, development, and metabolic processes. Nitrogen deficiency or excess can compromise nitrogen metabolism, resulting in reduced productivity, poor health, and inefficient feed use. An optimal nitrogen balance improves protein absorption and digestibility, which directly affects growth and performance (Gavrilenko & Koshchaev, 2019). Calcium is a crucial macronutrient needed for bone formation, the normal functioning of the nervous system, and metabolism. Its absorption is closely linked to phosphorus and vitamin D levels. Unbalanced calcium intake can lead to metabolic disorders, brittle bones, and reduced egg production in poultry (Li et al., 2024).

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Table 4: Diets of young geese at the age of 14–63 days by experimental groups

Parameters		Introduction %		
		Experimental group		
		Control 1	Experimental 2	Experimental 3
Sudan grain		11	8	5
Crushed maize		19	19	19
Millet		2	2	2
Rye		2	2	2
Sorghum		2	2	2
Barley		10	10	10
Crushed wheat		20	20	20
Soy		6	6	6
Cake		5	5	5
Soybean meal		5	5	5
Wheat bran		5	5	5
Sunflower meal		10	10	10
Fish meal		–	3	6
Seashell		3	3	3
Feed mix recipe content:				
Metabolizable energy	MJ	1.00	1.01	1.02
	Kcal	238.85	241.23	243.62
Dry matter, g		83.35	83.44	83.53
Crude protein, g		16.93	18.45	19.98
Digestible protein, g		10.77	11.77	12.77
Lysine, g		0.79	0.91	1.03
Methionine+cystine, g		0.51	0.56	0.62
Tryptophan, g		0.17	0.18	0.20
Crude fat, g		2.79	3.00	3.21
Crude fiber, g		4.22	4.11	4.00
NFE, g		52.03	50.45	48.87
Sugar, g		2.60	2.56	2.51
Phosphorus, g		1.34	1.43	1.52
Magnesium, g		0.55	0.60	0.66
Potassium, g		0.33	0.34	0.34
Sulfur, g		0.65	0.67	0.69
Iron, mg		0.10	0.11	0.12
Copper, mg		7.42	7.57	7.72
Zinc, mg		0.91	0.92	0.94
Manganese, mg		2.78	2.94	3.10
Cobalt, mg		3.01	2.97	2.94
Carotene, mg		0.02	0.02	0.02

The assessment of nitrogen and calcium balance sheds light on the efficiency of feed diets and reveals possible dietary abnormalities. By optimizing these parameters, it is possible to improve productivity, increase nutrient uptake, and reduce nitrogenous compound emissions, which are important for poultry health and for the environment.

The nitrogen balance parameter varies significantly across groups (Table 6). The intake of nitrogen in the control group was 5.28 g in males and 5.19 g in females, while in the experimental group 3 it was 5.30 g and 5.27 g, respectively. The control group has a higher level of nitrogen excretion (2.90–2.94 g), whereas in males in experimental group 3, this parameter dropped to 2.87 g, indicating more efficient nitrogen absorption.

Nitrogen balance also shows an upward trend in the experimental groups. Among males in experimental group 3, it amounts to 2.43 g, exceeding the control level. This same group also demonstrates the highest nitrogen use efficiency (45.8%), which indicates better protein absorption.

Calcium balance also shows variation between the groups. The intake of calcium with feed is higher in the experimental groups, especially in males in experimental group 2 (3.31 g). The excretion of nitrogen in droppings also varies, with the lowest value observed in males in experimental group 3 (1.75 g), suggesting better calcium retention.

Calcium use efficiency is the highest among males in experimental group 3, reaching 46.0%, or 0.2% higher than the control (45.8%). These results demonstrate that the diet tested in the experiment has a favorable effect on calcium absorption and, therefore, bone strength.

The analysis of nitrogen balance shows that both its consumption and absorption grow with age (Table 7). However, the greatest increase in nitrogen balance is observed in the experimental groups, where nitrogen use efficiency rose from 45.8% (at 14 days) to 53.3% (at 63 days) in males and from 44.2% to 51.5% in females.

Calcium use efficiency also improves. In the control group, it increased by 1.0% in males and 0.8% in females. The two experimental groups, however, show more pronounced changes: in experimental group 2, it increased by

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5.4% in males and 6.5% in females. This indicates more efficient calcium absorption at older ages, especially under the experimental conditions.

Table 5: Digestibility coefficients of nutrients in the diet of young geese by experimental groups, % ($\bar{x}$±Sx, n=5)

Parameters	Experimental/sex and age groups					
	Control I		Experimental 2		Experimental 3	
	♂	♀	♂	♀	♂	♀
7–14 days						
Dry matter	74.8±0.32	74.7±0.45	75.3±0.51	75.6±0.36	77.4±0.42	75.8±0.64
Crude protein	82.6±0.28	83.5±0.19	82.4±0.47	83.8±0.58	84.7±0.29	84.3±0.43
Crude fat	49.8±0.61	50.1±0.55	50.8±2.24	49.3±1.65	53.5±1.02	52.0±2.11
Crude fiber	32.1±0.87	29.2±0.36	33.8±0.48	32.2±0.96	35.6±0.58	34.1±1.08
NFE	75.0±0.63	74.2±0.78	74.9±1.01	75.1±1.24	78.2±1.39	77.3±0.98
35–42 days						
Dry matter	76.3±0.77	75.2±0.89	77.4±0.62	76.7±0.54	77.9±0.33	77.5±0.46
Crude protein	83.7±0.92	83.1±1.1	86.8±0.99	86.4±0.71	87.7±0.56	86.9±0.42
Crude fat	54.8±2.06	52.1±1.33	59.2±1.32	57.6±1.68	61.8±1.25	60.6±1.18
Crude fiber	33.4±1.61	32.3±0.98	36.1±0.47	35.4±0.56	38.7±0.29	37.9±0.37
NFE	73.9±0.81	73.1±0.75	77.6±0.59	75.9±0.43	81.3±0.25	78.4±0.31

Table 6: Nitrogen and calcium balance in the diet of young geese at the age of 14 days by experimental groups, ($\bar{x}$±Sx, n=5)

Parameters	Experimental/sex and age groups					
	Control I		Experimental 2		Experimental 3	
	♂	♀	♂	♀	♂	♀
Nitrogen balance						
Intake with feed, g	5.28±0.04	5.19±0.01	5.05±0.04	5.22±0.15	5.30±0.15	5.27±0.07
Excreted with droppings, MJ	2.90±0.02	2.94±0.01	2.81±0.15	2.93±0.13	2.87±0.09	2.94±0.04
Balance	2.38±0.03	2.25±0.02	2.24±0.16	2.29±0.16	2.43±0.11	2.33±0.07
Use efficiency, %	45.1±0.23	43.4±0.19	44.4±0.74	43.9±2.49	45.8±1.43	44.2±0.98
Calcium balance						
Intake with feed, g	3.19±0.04	3.25±0.02	3.31±0.03	3.28±0.09	3.24±0.09	3.30±0.04
Excreted with droppings, MJ	1.73±0.07	1.84±0.03	1.84±0.05	1.83±0.07	1.75±0.06	1.84±0.03
Balance	1.46±0.06	1.41±0.03	1.47±0.06	1.45±0.09	1.49±0.08	1.46±0.07
Use efficiency, %	45.8±1.99	43.4±0.92	44.4±1.61	44.2±2.06	46.0±1.72	44.2±1.63

Table 7: Nitrogen and calcium balance in the diet of young geese at the age of 63 days by experimental groups, ($\bar{x}$±Sx, n=5)

Parameters	Experimental/sex and age groups					
	Control I		Experimental 2		Experimental 3	
	♂	♀	♂	♀	♂	♀
Nitrogen balance						
Intake with feed, g	6.24±0.05	6.18±0.05	6.36±0.01	6.29±0.06	6.47±0.08	6.39±0.07
Excreted with droppings, MJ	3.25±0.07	3.36±0.14	3.16±0.03	3.20±0.09	3.02±0.04	3.10±0.06
Balance	2.99±0.10	2.82±0.17	3.20±0.03	3.09±0.09	3.45±0.10	3.29±0.11
Use efficiency, %	47.9±1.32	45.6±2.58	50.3±0.53	49.1±1.37	53.3±0.96	51.5±1.25
Calcium balance						
Intake with feed, g	3.87±0.05	3.64±0.11	3.89±0.03	3.79±0.01	4.21±0.04	3.97±0.04
Excreted with droppings, MJ	2.06±0.06	2.03±0.10	1.89±0.06	1.87±0.02	1.95±0.02	1.89±0.03
Balance	1.81±0.09	1.61±0.08	2.00±0.06	1.92±0.02	2.26±0.05	2.08±0.04
Use efficiency, %	46.8±2.02	44.2±1.91	51.4±1.47	50.7±0.48	53.7±0.71	52.4±0.57

Thus, as the goslings grew older, they consumed more nitrogen and calcium and absorbed them more efficiently, especially in the experimental groups with additional feed components. This confirms the feasibility of using enriched diets to increase metabolic efficiency and productivity.

The analysis of energy metabolism indicates that gross energy (GE) is higher in the experimental groups (Table 8). In experimental group 3, it amounted to 4.42 MJ in males and 4.30 MJ in females, which exceeded the control by 6.76% and 5.39%, respectively.

ME also increased, especially among males in experimental group 3, reaching up to 3.37 MJ and surpassing control levels by 15.81% (2.91 MJ). Among females, this parameter shows a similar upward trend. Energy loss due to heat production remained the same across all groups. However, net growth energy is significantly higher in the two experimental groups. In males in experimental group 3, it amounts to 1.18 MJ, which is 61.6% higher than the control value. Among females, net growth energy reaches 0.97 MJ, also significantly exceeding the control level.

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Table 8: Daily energy balance in the diet of young geese at the age of 63 days by experimental groups, ($\bar{x}$±Sx, n=5)

Parameters	Experimental/sex and age groups					
	Control I		Experimental 2		Experimental 3	
	♂	♀	♂	♀	♂	♀
Gross energy	4.14±0.1	4.08±0.05	4.38±0.02	4.25±0.12	4.42±0.01	4.30±0.01
Excreted with droppings, MJ	1.23±0.06	1.25±0.11	1.11±0.03	1.14±0.06	1.05±0.02	1.08±0.01
Metabolizable energy, MJ	2.91±0.07	2.83±0.10	3.27±0.04	3.11±0.10	3.37±0.01	3.22±0.01
Energy loss with heat production	2.18±0.01	2.24±0.02	2.22±0.01	2.26±0.06	2.19±0.01	2.25±0.02
Net growth energy, MJ/head% of GE	0.73±0.06	0.59±0.11	1.05±0.03	0.85±0.10	1.18±0.01	0.97±0.02
	17.63±1.50	14.46±2.74	23.97±0.63	20.00±2.09	26.70±0.35	22.56±0.42

4. DISCUSSION

As part of our research conducted in the West Kazakhstan Region, we studied the feeding system for goslings and conducted a detailed analysis of the chemical composition of the feeds and feed additives used. Based on the experimental data obtained, an optimized formulation of feed additives was developed to create a balanced diet for different sex and age groups of goslings kept at the studied farm.

The increased digestibility coefficients of dry matter and crude protein observed in the experimental groups are consistent with findings from previous studies on geese, in which optimization of feeding regimes and feed processing parameters improved apparent nutrient digestibility and overall productive performance (Liu et al., 2020; Cui et al., 2024). The positive effect is likely associated not only with changes in the chemical composition of the diet but also with increased nutrient availability to the goslings' digestive systems.

The higher digestibility observed in the experimental groups may also have a physiological basis. Studies in geese indicate that dietary composition can influence intestinal morphology, digestive enzyme activity, and gut microbiota structure, all of which are closely related to the efficiency of fiber and overall nutrient digestion (Liu et al., 2018; Fu et al., 2023). Therefore, the observed effect of fish meal may be mediated not only by its protein content but also by improvements in the intestinal environment.

The present study demonstrated that optimizing waterfowl diet has a positive effect on nutrient digestibility, nitrogen and calcium balance, and energy metabolism. Across all age groups, the experimental groups showed higher digestibility coefficients for dry matter, crude protein, fat, fiber, and nitrogen-free extractives than the control group.

With age, the efficiency of nitrogen and calcium utilization increased, particularly in experimental group III, where nitrogen utilization reached 53.3% and calcium utilization 53.7%. The increase in nitrogen utilization in groups receiving fish meal is biologically plausible, as both the source and level of dietary protein significantly affect nitrogen metabolism and the metabolic load on the excretory system (Chen et al., 2025). In addition, studies in geese have shown that variations in dietary protein levels and starch-to-fat ratios influence the digestibility of calcium, energy, and dry matter, which is consistent with the improved calcium utilization observed in the experimental groups (Shen et al., 2025). This indicates a more efficient use of protein and minerals in the birds' bodies.

Analysis of energy metabolism revealed that metabolizable and net growth energy were significantly higher in the experimental groups than in the control, indicating more efficient conversion of feed into productive energy. The increase in these parameters is consistent with studies showing that changes in feeding strategies and metabolizable energy levels in geese improve feed efficiency and productivity (Ran et al., 2021; Zhang et al., 2024). In this context, the rise in net growth energy reflects more efficient conversion of nutrients into productive output rather than simply increased nutrient intake. In the present study, the highest values were recorded in experimental group III, where net growth energy exceeded control values by more than 50%.

From a practical perspective, the results confirm the potential of moderate dietary enrichment with high-quality protein sources, provided that overall nutrient balance is maintained. Similar conclusions have been reported in studies on geese, in which optimizing energy supply, feeding patterns, and diet composition improved growth and slaughter performance without requiring excessive increases in dietary energy density (Ran et al., 2021; Zhang et al., 2024).

Overall, the findings confirm that the inclusion of additional feed components positively affects nutrient digestibility. The experimental groups demonstrated improved performance across all parameters, indicating enhanced feeding efficiency and metabolic processes. Improvements in nitrogen and calcium balance further suggest more efficient utilization of proteins and minerals. This approach can therefore be recommended to enhance poultry productivity.

At the same time, the interpretation of these results should be limited to the experimental conditions, as goslings' responses to changes in dietary protein depend on age, protein level, and overall diet structure. Recent studies in geese indicate that, even when the direction of the effect is similar, the magnitude of responses in

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digestibility, mineral metabolism, and metabolic markers varies with dietary protein levels and nutrient ratios (Chen et al., 2025; Shen et al., 2025).

5. CONCLUSION

The inclusion of fish meal in feed mixtures for young Linda geese improves nutrient digestibility and enhances metabolic efficiency. The most pronounced effect was observed in experimental group III, which received a diet containing 6% fish meal. At 35–42 days of age, dry matter digestibility reached 77.9%, crude protein 87.7%, crude fat 61.8%, crude fiber 38.7%, and nitrogen-free extractives 81.3%. By 63 days of age, nitrogen utilization reached 53.3%, calcium utilization 53.7%, metabolizable energy 3.37 MJ, and net energy gain 1.18 MJ per head. These results indicate more efficient utilization of protein, minerals, and dietary energy when fish meal is included in the diet.

The practical significance of the study lies in the potential application of the developed feed mixtures for formulating diets for young geese under farm conditions in the West Kazakhstan region, using locally available feed resources. However, the conclusions should be limited to digestibility and metabolic indicators, as data on live weight, feed conversion ratio, survival rate, and meat productivity were not provided. Future research should validate the proposed formulations under production conditions and expand the assessment to include growth performance, meat productivity, blood biochemical parameters, economic efficiency, and environmental effects associated with nitrogen utilization.

Declarations

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Conflicts of Interest: The authors declare no conflict of interest.

Data Availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics Statement: The animal study was approved by the Ethics Committee of the West Kazakhstan Agrarian and Technical University named after Zhangir Khan (protocol No. 20260401) and conducted in accordance with national legislation and institutional guidelines for the care and use of animals in research.

Author's Contributions: Aruzhan Nugmanova: conceptualization, methodology, and supervision. Nazerke Baktygerey: investigation and data curation. Askar Nametov: methodology and validation. Alzhan Shamshidin: formal analysis and writing—review and editing. Erbol Sengaliyev: investigation and resources. Zhanylsyn Makhimova: data analysis and manuscript preparation. All authors read and approved the final manuscript.

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