Tropical Animal Health and Production (2025) 57:394
https://doi.org/10.1007/s11250-025-04642-x

REGULAR ARTICLES

Milk-based supplementation in wet and dry feed forms: effects on growth performance, histomorphology, survivability, and economic outcomes in goslings

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Received: 18 March 2025 / Accepted: 2 September 2025 / Published online: 26 September 2025

Abstract

This study investigated the effects of supplementing starter diets for goslings with milk powder (MP), milk replacer (MR), and whey powder (WP) in two different forms (dry and wet) on growth performance, survivability, intestinal histomorphology, and economic evaluation. Early nutrition is critical in goslings, yet limited research has addressed how milk-based supplements influence gut development and economic outcomes in this species. Therefore, a total of 192 one-day-old goslings were randomly assigned to eight groups in a 2×4 factorial experimental design involving two feed forms (dry, wet) and four additive treatments (0%, MP-4%, MR-4%, and WP-4%). The experiment lasted 70 days. Feed form significantly affected the feed conversion ratio, with better efficiency in the dry group ($P<0.001$), while body weight, body weight gain, and feed intake were not significantly influenced by either feed form or additive ($P>0.05$). Villus length, villus width, and crypt depth were greater in the dry feed groups, whereas lamina muscularis thickness was higher in the wet groups ($P<0.001$). Among the additives, the WP groups had the highest villus length and lamina muscularis thickness, and the MR groups showed the highest villus width and crypt depth values ($P<0.001$). The most favorable economic outcome was observed in the Dry-WP group, which had the lowest carcass cost at 16.00 TL per kg, compared to TL18.63 TL in the highest-cost group (Wet-MR). Goslings in all supplemented groups (dry-MR, dry-WP, wet-MP, wet-MR, and wet-WP) exhibited a 100% survival rate throughout the trial, while slightly lower survival (95.83%) was recorded in the control groups ($P>0.05$). In conclusion, although milk-based supplementation did not significantly affect overall performance, it enhanced gut morphology and survivability. These findings suggest that WP, especially in dry form, may facilitate gastrointestinal development, enhance nutrient absorption and improve economic efficiency during the critical first three weeks of the early growth phase in goslings.

Keywords Geese · Wet-dry feed · Performance · Survivability · Histomorphology · Economic evaluation

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Introduction

Geese exhibit several advantageous traits, including adaptability to harsh environmental conditions, low feed intake, strong disease resistance, ease of breeding, short production cycles, and high return on investment, making them highly suitable for commercial farming (Wang et al. 2025). In recent years, goose production methods have significantly shifted from traditional water-based farming to fully enclosed, dry farming systems. As herbivorous birds that thrive in diverse environments and produce high-quality meat, geese are highly influenced by feed nutrient composition, which plays a crucial role in poultry production performance (Zhang et al. 2024). Despite the rapid expansion of the goose farming industry, research on digestive physiology and feed utilization remains insufficient, highlighting the need for further scientific studies to ensure sustainable development (Wang et al. 2025).

Proper nutrition during the early post-hatch period is critical for chick health and long-term productivity. Timely access to feed and water is essential for day-old chicks, as delayed nutrient intake can impair growth performance and reduce breast meat quality (Abd El-Azeem et al. 2024). For optimal feed utilization efficiency in poultry, newly hatched chicks must complete their digestive system development as quickly as possible and require a high level of nutrients, particularly during the first 7–10 days of life (Ebling et al. 2015). Furthermore, early post-hatch nutrition facilitates gastrointestinal development, improves nutrient absorption, and directly impacts final body weight, highlighting the importance of feed composition and digestibility during this period (Kamanlı and Durmuş 2014; Abd El-Azeem et al. 2024). A study reported that chicks fed highly digestible pre-starter diets achieved an average body weight increase from 160 to 170 g to up to 200 g by day 7 (Leeson 2008).

Animal protein is a nutrient-rich energy source that plays a crucial role in the growth and development of animals. Compared to plant-based proteins, animal proteins contain all essential amino acids, making them a complete protein source. Milk replacers (MR) are dried milk powders (MP) with high protein content and a rich amino acid profile. MR is a feed alternative to milk, typically produced by supplementing by-products derived from processed milk with animal and plant-based fat sources, vitamins, and minerals, containing 20–24% crude protein (Köse and Şehu 2020). In particular, MP is used as a protein supplement in broiler feed and contains a specific type of protein called casein (Ata and Al-Massad, 2015). Whey is a significant by-product of the cheese industry, and its alternative use is valuable both environmentally and economically. Its high lactose and protein content make it a potential ingredient in poultry nutrition. Findings indicate that dried whey powder (WP) supports broiler growth and improves feed conversion (Pineda-Quiroga et al. 2018).

Szczurek et al. (2013) reported that WP not only acts as a growth promoter in broilers but also has the ability to induce significant metabolic changes along the intestinal tract and contains certain organic acids such as citric and lactic acid. Ashour et al. (2019) conducted a study in which they supplemented broiler diets with WP protein concentrate (0%, 0.15%, 0.20%, and 0.25%) and found an improvement in broiler performance. Similarly, Zarei et al. (2018) determined that the addition of 4% WP altered intestinal morphology, thereby enhancing broiler performance. Pineda-Quiroga et al. (2018) found that WP, due to its high mineral digestibility and ability to increase feed intake, accelerates broiler growth. In broiler chickens, supplementation with acidified WP and yeast extract has been shown to significantly increase villus height and mucosal thickness, thereby improving intestinal morphology (Kermanshahi et al. 2017). These findings suggest that milk-based additives may positively influence intestinal development across different animal species. Although these effects have been well-documented in broilers, it can be postulated that similar mechanisms may also operate in goslings, thereby supporting the use of WP and other milk-derived additives not only for economic purposes but also based on physiological rationale.

In a study using MP in broilers, a group supplemented with 0.5% MP for 35 days exhibited greater body weight gain and improved feed conversion efficiency (Ata and Al-Massad, 2015). Recent studies have examined the effects of dietary nutrient levels and feed form on intestinal development in geese. For example, moderate dietary calcium and crude protein (CP) (0.96% Ca and 14.5–18.5% CP) in Jiangnan White goslings significantly improved villus height, crypt depth, and digestive enzyme activity compared to lower or higher levels (Chen et al. 2025). Moreover, feeding fermented roughage to goslings positively enhanced intestinal histomorphology (Xi et al. 2020). Compared to broilers and ducks, geese exhibit lower ileal amino acid digestibility rates, with values around 63%, as opposed to approximately 73% in broilers and 43–61% in ducks (Jamroz et al. 2002). These species-specific differences in intestinal digestion capacity suggest that geese may respond differently to milk-derived feed additives, such as whey or milk proteins, due to reduced efficiency in protein absorption. These goose-specific findings support the feasibility of using milk-based additives like MP, MR, and WP to target similar improvements in gut structure, bridging insights between poultry and waterfowl nutrition. However, no studies have been found investigating these feed additives' effects on goslings' growth performance. Moreover, limited research has addressed the specific effects of these additives on intestinal histomorphology and economic outcomes in goslings, highlighting a critical gap in current knowledge.

This study aims to evaluate the effects of WP, which has been reported to enhance performance and survival rates in broilers, along with MP, whose positive effects have been noted in a limited number of studies, and MR, whose impact on poultry performance has not been previously investigated, on the growth performance and meat quality characteristics of goslings. While there is insufficient information in the literature regarding the use of these feed additives in geese, observations from traditional farmers suggesting that the addition of milk to gosling diets improves growth performance have highlighted the need for further research on alternative feed additives. Considering the high cost and contamination risk of milk, WP, MR, and MP are proposed as more practical alternatives under field conditions. Therefore, this study aims to incorporate these additives into gosling diets in different forms and assess their effects on growth performance, intestinal development, survivability, and economic outcomes.

Materials and methods

Diet, experimental animals and design

A total of 192 goslings were used in the study. The experimental animals were selected from healthy goslings hatched from eggs obtained from breeding geese housed at the farm where the study was conducted. Within the first 24 h post-hatching, the goslings underwent general health checks and were individually weighed. Health certificates were available for all animals sourced from the facility. The birds were housed in an enclosed shelter equipped with wooden pens measuring 1 × 1.5 m, under a photoperiod of 23 h of light and 1 h of darkness. These goslings were allocated into 8 groups, each consisting of 4 replicates with 6 individuals per replicate.

The sample size for the study was determined via a post hoc power analysis using G*Power software (version 3.1.9.2). The parameters used in the analysis included a Type I error rate (α) of 0.05, statistical power (1 – β) of 0.85, and effect size (Cohen's f) of 0.295. Based on these criteria, it was calculated that a total of 192 animals (24 per group) would be sufficient to detect statistically significant differences (Cohen 1988; Faul et al. 2007). The initial body weights of all groups were balanced, and the goslings were raised in closed coops under intensive rearing conditions. Goslings were randomly distributed into groups according to a 2 × 4 factorial design, with two feed forms, dry and wet, and four additive treatments, including no additive (0%), 4% MP, 4% MR, and 4% WP in the first 3-week period (Cesari et al. 2014; Zarei et al. 2018). The supplementation was limited to the first three weeks to focus on the critical early growth phase, during which intestinal development and immune programming are most sensitive to dietary modulation. This timing reflects both the heightened physiological responsiveness of goslings and the practical feeding strategies often applied during the brooding period.

The 4% inclusion rate was determined based on previous studies in broilers, where similar levels of milk-derived additives resulted in improved intestinal morphology and performance (Cesari et al. 2014; Zarei et al. 2018). Due to the lack of data in goslings, this level was adopted as a reference point for evaluating early developmental effects. During the first 3-week period, the starter diet of goslings was supplemented with MP, MR, and WP. The feed additives were categorized into three groups: MP, MR, and WP each incorporated at a level of 4% (i.e., 40 g of additive per 1000 g of feed). For additives administered in liquid form, MP, MR, and WP were dissolved in an equal amount of water. The resulting solutions were sprayed uniformly onto the compound feed and mixed thoroughly. To prevent spoilage, liquid additives were added to the feed daily, and all prepared feed was offered to the goslings immediately without storage. Groups fed wet feed received freshly prepared diets daily, whereas dry feed was provided directly to the goslings without any additional processing.

The animals were fed a diet containing 20% CP and 2900 kcal/kg of metabolizable energy (ME) during the first to fourth weeks and 15% CP and 3000 kcal/kg ME from the fifth to tenth weeks (NRC 1994). The experiment lasted for a total of 10 weeks. The analysis of the diet was conducted according to the methods described by AOAC and NRC (NRC 1994; AOAC 2006). Diet and water were continuously available to all animals throughout the trial. The composition and crude nutrient contents of the diets are presented in Table 1.

Implementation of the experiment and monitoring of growth performance

Determination of body weight and body weight change

Initial body weights of the animals were determined using a scale with 1 g sensitivity on the first day of the study. The male goslings (a total of 192), whose initial body weights were equalized, were divided into subgroups of four and fattened in 1 × 1.5 m² wooden compartments within a closed shelter. They were weighed at 15-day intervals over 10 weeks.

Determination of feed intake

In the groups that received wet feeding for the first 3 weeks, feed was weighed daily and the remaining feed was weighed and taken daily. However, no correction was made for moisture loss due to evaporation from the wet feed during the feeding period. As a result, feed intake was calculated based on gross feed disappearance in 15-day periods, without accounting for potential water loss.

Table 1 Ingredients and chemical composition of the experimental diets

Items %	Starter diets				Finisher diet
	Control	MP	MR	WP	
Corn	61.21	58.40	56.40	58.31	69.96
Wheat bran	3.50	7.00	6.65	3.00	9.82
Corn gluten (43% CP)	5.00	3.00	5.00	3.00	5.80
Soybean meal (44% CP)	27.30	25.30	25.00	29.20	10.50
Vegetable oil	0.40	-	0.70	0.21	1.07
Di-calcium phosphate	0.94	0.65	0.62	0.80	0.95
Limestone	0.84	0.90	0.94	0.82	0.80
L-Lysine hydrocloride	0.06	-	-	-	0.36
DL-methionine	0.10	0.10	0.13	0.10	0.10
Salt	0.30	0.28	0.21	0.21	0.30
Sodium bicarbonate	0.10	0.12	0.10	0.10	0.01
Vitamin-mineral premix	0.25	0.25	0.25	0.25	0.25
MP	-	4	-	-	-
MR	-	-	4	-	-
WP	-	-	-	4	-
Total	100	100	100	100	100
Nutrient composition					
Dry matter, %	89.40	89.6	89.6	89.5	89.5
ME, kcal/kg	2900[1]	2900[1]	2900[1]	2900[1]	3000
Crude protein, %	20.00	19.88	19.95	19.90	15.00
Crude fiber, %	3.87	3.67	3.92	3.65	3.62
Crude fat, %	2.37	2.02	3.44	1.95	3.31
Crude ash, %	5.16	5.04	5.23	5.37	4.52
Calcium	0.65[1]	0.65[1]	0.65[1]	0.65[1]	0.60
Phosphorus	0.30[1]	0.31[1]	0.30[1]	0.31[1]	0.30
Sodium	0.18[1]	0.20[1]	0.18[1]	0.20[1]	0.19
Lysine	1.00[1]	1.01[1]	1.01[1]	1.02[1]	0.85

Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form; ME: metabolizable energy. [1]calculated according to NRC (1994)

Determination of feed conversion ratio

Feed conversion ratios were determined by dividing the average amount of feed consumed by the animals in two weighing intervals since the beginning of the trial by the average body weight gains determined in these two weighing intervals.

Determination of survival capacity

Subgroups within each group were monitored throughout the trial, and daily death numbers were recorded to determine survival capacity.

Carrying out the slaughtering process of the animals and taking tissue samples

In order to evaluate histomorphological analyses, a total of 48 geese were slaughtered at the end of the growth period, 6 geese from each group close to the group average. The geese were left hungry in the evening before slaughtering and slaughtered in the early morning.

Histomorphological analyses

The intestines of the slaughtered animals were separated from the ileum sections, and their weights and lengths were measured while empty. Tissue samples taken from the ileum were fixed with 10% buffered formaldehyde. Fixed samples were dehydrated using increasing alcohol concentrations (70%, 80%, 90% and 100%). After dehydration, the samples were subjected to a clarification process with xylol. At the end of the clearing process, tissue samples were blocked in paraffin and made ready for sectioning. 4–6 µm thick sections were taken from each prepared block and placed on slides. Ileum samples placed on slides were stained with hematoxylin-eosin staining method (Uni et al. 1999, 2003). Microscopic evaluations were performed at 10X magnification. Samples taken from the ileum of each animal were measured using the image analysis system for villus length, villus width, crypt depth, and lamina muscularis mucosa thickness. Villus length was determined by measuring from the tip of the villus to the villus-crypt junction, and villus width was determined by measuring from the middle region of the villus (Thompson and Applegat 2006). Crypt depth was determined by measuring the depth between adjacent villi (Awad et al. 2011). Photographs of the tissues were taken with a digital camera microscope. The photographs were taken using an image processing and analysis program to measure villus length, villus width, crypt depth and lamina muscularis mucosa thickness. To ensure reproducibility and account for intra-individual variation, three independent measurements were taken from the ileum section of each animal.

Economic evaluation

Feed cost was calculated for one kg carcass production. In the study, other expenses except feed costs were kept constant for all groups.

Statistical analyses

The obtained data were analyzed using the General Linear Model (GLM). Prior to analysis, data were checked for normality using the Shapiro-Wilk test and for homogeneity of variances using Levene's test; all assumptions were met. Based on the GLM results, the Tukey multiple comparison test was employed to identify which group contributed to the significant differences in the features (additive groups). For further analysis, Tukey's test was applied again to investigate which combinations of feed form and additive groups were responsible for the significant interactions. Survival rates were analyzed using the Chi-square test. All statistical analyses were conducted within a 95% confidence level, as part of the GLM framework. All data were processed using the SPSS 22 software. The statistical significance was set at $P<0.05$, and the results are presented as means with standard error of the mean (SEM).

Results

Growth performance

The average body weights of the experimental groups are presented in Table 2. As shown in Table 2, the effects of feed form and additives on body weight were not statistically significant ($P>0.05$). The interaction between feed form and additives significantly affected body weight at weeks 8 and 10 ($P<0.05$). It was observed that the MP, MR, and WP groups exhibited higher body weights in dry feeding compared to the control group. In wet feeding, the body weights of the control group were significantly higher than those of the groups supplemented with MP, MR, and WP ($P<0.05$). The difference between the average body weights of the MP, MR, and WP groups in both feed forms was insignificant ($P>0.05$).

The interaction between feed form and additives significantly affected the body weight gain of geese throughout the 10-week growth period (Table 3; $P<0.05$). When the body weight gain in the dry feeding groups was compared to the control group during the 0- 10th weeks, it was observed that the MP, MR, and WP groups exhibited higher body weight

Table 2 Effects of feed form and additives on body weight (g)

		Weeks					
		0	2	4	6	8	10
Wet		106	843	2403	3080	3710	4016
Dry		106	828	2305	3007	3613	3949
	P	0.994	0.533	0.108	0.394	0.346	0.530
	η^2	0.001	0.016	0.104	0.030	0.037	0.017
	Control	106	831	2367	2988	3655	3977
	MP	106	861	2374	3059	3684	4021
	MR	106	833	2378	3118	3683	3994
	WP	106	818	2298	3008	3626	3937
	P	1.000	0.632	0.743	0.706	0.973	0.954
	η^2	0.001	0.068	0.049	0.055	0.009	0.014
Dry	Control	106	834	2309	2837	3457^{b}	3756^{b}
	MP	106	837	2392	3112	3737^{a}	4058^{a}
	MR	106	865	2545	3280	3892^{a}	4190^{a}
	WP	106	836	2367	3092	3755^{a}	4063^{a}
Wet	Control	106	828	2426	3139	3853^{A}	4198^{A}
	MP	106	884	2356	3007	3630^{B}	3985^{B}
	MR	106	801	2211	2956	3474^{B}	3799^{B}
	WP	106	800	2228	2925	3497^{B}	3812^{B}
FFxA	*P*	1.000	0.394	0.076	0.087	0.048	0.050
	η^2	0.001	0.115	0.245	0.236	0.276	0.269
SEM		4.19	24.3	61.1	88.3	105	110

Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form; FF: feed form; A: additives; η²: partial eta squared (effect size); SEM: standard error of means. $^{a, b, A, B}$: Differences between means with different letters in the same column are significant. $^{a, b}$: It refers to the interaction between additive and dry feed groups. $^{A, B}$: It refers to the interaction between additive and wet feed groups

Table 3 Effects of feed form and additives on body weight gain (g)

		Weeks					
		0–2	2–4	4–6	6–8	8–10	0–10
Wet		52.6	111	48.3	45.0	27.8	55.2
Dry		51.6	105	50.1	43.3	30.4	54.7
	P	0.528	0.108	0.634	0.712	0.453	0.763
	η^2	0.017	0.104	0.010	0.006	0.024	0.004
	Control	51.8	109	44.3	47.6	29.3	55.2
	MP	53.8	108	48.9	44.6	30.6	55.5
	MR	51.9	110	52.8	40.3	27.8	54.5
	WP	50.8	105	50.7	44.1	28.7	54.8
	P	0.625	0.800	0.408	0.719	0.951	0.968
	η^2	0.069	0.040	0.112	0.053	0.014	0.010
Dry	Control	52.0	105	37.7	44.2	27.1	51.6^{b}
	MP	52.2	111	51.4	44.7	29.1	55.7^{a}
	MR	54.2	119	52.5	43.6	27.0	56.9^{a}
	WP	52.1	109	51.7	47.4	27.9	56.7^{a}
Wet	Control	51.5	114	50.9	50.9	31.4	58.8^{A}
	MP	55.5	105	46.4	44.5	32.2	55.2^{A}
	MR	49.7	100	53.2	36.9	28.6	52.0^{B}
	WP	49.5	102	49.7	40.8	29.5	52.9^{B}
FFxA	*P*	0.387	0.076	0.325	0.675	0.991	0.044
	η^2	0.116	0.245	0.132	0.061	0.004	0.281
SEM		1.71	3.71	3.77	4.64	3.62	1.61

Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form; FF: feed form; A: additives; η²: partial eta squared (effect size); SEM: standard error of means. $^{a, b, A, B}$: Differences between means with different letters in the same column are significant. $^{a, b}$: It refers to the interaction between additive and dry feed groups. $^{A, B}$: It refers to the interaction between additive and wet feed groups gains than the control group. In contrast, the highest body weight gains in the wet feeding groups were recorded in the control and MP groups ($P<0.05$).

As presented in Table 4, the average feed intake of the experimental groups revealed that the effects of both feed form and additives were not statistically significant ($P>0.05$). Although feed intake in the wet group increased by 1.9% compared to the dry group, this difference was found to be statistically insignificant ($P>0.05$).

Based on the feed form, the feed conversion ratio during the 0–10 week growth period was found to be significant, with values of 3.16 for the dry group and 3.97 for the wet group, respectively (Table 5; $P<0.001$). The differences between groups in terms of feed conversion ratio were not statistically significant. The addition of additives (MP, MR, and WP) to the ration, as well as the interaction between feed form and additives, did not affect the feed conversion ratio (Table 5; $P>0.05$).

Survivability

The effects of feed form and additives on the survivability of geese are presented in Table 6; Fig. 1. The highest survival rate was observed in dry-MR, dry-WP, wet-MP, wet-MR, and wet-WP groups, with 100% survival. A survival rate of 95.83% was determined in the dry-control, dry-MP, and wet-control groups. Statistically, no significant differences were observed during any week of the 10-week growth period or in the overall analysis, neither in terms of feed form, additives, nor the feed form-additive interaction ($P>0.05$).

Histomorphological measurements

Statistically significant differences were observed between the dry and wet feeding groups regarding villus length, villus width, crypt depth, and lamina muscularis thickness (Table 7; Figs. 2 and 4; $P<0.001$). Villus length (1049 µm), villus width (75.9 µm), and crypt depth (227 µm) values were observed to be higher in the dry group compared to the wet group (920 µm, 54.5 µm, and 216 µm, respectively). Conversely, the lamina muscularis thickness was higher in the wet group (92.4 µm) than in the dry group (69.2 µm). There was no significant difference between the dry (12.9 g and 5.69 mm) and wet groups (13.2 g and 6.28 mm) in terms of ileum weight and ileum length values ($P>0.05$).

When the supplementation groups (Control, MP, MR, and WP) were examined, the lowest villus length value was observed in the control group. The difference between the MP group and the control group was not statistically significant (Table 7; Fig. 4; $P>0.05$). The values for the MR and WP groups were found to be similar, with no significant

Table 4 Effects of feed form and additives on feed intake (g)

		Weeks					
		0–2	2–4	4–6	6–8	8–10	0–10
Wet		74.1	199	211	209	182	174
Dry		74.7	212	250	206	176	177
	P	0.660	0.002	0.002	0.741	0.437	0.528
	η^2	0.012	0.348	0.325	0.005	0.025	0.017
	Control	76.9	207	228	213	181	177
	MP	73.1	207	228	207	183	176
	MR	74.3	208	233	204	173	179
	WP	73.3	200	233	206	179	170
	P	0.179	0.400	0.984	0.871	0.757	0.595
	η^2	0.257	0.113	0.006	0.029	0.047	0.074
Dry	Control	77.1	204^{a}	200	208	183	172
	MP	71.0	206^{a}	214	209	188	174
	MR	76.0	192^{b}	220	215	185	180
	WP	72.3	194^{b}	211	205	172	170
Wet	Control	76.8	210^{B}	257	219	179	182
	MP	75.2	208^{B}	242	206	178	178
	MR	72.7	224^{A}	246	194	161	179
	WP	74.2	206^{B}	254	206	187	170
FFxA	*P*	0.245	0.036	0.760	0.574	0.265	0.858
	η^2	0.223	0.294	0.047	0.078	0.150	0.031
SEM		1.35	3.80	11.84	8.59	6.97	3.69

Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form; FF: feed form; A: additives; η^2: partial eta squared (effect size); SEM: standard error of means. $^{a, b, A, B}$: Differences between means with different letters in the same column are significant. $^{a, b}$: It refers to the interaction between additive and dry feed groups. $^{A, B}$: It refers to the interaction between additive and wet feed groups

Table 5 Effects of feed form and additives on feed conversion ratio (g feed/g gain)

		Weeks					
		0–2	2–4	4–6	6–8	8–10	0–10
Wet		1.43	1.92	4.59	4.81	6.78	3.16
Dry		1.48	1.59	5.13	5.31	6.43	3.97
	P	0.391	0.001	0.145	0.392	0.611	0.001
	η^2	0.046	0.564	0.086	0.031	0.011	0.630
	Control	1.54	1.75	5.53	4.80	6.70	3.61
	MP	1.38	1.77	4.79	4.96	6.34	3.51
	MR	1.45	1.74	4.46	5.41	6.92	3.69
	WP	1.46	1.74	4.66	5.08	6.45	3.47
	P	0.272	0.984	0.203	0.889	0.933	0.605
	η^2	0.211	0.006	0.171	0.025	0.018	0.073
Dry	Control	1.52	2.01	5.72	4.87	7.05	3.35
	MP	1.40	1.89	4.21	5.07	6.53	3.13
	MR	1.40	1.88	4.28	4.97	6.85	3.18
	WP	1.41	1.89	4.14	4.36	6.71	2.99
Wet	Control	1.56	1.50	5.35	4.73	6.35	3.88
	MP	1.36	1.66	5.36	4.86	6.15	3.87
	MR	1.49	1.61	4.65	5.86	7.00	4.20
	WP	1.51	1.59	5.18	5.81	6.20	3.95
FFxA	*P*	0.775	0.330	0.433	0.682	0.976	0.526
	η^2	0.065	0.131	0.106	0.059	0.008	0.087
SEM		0.06	0.06	0.38	0.59	0.72	0.13

Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form; FF: feed form; A: additives; η^2: partial eta squared (effect size); SEM: standard error of means

Table 6 Chi-square analysis table for groups' survivability rate (%)

Groups	Survivability (%)	sd	X^2	*P*
Control-Dry	95.83	7	5.079	0.650
MP-Dry	95.83			
MR-Dry	100			
WP-Dry	100			
Control-Wet	95.83			
MP-Wet	100			
MR-Wet	100			
WP-Wet	100			

Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form. sd: degrees of freedom; X^2: chi-square value

difference between them ($P>0.05$). However, when compared with the control group, villus length values in the MR and WP groups were significantly higher than those in the control group ($P<0.001$). Additionally, interactions between feed form and additive groups on villus length were found to be statistically significant ($P<0.001$).

The highest villus width was observed in the control group, and no significant difference was found between the MR and control groups (Table 7; Fig. 4; $P>0.05$). While there was no difference in villus width values between the MP and WP groups ($P>0.05$), the difference between the control group and these two groups was significant, favoring the control group ($P<0.001$). Interactions between feed form and supplement groups in terms of villus width were statistically significant ($P<0.001$).

The MR group had the highest crypt value, and no significant difference was found between the MR and control groups (Table 7; Fig. 4; $P>0.05$). There was no significant difference in crypt depth between the MP and WP groups ($P>0.05$), but both groups had lower values than the control group, with the difference being significant ($P<0.001$). Interactions between crypt depth values among the groups were statistically significant ($P<0.001$).

When examining the lamina muscularis muscle thickness values, it was observed that the highest value was in the WP group, with no significant difference between the WP and control groups. While the difference between the MP and WP groups was insignificant, both groups showed a significant difference when compared to the control group, favoring the control group. Interactions between the groups were

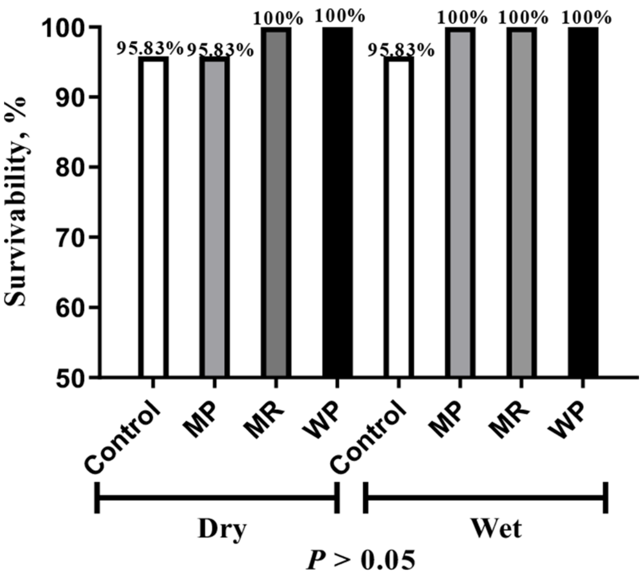

Fig. 1 Effects of feed form and additives on survivability rate (%). Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form

also found to be statistically significant (Table 7; Fig. 4; $P<0.001$).

No significant differences were found between the control, MP, MR, and WP groups regarding ileum weight and length values. Additionally, interactions between the groups for both ileum weight and length were not statistically significant (Table 7; Fig. 4; $P>0.05$).

Economic evaluation

Since all groups were raised under equivalent conditions, the cost of 1 kg of carcass was calculated based on the variable feed cost, with other expenses held constant. The net profit for each group was calculated by subtracting the carcass sales revenue from the total cost, including the price of 1 kg of carcass. The average cost of 1 kg of carcass was determined to be 16.86 TL in the dry groups and 17.53 TL in the wet groups. At the end of the trial, the cost per kg of carcass in the dry groups was found to be 17.12 TL, 17.03 TL, 17.31 TL, and 16.00 TL in the control, MP, MR, and WP groups, respectively.

The cost of 1 kg of carcass in the Wet-control, Wet-MP, Wet-MR, and Wet-WP groups was determined to be 16.70 TL, 17.53 TL, 18.63 TL, and 17.25 TL, respectively. Upon examining the economic analysis of the trial groups (Fig. 3),

Table 7 Effects of feed form and additives on ileum histomorphology

			Villus Length (µm)	Villus Width (µm)	Crypt Depth (µm)	Lamina Muscularis (µm)	Ileum Weight (g)	Ileum Length (mm)
Dry			1049	75.9	227	69.2	12.9	5.69
Wet			920	54.5	216	92.4	13.2	6.28
	P		0.001	0.001	0.001	0.001	0.682	0.117
	η^2		0.985	0.963	0.652	0.896	0.004	0.060
		Control	932^{b}	82.4^{a}	227^{a}	92.5^{a}	13.3	5.91
		MP	994^{b}	56.6^{b}	190^{b}	55.4^{b}	13.5	5.91
		MR	1001^{a}	73.9^{a}	271^{a}	64.1^{b}	12.2	5.51
		WP	1012^{a}	48.0^{b}	197^{b}	111^{a}	13.1	6.62
	P		0.001	0.001	0.001	0.001	0.421	0.220
	η^2		0.939	0.977	0.985	0.969	0.067	0.103
Dry		Control	926^{b}	86.6^{b}	190^{b}	92.5^{a}	12.4	5.67
		MP	988^{b}	60.5^{b}	175^{b}	55.5^{b}	12.9	5.35
		MR	1136^{a}	104^{a}	205^{a}	73.2^{a}	12.3	4.97
		WP	1148^{a}	52.4^{b}	337^{a}	55.6^{b}	14.0	6.77
Wet		Control	937^{B}	78.1^{A}	264^{A}	92.6^{C}	14.2	6.15
		MP	1000^{A}	52.6^{B}	205^{B}	55.2^{B}	14.1	6.47
		MR	865^{C}	43.6^{B}	205^{B}	55.1^{B}	12.0	6.05
		WP	877^{C}	43.6^{B}	190^{B}	166^{A}	12.3	6.47
FFxA	*P*		0.001	0.001	0.001	0.001	0.177	0.503
	η^2		0.988	0.967	0.990	0.977	0.115	0.056
SEM			2.62	0.69	1.27	1.29	0.62	0.39

Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form; FF: feed form; A: additives; η^2: partial eta squared (effect size); SEM: standard error of means. $^{a, b, A, B, C}$: Differences between means with different letters in the same column are significant. $^{a, b}$: It refers to the interaction between additive and dry feed groups. $^{A, B, C}$: It refers to the interaction between additive and wet feed gruops

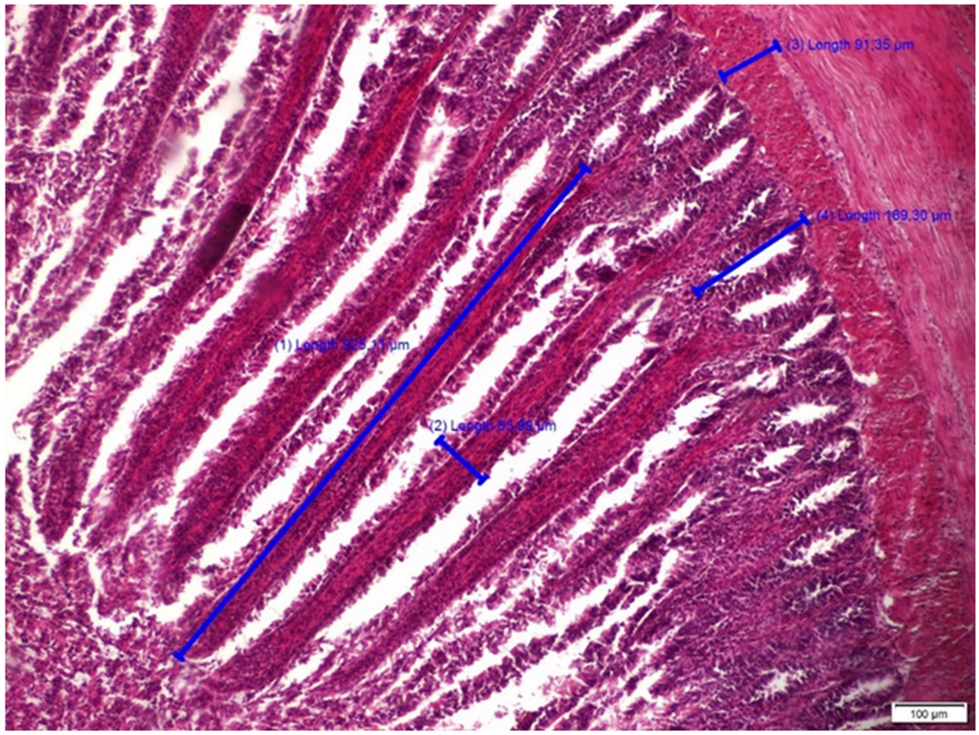

Fig. 2 A cross-section of the goose ileum (Hematoxylin & Eosin staining, 10X). (1: Villus length; 2: Villus width; 3: Lamina muscularis muscle thickness; 4: Crypt depth)

the highest cost was observed in the Wet-MR group (18.63 TL), while the lowest cost was found in the Dry-WP group (16.00 TL).

Discussion

The goose, as a herbivorous species, exhibits high adaptability to diverse environments and produces quality meat. Poultry growth performance is influenced by factors such as breed, feed nutrient composition, and feeding management. Among these, feed nutrient content plays a critical role in determining production performance under similar rearing conditions (Zhang et al. 2024). In recent years, goose farming has developed rapidly, but research in areas such as digestive physiology and feed allocation has lagged behind this progress (Wang et al. 2025). Early post-hatch nutrition is essentialfor growth performance, feed efficiency, and overall productivity in poultry. During the first week, rapid gastrointestinal development, especially in the small intestine, is essential for nutrient absorption. Feed deprivation during this period adversely affects villus morphology, thereby limiting nutrient uptake and growth (Abd El-Azeem et al. 2024). The care and nutrition of chicks during the first few days post-hatch significantly impact the flock's final body weight, making the form, digestibility, and nutrient content of the feed during this period crucial (Kamanlı and Durmuş 2014).

Growth performance

Dry feed is the most common method used to feed animals. However, in recent years, wet feed has been recognized as an important factor in enhancing animal productivity (Liu et al. 2019). De Lange et al. (2012) reported enhanced growth performance and feed utilization in pigs fed wet feed. Broiler chickens tend to prefer a wet diet when given the choice between wet and dry feed (Sampath and Atapattu 2007). Previous studies have shown that wet feeding improves dry matter intake, daily weight gain, and feed utilization in broiler chickens (Atapattu and Sudusinghe 2013; Tabeidian et al. 2015; Afsharmanesh et al. 2016). In support of these findings, Emadinia et al. (2014) reported that there was no statistically significant difference in body weight, body weight gain, feed intake, or feed conversion ratio between the wet feed and dry feed groups in their study on broiler chickens. In a study conducted with Muscovy ducks, it was reported that the wet feed form did not affect the feed conversion ratio (Farghly et al. 2018). Akinola et al. (2015) noted that broiler chickens fed wet feed had higher body weight and body weight gain compared to those fed dry feed; however, no difference was found between the groups in terms of feed intake and feed utilization. Consistent with these studies, the effects of wet and dry feed forms on average body weight, body weight gain, and feed intake in goslings during the initial period (0–3 weeks) were found to be statistically insignificant in this study. Although several studies in broilers have shown that feed form can influence

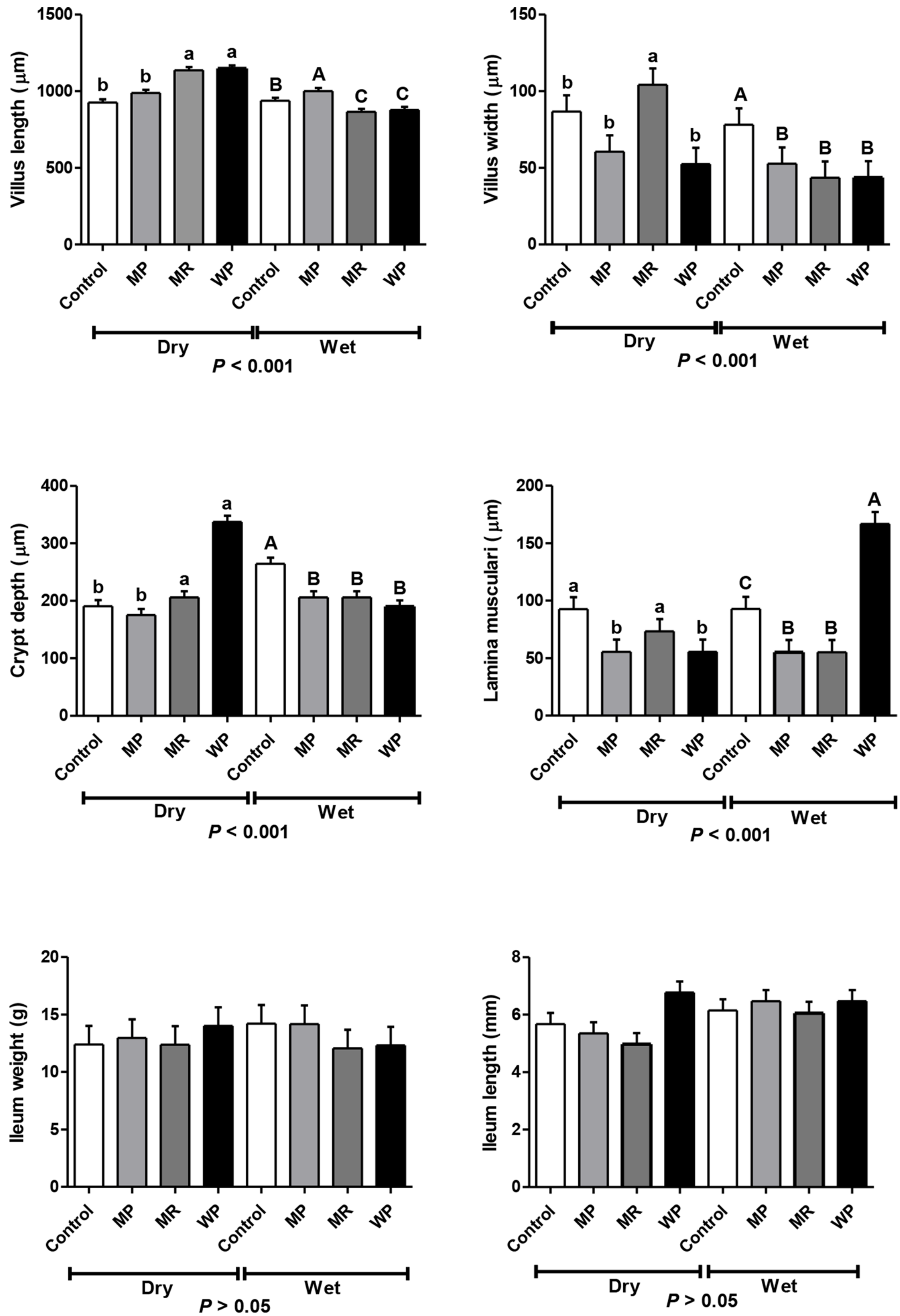

Fig. 3 Effects of feed form and dietary additives on ileum histomorphological parameters. **a**, **b**: Different lowercase letters within the same feed form indicate statistically significant differences among additive treatments ($P<0.001$). **A**–**C**: Different uppercase letters between feed forms for the same additive indicate significant interactions ($P<0.001$). No significant differences were found for ileum weight and length ($P>0.05$). Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form

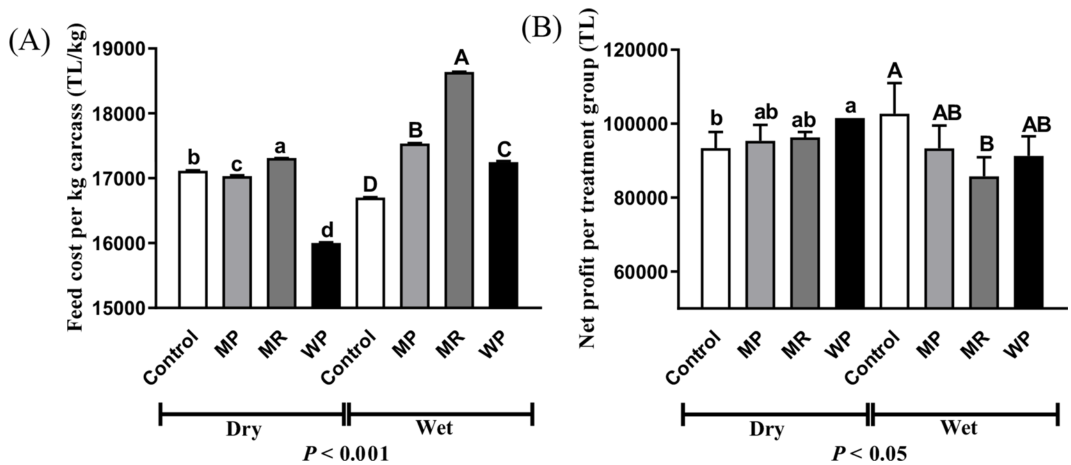

Fig. 4 Effects of feed form and dietary additives on (**A**) feed cost per kg of carcass (TL/kg) and (**B**) net profit per treatment group (TL). Capital letters indicate significant differences among wet-fed groups ($P<0.001$ for **A**; $P<0.05$ for **B**); lowercase letters indicate significant differences among dry-fed groups ($P<0.001$ for **A**; $P<0.05$ for **B**). Control: basal diet without additive supplementation; MP: milk powder; MR: milk replacer; WP: whey powder; Dry: dry feed form; Wet: wet feed form

growth performance, the lack of a significant effect in the present study may be attributed to physiological differences between species. Geese, as herbivorous waterfowl, possess a unique gastrointestinal structure and slower metabolic rate compared to broilers, which may reduce their responsiveness to feed form variations. Additionally, the controlled housing and sanitary conditions provided during the experiment may have minimized environmental stressors and helped maintain uniform growth across all groups (Liu et al. 2010; Zhang et al. 2024). Liu et al. (2019) reported that in 28- to 70-day-old geese, no statistical difference was found between the wet and dry feed groups in terms of body weight and body weight gain. However, a statistically significant difference was observed in average daily feed intake and feed conversion ratio. It has been suggested that this may be due to the ability of wet feeds to reduce digestive viscosity, thereby enabling digestive enzymes to better penetrate the feed, as well as their higher palatability. Therefore, further research is needed to elucidate the effects of feed forms on the performance of various poultry species.

Although feed form and additive treatments alone did not significantly affect body weight, body weight gain, or feed intake, their interaction yielded statistically significant effects on body weight and weight gain, particularly in the later stages of the trial. In the dry feed groups, MP, MR, and WP supplementation appeared to enhance both body weight and weight gain compared to the control group, while in the wet feed groups, this trend was reversed. Although the additive treatments did not yield statistically significant main effects on growth performance, the presence of significant interactions suggests that the influence of these additives may depend on the feed form, particularly favoring dry feeding conditions. Geese may require longer adaptation periods for morphological improvements to reflect in measurable weight gains, unlike broilers. This difference may be attributed to their slower growth rate, delayed metabolic responses, and potential age-dependent sensitivity to dietary interventions (Liu et al. 2010). Moreover, the trial duration may not have been sufficient to capture long-term performance benefits derived from intestinal development. This interaction may be indicative of enhanced nutrient availability or digestive efficiency when additives are administered with dry feed. These findings imply that the effectiveness of milk-based additives is context-dependent and highlights the importance of considering feed form in future dietary strategies for goslings. However, it has been noted that in the present study, no correction was applied for potential moisture loss due to evaporation in wet feed groups. This may have led to a slight overestimation of feed intake and may have influenced the interpretation of feed conversion and economic outcomes. Although all wet feeds were freshly prepared and offered daily, some degree of evaporation likely occurred. When body weight, body weight gain, feed intake, and feed conversion ratio were analyzed, it was observed that the addition of MP, MR, and WP to the diets of goslings during the initial period (0–3 weeks) had no statistically significant effect on these parameters. Whey is a by-product obtained during the production of casein from curd cheese or milk (Tsiouris et al. 2019). Tsiouris et al. (2019) conducted a study in which 1% WP was added to the diet of broiler chickens and found that whey supplementation did not affect performance. Our findings align with those reported by Tsiouris et al. (2019). Conversely, Zarei et al. (2018) reported that adding 4% WP to broiler diets enhanced the performance of broiler chickens. Similarly, Mehri et al. (2004) reported that the addition of 4% WP to broiler diets improved feed utilization. In another study, the supplementation of 2% WP and probiotics was observed to promote body weight gain in broiler chickens during days 0–21 (Rastad et al. 2008). Similarly, Ashour et al. (2019) demonstrated that broiler performance improved when WP concentrate (0%, 0.15%, 0.20%, and 0.25%) was added to the diet of broiler chickens in their study. In a study, Calik and Ergün (2015) incorporated lactulose, a prebiotic derived from lactose, into broiler chicken diets at concentrations of 0.4% and 0.6% and reported a significant performance improvement. It has been reported that both the level and form of whey supplementation have a significant impact on the performance of broiler chickens (Cheeke 2005; Kermanshahi and Rostami 2006). Pineda-Quiroga et al. (2018) concluded that whey positively influences the growth performance of broilers due to its high mineral digestibility, its ability to enhance feed intake. It has also been emphasized that the positive effects of whey are attributed to its low-dose usage, its rich content of proteins, vitamins, and minerals, its growth-promoting properties, and the utilization of lactose as a fermentation substrate by intestinal lactic acid bacteria (Pineda-Quiroga et al. 2018).

Survivability

In a study investigating the use of MP in broiler chickens, the group supplemented with 0.5% MP for 35 days demonstrated higher body weight gain and an improved feed conversion ratio compared to the control group. However, no significant difference was observed in feed intake (Ata and Al-Masad 2015). Similarly, Akdemir et al. (2018) supplemented the diets of 1-day-old Japanese quails with colostrum powder at levels of 2.5% and 5% for 42 days and reported that it significantly increased body weight, body weight gain, feed intake, and feed utilization efficiency. Previous studies have demonstrated that dietary supplementation with colostrum powder can have a positive impact on performance (Qureshi et al. 2004; King et al. 2005). Baran et al. (2017) supplemented the diets of 10-day-old Japanese quails with 2% and 4% liquid colostrum for 32 days. As a result, they observed that the experimental groups exhibited higher final body weight, body weight gain, feed intake, and feed conversion ratios compared to the control group (Baran et al. 2017). It has been reported that colostrum supplementation significantly enhances the beneficial microflora in the digestive system of animals and improves feed palatability, thereby promoting better digestion and nutrient absorption (Akdemir et al. 2018). Conversely, Cesari et al. (2014) reported that the addition of *L. acidophilus* and fat-free MP to the diets of laying hens did not influence performance or production parameters but significantly improved egg quality. In the present study, geese in the dry-MP group exhibited significantly higher body weight gain compared to those in the dry-control group.

MR is an alternative to milk, formulated by combining animal- and plant-based proteins and fats in specific proportions, typically containing 20–24% protein. Feeding with MR has been shown to produce results comparable to or better than those achieved with milk (Köse and Şehu 2020). It has been determined that feeding calves with MR containing up to 89% has a positive effect on growth rates. Body weight and body weight gain were higher in the Dry-MR group compared to the control group. However, there is a limited number of studies available that compare our data on MP and MR. The roles of WP, MP, and MR in poultry nutrition remain unclear, and further research is needed to elucidate their roles in goose nutrition.

No significant difference was observed between the wet and dry experimental groups in terms of survival rates. Mortality during the study period was noted to occur predominantly in the initial phase. Consistent with these findings, Akinola et al. (2015) reported that providing wet or dry feed to broiler chickens over a 56-day period had no effect on the mortality rate. Although geese are hardy birds, the mortality rate was reported to be 8.74% in one study and 13% in another study (Demir and Aksu Elmalı 2012; Demir et al. 2013). This observation has been attributed to breeders' inability to provide appropriate care and feeding conditions for goslings, as well as the reliance on traditional methods in goose breeding (Demir et al. 2013). Furthermore, providing careful management and proper feeding during the first three weeks, a critical period when goslings are particularly vulnerable, can significantly impact the success of goose rearing in later stages (Swatland 1994). Although the differences in survival rates were not statistically significant, the complete absence of mortality in several supplemented groups—including dry-MR, dry-WP, wet-MP, wet-MR, and wet-WP—is noteworthy. This pattern may suggest a potential protective effect of milk-derived additives during the critical early life period. Additionally, the controlled and hygienic experimental conditions likely contributed to the overall low mortality across groups. Further studies with larger cohorts are warranted to determine whether these supplements confer real biological benefits in terms of survivability under commercial or less controlled conditions.

Histomorphological measurements

In this study, structural features and associated parameters, including villus length, villus width, crypt depth, lamina muscularis thickness, ileum weight, and ileum length, were examined. The primary objective of analyzing these structures and parameters was to evaluate how the type of feed provided to animals, as well as its form (dry or wet), influences feed utilization. The small intestine, as a vital component of the digestive system, plays a crucial role in the overall physiological processes of the body. The small intestine plays a critical role in fulfilling the energy and structural needs of the organism. Consequently, any alterations in the morphological structure of the small intestine can significantly impact its functional capacity. Anatomically, the small intestine is divided into three distinct sections: the duodenum, jejunum, and ileum, each of which performs specialized functions (Swatland 1994; Wickramasuriya et al. 2022).

In this study, the ileum section of the small intestine was specifically examined. Generally, the primary functions of the ileum include the absorption of vitamin B_{12}, bile salts, and nutrients that remain undigested and unabsorbed in the jejunum. Additionally, the ileum is thought to play a significant role in the digestion and absorption of starch in fast-growing broilers. Accordingly, there is a positive correlation between the length and weight of the ileum and its functional efficiency in these processes (Swatland 1994; Svihus 2014). The structures known as villi, located in the small intestine, are ciliary-like formations that facilitate the absorption of nutrients into the bloodstream. These extensions enable the absorption of nutrients in their ground form, transferring their beneficial components to the circulatory system. Villi significantly increase the inner surface area of the small intestine, thereby enhancing the absorption capacity for digested materials. Furthermore, greater villus length and width are associated with a higher density of goblet cells. An increased number of goblet cells contributes to the secretion of more mucus, which aids in the lubrication and protection of the intestinal mucosa (Fontaine et al. 1996; Uni et al. 1999). Therefore, greater villus length and width can be regarded as favorable characteristics, as they enhance the adhesion and absorption surface area, promote the secretion of mucus for the protection and lubrication of the intestinal mucosa, and contribute to improved feed utilization in animals (Dellmann 1992; Swatland 1994).

Crypts are structures where epithelial cell proliferation takes place, and their development has a direct influence on villus formation and the absorptive surface area of the intestine (Parker et al. 2017). Additionally, crypts serve as the primary site for the production of goblet cells, which are essential for protecting the small intestinal epithelium and lubricating the intestinal surface. Paneth cells, located at the base of the crypts, secrete zinc and lysozyme, as well as substances with antibacterial and antifungal properties into the intestinal lumen, thereby playing a vital role in maintaining intestinal flora. As a result, crypt depth is positively associated with these functions, and greater crypt depth is considered a desirable trait (Swatland 1994; Wallaeys et al. 2023). Another critical process in the small intestine is motility, which refers to the movement of intestinal content toward the large intestine. The lamina muscularis contributes significantly to this process, as its muscle thickness is directly proportional to its positive impact on motility (Wickramasuriya et al. 2022; Tybinka 2023).

The villi and crypts of the intestinal mucosa are key indicators of gut health. Increased villus height and width enhance the absorptive surface, improving growth performance. Crypts form through epithelial cell proliferation and directly influence villus development and absorption capacity (Wickramasuriya et al. 2022; Tybinka 2023). One of the key factors contributing to profitability in the poultry industry is the efficient digestion of feed by animals. Consequently, numerous breeding and feed additive trials are conducted to enhance the digestive capacity of poultry feed materials (Sell-Kubiak et al. 2017). The efficiency of feed digestion is closely associated with the anatomical and physiological structures of the digestive tract (de Verdal et al. 2011). It has also been reported that the digestive tract and its capacity for digestion are strongly correlated in broiler chickens (Metzler-Zebeli et al. 2018). However, studies on the histological structure of the digestive tract in geese are limited. Existing research primarily focuses on comparing the digestive tract across different goose breeds and examining intestinal morphology (Kushch et al. 2019; Liu et al. 2010). The primary segments involved in digestion and absorption in the intestine are the duodenum and jejunum, while the ileum functions primarily as a reservoir. Studies have shown that the diameter of the jejunum varies across different goose breeds, whereas no significant differences have been observed in the ileum (Kushch et al. 2019).

Unlike the study by Kushch et al. (2019), the present study examined the effect of feed form (dry and wet) on intestinal morphology. It was observed that the length and width of the intestinal segments were generally greater in the groups fed dry feed. This may indicate that feed digestion is more efficient with wetted rations. In contrast, when feeds are provided in dry form, they are subjected to increased enzymatic activity within the digestive tract, which may contribute to an expansion in both intestinal length and width due to enhanced intestinal activity (Yamauchi and Tarachi 2000; Maneewan and Yamauchi 2004). It can be inferred that intestinal weight is positively associated with increases in intestinal length and width. However, some studies have reported that intestinal weight can vary even among individuals of the same breed (Sklan 2001). However, a study conducted by Akinola et al. (2015) on broiler chickens found that different feed forms (dry and wet) did not influence ileum morphology.

Jazi et al. (2020) reported that a 40 g/kg inclusion of WP did not affect the villus height or crypt depth in the duodenum, jejunum, and ileum of quails. In contrast, a study conducted in broiler chickens with 0.4% and 0.6% lactulose, a prebiotic derived from lactose, found that lactulose had a positive effect on small intestine morphology (Calık and Ergün, 2015). A study observed that adding 4% WP to the diet of broiler chickens for 42 days resulted in an increase in villus height, crypt depth, and the villus height/crypt depth ratio (Zarei et al. 2018). In accordance with these studies, the findings also demonstrated that WP supplementation increased villus length. The reduced villus length observed in the control and MP groups suggests a potential decrease in nutrient absorption. These findings suggest that the digestive and absorptive functions in young goslings may benefit from such interventions during the early growth phase. Previous studies have demonstrated that moderate dietary calcium and protein levels can improve growth performance and intestinal health in goslings by enhancing intestinal morphology and stimulating digestive enzyme activity (Chen et al. 2025). Similarly, dietary supplementation with propolis and bee pollen have been shown to increase villus height, crypt depth, and villus-to-crypt ratio, which expand the absorptive surface area of the small intestine and contribute to improved nutrient utilization and gut barrier function (Teng and Kim 2018; Prakatur et al. 2019). In the present study, the WP groups—particularly when provided in dry form—exhibited significantly greater villus height and lamina muscularis thickness, while the MR groups had the highest villus width and crypt depth values. These morphological enhancements suggest that early dietary supplementation with milk-derived additives may positively influence the functional development of the small intestine, even though no direct improvements were observed in growth performance parameters within the study period. This may reflect improved feed utilization efficiency, likely driven by the enhanced gut morphology—particularly in groups supplemented with WP and MR in dry form (Calık and Ergün 2015; Zarei et al. 2018). Increased villus height and deeper crypts are typically associated with improved absorptive capacity and epithelial renewal. However, such microstructural advantages may not always result in immediate growth responses, especially in geese, which exhibit slower developmental dynamics compared to broilers (Wickramasuriya et al. 2022; Tybinka 2023). Further studies extending beyond early growth phases are needed to fully understand the performance implications of these morphological changes. These findings suggest that improved intestinal morphology, particularly increased villus and crypt dimensions, may not always translate into enhanced growth performance within a short experimental window. This disconnect could be attributed to factors such as the relatively short supplementation duration, the high baseline husbandry standards, or the possibility that structural improvements require more time to impact measurable performance indicators. Further studies with extended feeding periods or additional physiological markers are needed to clarify the relationship between gut morphology and performance outcomes in goslings. Although no significant changes in performance were observed during the trial period, the increases in villus height and crypt depth may reflect improved absorptive efficiency and epithelial regeneration capacity. These structural advantages, if sustained, could contribute to better nutrient utilization and growth performance in longer-term feeding trials.

The villus length, villus width, and crypt depth values obtained in this study are consistent with or greater than values previously reported in poultry studies, particularly those conducted in broilers and ducks (Calık and Ergün 2015; Zarei et al. 2018; Jazi et al. 2020). In general, longer villi and deeper crypts are associated with improved absorptive capacity and enhanced epithelial turnover, respectively (Wickramasuriya et al. 2022; Tybinka 2023). These findings suggest that the observed structural improvements in intestinal morphology, especially in groups supplemented with WP and MR, could support better digestive efficiency, even if such benefits were not immediately reflected in performance parameters during the trial. Although morphological improvements were observed with certain feed additives, these changes did not always correspond with performance gains (Jazi et al. 2020). Therefore, it becomes important to also evaluate how such interventions align with economic efficiency, particularly under practical production conditions.

Economic evaluation

Proper care and nutrition should be provided during the first three weeks as goslings are highly sensitive during this period. Any reduction in the cost of goslings may adversely impact the success of raising geese in subsequent stages (Cilavdaroğlu et al. 2020). However, interventions made to the diet should also be evaluated economically. Therefore, in addition to the positive effects that may occur due to the use of additives, the costs should also be investigated. It has been determined that breeders give vitamin-mineral preparations to chicks to increase their body resistance and that the total vitamin-mineral and medicine cost is an average of 84.64 TL/goose per farm per year. It has been observed that this medicine application made by breeders is done because of the high mortality rate in goose chicks (Demir et al. 2013).

At the commencement of the trial (May 2021), the price of 1 kg of feed was 3.5 TL ($0.42), the cost of 1 kg of MP was 33.48 TL ($4.01), the price of 1 kg of MR was 20 TL ($2.40), and the price of 1 kg of WP was 7.29 TL ($0.87). The average cost of 1 kg of carcass was determined to be 16.86 TL for the dry group and 17.53 TL for the wet group. This result shows that wet feeding causes geese to waste feed, and wet feeding causes losses. The best economic result was obtained in the Dry-WP group; losses were in the dry and wet MR groups, and the worst was in the wet-MR group. Economic analysis revealed that wet feeding increased carcass cost due to higher feed wastage, while dry feeding—particularly with WP supplementation—yielded the most favorable cost outcomes. Given the variability in market prices of feed ingredients, future studies may consider incorporating sensitivity analyses to evaluate how fluctuations in the costs of MP, MR, and WP could influence economic performance. This approach would enhance the robustness of economic conclusions and broaden their practical relevance. Moreover, although cost-effectiveness per unit of histological improvement or survivability was not directly quantified in the present study, the concurrent improvements in gut morphology and 100% survival rates observed in some supplemented groups suggest a potential return on investment. Integrating biological benefits with economic metrics may offer more comprehensive insights for optimizing gosling feeding strategies under commercial production conditions. Economically, the dry-WP group demonstrated the lowest carcass cost, despite no significant differences in body weight. This may reflect improved feed utilization efficiency, likely driven by the enhanced gut morphology, which may reduce nutrient wastage and support better nutrient absorption. Therefore, aligning biological improvements with economic outcomes underscores the potential practical value of such additives in commercial gosling production.

Conclusion

In this study, the use of different feed forms and additives in the diet resulted in varying outcomes. The composition of the feed form, the dosage of additives, the administration duration, housing conditions, and environmental factors are key considerations for future research. The effectiveness of additives is influenced by factors such as the correct dosage, timing of administration, and method of incorporation; therefore, it is suggested that the effects of these factors should be examined in greater detail. In this study, it was determined that the addition of MP, MR, and WP to the diet did not affect performance parameters but improved intestinal morphology. Furthermore, it was concluded that the diet form and additives had a significant impact during the first three weeks of the goslings' sensitive period. This discrepancy between morphological and performance outcomes indicates that improvements in gut structure may not immediately translate into measurable growth advantages. While WP supplementation in dry form yielded favorable economic outcomes and supported intestinal development, further research is necessary to evaluate the long-term biological and practical impacts of such interventions. These findings underscore the value of early intestinal development as a foundation for long-term physiological resilience in goslings. Although the current study did not observe immediate performance gains, the improved gut morphology—particularly in WP and MR groups—may enhance nutrient utilization efficiency and health status in later stages of growth. Future studies with extended durations are recommended to explore the biological mechanisms and potential carry-over effects of these early-life dietary strategies.

Acknowledgements The authors would like to thank TÜBİTAK for their financial support.

Authors contributions Seda Iflazoglu Mutlu: Conceptualization; Project administration; Methodology; Investigation; Formal analysis; Writing—original draft and editing. Pinar Tatli Seven: Methodology; Investigation; Writing- review & editing. Ulku Gulcihan Simsek: Methodology; Investigation; Formal analysis; Writing- review & editing. Zeki Erisir: Methodology; Investigation; Writing- review & editing. Yasin Baykalir: Methodology; Investigation; Formal analysis; Writing- review & editing. Mehmet Hanifi Yalçın: Methodology; Formal analysis; Writing- review & editing. Muhsin Mutlu: Methodology; Investigation; Formal analysis; Writing—original draft.

Funding This study was supported by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) (Project No: TOVAG-120O943).

Data availability The data supporting this study are available from the corresponding author upon reasonable request.

Declarations

Ethics statement All animal experimental procedures were reviewed and approved according to the Animal Experiments Local Ethics Committee guidelines at Firat University (No: 2020/15).

Conflict of interest The authors declare no conflict of interest.

References

Abd El-Azeem NA, Madkour M, Hashem NM, Alagawany M (2024) Early nutrition as a tool to improve the productive performance of broiler chickens. World Poult Sci J 80:171–185

Afsharmanesh M, Lotfi M, Mehdipour Z (2016) Effects of wet feeding and early feed restriction on blood parameters and growth performance of broiler chickens. Anim Nutr 2:168–172

Akdemir F, Bayril T, Baran MS, Yildiz AS, Kahraman M, Orhan C, Sahin K (2018) The effect of dietary colostrum powder on performance, carcass yields and serum lipid peroxidation levels in Japanese quails (Coturnix coturnix japonica). J Appl Anim Res 46(1):39–43

Akinola OS, Onakomaiya AO, Agunbiade JA, Oso AO (2015) Growth performance, apparent nutrient digestibility, intestinal morphology and carcass traits of broiler chickens fed dry, wet and fermented-wet feed. Livest Sci 177:103–109

AOAC (2006) Official methods of analysis of AOAC international. Association of Official Analysis Chemists International, Washington, DC

Ashour EA, Abd El-Hack ME, Alagawany M, Swelum AA, Osman AO, Saadeldin IM, Abdel-Hamid M, Hussein OES (2019) Use of Whey protein concentrates in broiler diets. J Appl Poult Res 28:1078–1088

Ata M, Al-Masad M (2015) Effect of milk powder supplementation on growth performance of broilers. J Agric Sci 7:8

Atapattu NSBM, Sudusinghe HS (2013) Wet feeding mitigates the adverse effects of high dietary rice Bran levels on growth performance and nitrogen retention of broiler chickens. Iran J Appl Anim Sci 3:153–160

Awad WA, Hess M, Twarużek M, Grajewski J, Kosicki R, Böhm J, Zentek J (2011) The impact of the fusarium Mycotoxin Deoxynivalenol on the health and performance of broiler chickens. Int J Mol Sci 12(11):7996–8012

Baran MS, Bayrıl T, Akdemir F, Akşit H, Kahraman M (2017) Effect of supplementary liquid colostrum on growth performance, carcass yield, ceruloplasmin, Sialic acid and some antioxidant levels in quails. Kafkas Universitesi Veteriner Fakültesi Dergisi 23(5):729–734

Calik A, Ergün A (2015) Effect of lactulose supplementation on growth performance, intestinal histomorphology, cecal microbial population, and short-chain fatty acid composition of broiler chickens. Poult Sci 94:2173–2182

Cesari V, Mangiagalli MG, Giardini A, Galimberti P, Carteri S, Gallazzi D, Toschi I (2014) Egg quality and productive performance of laying hens fed different levels of skimmed milk powder added to a diet containing *Lactobacillus acidophilus*. Poult Sci 93:1197–1120

Cheeke PR (2005) Applied animal nutrition: feeds and Feding. Pearson Prentice Hall, New Jersey

Chen Y, Su G, Li N, Yang Z, Yang H, Wang Z (2025) Dietary calcium and protein levels influence growth performance, intestinal development, and nutrient utilization in goslings. Veterinary Sci 12(4):310

Cilavdaroğlu E, Yamak US, Boz MA (2020) Etlik Kaz yetiştiriciliği. Black Sea J Agric 3(1):66–70

Cohen J (1988) Statistical power analysis for the behavioral sciences. 2nd edn. Hillsdale, NJ, Erlbaum

De Lange CFM, Zhu CH (2012) Liquid Feding corn-based diets to growing pigs: practical considerations and use of co-products. Feed efficiency in swine. Wageningen Academic, Wageningen, pp 63–80

de Verdal H, Narcy A, Bastianelli D, Chapuis H, Même N, Urvoix S, Le Bihan-Duval E, Mignon-Grasteau S (2011) Improving the efficiency of feed utilization in poultry by selection. 2. Genetic parameters of excretion traits and correlations with anatomy of the gastro-intestinal tract and digestive efficiency. BMC Genet 17:12–71

Dellmann DH (1992) Textbook veterinary histology. (Fourth Edition). Lea & Febiger, U.S

Demir P, Aksu Elmalı D (2012) Economical analysis of Goose breeding commercially by small family farms. World's Poult Sci J 68:5–10

Demir P, Kırmızıbayrak T, Yazıcı K (2013) Kaz Yetiştiriciliğinin sosyo-ekonomik Önemi. Ankara Üniversitsi Veteriner Fakültesi Dergisi 60:129–134

Ebling PD, Kessler AM, Villanueva AP, Pontalti GC, Farina G, Ribeiro AML (2015) Rice and soy protein isolate in pre-starter diets for broilers. Poult Sci 94:2744–2752

Emadinia A, Toghyani M, Gheisari A, Tabeidian SA, Fosoul SSAS, Mohammadrezaei M (2014) Effect of wet feeding and enzyme supplementation on performance and immune responses of broiler chicks. J Appl Anim Res 42:32–37

Farghly MFA, Abd El-Hack ME, Alagawany M, Saadeldin IM, Swelum AA (2018) Wet feed and cold water as heat stress modulators in growing muscovy ducklings. Poult Sci 97:1588–1594

Faul F, Erdfelder E, Lang AG, Buchner A (2007) G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39:175–191

Fontaine N, Meslin JC, Lory S, Andrieux C (1996) Intestinal Musin distribution in the germ free rat and in the heteroxenic rat harbouring a human bacterial flora: effect of unilin in the diet. Br J Nutr 75:881–892

Jamroz D, Wiliczkiewicz A, Orda J, Wertelecki T, Skorupińska J (2002) Aspects of development of digestive activity of intestine in young chickens, ducks and geese. J Anim Physiol Anim Nutr 86:353–366

Jazi V, Farahi M, Khajali F, Abousaad S, Ferket P, Assadi Soumeh E (2020) Effect of dietary supplementation of Whey powder and *Bacillus subtilis* on growth performance, gut and hepatic function, and muscle antioxidant capacity of Japanese quail. J Anim Physiol Anim Nutr 104(3):886–897

Kamanlı S, Durmuş İ (2014) Civciv kalitesi Değerlendirme yöntemleri ve Civciv Kalitesinin iyileştirilmesi Konusundaki son Yaklaşımlar. Tavukçuluk Araştırma Dergisi 11(1):40–44

Kermanshahi H, Rostami H (2006) Influence of supplemental dried Whey on broiler performance and cecal flora. Int J Poult Sci 5(6):538–543

Kermanshahi HI, Heravi RMI, Attar AI, Abbasi Pour ARI, Bayat EII, Hossein Zadeh MI, Daneshmand AI, Ibrahim SA (2017) Effects of acidified yeast and Whey powder on performance, organ weights, intestinal microflora, and gut morphology of male broilers. Brazilian J Poult Sci 19(2):309–316

King M, Ravindran V, Morel P, Thomas D, Birtles M, Pluske J (2005) Effects of spray-dried colostrum and plasmas on the performance and gut morphology of broiler chickens. Crop Pasture Sci 56:811–817

Köse S, Şehu A (2020) Süt Ikame Yemi. Veteriner Farmakoloji Ve Toksikoloji Derneği Bülteni 11(1):27–37

Kushch MM, Kushch LL, Byrka EV, Byrka VV, Yaremchuk OS (2019) Morphological features of the jejunum and ileum of the middle and heavy Goose breeds. Ukrainian J Ecol 9(4):690–694

Leeson S (2008) Predictions for commercial poultry nutrition. J Appl Poult Res 17:315–322

Liu B, Wang Z, Yang H, Wang XB, Hu P, Lu J (2010) Developmental morphology of the small intestine in Yangzhou goslings. Afr J Biotechnol 9:7392–7400

Liu Z, Huang X, Luo Y, Xue J, Wang Q, Wang Y, Wang C (2019) Effect of dry and wet feed on growth performance, carcass traits, and apparent nutrient digestibility in geese. J Appl Poult Res 28:1115–1120

Maneewan B, Yamauchi K (2004) Effects of semi-purified pellet diet on the chicken intestinal villus histology. Br Poult Sci 45(2):163–170

Mehri M, Zare SA, Samie AH (2004) The effects of supplementation of Whey powder on broiler performance. Iran J Agric Sci 35:1007–1013

Metzler-Zebeli BU, Magowan E, Hollmann M, Ball MEE, Molná A, Witter K, Ertl R, Hawken RJ, Lawlor PG, O'Connell NE, Aschenbach J, Zebeli Q (2018) Differences in intestinal size, structure, and function contributing to feed efficiency in broiler chickens reared at geographically distant locations. Poult Sci 97(2):578–591

NRC (1994) National research council. Nutrient requirements of poultry, 9th edn. National Academic, Washington, D.C

Parker A, Maclaren OJ, Fletcher AG, Muraro D, Kreuzaler PA, Byrne HM, Maini PK, Watson AJ, Pin C (2017) Cell proliferation within small intestinal crypts is the principal driving force for cell migration on villi. FASEB J 31(2):636–649

Pineda-Quiroga C, Camarinha-Silva A, Borda-Molina D, Atxaerandio R, Ruiz R, García-Rodríguez A (2018) Feeding broilers with dry Whey powder and Whey protein concentrate affected productive performance, ileal digestibility of nutrients and cecal microbiota community. Animal 12(4):692–700
Prakatur I, Miskulin M, Pavic M, Marjanovic K, Blazicevic V, Miskulin I, Domacinovic M (2019) Intestinal morphology in broiler chickens supplemented with propolis and bee pollen. Animals 9(6):301
Qureshi MA, Ali R, Cheema MA, Ahmed Z, Roth H (2004) Immun milk feeding increases growth and immune responses in broiler chicks. Int J Poult Sci 3:305–312
Rastad A, Samie A, Daneshvar F (2008) Effect of Bactocell and dry Whey on performance and carcass characteristics of broiler chickens. JWSS - Isfahan Univ Technol 12:473–480
Sampath SJ, Atapattu NSBM (2007) Effects of wetting plant feed ingredients 6 on growth performance and tibia ashpercentage of broiler chicken. Br Poult Sci 3:33–34
Sell-Kubiak E, Wimmers K, Reyer H, Szwaczkowski T (2017) Genetic aspects of feed efficiency and reduction of environmental footprint in broilers: a review. J Appl Genet 58(4):487–498
Sklan D (2001) Development of the digestive tract of poultry. World Poult Sci 57:415–428
Svihus B (2014) Function of the digestive system. J Appl Poult Res 23:306–314
Swatland HJ (1994) Structure and development of meat animals and poultry. Technomic Publishing Company, Pennsylvania, USA
Szczurek W, Szymczyk B, Arczewska-Włosek A, J´ozefiak D, Alloui M (2013) The effects of dietary Whey protein concentrate level on performance, selected intestinal tract and blood parameters, and thiobarbituric acid reactive substances in the liver and breast meat of broiler chickens. J Anim Feed Sci 22:342–353
Tabeidian SA, Toghyani M, Toghyani AH, Barekatain MR, Toghyani M (2015) Effect of pre-starter diet ingredients and moisture content on performance, yolk sac utilization and small intestine morphology in broiler chickens. J Appl Anim Res 43:157–165
Teng PY, Kim WK (2018) Review: roles of prebiotics in intestinal ecosystem of broilers. Front Veterinary Sci 30(5):245
Thompson KL, Applegat TJ (2006) Feed withdrawal alters small-intestinal morphology and mucus of broilers. Poult Sci 85:1535–1540
Tsiouris V, Economou E, Lazou T, Georgopoulou I, Sossidou E (2019) The role of Whey on the performance and campylobacteriosis in broiler chicks. Poult Sci 98:236–243
Tybinka AM (2023) Comprehensive characteristics of rectal morphology in chickens with different types of autonomous regulation. Ukrainian J Veterinary Agricultural Sci 6(2):44–55
Uni Z, Noy Y, Sklan D (1999) Posthatch development of small intestinal function in the poult. Poult Sci 78(2):215–222
Uni Z, Smirnov A, Sklan D (2003) Pre- and posthatch development of goblet cells in the broiler small intestine: effect of delayed access to feed. Poult Sci 82(2):320–327
Wallaeys C, Garcia-Gonzalez N, Libert C (2023) Paneth cells as the cornerstones of intestinal and organismal health: a primer. EMBO Mol Med 15(2):e16427
Wang S, Wei C, Yan J, Zhang Y (2025) The impact of dietary metabolizable energy levels on the performance of medium-sized geese: A systematic review. Poult Sci 104(2):104743
Wickramasuriya SS, Park I, Lee K, Lee Y, Kim WH, Nam H, Lillehoj HS (2022) Role of physiology, immunity, microbiota, and infectious diseases in the gut health of poultry. Vaccines 10(2):172
Xi Y, Huang Y, Li Y, Yan J, Shi Z (2020) Fermented feed supplement relieves caecal microbiota dysbiosis and kidney injury caused by high-protein diet in the development of Gosling gout. Animals 10(11):2139
Yamauchi K, Tarachai P (2000) Changes in intestinal villi, cell area and intracellular autophagic vacuoles related to intestinal function in chickens. Br Poult Sci 41:416–423
Zarei A, Lavvaf A, Motlagh MM (2018) Effects of probiotic and Whey powder supplementation on growth performance, microflora population, and ileum morphology in broilers. J Appl Anim Res 46(1):840–844
Zhang Y, Qi S, Fan S, Jin Z, Bao Q, Zhang Y, Zhang Y, Xu Q, Chen G (2024) Comparison of growth performance, meat quality, and blood biochemical indexes of Yangzhou Goose under different feeding patterns. Poult Sci 103(2):103349

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