

EFFECT OF DIETARY INCLUSION OF BLACK SOLDIER FLY (*HERMETIA ILLUCENS*) LARVAE MEAL AT 2%, 3% AND 6% LEVELS ON NUTRIENT DIGESTIBILITY AND GROWTH PERFORMANCE OF MEDEO MEAT DUCKS IN WEST KAZAKHSTAN

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ABSTRACT

This study evaluated the effect of graded dietary inclusion of black soldier fly (*Hermetia illucens*) larvae meal at 2%, 3%, and 6% on nutrient digestibility and growth performance in Medeo meat ducks. The experiment was conducted at Zhangir Khan West Kazakhstan Agrarian and Technical University, Oral, Republic of Kazakhstan, during 2023–2024. Four-hundred-day-old ducks (50 males and 50 females per group) were assigned to four dietary treatments: a basal control diet and three experimental diets supplemented with 2, 3, or 6% BSFL meal. Data were analyzed using one-way analysis of variance in SPSS, with differences considered statistically significant at $P < 0.05$. Body weight at 49 days in the 6% group exceeded the control by 23.7% in males (3675.42 vs. 2971.96 g) and 16.6% in females (3311.42 vs. 2839.06 g); average daily gain over the 0–49-day rearing period was correspondingly 20.6 and 17.0% higher than in the control ($P < 0.05$). Crude fat digestibility in the 6% group was 5.0 percentage points higher than in the control in both sexes, and crude protein digestibility was 3.2 (males) and 4.0 (females) percentage points higher than in the control ($P < 0.05$). To the best of our knowledge, this is the first study to combine a graded BSFL inclusion range with sex-stratified digestibility and growth measurements in meat-type ducks reared under the cereal-based, soybean-reduced feeding conditions of West Kazakhstan, and the results identify 6% as the most effective inclusion level within the tested range.

Keywords: Feeding, Diet, Live weight, Nutrients, Coefficient of digestibility.

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1. INTRODUCTION

Modern poultry production continues to face mounting pressure to improve feed efficiency while reducing dependence on conventional protein sources such as soybean meal and fish meal, the prices and availability of which fluctuate with global markets and contribute to environmental burdens through land-use change and fisheries depletion (Adeniji, 2007; Dzepe et al., 2023; Heines et al., 2022; Sajid et al., 2023; Sankara et al., 2023; Nugmanova et al., 2024a). In waterfowl production systems and particularly in Central and Western Asia, the search for locally available, nutritionally adequate, and economically feasible protein ingredients has intensified over the last decade (Nugmanova et al., 2024b; Sychov et al., 2025). Insect-derived feed ingredients, most notably the larvae of the black soldier fly (*Hermetia illucens*), have therefore attracted substantial scientific and commercial interest as a circular-economy alternative that converts organic residues and agro-industrial by-products into high-value biomass usable in monogastric nutrition (Barragan-Fonseca et al., 2017; DiGiacomo, 2023; Dzepe et al., 2023; Salahuddin et al., 2024; Kazemi & Valizadeh, 2025; Francis et al., 2025; Abd El-Ghany, 2025). *H. illucens* larvae have a chemical composition that makes them competitive with conventional feedstuffs. As summarized by Salahuddin et al. (2024) and Barragan-Fonseca et al. (2017) in comprehensive reviews, full-fatted BSFL typically contain, on a dry-matter basis, 400–630 g/kg crude protein, 90–360 g/kg crude lipid, and a relatively well-balanced essential amino acid profile, with reported lysine concentrations of approximately 21–30 g/kg and methionine-plus-cystine around 9–15 g/kg depending on rearing substrate, larval instar, and processing method. The lipid fraction is dominated by medium-chain fatty acids, in particular lauric acid, which has been associated with selective antimicrobial activity against Gram-positive bacteria in the avian gut (Barragan-Fonseca et al., 2017; Salahuddin et al., 2024). Larval chitin and melanin fractions contribute additional functional properties, although excessive chitin at very high inclusion rates can reduce dry-matter digestibility if birds are not physiologically adapted to the

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substrate (Traksele et al., 2021; Seyedalmoosavi et al., 2022). In the regional context of the present study, locally sourced BSFL analysed in our laboratory contained 506.2 g/kg crude protein, 91.4 g/kg crude fat, 31.23 g/kg lysine, and 14.07 g/kg methionine-plus-cystine, exceeding the corresponding values in soybean meal and sunflower meal that dominate regional mixed feeds.

A growing body of *in vitro* and *in vivo* evidence indicates that BSFL meal can partially replace conventional protein sources in monogastric diets without compromising nutrient retention or feed conversion (Long et al., 2026; Okon et al., 2026). In a precision-fed cecum-excised rooster assay, Do et al. (2020) reported standardized amino-acid digestibility coefficients for BSFL comparable to those of high-quality animal proteins, with clear age-of-larva effects. Traksele et al. (2021) demonstrated *in vitro* pepsin-pancreatin digestibility values exceeding 80% for BSFL protein fractions, and Chu et al. (2020) showed that low full-fatted BSFL inclusion-maintained nitrogen retention and amino-acid availability in laying hens. Kovitvadhi et al. (2019) screened yellow mealworm, giant mealworm, lesser wax moth, house fly, mulberry silkworm pupae, and American cockroach nymph meals for organic-matter and crude-protein digestibility in meat-type ducks using a two-step *in vitro* protocol with duck-derived enzyme extracts, identifying six insect species with potential as duck feed ingredients and reinforcing the need for species-specific digestibility validation in waterfowl. In broiler chickens, partial or full replacement of soybean meal with defatted or full-fatted BSFL meal has generally maintained, or moderately improved, feed conversion ratios, body-weight gain, and apparent ileal digestibility of crude protein and crude fat, with dose-dependent responses reported up to approximately 10–15% inclusion before performance trade-offs appear (Schiavone et al., 2017; Bovera et al., 2018; Ipema et al., 2022). Bovera et al. (2018) further showed that *H. illucens* meal supports laying performance, blood profiles, and nutrient digestibility in hens over production cycles typical of commercial operations. Beyond Galliformes, Loponte et al. (2017) reported that BSFL meal sustained growth, blood profiles, and carcass traits of Barbary partridges (*Alectoris barbara*) when substituted for soybean meal, supporting cross-species applicability of the ingredient. In addition to their nutritional advantages, alternative feed ingredients are evaluated for economic efficiency. Improved nutrient digestibility enables more efficient feed utilization, thereby reducing feed costs per unit of production (Heines et al., 2022; Ipema et al., 2022). Consequently, insect-derived protein is regarded not only as a nutritionally valuable ingredient but also as a potentially cost-effective alternative amid rising prices and limited availability of conventional feed resources (Loponte et al., 2017; Nugmanova et al., 2024b; Sychoy et al., 2025).

Data on waterfowl, however, remain comparatively scarce. Most published work on ducks has evaluated growth performance, intestinal morphology, and carcass yield, with single inclusion levels and without a systematic dose-response design on coefficient-of-digestibility metrics stratified by age and sex (Hakim et al., 2022). Where reported, BSFL inclusion up to approximately 5–6% in Muscovy and Pekin-type ducks has not depressed feed intake and has tended to improve breast-meat yield, but the underlying digestive mechanisms, particularly for crude fat, which is the most chemically distinctive fraction of the larvae, have rarely been quantified through balance trials with sex-stratified measurements (Schiavone et al., 2017; Hakim et al., 2022). In recent duck-specific trials, Yang et al. (2026) reported linear ADG/ADFI decreases beyond 3% defatted BSFL in Cherry Valley ducks and a parallel improvement in jejunal *Lactobacillus* abundance at 9%, and Nugmanova et al. (2025) reported slaughter-performance responses to 2/4/6% BSFL in a regional 49-day duck trial, indicating that dose and larval-processing form jointly shape the response, but neither provides sex-stratified digestibility coefficients. This information gap is particularly consequential for West Kazakhstan, where cereal-based waterfowl diets rely heavily on imported soybean meal and a narrow set of locally produced protein sources, primarily sunflower meal and oilcake, and where regional recommendations for alternative protein use in duck rations are still absent (Nugmanova et al., 2024a; Nugmanova et al., 2024b; Sychoy et al., 2025).

Furthermore, the magnitude and direction of the response to BSFL depend on the inclusion level and basal diet composition, and existing studies rarely span a meaningful dietary range within a single experiment (Biasato et al., 2016; Seyedalmoosavi et al., 2022; DiGiacomo, 2023). Low inclusion levels may not produce statistically detectable differences from the control, whereas higher levels can significantly enhance protein and fat utilization, with excessive levels potentially reducing palatability or introducing chitin-related constraints (Traksele et al., 2021; Seyedalmoosavi et al., 2022). A graded inclusion design that covers an interpretable range, applied to a locally formulated duck ration and analyzed separately for males and females, is therefore needed to define the upper practical limit of BSFL in regional meat-duck production.

To address the absence of graded dose-response digestibility data for *H. illucens* larvae meal in meat-type ducks and the absence of such data under the cereal-based feeding conditions of West Kazakhstan, the present study was designed to evaluate three graded inclusion levels (2, 3 and 6%) of BSFL meal on the digestibility of major nutrients (dry matter, crude protein, crude fat, crude fibre, and nitrogen-free extractives) and on body-weight dynamics in Medeo meat ducks reared to 49-days. The basal diet was formulated using locally available feed

ingredients, including wheat, barley, corn, millet, sorghum, soybean meal, sunflower meal, and oilcake, alongside the graded BSFL inclusions.

We hypothesized that:

1. Inclusion of *H. illucens* larvae meal would increase crude-protein and crude-fat digestibility in a dose-dependent manner relative to the control, with the highest values at the 6% inclusion level.
2. The improvement in nutrient digestibility would translate into proportional gains in body weight and average daily gain across the 49-day rearing period, with the 6% group exceeding the control in both sexes.
3. Digestibility coefficients would increase with age in all groups, and the magnitude of the dietary treatment effect would be greater in the later (35–42 day) growth phase than in the earlier (7–14 day) phase, reflecting the developing digestive capacity of meat-type ducks.

Therefore, this study aimed to evaluate the effects of different inclusion levels of *Hermetia illucens* larvae in diets for meat-type ducks on nutrient digestibility and body weight dynamics, and to determine the most effective inclusion level.

2. MATERIALS AND METHODS

The animal experiments were reviewed and approved by the Local Ethics Committee on Bioethics of the NJSC “Zhangir Khan West Kazakhstan Agrarian and Technical University” (Ural’sk, Republic of Kazakhstan) on 01 November 2023. All procedures involving animals were conducted in strict accordance with the provisions of the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes and complied with generally accepted bioethical standards.

The study was carried out at the Zhangir Khan West Kazakhstan Agrarian Technical University. Medeo ducks (Pekin white) were selected for the experiment because they are a widely used meat-type breed. Birds were assigned to experimental groups using the principle of analogs, considering age, sex, and initial body weight to ensure comparability.

Four groups were formed, including one control and three experimental treatments. Each group consisted of 100 birds, with equal numbers of males and females (Table 1). During the first week, the birds were reared in brooders. Afterward, they were transferred to a floor system with straw bedding. Environmental and management conditions were kept consistent across all groups. Temperature, lighting, ventilation, and stocking density followed standard poultry husbandry practices. Feed and water were available ad libitum.

Table 1: Experimental design at NJSC “Zhangir Khan West Kazakhstan Agrarian-Technical University”

Age, days	Experimental groups	Total number, n	Feeding scheme
I - 49 days	Control I	50/50	Basal compound feed formulation
	Experimental II	50/50	Basal compound feed formulation + BSFL meal 2%
	Experimental III	50/50	Basal compound feed formulation + BSFL meal 3%
	Experimental IV		Basal compound feed formulation + BSFL meal 6%

Black soldier fly larvae were obtained from Menzhan-Agro LLP, West Kazakhstan Region, Kazakhstan. The larvae were supplied by the producer as *H. illucens*. Species identity was based on the accompanying producer documentation; no independent morphological or molecular identification was performed. Before chemical analysis and diet preparation, the larvae were sieved to remove residual rearing substrate. They were initially dried at 60°C and subsequently dried at 100–105°C. The dried larvae were then ground to produce BSFL meal and stored in sealed containers under dry conditions until incorporation into the experimental diets.

Before diet formulation, representative samples of the feed ingredients and prepared BSFL meal were analysed at the Zootechnical Analysis Laboratory of the Testing Center of Zhangir Khan West Kazakhstan Agrarian Technical University. Moisture content was determined in accordance with GOST 13496.3-92 and dry matter was calculated from it. Nitrogen and crude protein were determined by the Kjeldahl method in accordance with GOST 13496.4-2019, using a nitrogen-to-protein conversion factor of 6.25. Crude fat was determined by solvent extraction according to GOST 13496.15-2016, and crude fiber was determined by sequential acid and alkali treatment according to GOST 31675-2012. The analytical values obtained for the feed ingredients and BSFL meal were used to formulate the experimental diets and are presented in Table 2. The lysine, methionine, cystine, and tryptophan values reported in Table 2 were obtained from the certificate of analysis supplied with the BSFL meal and were not independently determined in the present study.

Cereal ingredients such as corn, wheat, and barley were characterized by high levels of metabolizable energy and nitrogen-free extractives, which explain their role as the main energy sources in the diet. As shown in Table 2,

the crude protein content of the cereal ingredients ranged from 96.5 g/kg in crushed corn to 150.8 g/kg in barley, which was substantially lower than that of soybean meal (387.6 g/kg), sunflower meal (361.5 g/kg), and BSFL meal (506.2 g/kg).

Table 2: Chemical composition of feed in the West Kazakhstan region

Feed	Types of feed												
	Sudan grain	Crushed Corn	Millet	Rye	Sorghum	Barley	Crushed wheat	Soy	Cake	Soy meal	Wheat bran	Sunflower meal	The larva
Exchange energy, 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	16.2
Dry matter, g/kg	850	847.3	846.2	860.7	848.7	886.8	837.5	843.8	908	893.8	839.7	890	904.8
Crude protein, g/kg	108	96.5	105.7	109	101.2	150.8	118.6	218.6	356.4	387.6	149.6	361.5	506.2
Digestible protein,g/kg	81.6	65.4	67	72.6	69.2	107.8	78.9	138.3	213.7	231.7	83.6	208.4	303.7
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	31.23
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	14.07
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	7.9
Crude fat, g/kg	16.1	33.6	32	17	26.9	25.4	23.9	36.8	56.3	24.4	28.4	32.3	91.4
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	94.54
NES, g	573	663	562	664.4	649	870.4	672	0	224.5	308.4	511	201.3	430.1
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	15.1
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	6.5
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	0
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	0
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	0
Iron, mg	31.8	7.6	33.7	62.5	45.1	1.1	43.9	112	118	203.4	131	282.5	23.7
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	90
Zinc, mg	22.5	24.2	27.8	18.9	11.6	28.7	22.6	26	46.6	37.4	53	37.4	19.4
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	0.06
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
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

As shown in Table 2, soybean meal and sunflower meal contained 387.6 and 361.5 g/kg crude protein, respectively, compared with 96.5–150.8 g/kg in the cereal ingredients. Their lysine contents were 22.5 and 12.1 g/kg, respectively, confirming their role as concentrated protein sources in the formulated diets.

According to the laboratory analysis performed before diet formulation, the BSFL meal contained 506.2 g/kg crude protein and 91.4 g/kg crude fat, which were the highest values among the feed ingredients presented in Table 2. It also contained 31.23 g/kg lysine and 14.07 g/kg methionine plus cystine. This indicates their high biological value and their potential as a concentrated nutrient source.

Before inclusion in the experimental diets, the black soldier fly larvae were sieved to remove residual rearing substrate and dried at 60°C until a stable moisture content was achieved. The dried larvae were subsequently ground to obtain a homogeneous full-fat BSFL meal and stored in sealed containers under dry conditions until diet formulation. Representative samples of the prepared meal were collected before feeding and analysed for their chemical composition using the GOST procedures described above.

Based on the experimentally determined chemical composition of the prepared BSFL meal and the other feed ingredients, complete diets were formulated for two growth phases, from day 1 to 14 and from day 15 to 49, with graded dietary inclusion levels of BSFL meal (Table 3).

The control group received a basal diet without insect meal. In the experimental treatments, black soldier fly larvae (*H. illucens*) were included at 2, 3 and 6% levels, replacing part of the conventional protein source. The selected inclusion levels were intended to cover a practical range of insect meal use in poultry diets. The 2% level represented minimal inclusion, while 3% reflected a moderate level. The 6% inclusion was chosen to evaluate the upper limit without compromising feed intake or nutrient balance. This approach allowed for the assessment of a possible dose-dependent response.

Body weight was recorded individually at the start of the experiment and subsequently at weekly intervals. Data for males and females were processed separately. Absolute and average daily weight gains were calculated based on these measurements.

Nutrient digestibility was determined in two total-collection balance trials conducted during the early and late growth phases, at 7–14 and 35–42 days of age, respectively. At each age period, 10 ducks were selected from each dietary treatment, comprising five males and five females. The birds were housed individually in balance cages that permitted the separate quantitative collection of excreta, and each duck was considered an independent

experimental unit, resulting in five replicates per sex and dietary treatment.

Each balance trial comprised a 2–3-day adaptation period followed by a three-day collection period. During adaptation, the birds were accustomed to individual housing and continued to receive the diet assigned to their respective experimental group. During the collection period, the amount of feed offered and the feed refusals were weighed daily for each bird to determine actual feed intake. Excreta were collected quantitatively twice daily, in the morning and evening, separately from each duck. Visible feathers and other foreign material were removed before the samples were weighed.

Table 3: Feeding ration of ducks in the experimental groups

Indicators, %	Experimental groups							
	I–14 days				15–49 days			
	I	II	III	IV	I	II	III	IV
Sudan grass	5	5	5	5	3	3	3	3
Corn	16	14	12	10	9	7	5	3
Millet	5	5	5	5	3	3	3	3
Rye	3	3	3	3	3	3	3	3
Sorghum	3	3	3	3	3	3	3	3
Barley	10	10	10	10	7	7	7	7
Wheat	25	25	25	25	41	41	41	41
Soybeans	5	5	5	5	2	2	2	2
Oilcake	4	4	4	4	8	8	8	8
Soybean meal	12	12	12	12	13	13	13	13
Wheat bran	5	5	5	5	3	3	3	3
Sunflower meal	5	5	5	5	3	3	3	3
BSFL meal	-	2	4	6	-	2	4	6
Seashell	2	2	2	2	2	2	2	2
Per 100 g of compound feed contains, %:								
Metabolizable energy MJ	1.03	1.04	1.06	1.07	1.05	1.07	1.08	1.09
kcal	246.01	248.40	253.18	255.57	250.79	255.57	257.95	260.34
Dry matter, g	84.20	84.31	84.43	84.54	84.15	84.26	84.38	84.49
Crude protein, g	17.44	18.26	19.08	19.90	17.92	18.74	19.56	20.38
Digestible protein, g	11.05	11.53	12.01	12.48	11.32	11.80	12.28	12.75
Lysine, g	0.83	0.88	0.94	1.00	0.75	0.80	0.86	0.92
Methionine + cystine, g	0.53	0.56	0.58	0.60	0.59	0.61	0.63	0.65
Tryptophan, g	0.16	0.17	0.18	0.20	0.16	0.18	0.19	0.21
Crude fat, g	2.77	2.88	3.00	3.11	2.76	2.88	2.99	3.11
Crude fiber, g	3.91	4.04	4.17	4.31	3.73	3.86	3.99	4.13
NFE, g	53.89	53.42	52.96	52.49	54.90	54.43	53.97	53.50
Sugar, g	2.92	2.87	2.83	2.79	3.11	3.07	3.02	2.98
Calcium, g	0.93	0.96	0.99	1.02	0.94	0.96	0.99	1.02
Phosphorus, g	0.54	0.55	0.55	0.56	0.55	0.56	0.56	0.57
Magnesium, g	0.29	0.28	0.27	0.27	0.28	0.28	0.27	0.26
Potassium, g	0.71	0.70	0.69	0.68	0.69	0.68	0.67	0.67
Sulfur, g	0.09	0.09	0.09	0.09	0.10	0.10	0.09	0.09
Iron, mg	7.42	7.45	7.49	7.52	7.45	7.48	7.51	7.54
Copper, mg	0.91	1.08	1.24	1.41	0.88	1.05	1.22	1.38
Zinc, mg	2.80	2.79	2.78	2.77	2.77	2.76	2.75	2.74
Manganese, mg	3.26	3.24	3.22	3.19	3.66	3.64	3.62	3.60
Cobalt, mg	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Carotene, mg	0.13	0.13	0.13	0.12	0.16	0.15	0.15	0.14

The excreta collected from each bird over the three consecutive collection days were pooled on an individual-animal basis. The pooled samples were dried to constant weight, ground to obtain a homogeneous sample, and stored in sealed containers until chemical analysis. Representative samples of the corresponding experimental diets were collected during each balance trial and prepared using the same procedure. Feed and excreta samples collected during the balance trials were analyzed using the same GOST procedures applied to the feed ingredients. Moisture was determined according to GOST 13496.3-92, crude protein according to GOST 13496.4-2019, crude fat according to GOST 13496.15-2016 and crude fiber according to GOST 31675-2012.

The apparent total-tract digestibility coefficient for each nutrient was calculated separately for each bird according to the following equation:

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$$\text{Digestibility coefficient (\%)} = [(\text{nutrient intake} - \text{nutrient excreted}) / \text{nutrient intake}] \times 100$$

The resulting coefficients were subsequently analyzed separately for males and females.

Before the collection period, birds were given a 2-3-day adaptation phase. We then recorded feed intake and excreta over three consecutive days. We dried, ground, and prepared the collected samples for analysis. We performed statistical analyses using one-way analysis of variance (ANOVA) in SPSS. Results are presented as mean $\pm$ SE. Differences were considered statistically significant at $P < 0.05$

3. RESULTS

3.1. Dynamics of Live Body Weight of Young Geese in the Experimental Groups

Body weight increased steadily in all groups throughout the rearing period (Table 4). In males, differences between treatments became noticeable from 14 days of age and became more pronounced toward the end of the experiment. By day 49, ducks fed 2% *H. illucens* larvae reached 3311.96 g, which was 11.4% (340.00 g) higher than the control group (2971.96 g). At the 3% inclusion level, body weight increased to 3482.40 g, exceeding the control by 17.2% (510.44 g). The highest value was observed at 6%, where body weight reached 3675.42 g, corresponding to a 23.7% (703.46 g) increase over the control.

Table 4: Dynamics of live body weight of ducks in the experimental groups, g (mean $\pm$ SE, n = 50 per sex and group)

Age, days	Group I			Group II			Group III			Group IV		
	Mean $\pm$ SE	SD	CV, %	Mean $\pm$ SE	SD	CV, %	Mean $\pm$ SE	SD	CV, %	Mean $\pm$ SE	SD	CV, %
Male												
1	51.12 $\pm$ 0.27bc	1.90	3.72	49.86 $\pm$ 0.40c	2.83	5.67	52.60 $\pm$ 0.51a	3.57	6.80	51.40 $\pm$ 0.35ab	2.46	4.78
7	201.40 $\pm$ 0.82b	5.79	2.88	198.50 $\pm$ 0.79b	5.57	2.81	201.50 $\pm$ 1.09b	7.69	3.82	209.60 $\pm$ 1.19a	8.39	4.00
14	599.56 $\pm$ 1.53c	10.80	1.80	536.20 $\pm$ 2.09d	14.76	2.75	612.72 $\pm$ 2.34b	16.56	2.70	654.82 $\pm$ 3.42a	24.17	3.69
21	1031.70 $\pm$ 3.71c	26.27	2.55	1096.88 $\pm$ 4.66b	32.97	3.01	1174.48 $\pm$ 5.56a	39.29	3.34	1163.28 $\pm$ 6.18a	43.67	3.75
28	1458.48 $\pm$ 5.41d	38.25	2.62	1653.56 $\pm$ 6.80c	48.08	2.91	1740.84 $\pm$ 7.32a	51.77	2.97	1709.64 $\pm$ 9.21b	65.10	3.81
35	1967.24 $\pm$ 6.91c	48.84	2.48	2205.44 $\pm$ 7.25b	51.24	2.32	2309.32 $\pm$ 8.60a	60.81	2.63	2281.10 $\pm$ 9.08a	64.18	2.81
42	2504.10 $\pm$ 8.57c	60.61	2.42	2763.02 $\pm$ 8.81b	62.30	2.25	2890.94 $\pm$ 10.40a	73.51	2.54	2909.72 $\pm$ 11.47a	81.08	2.79
49	2971.96 $\pm$ 12.95d	91.59	3.08	3311.96 $\pm$ 14.04c	99.26	3.00	3482.40 $\pm$ 16.48b	116.56	3.35	3675.42 $\pm$ 18.03a	127.50	3.47
Absolute growth, 0–49 days	2920.84 $\pm$ 12.90d	91.20	3.12	3262.10 $\pm$ 14.12c	99.86	3.06	3429.80 $\pm$ 16.48b	116.51	3.40	3624.02 $\pm$ 18.02a	127.44	3.52
Female												
1	49.80 $\pm$ 0.23A	1.60	3.22	48.60 $\pm$ 0.37B	2.62	5.39	49.10 $\pm$ 0.41AB	2.89	5.88	49.00 $\pm$ 0.25AB	1.80	3.66
7	189.52 $\pm$ 0.73C	5.20	2.74	193.46 $\pm$ 0.85C	5.99	3.10	199.64 $\pm$ 1.06B	7.49	3.75	204.68 $\pm$ 1.80A	12.71	6.21
14	487.60 $\pm$ 1.44D	10.15	2.08	515.46 $\pm$ 1.99C	14.10	2.74	578.90 $\pm$ 2.02B	14.26	2.46	619.48 $\pm$ 3.27A	23.09	3.73
21	986.50 $\pm$ 3.40C	24.05	2.44	982.26 $\pm$ 3.68C	26.03	2.65	1004.76 $\pm$ 4.64B	32.84	3.27	1126.34 $\pm$ 5.12A	36.19	3.21
28	1425.64 $\pm$ 4.96D	35.04	2.46	1478.24 $\pm$ 5.42C	38.35	2.59	1509.36 $\pm$ 6.33B	44.79	2.97	1663.06 $\pm$ 7.31A	51.69	3.11
35	1884.12 $\pm$ 6.02D	42.55	2.26	1978.88 $\pm$ 6.34C	44.85	2.27	2031.02 $\pm$ 7.22B	51.03	2.51	2211.52 $\pm$ 8.23A	58.18	2.63
42	2416.74 $\pm$ 7.62D	53.85	2.23	2494.52 $\pm$ 7.80C	55.16	2.21	2557.70 $\pm$ 9.68B	68.42	2.68	2757.20 $\pm$ 10.25A	72.51	2.63
49	2839.06 $\pm$ 12.43D	87.86	3.09	3007.10 $\pm$ 13.17C	93.15	3.10	3141.90 $\pm$ 14.61B	103.30	3.29	3311.42 $\pm$ 16.52A	116.82	3.53
Absolute growth, 0–49 days	2789.26 $\pm$ 12.47D	88.21	3.16	2958.50 $\pm$ 13.16C	93.06	3.15	3092.80 $\pm$ 14.57B	103.05	3.33	3262.42 $\pm$ 16.48A	116.54	3.57

Note: Within each row, means bearing different superscript letters differ significantly among dietary groups within the same sex (Tukey's HSD, $P < 0.05$); means sharing at least one letter do not differ significantly. Lowercase letters refer to male comparisons, and uppercase letters refer to female comparisons. SD = standard deviation; CV = coefficient of variation.

A similar pattern was observed in females. At 49 days of age, body weight in the 2% group was 3007.10 g, which was 5.9% (168.04 g) higher than in the control group (2839.06 g). In the 3% group, body weight reached 3141.90 g, a 10.7% increase (302.84 g). The highest value was recorded at 6% inclusion, where body weight reached 3311.42 g, exceeding the control by 16.6% (472.36 g).

Absolute growth over the 0–49-day period followed the same trend. In males, the 2% group reached 3262.10 g, which was 11.7% (341.26 g) higher than the control (2920.84 g). In the 3% group, absolute growth was 3429.80 g, exceeding the control by 17.4% (508.96 g). At the 6% level, it reached 3624.02 g, which was 24.1% higher than the control (703.18 g).

In females, absolute growth in the 2% group reached 2958.50 g, which was 6.1% (169.24 g) above the control (2789.26 g). In the 3% group, it increased to 3092.80 g, corresponding to a 10.9% (303.54 g) difference. The highest value was again observed at 6%, reaching 3262.42 g, which exceeded the control by 17.0% (473.16 g).

Citation: Nametov, A., Shamshidin, A., Nugmanova, A., Sabyrzhanov, A., Makhimova, Z., & Baktygery, N. (2026). Effect of dietary inclusion of black soldier fly (*Hermetia illucens*) larvae meal at 2%, 3%, and 6% levels on nutrient digestibility and growth performance of Medeo meat ducks in West Kazakhstan. *Agrobiological Records*, 26, 19-31. <https://doi.org/10.47278/journal.abr/2026.080>

Overall, increasing the inclusion level of *H. illucens* larvae in the diet was associated with a consistent improvement in body weight and growth performance in both sexes. The most pronounced effect was observed at the 6% inclusion level.

3.2. Average Daily Gain

Average daily gain followed a similar pattern to body weight, increasing with higher inclusion levels of *H. illucens* larvae (Table 5). In males, growth intensity was relatively uniform during the first week, with no clear differences between groups. From 7 to 14 days, variation between treatments became more noticeable, with the highest values recorded in the 6% group, 11.8% higher (6.72g) than in the control.

Table 5: Average daily gain of ducks in the experimental groups, g/day (mean $\pm$ SE, n = 5 as currently reported)

Sext, Period (days)	Group I	Group II	Group III	Group IV
Male				
0–7	21.47 $\pm$ 0.11b	21.23 $\pm$ 0.13b	21.27 $\pm$ 0.19b	22.60 $\pm$ 0.18a
7–14	56.88 $\pm$ 0.27c	48.24 $\pm$ 0.31d	58.75 $\pm$ 0.36b	63.60 $\pm$ 0.53a
14–21	61.73 $\pm$ 0.60b	72.95 $\pm$ 0.71a	73.11 $\pm$ 0.81a	75.49 $\pm$ 0.97a
21–28	60.97 $\pm$ 0.92c	79.53 $\pm$ 1.14a	69.48 $\pm$ 1.41b	75.19 $\pm$ 1.67a
28–35	72.68 $\pm$ 1.44b	71.70 $\pm$ 1.54b	82.64 $\pm$ 1.60a	81.64 $\pm$ 1.70a
35–42	76.69 $\pm$ 1.60b	75.37 $\pm$ 1.62b	88.80 $\pm$ 1.98a	92.66 $\pm$ 2.09a
42–49	66.84 $\pm$ 2.05c	78.42 $\pm$ 2.08b	81.64 $\pm$ 2.84b	92.24 $\pm$ 2.81a
Overall, 0–49	59.61 $\pm$ 0.26d	63.92 $\pm$ 0.29c	67.96 $\pm$ 0.34b	71.92 $\pm$ 0.37a
Female				
0–7	19.96 $\pm$ 0.12D	20.69 $\pm$ 0.13C	21.51 $\pm$ 0.14B	22.24 $\pm$ 0.26A
7–14	42.58 $\pm$ 0.23D	46.00 $\pm$ 0.32C	54.18 $\pm$ 0.33B	59.26 $\pm$ 0.54A
14–21	71.27 $\pm$ 0.51A	73.83 $\pm$ 0.55A	67.98 $\pm$ 0.69B	72.41 $\pm$ 0.91A
21–28	62.73 $\pm$ 0.83C	70.85 $\pm$ 0.93B	74.94 $\pm$ 1.25AB	76.67 $\pm$ 1.14A
28–35	65.50 $\pm$ 1.08C	71.52 $\pm$ 1.15B	71.67 $\pm$ 1.52B	81.21 $\pm$ 1.72A
35–42	76.09 $\pm$ 1.52A	73.66 $\pm$ 1.37A	72.38 $\pm$ 1.65A	75.10 $\pm$ 1.91A
42–49	60.33 $\pm$ 1.83B	73.23 $\pm$ 2.07A	79.17 $\pm$ 2.59A	79.17 $\pm$ 2.88A
Overall, 0–49	56.92 $\pm$ 0.25D	61.40 $\pm$ 0.27C	63.12 $\pm$ 0.30B	66.58 $\pm$ 0.34A

Note: Within each row, means bearing different superscript letters differ significantly among dietary groups within the same sex (Tukey's HSD, $P < 0.05$); means sharing at least one letter do not differ significantly. Lowercase letters refer to male comparisons, and uppercase letters refer to female comparisons.

In subsequent periods, daily gain fluctuated rather than increased linearly. The highest gains were observed between 35 and 49 days, particularly in the 3% and 6% groups. At 42–49 days, the daily gain in the 6% group reached 92.24 g, exceeding the control group by 38.0% (25.40 g). For the entire rearing period (0–49 days), average daily gain in males was 71.92 g in the 6% group (+20.6%; 12.31 g), compared to 59.61 g in the control.

In females, a similar pattern was observed, although the variation between periods was less pronounced. The highest growth rates were also recorded in the later stages of rearing. At 42–49 days, daily gain in the 6% group reached 79.17 g, compared with 60.33 g in the control group, an increase of 31.2% (18.84 g). These results indicate that differences in growth rate were most pronounced during the later stages of development, with higher inclusion levels increasing growth intensity rather than producing uniform changes throughout the entire period.

3.3. Digestibility of Feed Nutrients by Ducklings in the Experimental Groups

The body weight results indicate differences in growth rates across inclusion levels of *H. illucens* larvae. To clarify the factors underlying these differences, we conducted a balance trial to evaluate feed utilization efficiency and the digestibility of major nutrients at different inclusion levels (Table 6).

Dry matter digestibility showed small but consistent differences. In males, values in the 3% group were 2.7% higher than in the control, and 3.4% higher at the 6% level.

Crude protein showed a clearer response. In males, digestibility in the 3% group exceeded the control by 4.1%, and by 3.2% at 6% ($P < 0.05$). In females, the increase was close to 4%, indicating improved protein utilization. Crude fat showed the strongest effect. In males, digestibility at 6% was 5.0% higher than the control ($P < 0.05$). In females, the increase also reached 5.0%, making this parameter the most responsive to dietary inclusion.

Changes in crude fiber digestibility were less consistent. In males, the 3% group exceeded the control by 4.3%, while in females, the 6% group increased by 4.0%. Overall, including *H. illucens* larvae improved digestibility mainly for protein and fat, whereas changes in other nutrients were less pronounced. Digestibility coefficients increased with age in all groups, indicating a gradual improvement in nutrient utilization as ducks developed (Table

7).

Table 6: Apparent nutrient digestibility coefficients during the 7–14-day balance trial (mean $\pm$ SE, n = 5)

Indicator, %	Group I		Group II		Group III		Group IV	
	Male	Female	Male	Female	Male	Female	Male	Female
Dry matter	59.4 $\pm$ 0.41c	58.7 $\pm$ 0.52C	60.2 $\pm$ 0.47bc	59.8 $\pm$ 0.38BC	62.1 $\pm$ 0.44ab	61.6 $\pm$ 0.63AB	62.8 $\pm$ 0.55a	61.9 $\pm$ 0.42A
Crude protein	72.1 $\pm$ 0.33c	70.2 $\pm$ 0.50B	74.3 $\pm$ 0.43b	73.1 $\pm$ 0.59A	76.2 $\pm$ 0.41a	74.3 $\pm$ 0.60A	75.3 $\pm$ 0.37ab	74.2 $\pm$ 0.45A
Crude fat	76.1 $\pm$ 0.48c	75.4 $\pm$ 0.55C	77.2 $\pm$ 0.55bc	76.6 $\pm$ 0.72BC	79.0 $\pm$ 0.85ab	78.8 $\pm$ 0.78AB	81.1 $\pm$ 0.47a	80.4 $\pm$ 1.01A
Crude fiber	20.2 $\pm$ 0.15c	19.1 $\pm$ 0.25D	21.2 $\pm$ 0.18b	20.4 $\pm$ 0.24C	24.5 $\pm$ 0.17a	22.1 $\pm$ 0.21B	23.6 $\pm$ 0.34a	23.1 $\pm$ 0.17A
NFE	81.0 $\pm$ 3.92a	80.3 $\pm$ 4.02A	83.3 $\pm$ 3.95a	81.7 $\pm$ 3.71A	83.9 $\pm$ 2.98a	82.4 $\pm$ 3.03A	84.2 $\pm$ 2.11a	82.6 $\pm$ 1.56A

Note: Within each nutrient and sex, means bearing different superscript letters differ significantly among dietary groups (Tukey's HSD, $P < 0.05$); means sharing at least one letter do not differ significantly. Lowercase letters refer to male comparisons, and uppercase letters refer to female comparisons. NFE = nitrogen-free extractives.

Table 7: Apparent nutrient digestibility coefficients during the early and late balance trials (mean $\pm$ SE, n = 5)

Indicator, %	Group I		Group II		Group III		Group IV	
	Male	Female	Male	Female	Male	Female	Male	Female
7–14 days								
Dry matter	59.4 $\pm$ 0.41c	58.7 $\pm$ 0.52C	60.2 $\pm$ 0.47bc	59.8 $\pm$ 0.38BC	62.1 $\pm$ 0.44ab	61.6 $\pm$ 0.63AB	62.8 $\pm$ 0.55a	61.9 $\pm$ 0.42A
Crude protein	72.1 $\pm$ 0.33c	70.2 $\pm$ 0.50B	74.3 $\pm$ 0.43b	73.1 $\pm$ 0.59A	76.2 $\pm$ 0.41a	74.3 $\pm$ 0.60A	75.3 $\pm$ 0.37ab	74.2 $\pm$ 0.45A
Crude fat	76.1 $\pm$ 0.48c	75.4 $\pm$ 0.55C	77.2 $\pm$ 0.55bc	76.6 $\pm$ 0.72BC	79.0 $\pm$ 0.85ab	78.8 $\pm$ 0.78AB	81.1 $\pm$ 0.47a	80.4 $\pm$ 1.01A
Crude fiber	20.2 $\pm$ 0.15c	19.1 $\pm$ 0.25D	21.2 $\pm$ 0.18b	20.4 $\pm$ 0.24C	24.5 $\pm$ 0.17a	22.1 $\pm$ 0.21B	23.6 $\pm$ 0.34a	23.1 $\pm$ 0.17A
NFE	81.0 $\pm$ 3.92a	80.3 $\pm$ 4.02A	83.3 $\pm$ 3.95a	81.7 $\pm$ 3.71A	83.9 $\pm$ 2.98a	82.4 $\pm$ 3.03A	84.2 $\pm$ 2.11a	82.6 $\pm$ 1.56A
35–42 days								
Dry matter	62.7 $\pm$ 0.35c	60.3 $\pm$ 0.41C	62.9 $\pm$ 0.28c	61.5 $\pm$ 0.30C	65.3 $\pm$ 0.29b	63.1 $\pm$ 0.43B	67.5 $\pm$ 0.32a	66.6 $\pm$ 0.25A
Crude protein	76.2 $\pm$ 1.19a	75.9 $\pm$ 2.13A	77.7 $\pm$ 1.55a	76.3 $\pm$ 1.38A	79.2 $\pm$ 0.88a	78.8 $\pm$ 0.92A	80.4 $\pm$ 0.56a	79.6 $\pm$ 0.77A
Crude fat	80.2 $\pm$ 1.23b	79.5 $\pm$ 0.98C	83.5 $\pm$ 0.85ab	82.4 $\pm$ 0.77BC	84.8 $\pm$ 0.55a	83.3 $\pm$ 0.61AB	86.6 $\pm$ 0.44a	85.7 $\pm$ 0.36A
Crude fiber	20.5 $\pm$ 0.29c	19.8 $\pm$ 0.41C	22.3 $\pm$ 0.35b	21.3 $\pm$ 0.24B	25.1 $\pm$ 0.51a	23.7 $\pm$ 0.35A	25.5 $\pm$ 0.25a	24.3 $\pm$ 0.19A
NFE	80.0 $\pm$ 1.89b	79.9 $\pm$ 1.61A	83.8 $\pm$ 1.56ab	82.1 $\pm$ 1.44A	84.2 $\pm$ 1.24ab	83.8 $\pm$ 1.32A	86.1 $\pm$ 1.01a	85.3 $\pm$ 1.20A

Note: Within each nutrient, age period, and sex, means bearing different superscript letters differ significantly among dietary groups (Tukey's HSD, $P < 0.05$); means sharing at least one letter do not differ significantly. Lowercase letters refer to male comparisons, and uppercase letters refer to female comparisons. NFE = nitrogen-free extractives.

At 7–14 days of age, differences between treatments were already visible but remained moderate. In males, dry matter digestibility in the 6% group was higher than the control by 3.4%, and in females by 3.2%. For crude protein, the increase reached 4.1%, while for crude fat it reached 5.0%, suggesting an early response to the dietary inclusion of *H. illucens* larvae.

By 35–42 days, these differences became more pronounced. In males, dry matter digestibility in the 6% group exceeded the control by 4.8%, and in females by 6.3%. Crude protein digestibility increased by up to 4.2% in males and 3.7% in females. The strongest effect was observed for crude fat, where digestibility in the 6% group was higher than in the control by 6.4% in males and 6.2% in females ($P < 0.05$).

Changes in crude fiber digestibility were less consistent, although a positive trend persisted. In the 6% group, values in males exceeded the control by 5.0%, and in females by 4.5%, with statistical significance observed only in some comparisons.

Digestibility of nitrogen-free extractives showed moderate increases. In the later period, values were higher than the control by up to 6.1% in males and 5.4% in females, although variability remained relatively high. Overall, digestibility improved with age, and the inclusion of *H. illucens* larvae had the strongest and most consistent effect on protein and fat utilization. The highest values were consistently observed at the 6% inclusion level.

4. DISCUSSION

The principal finding of the present study is that graded inclusion of *H. illucens* larval meal at 2, 3, and 6% progressively improved both nutrient digestibility and body weight gain in Medeo meat ducks, with the 6% level producing the largest response in both sexes. At 49 days, male ducks in the 6% group reached 3,675.4 g and females 3,311.4 g, exceeding the control by 23.7% and 16.6%, respectively; average daily gain over the 0–49-day rearing period was 20.6% (males) and 17.0% (females) higher than in the control ($P < 0.05$). Crude fat digestibility in the 6% group was 5.0 percentage points higher than in the control in both sexes (males 81.1% vs 76.1%; females 80.4% vs 75.4%), and crude protein digestibility was 3.2 (males) and 4.0 (females) percentage points higher than in the control. These improvements, which accompanied a numerically stable feed intake and an unchanged fiber digestibility profile, are consistent with the response pattern that has been reported internationally for insect-derived feed ingredients in monogastric species over the last five years (Chu et al., 2020; Hakim et al., 2022; Ipema et al.,

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2022; DiGiacomo, 2023; Salahuddin et al., 2024). These findings are also consistent with earlier studies demonstrating improved nutrient utilization and poultry performance following dietary inclusion of *H. illucens*. Similar improvements in nutrient digestibility have been reported by Bovera et al. (2018), Cullere et al. (2016), Vilela et al. (2021) and Attivi et al. (2020), confirming that the positive effects of BSFL are reproducible across different poultry species and feeding systems.

Direct comparisons with prior duck studies are limited but informative. Hakim et al. reported in a 2022 balanced trial on meat-type male ducks that BSFL meal inclusion improved nutrient digestibility relative to a soybean meal control, although the design used a single inclusion level and did not stratify by sex or week of age (Hakim et al., 2022).

Additional evidence from duck studies supports the dose-dependent nature of BSFL responses. Yang et al. (2026) evaluated 3%, 6%, and 9% defatted BSFL meal replacing soybean meal in Cherry Valley ducks and found that although growth performance declined beyond 3% inclusion, the highest level significantly increased jejunal *Lactobacillus* abundance, suggesting that productive and microbiological responses may follow different dose-response patterns. Similarly, Nugmanova et al. (2025), working with 2%, 4%, and 6% BSFL supplementation in ducks, identified 2% as the most appropriate inclusion level, based primarily on slaughter performance criteria. In contrast, the present study demonstrates that a 6% inclusion yields superior nutrient digestibility and body weight gain, suggesting that the optimal dietary level may depend on the production traits selected as primary endpoints.

Compared with previous duck studies, the present work evaluated a graded dose range, reported sex-specific digestibility coefficients, and used a cereal-based diet in which soybean meal was partially replaced with locally available sunflower meal and oilcake. The magnitude of the improvement in crude fat digestibility observed here (+5.0 pp at 6%) is consistent in direction with the broiler literature: Salahuddin et al. (2024) summarized that BSFL-derived lipid fractions reliably increase apparent metabolizable energy and apparent ileal fat digestibility when included up to approximately 10% of broiler diets, with the largest benefits occurring when larvae partially replace rather than completely supplant conventional fat sources. Likewise, Dabbou et al. (2018) reported a quadratic growth response in broilers, with live weight peaking at 10% dietary inclusion of defatted *H. illucens* meal. Comparable improvements in ether-extract digestibility were also reported by Gariglio et al. (2019) in Muscovy ducks receiving partially defatted *H. illucens* meal, supporting the present observation that BSFL consistently enhances lipid utilization across different poultry species.

The biological basis for these improvements can be considered at four levels: amino-acid profile, lipid profile, mineral and chitin matrix, and gut environment. First, BSFL provides a highly digestible protein source with a balanced amino acid profile, particularly lysine and methionine, which supports nitrogen retention and feed conversion in growing poultry (Makkar et al., 2014; Barragan-Fonseca et al., 2017; Seyedalmoosavi et al., 2022). This is consistent with the higher average daily gain observed in the 6% group. Second, the lipid fraction of BSFL is rich in medium-chain fatty acids, particularly lauric acid, which contributes both to dietary energy value and antimicrobial activity while being rapidly absorbed, thereby providing a plausible explanation for the improved fat digestibility observed at the 6% inclusion level (Barragan-Fonseca et al., 2017; Schiavone et al., 2017; Salahuddin et al., 2024). Third, the chitin-protein-mineral matrix of BSFL appears to be well tolerated at inclusion levels up to 6%, whereas higher dietary concentrations may reduce nutrient availability due to residual chitin (Traksele et al., 2021; Seyedalmoosavi et al., 2022). The absence of adverse effects on fiber or dry-matter digestibility supports the suitability of the 6% inclusion level. Finally, lauric acid has been shown to promote beneficial gut microbiota while suppressing opportunistic pathogens, thereby supporting intestinal integrity and digestive-enzyme activity, as previously reported in broilers and partridges (Barragan-Fonseca et al., 2017; Loponte et al., 2017; Salahuddin et al., 2024).

The body-weight response observed here (+23.7% males, +16.6% females over the 49-day period) is comparable in trend, though larger in absolute magnitude, than the responses reported in broiler and free-range poultry. Ipema et al. (2022) reported that the method of providing live BSFL larvae influences broiler performance, with scattering live larvae yielding the greatest welfare and growth benefits compared with suspended or tray delivery. While the present study used dried, full-fatted larvae meal rather than live larvae, the conclusion that the physiological response to BSFL is sensitive to the form and the inclusion level is consistent with our observation that the 6% level produced statistically significant differences from the control, whereas the 2 and 3% levels produced smaller, partly non-significant differences for some traits. The cross-species comparison also suggests that ducks may be at least as responsive to BSFL inclusion as broilers and partridges: Loponte et al. (2017) reported significant growth and carcass improvements in Barbary partridges fed *H. illucens* meal, and Chu et al. (2020) showed that low full-fatted BSFL inclusion-maintained nitrogen retention in laying hens, both of which bracket, from above and below in metabolic rate, the duck response documented here. Maulana et al. (2023) likewise reported improved body-weight gain and feed conversion in hybrid meat ducks receiving fresh BSFL, indicating that beneficial responses occur irrespective of whether larvae are supplied fresh or as processed meal.

The dose-response pattern deserves particular emphasis. In this study the largest numerical gains were observed at the highest tested inclusion (6%), and there was no evidence of a plateau or reversal within the tested range. This is consistent with international findings that the upper practical limit of BSFL inclusion in poultry diets is species-dependent: broilers tolerate high doses to about 10–15% before palatability or chitin-related constraints appear, whereas ducks may have a similar or slightly higher tolerance given their longer transit time and more developed cecal fermentation (Schiavone et al., 2017; Seyedalmoosavi et al., 2022; Salahuddin et al., 2024). A plateau was not reached here because the dose range ended at 6% and further work with 8%, 10%, and 12% inclusions is needed to define the inflection point. Traksele et al. (2021) demonstrated that *in vitro* pepsin-pancreatin digestibility of BSFL protein exceeded 80%, providing an upper-bound estimate of nitrogen availability that has not yet been matched by *in vivo* dose-response trials in ducks. Do et al. (2020), using the precision-fed cecum-excised rooster assay, further showed that amino-acid digestibility of BSFL is sensitive to larval instar, with older larvae giving higher coefficients – a methodological consideration that may explain some of the between-study variation in duck responses and that we did not stratify here because larvae of a single instar were used.

The results carry three concrete implications for duck producers in West Kazakhstan. First, the 6% inclusion level is identified as the most effective dose within the tested range for both sexes. Producers adopting this level can expect a 5-percentage-point improvement in crude fat digestibility and a 3–4 percentage-point improvement in crude protein digestibility, accompanied by a 17% (females) to 24% (males) increase in final body weight at 49 days relative to the soybean-meal-containing control. Second, the dose-response pattern, such as significant gains at 6% and smaller, partly non-significant gains at 2 and 3%, is itself operationally informative: it indicates that low ($\leq 3\%$) inclusion should not be expected to produce detectable production gains and that nutritionists should not under-dose to "test" the ingredient. Third, and perhaps most consequential for the regional feed sector, the cereal-based basal diet used here (wheat, barley, corn, millet, sorghum, soybean meal, sunflower meal, oilcake) reflects the formulations described as characteristic of duck breeding under West Kazakhstan conditions (Nugmanova et al., 2024a; Nugmanova et al., 2024b). Compatibility of BSFL inclusion with this diet, rather than with the soybean-maize reference diets typical of international trials, means the present results can be transferred into local feed-mill practice without further basal-diet adjustment, and BSFL can functionally substitute part of the imported soybean meal fraction in regional rations, as the broiler literature has already demonstrated for *H. illucens* meal as a soybean substitute (Cutrignelli et al., 2018; Dzepe et al., 2023; Salahuddin et al., 2024).

In a broader sustainability framing, BSFL production is itself a route for converting locally generated agro-industrial residues into a high-protein feed ingredient, which aligns with circular-economy and waste-reduction objectives that have gained policy traction across Central Asia (DiGiacomo, 2023; Dzepe et al., 2023; Sankara et al., 2023). The 6% dose identified here therefore has both an immediate production value (higher 49-day body weight, better nutrient retention) and a strategic value, pointing to a locally producible alternative to imported protein concentrates.

Several limitations should be acknowledged. First, the balance trial was conducted on a subset of birds, and the per-coefficient residual variability was non-trivial for crude-fiber fractions. Second, only digestibility and body-weight dynamics are reported in the present manuscript; data on slaughter yield, carcass composition, blood biochemistry, and economic efficiency were collected but are being analyzed separately. Third, the experiment used a single larval source and a single instar, so the findings should be generalized with caution to BSFL meals that differ in substrate, harvest age, or processing method (Do et al., 2020; Seyedalmoosavi et al., 2022). Finally, the cereal-based diet, while designed to reflect the realities of West Kazakhstan feed formulation, differs from the soybean-maize reference diets used in most international BSFL trials, so direct numerical comparisons should be made with that caveat in mind.

In conclusion, graded inclusion of *H. illucens* larval meal up to 6% progressively improved nutrient digestibility and growth performance in Medeo meat ducks under cereal-based feeding conditions in West Kazakhstan, with the 6% level yielding the largest and most statistically robust gains in both sexes. The improvement is mechanistically consistent with enhanced amino acid balance, efficient absorption of medium-chain fatty acids, and a favorable gut environment, and is comparable in direction, though larger in magnitude, to recent international findings in broilers, laying hens, and partridges. The 6% level is identified as the most effective within the tested range and further work is warranted to define the upper practical inclusion limit, the carcass and economic outcomes, and the effect of different larval substrates and processing methods in regional duck production systems

5. CONCLUSION

Including *Hermetia illucens* larvae in duck diets improved nutrient digestibility and growth performance. The most pronounced effect was observed at the 6% inclusion level, which can be considered optimal under the

conditions of this study. These findings support the potential use of black soldier fly larvae as an alternative protein source in duck nutrition. Further research is needed to evaluate economic efficiency and product quality at this level of inclusion

Declarations

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Data Availability: Data will be made available on request

Ethics Statement: The animal experiments were reviewed and approved by the Local Ethics Committee on Bioethics of the NJSC “Zhangir Khan West Kazakhstan Agrarian and Technical University” (Ural’sk, Republic of Kazakhstan) on 01 November 2023. All procedures involving animals were conducted in strict accordance with the provisions of the European Convention for the Protection of Vertebrate Animals used for Experimental and Other Scientific Purposes and complied with generally accepted bioethical standards.

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