

Fermented tofu dregs as a waste-derived biological feed resource for Pekin ducks (*Anas platyrhynchos domesticus*)

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Abstract. Asnawi, Purnamasari DK, Ninggrum VJA, Pratama AY, Rizqi M. 2026. Fermented tofu dregs as a waste-derived biological feed resource for Pekin ducks (*Anas platyrhynchos domesticus*). *Biodiversitas* 27 (3): d270314. <https://doi.org/10.13057/biodiv/d270314>.

Tofu dregs, a protein- and mineral-rich by-product of tofu production, remain underutilized in duck feed due to high fiber content, anti-nutritional factors, and variable moisture that limit their direct inclusion in practical diets. This study evaluated the effects of EM4-based solid-state fermentation on the nutritional quality of tofu dregs and assessed the performance of Pekin ducks fed diets in which commercial feed was partially replaced with fermented tofu dregs. Fermentation improved the nutritional profile of tofu dregs by increasing crude protein, total fat, selected essential and non-essential amino acids, and several macro- and micro-minerals, while reducing crude fiber, moisture, and ash contents. Feeding trials were conducted using 100 Pekin ducks allocated to four dietary treatments containing 0%, 10%, 20%, and 30% fermented tofu dregs in isoenergetic and isonitrogenous rations. Increasing inclusion of fermented tofu dregs up to 30% did not significantly affect final body weight, body weight gain, or feed conversion ratio, although feed intake increased at higher inclusion levels. These findings demonstrate that EM4-fermented tofu dregs can be utilized as a sustainable waste-derived feed resource to partially replace commercial feed in Pekin duck diets without compromising growth performance. Integrating fermented tofu dregs into duck feeding strategies offers a practical approach to valorize tofu processing waste, reduce reliance on conventional feed ingredients, and support more circular and environmentally friendly duck production systems in regions where tofu dregs are abundantly available.

Keywords: Agro-industrial by-products, alternative feed resources, duck nutrition, EM4 fermentation, tofu dregs

INTRODUCTION

Since the early 2000s, duck cuisine has expanded rapidly in street vendors, restaurant chains, and online delivery platforms, driving the growth of duck farming and increasing demand for broiler duck meat. Feed costs constitute the largest component of production expenses in broiler ducks, so identifying locally available, low-cost feed ingredients is crucial to maintain farm profitability and long-term sustainability. Tofu dregs, a by-product of tofu manufacturing, are often disposed of improperly and can cause water, soil, and air pollution as well as odor and disease problems in surrounding communities (Faisal et al. 2016; Pagoray et al. 2021; Sagita et al. 2024). At the same time, tofu dregs contain considerable crude protein, crude fat, crude fiber, and minerals such as calcium and phosphorus, making them a promising sustainable alternative feed resource that may reduce feed costs while helping to mitigate environmental problems associated with tofu waste accumulation (Ginting et al. 2024).

However, direct inclusion of tofu dregs in duck diets is constrained by anti-nutritional factors such as phytic acid, arabinoxylan, trypsin inhibitors, and tannins, which bind minerals, reduce protein digestibility, and impair lipid and energy absorption, thereby depressing growth performance (Yin et al. 2022; Gao et al. 2023; Kim et al. 2025).

Fermentation is a well-established strategy to improve the nutritional value of fibrous plant by-products by degrading such anti-nutritional compounds, modifying fiber structure, and enhancing nutrient digestibility and bioavailability (Sharma et al. 2020; Chotinu-Kul et al. 2025). EM4, which contains lactic acid bacteria, yeast, and phototrophic bacteria, has been widely used to ferment agricultural residues, including tofu dregs, and can increase crude protein, essential amino acids, and mineral availability while reducing crude fiber content (Anggraeni et al. 2013; Shih et al. 2022; Xu et al. 2023; Tan et al. 2024).

Previous studies have shown that fermentation of tofu dregs or similar soybean by-products (such as okara and soybean curd residue) improves proximate composition and can support poultry performance, allowing their use as alternative feed ingredients (Asghar et al. 2023; Xu et al. 2023). In broilers and laying hens, fermented soybean by-products have been reported to maintain or slightly improve growth performance and feed efficiency at moderate inclusion levels, while reducing reliance on conventional commercial feeds (Sharma et al. 2020; Chotinu-Kul et al. 2025). Some studies also suggest benefits for gut health and nutrient digestibility when fermented soybean residues are incorporated into poultry rations (Yin et al. 2022; Gao et al. 2023). However, most of these works focus on

chickens or other non-duck species, or report only broad nutrient changes without combining detailed amino acid and mineral profiles with duck performance data (Sharma et al. 2020; Asghar et al. 2023; Xu et al. 2023; Chotinu-Kul et al. 2025), so species-specific responses in ducks remain less clearly defined than in chickens.

Pekin ducks are a fast-growing meat breed with distinct digestive and metabolic characteristics compared with other duck types and chickens, so their response to fermented by-product ingredients may differ from responses reported in other poultry (Tan et al. 2024). Information on how EM4-fermented tofu dregs, characterized beyond basic proximate composition, affect feed intake, growth, and feed conversion ratio in Pekin ducks at practical inclusion levels remains limited (Anggraeni et al. 2013; Xu et al. 2023; Tan et al. 2024). In particular, few studies have combined detailed amino acid profiling and macro- and micro-mineral analyses with growth performance and feed intake data in this species (Asghar et al. 2023; Xu et al. 2023). Therefore, this study was conducted to characterize changes in proximate composition, amino acid profile, and macro- and micro-mineral contents of tofu dregs following EM4-based fermentation, and to determine whether these changes translate into measurable effects on feed intake, body weight gain, final body weight, and feed conversion ratio in Pekin ducks fed diets containing 10%, 20%, and 30% fermented tofu dregs. By integrating detailed nutrient characterization with performance data, this study aims to refine expectations regarding the use of fermented tofu dregs in Pekin duck diets and to support more rational formulation of sustainable duck feeds in regions where tofu dregs are abundant (Faisal et al. 2016; Ginting et al. 2024; Tan et al. 2024).

MATERIALS AND METHODS

Research location

Fermentation of tofu dregs and ration preparation were carried out in the laboratories of the Faculty of Animal Husbandry, Universitas Mataram, Mataram, Indonesia, while proximate composition, amino acid profile, and macro- and micro-mineral contents of fermented and non-fermented tofu dregs were analyzed at Saraswati Indo Genetech Laboratory, Surabaya, Indonesia. The biological experiment evaluating the effects of fermented tofu dregs on Pekin duck performance was conducted at the Teaching Farm, Faculty of Animal Husbandry, Universitas Mataram, under approved animal welfare and ethical guidelines (No: 171/UN18.F8/ETIK/2025).

Fermentation conditions (Stage 1)

Fermentation was conducted to convert tofu dregs into a high-value feed ingredient through controlled microbial activity. Approximately 2,000 kg of wet tofu dregs were first air-dried for 24 h under ambient conditions to reduce moisture content from about 70-80% to a target of 10-15%, thereby minimizing the risk of microbial spoilage before

fermentation (Shih et al. 2022). The dried tofu dregs were then thoroughly mixed with EM4 and molasses according to standard fermentation practices; EM4 provided a mixed culture of lactic acid bacteria, yeast, and phototrophic bacteria, while molasses served as an energy source to support microbial growth and activity (Anggraeni et al. 2013; Tan et al. 2024). For each 100 kg of dried tofu dregs, 2 L of EM4 were diluted in 4 L of clean water and mixed with 4 kg of molasses, and the resulting solution was sprayed uniformly onto the substrate while mixing until a moisture content suitable for solid-state fermentation was achieved.

The homogenized mixture was packed into sterilized plastic drums of 175 L capacity, each filled to approximately 80% of its volume to reduce headspace and maintain predominantly anaerobic conditions. Drums were tightly sealed and incubated for 14 d at 30-32°C, a temperature range and duration previously reported as suitable for optimal microbial activity and nutrient enhancement in fermented plant residues (Gudisa 2022; Shih et al. 2022; Xu et al. 2023; Tan et al. 2024). Temperature was monitored throughout the fermentation period to ensure process stability.

After 14 d, the fermented tofu dregs were removed from the drums and air-dried for an additional 3 d to further reduce moisture content and improve product stability prior to storage and use in feed formulation (Tan et al. 2024). The final product exhibited a brown color, lightweight texture, and porous structure, which were used as visual indicators of successful fermentation.

Nutritional analysis procedures (Stage 1 and Stage 2)

After fermentation, both fermented and non-fermented tofu dregs were subjected to detailed nutritional analysis.

Proximate analysis

Proximate composition (moisture, crude protein, crude fat, crude fiber, ash, and gross energy) was determined following standard procedures. Moisture content was measured by oven drying at 105°C to constant weight (AOAC 2019). Gross energy was determined using an adiabatic bomb calorimeter as described by Basu (2018). Crude protein ($N \times 6.25$), crude fat, crude fiber, and ash were analyzed according to AOAC proximate analysis methods (Weende system), with crude protein determined by the Kjeldahl method (FAO 2003; Sáez-Plaza et al. 2013).

Amino acid composition

Amino acid profiles of fermented and non-fermented tofu dregs were analyzed by High-Performance Liquid Chromatography (HPLC). Samples were hydrolyzed with 6 N HCl at 110°C for 24 h, neutralized, and filtered before injection. Separation was performed on a C18 reversed-phase column with pre-column derivatization and UV detection, following the procedure of Lestari et al. (2022) with minor modifications to quantify both essential and non-essential amino acids.

Table 1. Nutritional composition of the feed ingredients utilized in the study

Nutrient	Feed ingredients		
	Tofu dregs*)	Tofu dregs fermentation*)	Commercial feed**)
Metabolizable energy (Kcal/kg)***)	2472.81	2945.00	2950.00
Crude protein (%)	19.38	20.84	22.00
Total fat (%)	8.00	10.49	5.00
Crude fiber (%)	19.45	17.06	6.00
Ca (%)	0.04	0.07	5.00
P (%)	0.33	0.30	0.80
L-Lysine (%)	0.93	1.33	1.30
L-Methionine (%)	0.12	0.13	0.55

Note: *: Saraswati Indo Genetech Laboratory, Surabaya, Indonesia, **: Japfa Comfeed Indonesia (2017), ***: Bidura et al. (2023)

Table 2. Nutrient content of rations for Pekin ducks

Composition	Tofu dregs fermentation level in rations (%)			
	T0	T1	T2	T3
Ingredients (%)				
Commercial feed	100	90	80	70
Tofu dregs fermentation		10	20	30
Total	100	100	100	100
Nutrient (calculated)				
ME (kcal/kg)	2950.00	2949.50	2949.00	2948.50
Crude protein (5)	22.00	21.88	21.77	21.65
Crude fat (%)	5.00	5.55	6.10	6.65
Crude fiber (%)	6.00	7.11	8.21	9.32
Ca (%)	5.00	4.51	4.01	3.52
P (%)	0.80	0.75	0.70	0.65
L-Lysine (%)	1.30	1.30	1.31	1.31
L-Methionine (%)	0.55	0.51	0.47	0.42

Note: The observed variables include final body weight, weight gain, feed intake, and feed consumption conversion

Mineral content

Macro- and micro-minerals (e.g. Ca, P, Mg, K, Fe, Zn, Cu, Mn) in tofu dregs were determined using Atomic Absorption Spectrophotometry (AAS) at Saraswati Indo Genetech, Surabaya, Indonesia. Samples were dry-ashed in a muffle furnace, dissolved in acid, and analyzed according to AOAC Official Method 975.03 and 968.08 for minerals in feed and pet food, with appropriate calibration standards and quality control checks.

Experimental design (Stage 2)

The second phase of the study involved feeding 100 Pekin ducks with varying levels of fermented tofu dregs. The experimental design was as follows:

Feeding treatments

The second stage of the study evaluated the effects of fermented tofu dregs on the performance of Pekin ducks using a Completely Randomized Design (CRD). A total of 100 Pekin ducks were randomly assigned to four dietary treatments, each treatment consisting of 5 replicates with 5 ducks per replicate. The treatments were: i) T0: 100% commercial feed (control group), ii) T1: 90% commercial

feed + 10% fermented tofu dregs, iii) T2: 80% commercial feed + 20% fermented tofu dregs, iv) T3: 70% commercial feed + 30% fermented tofu dregs.

Data collection parameters

The nutritional composition of the main feed ingredients used in this study is shown in Table 1. Fermentation with EM4 increased the metabolizable energy, crude protein, total fat, and calcium contents of tofu dregs, while slightly reducing crude fiber compared with non-fermented tofu dregs, indicating an overall improvement in their nutritional value as a feed ingredient. Commercial duck feed, used as the basal diet, contained higher crude protein but lower crude fiber and fat than both forms of tofu dregs, providing a suitable reference for evaluating the contribution of the fermented by-product to the diet. Based on these ingredient profiles, experimental diets were formulated by partially replacing commercial feed with 10%, 20%, and 30% fermented tofu dregs. All rations were designed to be approximately isoenergetic and to maintain similar crude protein levels across treatments, while allowing systematic changes in crude fat, crude fiber, and mineral contents. The calculated nutrient composition of the experimental rations for Pekin ducks is presented in Table 2.

Statistical analysis

Statistical analysis was performed on both chemical composition data and biological performance variables. Proximate composition (crude protein, crude fat, crude fiber, ash, moisture, and energy), amino acid concentrations, and macro- and micro-mineral contents of fermented and non-fermented tofu dregs were summarised as mean±standard deviation and evaluated using one-way Analysis of Variance (ANOVA). For the biological trial, the replicate cage (five ducks per cage) was considered the experimental unit, and performance variables (feed intake, final body weight, body weight gain, and feed conversion ratio) were calculated on a cage basis and analyzed by one-way ANOVA. When a significant treatment effect was detected ($p < 0.05$), differences among means were further examined using Duncan's Multiple Range Test. All statistical analyses were conducted using SPSS software, and results are presented in the tables with corresponding p-values and superscript letters to indicate significant differences where applicable (Kwak 2023).

RESULTS AND DISCUSSION

Proximate composition of tofu dregs

The proximate composition of Non-Fermented Tofu Dregs (TD-NF) and Fermented Tofu Dregs (TD-F) is presented in Table 3. Fermentation tended to increase crude protein and total fat and to reduce gross energy and carbohydrate, but these changes were not statistically significant ($p > 0.05$). In contrast, crude fiber, moisture, and ash contents were significantly lower in TD-F than in TD-NF ($p < 0.05$), indicating that EM4-based fermentation produced a drier, less fibrous product with reduced mineral residue. Energy derived from fat also decreased significantly following

fermentation ($p < 0.05$), reflecting changes in both fat content and overall energy density.

Amino acid profile

The essential and non essential amino acid contents of TD NF and TD F are shown in Table 4. Fermentation selectively increased several essential amino acids, particularly histidine, leucine, lysine, and tryptophan, while other essential amino acids remained unchanged ($p > 0.05$). Among non essential amino acids, alanine, arginine, aspartic acid, glutamic acid, cystine, and tyrosine were significantly higher in TD F than in TD NF, whereas glycine, proline, and serine did not differ between treatments. Overall, total amino acid concentration was significantly greater in fermented than in non fermented tofu dregs ($p < 0.05$), indicating an improved amino acid profile after EM4 based fermentation.

Macro- and micro-mineral concentrations

Macro- and micro-mineral concentrations of TD-NF and TD-F are summarised in Table 5. Fermentation increased several major minerals, including calcium, potassium, magnesium, chloride, and sulfur, while sodium and phosphorus were not significantly affected ($p > 0.05$). For micro-minerals, fluoride, selenium, zinc, molybdenum, iron, copper, and chromium were significantly higher in TD-F than in TD-NF, whereas manganese and iodine remained unchanged. These findings suggest that EM4-based fermentation enhances the content of multiple essential macro- and trace minerals in tofu dregs, particularly calcium and several key micro-elements.

Performance of Pekin ducks

The performance of Pekin ducks fed diets containing different levels of fermented tofu dregs is presented in Table 6. Initial body weights did not differ among treatments, indicating similar starting conditions. Increasing inclusion of fermented tofu dregs up to 30% did not significantly affect final body weight, body weight gain, or feed conversion ratio ($p > 0.05$), showing that growth performance was maintained across all diets. However, feed intake increased progressively with higher levels of fermented tofu dregs ($p < 0.05$), suggesting that ducks consumed more feed without a corresponding improvement in growth or feed efficiency.

Weekly body weight gain

Weekly body weight gain patterns for Pekin ducks are illustrated in Figure 1. All treatment groups showed a similar temporal pattern, with rapid gains during the early weeks, peak gains around week 4, and a subsequent plateau or slight decline towards week 8, and there was no consistent separation among diets containing 0-30% fermented tofu dregs.

Discussion

Nutritional enhancement of fermented tofu dregs

The changes in proximate composition, amino acid profile, and mineral concentrations observed in the present study confirm that EM4-based fermentation can improve the nutritional quality of tofu dregs. Fermented tofu dregs

showed higher crude protein, total fat, total amino acids, and several key macro- and micro-minerals, together with reduced crude fiber, compared with non-fermented tofu dregs. These findings are consistent with previous reports demonstrating that lactic acid bacteria such as *Lactobacillus plantarum*, *L. acidophilus*, and *Pediococcus acidilactici* can enhance apparent protein content and amino acid concentrations in tofu dregs and other soybean by-products by degrading non-protein components and contributing microbial protein (Saadoun et al. 2021; Gao et al. 2024).

Table 3. Proximate analysis results of fermented and non-fermented tofu dregs

Parameter	Treatment		p-value
	TD-F (Fermented)	TD-NF (Non-Fermented)	
Gross energy (kcal/100 g)	414.76±2.35 ^a	441.52±3.12 ^a	0.082ns
Energy from fat (kcal/100 g)	104.58±1.45 ^b	151.38±2.01 ^a	0.031*
Ash content (%)	2.96±0.08 ^b	5.26±0.11 ^a	0.017*
Moisture content (%)	10.17±0.22 ^b	18.47±0.36 ^a	0.009**
Carbohydrate (%)	52.99±1.02 ^a	57.75±1.18 ^a	0.065ns
Total fat (%)	10.49±0.15 ^a	8.00±0.13 ^a	0.114ns
Crude protein (%)	20.84±0.41 ^a	19.38±0.35 ^a	0.093ns
Crude fiber (%)	17.06±0.29 ^b	19.45±0.33 ^a	0.028*

Note: Values are presented as mean±SD of triplicate analysis, Different superscripts (a, b) within a row indicate significant differences ($p < 0.05$), ns: Not significant ($p > 0.05$), *Significant ($p < 0.05$), **Highly significant ($p < 0.01$)

Table 4. Content of essential and non-essential amino acids of fermented and non-fermented tofu dregs

Amino acid (mg/g)	Treatment		p-value
	TD-F (Fermented)	TD-NF (Non-Fermented)	
Essential amino acids			
L-Histidine	5050.20±112.33 ^a	3648.90±98.26 ^b	0.021*
L-Isoleucine	9411.21±185.15 ^a	8688.02±174.11 ^a	0.084ns
L-Leucine	15329.19±201.08 ^a	14020.89±192.45 ^b	0.036*
L-Lysine	13284.73±176.24 ^a	9344.23±158.18 ^b	0.014*
L-Methionine	1322.72±45.33 ^a	1191.25±38.21 ^a	0.097ns
L-Tryptophan	2174.12±51.19 ^a	1509.36±42.77 ^b	0.028*
L-Valine	10420.13±198.55 ^a	10337.18±201.76 ^a	0.112ns
L-Phenylalanine	9315.25±165.14 ^a	9496.54±170.32 ^a	0.089ns
L-Threonine	8430.59±154.22 ^a	8256.43±152.11 ^a	0.071ns
Non-essential amino acids			
L-Alanine	9976.35±182.44 ^a	8635.40±176.09 ^b	0.032*
L-Arginine	12406.92±211.37 ^a	10665.02±198.11 ^b	0.025*
L-Aspartic acid	19488.55±230.51 ^a	15880.28±224.44 ^b	0.019*
Glycine	9842.87±156.22 ^a	9803.46±148.77 ^a	0.094ns
L-Glutamic acid	32046.98±265.11 ^a	22522.05±249.33 ^b	0.008**
L-Cystine	5942.50±141.25 ^a	4115.82±122.14 ^b	0.016*
L-Proline	9100.53±173.31 ^a	8819.99±165.41 ^a	0.081ns
L-Serine	9783.44±161.19 ^a	9316.33±158.27 ^a	0.072ns
L-Tyrosine	5003.36±139.25 ^a	4549.70±127.13 ^b	0.041*
Total amino Acids	18.84±0.52 ^a	16.08±0.48 ^b	0.013*

Note: Values are expressed as mean±SD of triplicate analysis, Different superscripts (a, b) within the same row indicate significant differences at $p < 0.05$, ns: Not significant ($p > 0.05$), *Significant ($p < 0.05$), **Highly significant ($p < 0.01$)

The reduction in crude fiber agrees with studies showing that fermentation involving cellulase- and xylanase-producing microbes breaks down cellulose and hemicellulose into soluble oligosaccharides, thereby lowering analytically measured crude fiber and improving the fermentability of high-fiber substrates (Chen et al. 2022; Yue et al. 2023; Kitessa 2024). In ducks, a lower proportion of indigestible fiber may reduce digesta bulk and improve the efficiency of nutrient absorption in the small intestine, although such physiological responses were not directly measured in the present work.

The higher fat content in fermented tofu dregs compared with non-fermented samples also agrees with research indicating that lipase-producing bacteria and yeasts, including systems involving *Yarrowia lipolytica*, can hydrolyze and, in some cases, synthesize lipids during fermentation, leading to increased total fatty acid content in fermented tofu lees (Vong et al. 2016; Mok et al. 2019). In

principle, such changes can increase the contribution of fermentable ingredients to dietary energy supply in ducks, but in this study, the actual metabolizable energy of fermented tofu dregs was not determined, so their impact on available energy remains inferential.

The decrease in carbohydrate content, together with numerical changes in gross energy and energy from fat, is consistent with the general pattern that lactic acid bacteria and other fermentative microorganisms utilise soluble carbohydrates (e.g. glucose, sucrose, and oligosaccharides) as primary energy sources, converting them into organic acids and gases rather than retaining them as caloric substrates (Gudisa 2022; Ningrum et al. 2025). Studies on fermented tofu dregs and soybean dregs have reported similar reductions in various carbohydrates and shifts in energy distribution without necessarily compromising overall nutrient availability (Privatti and Da Costa Rodrigues 2021; Zulkarnain et al. 2022; Chen et al. 2025).

Table 5. Concentrations of macro and micro minerals in fermented and non-fermented tofu dregs

Parameter	Unit	Treatment		p-value
		TD-F (Fermented)	TD-NF (Non-Fermented)	
Macro-minerals				
Chloride (Cl)	mg/kg	1667.60±42.20 ^a	543.30±21.50 ^b	0.018*
Potassium (K)	mg/kg	15958.00±251.10 ^a	9577.70±204.40 ^b	0.012*
Magnesium (Mg)	mg/kg	2032.00±63.70 ^a	1661.80±52.10 ^b	0.031*
Sodium (Na)	mg/kg	1453.70±38.80 ^a	1294.20±31.20 ^a	0.083ns
Phosphorus (P)	mg/kg	3029.69±44.18 ^a	3322.36±51.24 ^a	0.097ns
Sulphur (S)	mg/kg	3298.16±56.10 ^a	1675.80±43.37 ^b	0.014*
Calcium (Ca)	mg/kg	7227.50±142.50 ^a	4168.00±120.90 ^b	0.009**
Micro-minerals				
Fluoride (F)	mg/kg	5.00±0.19 ^a	3.44±0.11 ^b	0.027*
Manganese (Mn)	mg/kg	26.31±1.02 ^a	24.41±0.97 ^a	0.066ns
Selenium (Se)	µg/kg	189.30±4.20 ^a	70.30±2.60 ^b	0.011*
Zinc (Zn)	mg/kg	28.40±1.00 ^a	24.30±0.80 ^b	0.033*
Molybdenum (Mo)	mg/kg	0.88±0.03 ^a	0.49±0.02 ^b	0.025*
Iodine (I)	µg/kg	558.10±17.20 ^a	672.70±18.80 ^a	0.071ns
Iron (Fe)	mg/kg	246.20±6.60 ^a	73.20±2.90 ^b	0.006**
Copper (Cu)	mg/kg	4.37±0.15 ^a	3.39±0.12 ^b	0.029*
Chromium (Cr)	µg/kg	1149.60±30.50 ^a	804.00±24.40 ^b	0.015*

Note: All values are expressed as mean±SD of triplicate analysis on a Dry Matter (DM) basis, Different superscripts (a, b) within a row indicate significant differences at p<0.05, ns: Not significant (p>0.05), *: Significant (p<0.05), **: Highly significant (p<0.01), Macro-minerals reported in mg/kg DM, trace elements Se, I, and Cr reported in µg/kg DM due to lower concentrations

Table 6. Performance of Pekin ducks fed with fermented tofu dregs

Observed variable	Treatment				p-value
	F0 (100% Commercial feed)	F1 (90% + 10% TD-F)	F2 (80% + 20% TD-F)	F3 (70% + 30% TD-F)	
Initial body weight (g)	38.71±1.02 ^a	38.77±1.30 ^a	37.91±0.94 ^a	38.34±1.16 ^a	0.911 ns
Final body weight (g)	1462.68±65.23 ^a	1428.40±79.12 ^a	1453.84±56.21 ^a	1446.56±93.33 ^a	0.728 ns
Body weight gain (g)	1415.68±168.05 ^a	1402.78±112.51 ^a	1425.02±82.34 ^a	1501.36±187.20 ^a	0.648 ns
Feed intake (g)	4908.03±209.83 ^a	5242.74±274.15 ^b	5470.70±157.79 ^c	5689.02±165.28 ^d	0.021 *
Feed conversion ratio	3.51±0.49 ^a	3.76±0.40 ^a	3.85±0.22 ^a	3.83±0.43 ^a	0.081 ns

Note: Values are expressed as mean±SD, Different superscripts (a, b, c, d) within the same row indicate significant differences at p<0.05, ns: not significant (p>0.05), *: Significant (p<0.05), F0: 100% commercial feed, F1: 90% commercial feed+10% fermented tofu dregs (TD-F), F2: 80% commercial feed+20% TD-F, F3: 70% commercial feed+30% TD-F

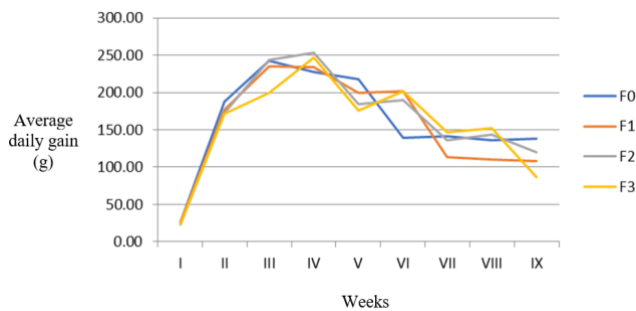


Figure 1. Weekly body weight gain of Pekin ducks fed diets containing 0% (F0), 10% (F1), 20% (F2), and 30% (F3) Fermented Tofu Dregs (TD-F) over an 8-week period. Each point represents the mean body weight gain per cage ($n = 5$ ducks per cage), with vertical bars indicating standard deviation. No significant differences among treatments were detected at any week ($p > 0.05$)

The increases in several macro- and micro-minerals, including calcium and a range of trace elements, suggest that EM4 fermentation may enhance mineral solubility or release minerals bound to fiber or phytate complexes (Yin et al. 2022; Gao et al. 2023). From a physiological perspective, improved mineral availability could support bone development, enzymatic functions, and antioxidant defense in ducks; however, body mineral status and bone traits were not evaluated in this trial, so such functional implications should be considered as hypotheses rather than confirmed outcomes. Overall, the pattern of chemical changes supports the use of EM4-based fermentation as a practical method to upgrade tofu dregs by improving protein, amino acid, and mineral profiles while reducing fiber content.

Lack of growth and FCR responses in Pekin ducks

Despite clear improvements in the nutritional profile of fermented tofu dregs, dietary inclusion of 10-30% TD-F did not significantly affect final body weight, body weight gain, or FCR in Pekin ducks, although feed intake increased with higher inclusion levels. The FCR values observed in this study (3.51-3.85) are comparable to those reported for meat-type ducks in other studies, such as Magelang ducks and hybrid meat ducks, in which FCR values of around 3.0-3.3 have been obtained during similar grower phases (Listyowati et al. 2020; Ridwan et al. 2020). This indicates that partial replacement of commercial feed with fermented tofu dregs maintained performance within the expected range for meat ducks but did not yield additional improvements in feed efficiency.

The weekly body weight gain pattern (Figure 1) shows that most growth occurred during the first four weeks, after which gains tended to plateau or decline slightly, suggesting a shift from rapid tissue accretion to increased feather growth and maintenance later in the rearing period. Physiologically, this shift is associated with higher demands for specific amino acids, particularly sulfur containing amino acids for feather keratin synthesis. Under such conditions, when the basal diet already meets or exceeds the requirements of fast-growing Pekin ducks, the

incremental nutrient enhancements contributed by the fermented tofu dregs fraction may not be sufficient to elicit additional growth responses, which is consistent with the absence of significant treatment effects on final body weight and FCR.

The absence of a significant growth response contrasts with some findings in chickens and other poultry species where fermented tofu dregs or soybean dregs have improved growth performance or feed efficiency, suggesting that species- or breed-specific differences may influence the capacity to utilize fermented by-products. Several studies in broilers, for example, reported positive responses when fermented soybean by-products were included at moderate levels, sometimes under conditions where basal diets were closer to minimum nutrient specifications or where fermentation protocols produced more pronounced improvements in fiber degradation and energy availability (Sharma et al. 2020; Asghar et al. 2023; Xu et al. 2023; Chotinu-Kul et al. 2025). In contrast, in the present experiment all diets were formulated to be isoenergetic with similar crude protein contents, so the improvements observed in the tofu dregs fraction may have had only a marginal effect on the overall nutrient supply of the complete diets offered to Pekin ducks.

Biological and methodological considerations

Several biological and methodological factors may help to explain why the improved nutrient composition of fermented tofu dregs did not translate into enhanced growth performance in Pekin ducks. These factors were not directly measured in the present study and should therefore be regarded as hypotheses for future research rather than conclusions based on current data.

Biologically, nutrient bioavailability and metabolizable energy of fermented tofu dregs may differ from expectations based on chemical composition alone. Without direct measurements of digestibility and metabolizable energy in ducks, it is not possible to determine how much of the increased amino acids, lipids, and minerals in TD F was effectively absorbed and utilized for tissue accretion. In addition, species and breed specific differences in digestive physiology, fiber fermentation capacity in the caeca, and energy metabolism between Pekin ducks and other poultry species could influence how efficiently fermented by products are utilized. Fast growing Pekin ducks may be less tolerant of changes in dietary bulk and fiber than slower growing birds, potentially limiting the extent to which benefits from improved ingredient composition can be expressed at the whole animal level.

From a methodological perspective, the use of a single fermentation protocol and a relatively narrow inclusion range (10-30%) over an 8-week period may have constrained the magnitude of detectable responses. Research on other fermented substrates has shown that extending fermentation duration, optimizing temperature and moisture, or employing different microbial strains can further enhance fiber degradation and nutrient release (Anyiam et al. 2023; Li et al. 2023; Fitsum et al. 2025). Future experiments should therefore include direct measurements of nutrient digestibility and metabolizable energy of EM4-fermented

tofu dregs in Pekin ducks, and systematically evaluate alternative fermentation conditions and a broader range of dietary inclusion levels. Such studies could also incorporate assessments of gut microbiota, intestinal morphology, and immune status to determine whether fermented tofu dregs exert benefits beyond growth performance, for example, on gut health or robustness.

Taken together, the present results indicate that EM4-fermented tofu dregs can be used as a sustainable waste-derived feed resource to partially replace commercial feed in Pekin duck diets without compromising growth performance. However, under the conditions tested, these improvements in ingredient quality did not translate into measurable gains in growth or feed efficiency. Clarifying the roles of digestibility, metabolizable energy, and gut microbial responses will be essential to identify circumstances under which fermented tofu dregs can provide not only nutritional and environmental advantages but also tangible performance benefits in duck production systems.

Implications and limitations

The present findings indicate that EM4-fermented tofu dregs can be included in Pekin duck diets at levels up to 30% without detrimental effects on growth performance or feed conversion, while significantly increasing feed intake. This demonstrates that fermented tofu dregs are a viable ingredient for partial replacement of commercial feed and for valorizing tofu processing waste in regions where tofu dregs are abundant, thereby contributing to more sustainable and circular duck production systems.

However, the lack of clear improvements in growth or FCR despite enhanced nutrient composition of the ingredient highlights several important limitations. First, metabolizable energy and nutrient digestibility of fermented tofu dregs were not measured, so it remains unclear to what extent the observed increases in amino acids, lipids, and minerals translated into usable energy and absorbable nutrients for Pekin ducks. Second, the efficiency of microbial fermentation under the chosen conditions (in terms of fiber degradation, anti-nutritional factor breakdown, and energy release) was inferred from chemical composition only; direct indicators of fermentation efficiency, such as *in vivo* digestibility trials or *in vitro* fermentation assays, were not included. Third, no data were collected on gut microbiota, intestinal morphology, or markers of gut health, so potential non-growth benefits of fermented tofu dregs—such as improved gut environment or resilience—could not be evaluated.

Addressing these limitations in future research, by combining EM4-fermented tofu dregs with measurements of metabolizable energy, digestibility, and gut health parameters across a wider range of inclusion levels and fermentation protocols, will be essential to determine under which conditions fermentation-induced improvements in ingredient composition can be translated into meaningful production gains in duck production systems.

In conclusion, EM4-based fermentation improved the nutritional quality of tofu dregs by increasing crude protein, selected essential and non-essential amino acids, and

several macro- and micro-minerals, while reducing crude fiber. Under the conditions tested, partial replacement of commercial feed with up to 30% fermented tofu dregs did not significantly alter growth performance or feed conversion ratio in Pekin ducks, although it increased feed intake. These results indicate that EM4-fermented tofu dregs can be safely utilised as a waste-derived alternative feed resource for Pekin ducks without compromising productivity. Integrating such fermented by-products into duck diets offers a practical strategy to valorize tofu processing waste and support more sustainable and circular duck feeding systems, particularly in regions where tofu dregs are abundantly available.

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