DOI: http://dx.doi.org/10.15578/iaj.20.2.2025.221-230 *Indonesian Aquaculture Journal, 20 (2), 2025, 221-230*

Available online at: http://ejournal-balitbang.kkp.go.id/index.php/iaj

ENHANCING PROTEIN UTILIZATION AND GROWTH PERFORMANCE IN STRIPED CATFISH WITH CINNAMALDEHYDE AND OPTIMIZED ENERGY-TO-PROTEIN RATIOS

Imam Tri Wahyudi [*)#], Dedi Jusadi[**)], Mia Setiawati[**)], Julie Ekasari[**)], Muhammad Agus Suprayudi[**)], Mohamad Iqbal Kurniawinata[*)], and Ainulyakin Hasan Imlani[***)]

[*)] Study Program of Technology and Management of Applied Aquaculture, College of Vocational Studies, IPB University, Bogor, 16128. Indonesia

[**)] Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University, Bogor, 16680. Indonesia

[***)] Aquaculture Department, College of Fisheries, Mindanao State University Tawi-Tawi College of Technology and Oceanography, Sanga-Sanga, Bongao 7500, Tawi-Tawi, Philippines

(Received: April 23, 2025; Final revision: December 1, 2025; Accepted: December 2, 2025)

ABSTRACT

Efficient dietary protein utilization is essential to reduce feed costs and environmental impacts in sustainable aquaculture. This study aimed to evaluate the effects of cinnamaldehyde (CA) supplementation in feed with various energy-to-protein (E:P) ratios on the chemical composition of Pangasianodon hypophthalmus. The five feed formulas that made up the treatment feed were as follows: 28:13-C0 (28 % Protein with an E:P ratio of 13 and CIN 0 g kg^{-1}); 25:14-C1 (25 % protein with an E:P ratio of 14 and CIN 1.2 g kg^{-1}); 25:14-C2 (25 % protein with an E:P ratio of 14 and CIN 1.7 g kg^{-1}); 25:15-C1 (25 % protein with an E:P ratio of 15 and CIN 1.2 g kg^{-1}); and 25:15-C2 (25 % Protein with an E:P ratio of 15 and CIN 1.7 g kg^{-1}). Striped catfish weighing 28.06 ± 0.19 g were placed in a hapa (2 × 1 × 1 m^3) at a density of 25 fish per cage. Fish were fed to apparent satiation three times daily for 60 d. The 25:14-C2, 25:15-C1, and 25:15-C2 diets increased albumin levels and reduced cholesterol, while 25:15-C2 also yielded the highest total protein and lowest triglyceride levels. Growth performance and feed efficiency were comparable among 28:13-C0, 25:14-C2, 25:15-C1, and 25:15-C2 (final weight: 141.62–143.75 g; FCR: 1.16–1.19). Protein efficiency ratio was highest in 25:15-C1 and 25:15-C2, whereas protein retention peaked in 25:14-C2. The hepatosomatic index was elevated in 25:14-C1, 25:14-C2, and 25:15-C1. Body lipid content was highest in 25:15-C1, while muscle lipid content was lowest in 25:14-C2 and 25:15-C1. Reducing dietary protein from 28 % to 25 % did not compromise growth performance at the E:P ratio level of 15 with a supplementation of 1.2 g kg^{-1} CIN.

KEYWORDS: cinnamaldehyde; energy-to-protein ratio; growth; protein-sparing effect; striped catfish

INTRODUCTION

Striped catfish (*Pangasianodon hypophthalmus*) is one of the most economically important aquaculture species in Southeast Asia due to its rapid growth, adaptability to intensive systems, and strong global market demand (FAO, 2022; Nguyen *et al.*, 2023). However, feed costs remain a major constraint in striped catfish farming, with dietary protein representing the most expensive component of formulated feeds (Da *et al.*, 2013; Ngoc *et al.*, 2018). Factors such as post-pandemic global recovery, ongoing geopolitical conflicts, and climate change have led to higher prices for these critical ingredients, thereby increasing feed costs(Barange *et al.*, 2018; Hudecová & Rajèániová, 2023). Improving protein utilization efficiency without compromising growth performance is therefore a central objective in sustainable aquafeed development.

One effective strategy to improve feed efficiency is the protein-sparing effect (PSE), which optimizes protein utilization to achieve cost-effective and nutritionally balanced aquafeeds (Kamalam *et al.*, 2017; National Research Council, 2011). The energy-to-protein (E:P) ratio is a crucial aspect of aquafeed formulations, as it governs the balance between dietary energy from non-protein sources and protein utilization for growth. Pangasiid fingerlings typically require 27–29% dietary protein depending on energy supply (Webster & Lim, 2002), while recent studies on striped catfish indicate a broader optimal range of 25–37% (Teles *et al.*, 2020), supporting the evaluation of both 25% and 28% protein levels in this study.

[#] Correspondence: Study Program of Technology and Management of Applied Aquaculture, College of Vocational Studies, IPB University, Bogor, 16128. Indonesia
E-mail: imamtriw@apps.ipb.ac.id

High E:P ratios have been shown to maintain growth performance in protein-restricted diets across multiple species, including rainbow trout (*Oncorhynchus mykiss*) and Asian seabass (*Lates calcarifer*), while improving protein efficiency and reducing nitrogenous waste (Green & Hardy, 2008; Kim *et al*., 2017; Wang *et al*., 2017), and similar responses have been reported in striped catfish (Ali *et al*., 2018; Poernomo *et al*., 2015). However, excessive non-protein energy, particularly carbohydrates, may induce metabolic disturbances such as hyperglycemia, lipid deposition, and oxidative stress, ultimately impairing growth and feed efficiency (Asemani *et al*., 2019; Luo *et al*., 2020; Xu *et al*., 2019).

Cinnamaldehyde (CIN), a bioactive compound from Cinnamomum spp., has emerged as a functional feed additive to enhance metabolic efficiency and fish health. Previous studies have shown that CIN promotes â-oxidation and nutrient absorption (Chen *et al*., 2022; Gu *et al*., 2022), enhanced antioxidant activity (Abd El-Hamid *et al*., 2021), improved carbohydrate utilization (Hendriana *et al*., 2023; Imlani *et al*., 2024), improved muscle protein content (Zhou *et al*., 2023), and improved growth and protein retention (Setiawati *et al*., 2016). In striped catfish, supplementation of 1.2 g kg^{-1} CIN has been reported to improve physiological carbohydrate metabolism (Wahyudi *et al*., 2024). Despite these benefits, the combined effects of CIN supplementation and dietary energy-to-protein (E:P) ratios remain unclear. Therefore, this study aimed to evaluate the effects of CIN-supplemented diets with different E:P ratios on blood biochemical profiles, growth performance, and body composition, contributing to more sustainable and cost-effective aquafeed formulations.

MATERIALS AND METHODS

Research Design and Test Feed Preparation

This study employed a completely randomized design consisting of five dietary treatments with four replicates each. Experimental diets were formulated using two protein levels (25% and 28%), three energy-to-protein (E:P) ratios (13, 14, and 15^{-1} kcal g^{-1} protein), and three cinnamaldehyde (CIN) doses (0, 1.2, and 1.7 g kg^{-1}), resulting in five treatment combinations (Table 1). The experimental diets were not isoenergetic, as gross energy levels varied intentionally to achieve the targeted E:P ratios (13, 14, and 15 kcal g^{-1} protein), allowing evaluation of protein utilization under different dietary energy supplies. The dietary protein levels of 28% and 25% were selected based on both conventional feeding practices and protein-sparing objectives. A protein level of 27–29% is commonly recommended for Pangasiid fingerlings under commercial conditions (Webster & Lim, 2002), while recent studies indicate that *P. hypophthalmus* can maintain optimal growth at lower protein levels (≈25%) when diets are formulated with adequate energy supply (Teles *et al*., 2020; Poernomo *et al*., 2015). Thus, 28% protein was used as a reference diet, whereas 25% protein represented a protein-reduced formulation relevant to cost-efficient commercial aquafeeds. The CIN used was 99 % trans-cinnamaldehyde (Himidea, India). The additional dose of CIN used refers to the previous study, C0 is without CIN, C1 is the optimal dose obtained in previous research, namely 1.2 g kg^{-1}, C2 is above the optimal dose, namely 1.7 g kg^{-1} (Wahyudi *et al*., 2024).

Table 1. Dietary treatments

Treatment code	Protein (%)	E:P ratio (kcal g^{-1} protein)	CIN (g kg^{-1})
28:13-C0 (control diet)	28	13	0.0
25:14-C1	25	14	1.2
25:14-C2	25	14	1.7
25:15-C1	25	15	1.2
25:15-C2	25	15	1.7

Note: E:P ratio (energy-to-protein ratio), CIN (cinanaldehyde).

The treatment feed consisted of five different feed formulas, as in Table 2. The raw feed materials were floured and sifted using a grinder and sieve, respectively. Next, the ingredients were weighed according to the formulation, mixed using a 5 kg capacity mixer, and 300 mL kg^{-1} of water was added. After the raw material was homogenized, the mixture was printed using an extruder with a feed diameter of 1 mm. The feed was dried in an oven at 50 °C for approximately 1-2 hours until the water content reaches 8-10 %. The test feed was placed in a dry container, and feed samples were collected for the proximate analysis of the test feed.

Table 2. Ingredients diet formulations

Ingredients	Treatments				
	28:13-C0	25:14-C1	25:14-C2	25:15-C1	25:15-C2
Fish meal	5.00	5.00	5.00	5.00	5.00
Meat bone meal	6.00	5.00	5.00	5.00	5.00
Poultry by-product meal	5.00	5.00	5.00	5.00	5.00
Soy bean meal	21.00	5.67	5.67	8.50	8.50
Wheat flour	13.00	20.00	20.00	14.00	14.00
Wheat Pollard	29.60	30.00	30.00	30.00	30.00
DDGS	3.00	10.80	10.75	9.47	9.42
Casava flour	10.00	3.00	3.00	10.00	10.00
Rice bran	0.00	10.00	10.00	6.00	6.00
Fish Oil	1.00	1.00	1.00	1.00	1.00
Palm Oil	3.00	1.00	1.00	2.50	2.50
Methionine	0.50	0.50	0.50	0.50	0.50
Lysine	0.30	0.30	0.30	0.30	0.30
Premix	0.20	0.20	0.20	0.20	0.20
Phytase	0.05	0.05	0.05	0.05	0.05
Choline chloride	0.50	0.50	0.50	0.50	0.50
Dicalsium phosphate	0.50	0.50	0.50	0.50	0.50
Vitamin C	0.02	0.02	0.02	0.02	0.02
Vitamin E	0.03	0.03	0.03	0.03	0.03
NaCl	1.00	1.00	1.00	1.00	1.00
Polymethylolcarbamide	0.30	0.30	0.30	0.30	0.30
Cinnamaldehyde	0.00	0.13	0.18	0.13	0.18
Total	100	100	100	100	100
Proximate composition					
Moisture, %	10.70	10.53	9.73	10.37	10.14
Protein, %	28.14	25.17	25.45	25.13	25.32
Lipid, %	7.00	4.00	4.17	6.00	6.17
Fiber, %	3.82	6.17	5.70	3.98	3.59
Ash, %	11.57	10.52	11.49	9.35	9.06
NFE, %	38.78	43.60	43.46	45.17	45.72
GE, kcal kg^{-1}	3823.86	3573.28	3599.05	3823.35	3872.17
E:P, kcal g^{-1} protein	13.59	14.19	14.14	15.21	15.29

Note: The premix contained vitamins and minerals. Vitamin mix contained 900 IU kg^{-1} retinole (A), 200 mg kg^{-1} ascorbic acid (C), 200 IU kg^{-1} cholecalciferol (D), 10 mg kg^{-1} menadione (K3), 100 mg kg^{-1} á-tocopherol (E), 1000 mg kg^{-1} choline, 100 mg kg^{-1} inositol, 15 mg kg^{-1} thiamine (B1), 20 mg kg^{-1} riboflavin (B2), 15 mg kg^{-1} pyridoxine (B6), 50 mg kg^{-1} d-pantothenic acid (B5), 75 mg kg^{-1} nicotinic acid, 0.5 mg kg^{-1} biotin, 0.05 mg kg^{-1} cyanocobalamin (B12), 5 mg kg^{-1} folic acid; mineral mix contained 0.5 mg kg^{-1} Co ($CoCl_2.6H_2O$), 5 mg kg^{-1} Cu ($CuSO_4.5H_2O$), 50 mg kg^{-1} Fe ($FeSO_4.7H_2O$), 4 mg kg^{-1} I (KI), Cr ($CrCl_3.6H_2O$) 0.1 mg kg^{-1}, 150 mg kg^{-1} Mg ($MgSO_4.7H_2O$), 25 mg/kg Mn ($MnSO_4.H_2O$), 0.1 mg kg^{-1} Se ($NaSeO_3$), 100 mg kg^{-1} Zn ($ZnSO_4.7H_2O$). NFE (nitrogen-free extract). GE (Gross energy).

Fish Maintenance and Sampling

Striped catfish with a size of 28.06 ± 0.19 g were obtained from farmers around Bogor, Indonesia, and adapted for 1 month in the Experimental Pond, Department of Aquaculture, FPIK, IPB University. Fish were stocked in hapas (2 × 1 × 1 m) at a density of 25 fish per cage, which were installed in an HDPE-lined pond with a surface area of 200 m² and a water depth of 1.5 m. The pond operated under a continuous flow-through system with an inflow rate of approximately 1 L s^{-1}, resulting in an estimated daily water exchange of 35–40%, without additional mechanical aeration. Fish were maintained under a natural photoperiod (approximately 12 h light : 12 h dark). Experimental diets were hand-fed and evenly scattered to apparent satiation three times daily (08:00, 13:00, and 17:00 h) for 60 days. Water quality was monitored during maintenance with a temperature range of 28.3-30.1 °C, DO 4.60-6.74, pH 7-9, TAN 0.36-1.06 mg L^{-1}, nitrite 0.09 -0.14 mg L^{-1}, and nitrate 0.72-1.21 mg L^{-1}.

Sampling was conducted at the beginning and end of the feeding trial. At the start of the experiment, five fish were randomly sampled from the initial population (n = 5, pooled sample) for baseline whole-body proximate composition analysis. After 60 days, three fish per replicate cage (n = 3 per replicate) were randomly collected for final whole-body proximate analysis. Fish were anesthetized using clove oil at a concentration of 0.05 mL L^{-1}prior to handling (Varner, 2000).

After 60 d of rearing, three fish were collected for proximate body composition analysis. Blood plasma was collected from two fish per day for biochemical blood analysis, with anesthesia using 0.05 mg L^{-1} clove oil. Eight fish were euthanized with high doses of clove oil and dissected, and the liver and viscera were weighed to calculate the hepatosomatic index (HSI) and visceral somatic index (VSI). Fish meat, liver, and viscera were collected and immediately stored at -20 °C for proximate analysis. In addition to the liver, two pieces of meat were used for the chemical analysis.

Biochemical analysis of blood

Biochemical blood analysis was conducted to determine plasma albumin, total protein, triglyceride, cholesterol, and high-density lipoprotein (HDL) levels. Prior to blood sampling, fish were fasted for 24 h to minimize postprandial variation in metabolic parameters. Blood was collected in the morning (08:00–10:00 h) to reduce the influence of diurnal metabolic fluctuations. Blood was collected from the caudal vein using 1 mL syringes and collection tubes pre-rinsed with ethylenediamine tetra-acetate (EDTA) as an anticoagulant. The samples were transferred into 1.5 mL microtubes and centrifuged at 5000 rpm for 10 min to separate plasma. Plasma was carefully collected using a micropipette and transferred into clean microtubes for subsequent analyses. Total protein (TP) and albumin levels were analyzed using commercial assay kits (Total Protein Kit and Albumin Kit, Biomaxima, Poland), following the manufacturer's instructions. Triglyceride, cholesterol, and high-density lipoprotein (HDL) levels were measured using Triglycerides Liquiform Ref 87, Cholesterol Liquid Ref 76, and HDL-LE Ref 98 kits (Labtest, Brazil), also in accordance with the manufacturer's protocols.

Growth Performance

The growth parameters observed were specific growth rate, feed conversion ratio, protein efficiency ratio, and protein and lipid retention, based on the following formulas:

Survival Rate (%) = (number of final fish/number of initial fish) × 100.

Specific growth rate (% day^{-1}) = [(ln (final weight (g)) – ln (initial weight (g))/maintenance period (days)] × 100

Feed conversion ratio = total feed given (g)/[final total fish biomass (g) – initial total fish biomass (g)]

Protein efficiency ratio = weight gain (g)/protein intake (g)

Protein retention (%) = [final biomass protein (g) – initial biomass protein (g)]/total feed protein consumed (g) × 100.

Lipid retention (%) = [final biomass lipid (g) – initial biomass lipid (g)]/total feed lipid consumed (g) × 100.

Hepato somatic index (%) = liver weight / whole body weight x 100

Visceral somatic index (%) = visceral weight / whole body weight x 100

Proximate and Chemical Analysis

Proximate analysis was conducted on feed samples, as well as on the whole bodies of fish at the beginning and end of the trial, including muscle, liver, and viscera. The analyses followed the standard procedures outlined by (AOAC, 2012). Moisture content was determined using the oven-drying method at 105–110 °C until a constant weight was achieved. Crude protein was analyzed using the Kjeldahl method with an added digestion catalyst. Crude fiber was measured using the acid-base digestion method, while ash content was determined by incinerating the samples in a muffle furnace at 600 °C. Lipid content in feed was determined using Soxhlet extraction. The nitrogen-free extract (NFE) was calculated by difference using the formula:

NFE (%) = 100 – (moisture + ash + protein + lipid + crude fiber)

To calculate the energy-to-protein (E:P) ratio, gross energy (GE, kcal/kg feed) was estimated from the proximate composition using specific conversion factors: 5.6 kcal/g for protein, 4.1 kcal/g for carbohydrates (NFE), and 9.4 kcal/g for lipid, as described by

Watanabe (1998). The E:P ratio was then calculated using the formula:

E:P ratio = GE (kcal/kg feed) / protein content (g/kg feed)

Lipid content in fish body, muscle, liver, and viscera was further analyzed using a 2:1 methanol–chloroform extraction method according to Folch (Watanabe, 1998).

Analysis Data

Data are presented as mean ± standard deviation. Homogeneity and normality tests were performed using Levene's and Shapiro-Wilk tests. The experimental design was analyzed using one-way ANOVA. Significant differences between treatments were further tested using Duncan's post-hoc test with a 0.05 confidence interval. Statistical analyses were performed using SPSS 24.0 and data tabulation was performed using Microsoft Excel.

RESULTS AND DISCUSSION

Blood Biochemistry

The blood biochemical results of striped catfish fed different feed treatments (Table 3) showed that total protein (TP) and albumin levels were significantly higher in the 25:15-C2 group (152.1 ± 8.1 g dL^{-1} and 5.8 ± 0.4 g dL^{-1}, respectively) than in the control group (140.9 ± 9.91 g dL^{-1} and 5.5 ± 0.1 g dL^{-1}, respectively). Triglyceride (TG) and cholesterol (CHO) levels were significantly reduced in the 25:15-C2 group (355.8 ± 85.9 mg dL^{-1} and 264.2 ± 15.5 mg dL^{-1}) compared to the control (510.5 ± 98.9 mg dL^{-1} and 298.2 ± 20.5 mg dL^{-1}), while HDL levels decreased slightly in the CIN-supplemented diets (73.8–75.1 mg dL^{-1}) compared to the control (80.8 ± 3.0 mg dL^{-1}).

CIN supplementation enhanced the metabolic response to an optimized E:P ratio, as reflected by changes in lipid-related blood parameters. The reduction in triglyceride (TG) and cholesterol (CHO) levels in CIN-supplemented treatments suggests improved lipid utilization and moderated lipid deposition under adequate dietary energy supply, consistent with findings reported in Nile tilapia (*Oreochromis niloticus*) and juvenile fat greenling (*Hexagrammos otakii*) (Gu *et al*., 2022; Luo *et al*., 2020). By potentially reducing de novo lipogenesis (DNL) and enhancing glycogen synthesis, CIN may influence carbohydrate and lipid metabolism, thereby reducing the reliance on dietary protein for energy and allowing greater protein allocation for growth and tissue maintenance (Gu *et al*., 2022; Salmerón, 2018; Wahyudi *et al*., 2024). Furthermore, the observed increase in plasma albumin and total protein (TP) levels in the CIN-supplemented groups was indicative of enhanced protein metabolism and systemic health. Albumin, a marker of protein turnover and transport, is associated with improved nutrient mobilization and immune responses in fish under metabolic stress (Lehninger *et al*., 2008). These findings align with earlier studies demonstrating that functional additives, such as CIN, improve nutrient bioavailability and cellular energy dynamics, particularly under reduced-protein diets (Wahyudi *et al*., 2024).

Table 3. Blood biochemical of striped catfish fed difference diets

Parameters	Treatments				
	28:13-C0	25:14-C1	25:14-C2	25:15-C1	25:15-C2
TP, g dL^{-1}	140.9 ± 9.91^{b}	125.9 ± 2.5^{a}	130.9 ± 5.1^{ab}	140.0 ± 3.7^{b}	152.1 ± 8.1^{c}
Albumin, g dL^{-1}	5.5 ± 0.1^{ab}	5.3 ± 0.1^{a}	6.0 ± 0.2^{b}	5.8 ± 0.4^{b}	5.8 ± 0.4^{b}
TG, mg dL^{-1}	510.5 ± 98.9^{b}	516.7 ± 26.9^{b}	456.5 ± 76.3^{ab}	429.3 ± 31.9^{ab}	355.8 ± 85.9^{a}
CHO, mg dL^{-1}	298.2 ± 20.5^{b}	292.6 ± 10.9^{b}	250.6 ± 13.5^{a}	251.2 ± 16.4^{a}	264.2 ± 15.5^{a}
HDL, mg dL^{-1}	80.8 ± 3.0^{b}	74.9 ± 1.6^{a}	76.6 ± 2.1^{a}	73.8 ± 1.7^{a}	75.1 ± 0.8^{a}

Note: Values are expressed as mean ± SD (n = 5). Different letters in the same row indicate significant differences (One-way ANOVA and Duncan's post hoc test, $P < 0.05$). Total protein (TP), triglyceride (TG), cholesterol (CHO), and high-density lipoprotein (HDL) levels were measured.

In addition to energy metabolism, the antioxidative properties of CIN may have contributed to the improved metabolic efficiency observed in this study. CIN enhances the activity of antioxidant enzymes, reduces oxidative stress, and improves nutrient utilization in high-carbohydrate diets (Hendriana *et al*., 2023; Xu *et al*., 2019). The observed increases in plasma albumin and total protein (TP) in the CIN-supplemented treatments further indicated improved metabolic health and nutrient availability, which are critical for sustaining growth under reduced protein regimes (Amer *et al*., 2018; Wahyudi *et al*., 2023a; Wahyudi *et al*., 2024). These findings highlight the practical implications of adopting protein-sparing strategies using optimal E:P ratios and CIN supplementation in aquafeed. This approach offers a viable solution for cost-effective and sustainable feed formulation for striped catfish, a species that is central to global aquaculture production (FAO, 2022). The integration of CIN as a metabolic modulator has been validated in previous studies (Imlani *et al*., 2024; Wahyudi *et al*., 2024), positioning it as a key tool for improving feed efficiency and fish health in reduced-protein diets.

Growth Performance

The growth performance and feed efficiency results are shown in Table 4. The results indicated that the final body weights in the 25:15-C1 (142.96 ± 1.23 g) and 25:15-C2 (143.75 ± 1.87 g) groups were significantly higher than that in the 25:14-C1 group (138.80 ± 1.02 g). The specific growth rate (SGR) was significantly highest in the 25:15-C1 group (2.72 ± 0.02% day^{-1}), whereas the lowest feed conversion ratio (FCR) was observed in the 25:14-C2 group (1.17 ± 0.01). The protein efficiency ratio (PER) and protein retention (PR) were significantly higher in the 25:15-C1 and 25:15-C2 treatments, indicating enhanced protein utilization.

The present findings demonstrate that reducing dietary protein levels from 28 % to 25 %, when combined with appropriate E:P ratios and CIN supplementation, did not impair the growth performance of striped catfish. (*Pangasianodon hypophthalmus*). Notably, the 25:15-C1 treatment (25 % protein, E:P ratio of 15 kcal g^{-1}, and 1.2 g kg^{-1} CIN) produced growth and feed efficiency comparable to the control diet, confirming the effectiveness of protein-sparing strategies when dietary energy is sufficient. These results reaffirm the pivotal role of dietary protein as the primary driver of fish growth while highlighting the critical importance of efficiency in protein utilization to achieve sustainable aquaculture practices (Hardy & Kaushik, 2022; National Research Council, 2011).

The protein-sparing effect (PSE), in which energy derived from non-protein sources reduces the reliance on dietary protein for metabolic functions, is fundamental to aquafeed optimization. By meeting the energy requirements of carbohydrates and lipids, dietary proteins can be allocated to anabolic processes, such as muscle accretion, rather than to catabolic energy production (Kamalam *et al*., 2017; Wen *et al*., 2022). The E:P ratio of 15 kcal g^{-1} in this study aligns with previous findings in Asian seabass (*Lates calcarifer*) and rainbow trout (*Oncorhynchus mykiss*), where similar ratios improved the protein efficiency ratio (PER), protein retention (PR), and nitrogen utilization (Alam *et al*., 2020; Kim *et al*., 2017). The underperformance of the 25:14-C1 treatment highlights the metabolic inefficiencies arising from insufficient dietary energy intake. When energy intake is inadequate, fish are forced to catabolize proteins to fulfill their energy needs, leading to reduced growth efficiency and increased nitrogen excretion (Hardy & Kaushik, 2022). These findings underscore the importance of achieving an energy balance that minimizes protein catabolism while avoiding excessive energy supply, which could lead to lipid overaccumulation.

Table 4. Growth performance of striped catfish fed diets supplemented with cinnamaldehyde

Parameters	Treatments				
	28:13-C0	25:14-C1	25:14-C2	25:15-C1	25:15-C2
Initial weight, g	28.03 ± 0.15^{a}	28.04 ± 0.17^{a}	28.23 ± 0.42^{a}	28.01 ± 0.12^{a}	27.98 ± 0.17^{a}
Final weight, g	143.06 ± 1.08^{b}	138.80 ± 1.02^{a}	141.62 ± 0.78^{b}	142.96 ± 1.23^{b}	143.75 ± 1.87^{b}
Feed intake, kg	3.34 ± 0.03^{b}	3.31 ± 0.05^{b}	3.16 ± 0.09^{a}	3.36 ± 0.10^{b}	3.36 ± 0.07^{ab}
SR, %	100 ± 0.00	96.00 ± 0.00	94.67 ± 4.62	98.67 ± 2.31	96.00 ± 4.00
SGR, % day^{-1}	2.72 ± 0.01^{b}	2.67 ± 0.00^{a}	2.69 ± 0.02^{a}	2.72 ± 0.02^{b}	2.73 ± 0.02^{b}
FCR	1.16 ± 0.02^{a}	1.25 ± 0.01^{b}	1.18 ± 0.05^{a}	1.19 ± 0.01^{a}	1.17 ± 0.01^{a}
PER	3.03 ± 0.05^{a}	3.12 ± 0.05^{ab}	3.25 ± 0.03^{bc}	3.31 ± 0.03^{c}	3.31 ± 0.07^{c}
PR, %	38.33 ± 0.58^{a}	39.03 ± 0.33^{ab}	43.15 ± 2.21^{d}	40.91 ± 0.29^{bc}	41.79 ± 0.82^{cd}
LR, %	102.18 ± 1.54^{a}	164.51 ± 1.38^{d}	159.92 ± 8.25^{d}	132.16 ± 0.77^{c}	115.47 ± 2.21^{b}
HSI, %	2.12 ± 0.39^{a}	2.49 ± 0.29^{b}	2.49 ± 0.22^{b}	2.39 ± 0.31^{b}	2.23 ± 0.33^{ab}
VSI, %	15.06 ± 2.56^{a}	16.40 ± 2.22^{a}	16.61 ± 2.07^{a}	15.43 ± 2.09^{a}	14.64 ± 1.53^{a}

Note: Values are expressed as mean ± SD (n = 4). Different letters in the same row indicate significant differences (One-way ANOVA and Duncan's post hoc test, $P<0.05$). SR (survival rate), SGR (specific growth rate), FCR (feed conversion ratio), PER (protein efficiency ratio), PR (protein retention), LR (lipid retention), HSI (hepato somatic index), VSI (visceral somatic index).

The observed improvements in the specific growth rate (SGR) and feed conversion ratio (FCR) validated the synergy between the optimized E:P ratios and CIN supplementation. Treatments such as 25:15-C1 consistently outperformed their lower-energy counterparts, emphasizing the importance of sufficient energy availability for maximizing growth efficiency. These findings are consistent with those of studies on gilthead sea bream (*Sparus aurata*) and Chinese perch (*Siniperca chuatsi*), in which balanced energy levels enhanced nutrient utilization and reduced feed costs (Alam *et al*., 2020; García-Meilán *et al*., 2013). From an industry perspective, these results highlight that optimizing the E:P ratio is a more effective strategy than increasing dietary protein levels alone. The inclusion of CIN may support this optimization by maintaining growth efficiency under reduced-protein diets, which is particularly relevant for improving feed cost efficiency in commercial striped catfish production.

Proximate body, meat, liver, and viscera

The body, meat, liver, and visceral lipid levels are shown in Table 5. Proximate analysis revealed that whole-body lipid content was highest in the 25:15-C1 group (9.00 ± 0.33 %), whereas muscle lipid content was lowest in the 25:14-C2 and 25:15-C1 groups (1.34 ± 0.31 % and 1.34 ± 0.65 %, respectively). Liver lipid content ranged from 3.03 ± 0.18% to 3.98 ± 0.40 %, with no significant differences. Visceral lipid content was slightly lower in CIN-supplemented diets (26.21–27.63 %) compared to the control (28.29 ± 1.05%), although differences were not statistically significant.

Although differences in whole-body lipid content among treatments were relatively small, they reflect changes in nutrient partitioning associated with dietary energy balance. Even modest variations in body lipid content may be relevant in commercial aquaculture, as prolonged feeding periods can amplify their effects on feed efficiency and carcass composition (Orban *et al*., 2008; Wang *et al*., 2017). The slightly higher whole-body lipid content observed in the 25:15-C1 group is consistent with improved energy availability, while the lower muscle lipid levels in the 25:14-C2 and 25:15-C1 treatments may be beneficial for fillet quality.

Muscle lipid content is closely associated with fillet texture and consumer acceptance, and reduced intramuscular lipid accumulation has been reported to improve product quality in catfish and other freshwater species (Wahyudi *et al*., 2023a; Wahyudi *et al*., 2023b). The absence of significant differences in liver lipid content among treatments indicates that dietary energy levels and CIN supplementation did not induce excessive hepatic lipid accumulation, suggesting that lipid metabolism remained within a normal physiological range.

Overall, the relatively stable moisture, protein, and lipid composition of muscle and liver tissues suggests that the tested diets supported balanced metabolism without compromising fillet quality. These results indicate that optimizing the E:P ratio with CIN supplementation can improve growth efficiency while maintaining acceptable body composition, which is important for both production performance and market quality.

Table 5. Proximate whole-body, muscle, and liver of striped catfish fed diets supplemented with cinnamaldehyde

Parameter	Treataments				
	28:13-C0	25:14-C1	25:14-C2	25:15-C1	25:15-C2
			Whole-body		
Moisture, %	73.00 ± 1.08	72.73 ± 1.14	73.09 ± 0.21	72.69 ± 0.82	73.62 ± 0.91
Protein, %	12.35 ± 0.40	12.20 ± 0.58	12.62 ± 0.32	12.10 ± 0.46	12.29 ± 0.86
Lipid, %	8.10 ± 0.10[a]	8.06 ± 0.46[a]	7.8 ± 0.20[a]	9.00 ± 0.33[b]	8.16 ± 0.19[a]
			Muscle		
Moisture, %	80.76 ± 0.86	80.26 ± 1.82	80.64 ± 0.86	80.47 ± 0.68	79.74 ± 1.25
Lipid, %	2.20 ± 0.20[bc]	1.50 ± 0.65[ab]	1.34 ± 0.31[a]	1.34 ± 0.65[a]	2.36 ± 0.84[c]
			Liver		
Moisture, %	74.18 ± 0.86	73.43 ± 1.11	73.63 ± 0.44	74.13 ± 0.60	73.31 ± .59
Lipid, %	3.03 ± 0.18	3.87 ± 0.14	3.98 ± 0.40	3.66 ± 0.78	3.29 ± 0.84
Visceral					
Moisture, %	73.72 ± 1.22	72.97 ± 0.41	73.63 ± 0.86	74.72 ± 0.92	73.31 ± 0.59
Lipid, %	28.29 ± 1.05	26.52 ± 3.05	27.63 ± 1.58	26.45 ± 2.16	26.21 ± 2.22

Note: Values are expressed as mean ± SD (n = 4). Different letters in the same row indicate significant differences (One-way ANOVA and Duncan's post hoc test, $P<0.05$).

CONCLUSION

In conclusion, reducing dietary protein to 25 % in striped catfish feed is achievable without compromising growth performance, provided that the E:P ratio is optimized to 15 kcal/g and supplemented with 1.2 g/kg CIN. This approach not only enhances sustainability but also addresses the economic challenges of high-protein diets, paving the way for innovative feeding strategies in aquaculture. Future studies should explore the long-term effects of these formulations on fish health and adaptability to different aquaculture species and environments.

ACKNOWLEDGEMENTS

This study was funded by the Kementerian Pendidikan dan Kebudayaan (Ministry of Education and Culture, Republic of Indonesia) (grant no. 3696/IT3. L1/PT.01.03/P/B/2022) through the PMDSU scholarship scheme.

REFERENCES

Abd El-Hamid, M. I., Ibrahim, S. M., Eldemery, F., El-Mandrawy, S. A. M., Metwally, A. Sh., Khalifa, E., Elnahriry, S. S., & Ibrahim, D. (2021). Dietary cinnamaldehyde nanoemulsion boosts growth and transcriptomes of antioxidant and immune related genes to fight *Streptococcus agalactiae* infection in Nile tilapia (*Oreochromis niloticus*). *Fish & Shellfish Immunology*, *113*, 96–105. https://doi.org/10.1016/j.fsi.2021.03.021

Alam, M. S., Liang, X.-F., & Liu, L. (2020). Indirect effect of different dietary protein to energy ratio of bait fish mori diets on growth performance, body composition, nitrogen metabolism and relative AMPK & mTOR pathway gene expression of Chinese perch. *Aquaculture Reports*, 16, 100276. https://doi.org/10.1016/j.aqrep.2020.100276

Ali, Z., Paul, M., Jana, P., Rahman, K., & Mahmud, Y. (2018). Optimization of dietary protein to energy ratio (P/E ratio) for Sutchi catfish, *Pangasianodon hypophthalmus* (Sauvage, 1878) fingerlings. *Journal of Entomology and Zoology Studies*, *6(*5), 2162–2167.

Amer, S. A., Metwally, A. E., & Ahmed, S. A. A. (2018). The influence of dietary supplementation of cinnamaldehyde and thymol on the growth performance, immunity and antioxidant status of monosex Nile tilapia fingerlings (*Oreochromis niloticus*). *The Egyptian Journal of Aquatic Research*, 44(3), 251–256. https://doi.org/10.1016/j.ejar.2018.07.004

AOAC. (2012). *Official Methods of Analysis of AOAC International* (Ed ke-19). AOAC International.

Asemani, M., Sepahdari, A., Pourkazemi, M., Hafezieh, M., Aliyu Paiko, M., & Dadgar, S. (2019). Effect of different sources and forms of dietary carbohydrates on growth performance, body indices and lipogenesis activity of striped catfish *Pangasianodon hypophthalmus* fingerlings. *Aquaculture Nutrition*, *25*(6), 1399–1409. https://doi.org/10.1111/anu.12960

Barange, M., Bahri, T., Beveridge, M. C. M., Cochrane, K. L., Funge-Smith, S. & P., & F., eds. (2018). *Impacts of climate change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options*. FAO.

Chen, Z., Jing, F., Lu, M., Su, C., Tong, R., & Pan, L. (2022). Effects of dietary trans-cinnamaldehyde on growth performance, lipid metabolism, immune response and intestinal microbiota of *Litopenaeus vannamei*. *Fish & Shellfish Immunology*, *131*, 908–917. https://doi.org/10.1016/j.fsi.2022.11.008

Da, C. T., Hung, L. T., Berg, H., Lindberg, J. E., & Lundh, T. (2013). Evaluation of potential feed sources, and technical and economic considerations of small-scale commercial striped catfish (*P angasius hypothalamus*) pond farming systems in the Mekong Delta of Vietnam. *Aquaculture Research*, 44(3), 427–438. https://doi.org/10.1111/j.1365-2109.2011.03048.x

FAO. (2022). *The State of World Fisheries and Aquaculture 2022*. FAO. https://doi.org/10.4060/cc0461en

García-Meilán, I., Valentín, J. M., Fontanillas, R., & Gallardo, M. A. (2013). Different protein to energy ratio diets for gilthead sea bream (*Sparus aurata*): Effects on digestive and absorptive processes. *Aquaculture*, 412–413, 1–7. https://doi.org/10.1016/j.aquaculture.2013.06.031

Green, J. A., & Hardy, R. W. (2008). The effects of dietary protein:energy ratio and amino acid pattern on nitrogen utilization and excretion of rainbow trout *Oncorhynchus mykiss* (Walbaum). *Journal of Fish Biology*, *73*(3), 663–682. https://doi.org/10.1111/j.1095-8649.2008.01965.x

Gu, Y., Han, J., Wang, W., Zhan, Y., Wang, H., Hua, W., Liu, Y., Guo, Y., Xue, Z., & Wang, W. (2022). Dietary cinnamaldehyde enhances growth performance, digestion, immunity, and lipid metabolism in juvenile fat greenling (*Hexagrammos otakii*). *Aquaculture Nutrition*, *2022*, 1–12. https://doi.org/10.1155/2022/2132754

Hardy, R. W., & Kaushik, S. J. (2022). *Fish Nutrition* (4th ed.). Academic Press.

Hendriana, A., Setiawati, M., Jusadi, D., Suprayudi, M. A., Ekasari, J., & Wahjuningrum, D. (2023).

Evaluation of the administration of cinnamaldehyde to feed on the growth performance and carbohydrate metabolism of Pacific whiteleg shrimp (*Litopenaeus vannamei*). *AACL Bioflux*, 16(5), 2660–2670.

Hudecová, K., & Rajèániová, M. (2023). The impact of geopolitical risk on agricultural commodity prices. *Agricultural Economics (Zemìdìlská Ekonomika)*, 69(4), 129–139. https://doi.org/10.17221/374/2022-AGRICECON

Imlani, A. H., Jusadi, D., Suprayudi, M. A., Ekasari, J., Fauzi, I. A., Guinto-Sali, M. J., & Wahyudi, I. T. (2024). Evaluation of the effects of dietary cinnamaldehyde on growth and nutrient use in Nile Tilapia (*Oreochromis niloticus*). *Aquaculture Reports*, 36, 102125. https://doi.org/10.1016/j.aqrep.2024.102125

Kamalam, B. S., Medale, F., & Panserat, S. (2017). Utilisation of dietary carbohydrates in farmed fishes: New insights on influencing factors, biological limitations and future strategies. *Aquaculture*, 467, 3–27. https://doi.org/10.1016/j.aquaculture.2016.02.007

Kim, K., Kim, K., Han, H. S., Moniruzzaman, M., Yun, H., Lee, S., & Bai, S. C. (2017). Optimum Dietary Protein Level and Protein to energy Ratio for Growth of Juvenile Parrot Fish, *Oplegnathus fasciatus*. *Journal of the World Aquaculture Society*, 48(3), 467–477. https://doi.org/10.1111/jwas.12337

Lehninger, A. L., Nelson, D. L., & Cox, M. M. (2008). *Principles of Biochemistry* (5th ed). W.H. Freeman.

Luo, Y., Hu, C.-T., Qiao, F., Wang, X.-D., Qin, J. G., Du, Z.-Y., & Chen, L.-Q. (2020). Gemfibrozil improves lipid metabolism in Nile tilapia *Oreochromis niloticus* fed a high-carbohydrate diet through peroxisome proliferator activated receptor-á activation. *General and Comparative Endocrinology*, *296*, 113537. https://doi.org/10.1016/j.ygcen.2020.113537

National Research Council (Ed.). (2011). *Nutrient Requirements of Fish and Shrimp*. National Academies Press.

Ngoc, P. T., Gaitán-Cremaschi, D., Meuwissen, M. P. M., Le, T. C., Bosma, R. H., Verreth, J., & Lansink, A. O. (2018). Technical inefficiency of Vietnamese pangasius farming: A data envelopment analysis. *Aquaculture Economics & Management*, 22(2), 229–243. https://doi.org/10.1080/13657305.2017.1399296

Nguyen, T. A. T., Nguyen, Q. T. T., Tran, T. C., Nguyen, K. A. T., & Jolly, C. M. (2023). Balancing the aquatic export supply chain strategy- A case study of the Vietnam pangasius industry. *Aquaculture*, *566*, 739139. https://doi.org/10.1016/j.aquaculture.2022.739139

Orban, E., Nevigato, T., Lena, G. D., Masci, M., Casini, I., Gambelli, L., & Caproni, R. (2008). New trends in the seafood market sutchi catfish (*Pangasius hypophthalmus*) fillets from Vietnam: Nutritional quality and safety aspects. *Food Chemistry*, *110*(2), 383–389. https://doi.org/10.1016/j.foodchem.2008.02.014

Poernomo, N., Utomo, N. B. P., & Azwar, Z. I. (2015). The growth and meat quality of Siamese catfish fed different level of protein. *Jurnal Akuakultur Indonesia*, 14(2), 104-111. https://doi.org/10.19027/jai.14.104-111.

Salmerón, C. (2018). Adipogenesis in fish. *Journal of Experimental Biology*, 221(Suppl_1), jeb161588. https://doi.org/10.1242/jeb.161588

Setiawati, M., Jusadi, D., Laheng, S., Suprayudi, M. A., & Vinasyiam, A. (2016). The enhancement of growth performance and feed efficiency of Asian catfish, *Pangasianodon hypophthalmus* fed on *Cinnamomum burmannii* leaf powder and extract as nutritional supplementation. *AACL Bioflux*, *9*(6).

Teles, A. O., Couto, A., Enes, P., & Peres, H. (2020). Dietary protein requirements of fish – a meta analysis. *Reviews in Aquaculture*, 12(3), 1445–1477. https://doi.org/10.1111/raq.12391

Varner, W. (2000). Anesthetics. In R. R. Stickney (Ed.), *Encyclopedia of Aquaculture* (pp. 33–38). John Wiley 439 & Sons, Inc.

Wahyudi, I. T., Jusadi, D., Setiawati, M., & Ekasari, J. (2023a). Effects of dietary supplementation with cinnamon powder and lysine on blood chemistry, liver histology, growth performance, and fillet quality of striped catfish *Pangasianodon hypophthalmus*. *Aquaculture International*, 31(6), 3513–3529. https://doi.org/10.1007/s10499-023-01141-4

Wahyudi, I. T., Jusadi, D., Setiawati, M., Ekasari, J., & Suprayudi, M. A. (2023b). Suplementasi l-karnitin dan kayu manis pada pakan terhadap penurunan lemak dan tekstur filet ikan patin *Pangasianodon hypophthalmus* pada fase pembesaran. *Jurnal Riset Akuakultur*, 18(1), 1–14. https://doi.org/10.15578/jra.18.1.2023.1-14

Wahyudi, I. T., Jusadi, D., Setiawati, M., Ekasari, J., & Suprayudi, M. A. (2024). Dietary supplementation of cinnamaldehyde positively affects the physiology, feed utilization, growth, and body composition of striped catfish *Pangasianodon hypophthalmus*. *Fish Physiology and Biochemistry*, *50*. https://doi.org/10.1007/s10695-023-01287-1

Wang, J. T., Han, T., Li, X. Y., Yang, Y. X., Yang, M., Hu, S. X., Jiang, Y. D., & Harpaz, S. (2017). Effects of dietary protein and lipid levels with different protein-to-energy ratios on growth performance, feed utilization and body composition of juvenile red-spotted grouper, *Epinephelus akaara*. *Aquaculture Nutrition*, 23(5), 994–1002. https://doi.org/10.1111/anu.12467

Watanabe, T. (1998). *Fish Nutrition and Mariculture*. Japan International Cooperation Agency.

Webster, C. D., & Lim, C. (Eds.). (2002). *Nutrient Requirements and Feeding of Finfish for Aquaculture*. CABI. https://doi.org/10.1079/9780851995199.0000

Wen, C., Ma, S., Tian, H., Jiang, W., Jia, X., Zhang, W., Jiang, G., Li, X., Chi, C., He, C., Liu, W., & Zhang, D. (2022). Evaluation of the protein-sparing effects of carbohydrates in the diet of the crayfish, *Procambarus clarkii*. *Aquaculture*, *556*, 738275. https://doi.org/10.1016/j.aquaculture.2022.738275

Xu, C., Liu, W.-B., Remø, S. C., Wang, B.-K., Shi, H.-J., Zhang, L., Liu, J.-D., & Li, X.-F. (2019). Feeding restriction alleviates high carbohydrate diet-induced oxidative stress and inflammation of *Megalobrama amblycephala* by activating the AMPK-SIRT1 pathway. *Fish & Shellfish Immunology*, 92, 637–648. https://doi.org/10.1016/j.fsi.2019.06.057

Zhou, Y., Wu, P., Jiang, W.-D., Liu, Y., Peng, Y., Kuang, S.-Y., Tang, L., Li, S.-W., Feng, L., & Zhou, X.-Q. (2023). Dietary cinnamaldehyde improves muscle protein content by promoting muscle fiber growth via PTP1B/IGF1/PI3K/AKTs-TOR/FOXO3a signaling pathway in grass carp (*Ctenopharyngodon idella*). *Food Chemistry*, 399, 133799. https://doi.org/10.1016/j.foodchem.2022.133799

