

Original Research Articles

Effect of dietary vitamin C dosage on rearing performance and hematological indices in swamp eel (*Monopterus albus* Zuiew, 1793) juveniles

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Israeli Journal of Aquaculture - Bamidgeh

Vol. 78, Issue 1, 2026

The swamp eel (*Monopterus albus*) is a freshwater species widely cultured in Southeast Asia due to its high nutritional and economic value. Vitamin C is required for antioxidant defense, immune function, and collagen synthesis as a cofactor for fish health and growth. This study examined the effects of five dietary vitamin C (L-ascorbic acid) supplement levels (0, 80, 140, 200, and 260 mg/kg) in pellet feed on the growth performance and hematological indices of *M. albus* juveniles. A 60-day feeding trial was carried out using a completely randomized design with three replicates on the juveniles (initial average sizes of 5.61 g and 18.69 cm) in rectangular Styrofoam basins with a volume of 16.4 liters. From day 15 onward, most of the weight growth parameters progressively increased with dietary vitamin C levels (80–260 mg/kg), with significant improvement at ≥ 200 mg/kg ($P \leq 0.05$); however, there was no difference between 200 and 260 mg/kg ($P \geq 0.05$). Length growth parameters did not differ significantly at vitamin C levels of 80–200 mg/kg ($P \geq 0.05$), but significant differences in length means, daily length gain, and specific length growth rate were observed between 260 and 0 mg/kg ($P \leq 0.05$). There was no significant difference in most hematological indices at the treatments ($P \geq 0.05$), except for mean corpuscular hemoglobin, which declined significantly at ≥ 200 mg/kg ($P \leq 0.05$). Mid-sized cells and granulocytes showed no consistent response to the tested vitamin C levels. The findings indicate that dietary vitamin C had minimal effects on hematological indices, with 200 mg/kg recommended as the optimal supplementation level for rearing *M. albus* juveniles under the study conditions.

INTRODUCTION

Vitamin C (L-ascorbic acid) is a crucial water-soluble micronutrient that plays a vital role in supporting antioxidant defense, immunity, stress resistance, and collagen synthesis. These functions are essential for improving physiological processes, maintaining tissue integrity, and enhancing overall health, survival, and growth performance in aquatic animals.^{1–4} Most teleost fish, including eel species, lack the enzyme L-gulonolactone oxidase required for endogenous vitamin C synthesis and therefore depend entirely on dietary sources.^{5,6} Additionally, ascorbic acid is unstable when exposed to temperature and light, resulting in a significant loss of its activity during processing and storage. Therefore, supplementing vitamin C in artificial feeds used in aquaculture is essential.^{2,7,8} Although fish can tolerate moderate excesses of vitamin C, excessive supplementation

may disrupt redox balance and impair other physiological processes.⁹ Inadequate dietary vitamin C supplementation may result in detrimental effects in farmed animals, including growth retardation, skeletal deformities, gill filament distortion, fin erosion, hemorrhages, anorexia, and elevated mortality.^{10,11} Previous research has shown that the dietary vitamin C requirements for freshwater aquatic animal species may range from 150 to 1,200 mg/kg, while for marine and brackish species, it is approximately 156–259.09 mg/kg, depending on the specific species, life stages, farmed conditions, and the forms of vitamin C used (pure or derivative).^{4,12,13}

The swamp eel (*M. albus*) is a freshwater species that breathes air and can breathe through its skin and mouth. It can live in many different places, such as rice fields, canals, ponds, swamps, and other shallow, muddy freshwater habitats, even when the oxygen levels are low and the salinity levels change across East and Southeast Asia.^{14–16}

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M. albus meat is characterized by high protein content, low lipid levels, and the presence of bioactive compounds with nutritional and medicinal value.^{17,18} The rapid increase in consumer demand, together with advances in artificial breeding and larval rearing technologies, has driven the expansion of swamp eel aquaculture in Vietnam.¹⁹⁻²¹ However, production efficiency is still limited because this scaleless teleost species has slow growth, high size variations in populations, poor use of artificial feed, and high death rates in the early stages of life.²²⁻²⁴ Moreover, its natural populations have declined markedly due to over-exploitation and habitat degradation.^{24,25} These challenges show the need to implement optimized nutritional strategies to effectively enhance swamp eel production for both conservation and commercial purposes.

Hematological indices are crucial for evaluating the physiological and immunological status of *M. albus*, which often inhabits areas with poor, highly variable water quality.²⁶⁻²⁸ Numerous studies have shown that dietary vitamin C has positive effects on hematological and immune parameters in aquacultured species. For example, it has been shown to significantly increase hematocrit, hemoglobin, and red blood cell counts, thereby improving oxygen transport and overall stress resistance.²⁹⁻³² The available literature on dietary vitamin C in *M. albus*, however, is limited. Swamp eel fry at the onset of the exogenous feeding stage (≈ 0.028 g) were fed diets supplemented with pure L-ascorbic acid (80–140 mg/kg). The best growth performance, survival rate, and coefficient of variation were exhibited at 140 mg/kg after 60 days of rearing.³³ A 10-week feeding trial on *M. albus* (≈ 32.6 g) showed dietary vitamin C in the L-ascorbyl-2-monophosphate (35% ascorbic acid equivalent, Roche) form at $0.1\text{--}278.5\text{ mg kg}^{-1}$ significantly improved growth, antioxidant capacity, immunity, and disease resistance, with quadratic analysis indicating optimal growth at approximately 80.66 mg/kg.²³ In migratory eel species, *Anguilla japonica* juveniles (≈ 11.0 g), fed diets supplemented with calcium L-ascorbate at $3\text{--}3,135\text{ mg/kg}$, exhibited an estimated optimal ascorbic acid requirement for growth exceeding 27 mg/kg, while higher inclusion levels ($>645\text{ mg/kg}$) enhanced hematological indices and tissue vitamin C concentrations³⁴; meanwhile, the juvenile (≈ 75.5 g) showed a significant improvement in liver vitamin C levels, blood biochemical indices, and non-specific immune responses when fed a diet supplemented with ascorbyl-2-monophosphate (762 mg/kg).³⁵ This study aimed to evaluate the effect of dietary vitamin C (L-ascorbic acid) dosage on the rearing performance and hematological indices of *M. albus* juveniles (≈ 5.6 g). These findings are expected to provide stage-specific data on vitamin C supplementation and contribute to the development of nutritionally balanced feeds for swamp eel aquaculture.

MATERIALS AND METHODS

EXPERIMENTAL ANIMALS AND REARING CONDITIONS

M. albus juveniles, averaging 5.61 g in weight and 18.69 cm in length, were sourced from a local hatchery and trans-

ferred to the Wet Lab at Tra Vinh University. They were transported in slightly oxygenated Styrofoam boxes filled with hatchery freshwater. The travel time was approximately 30 minutes. The juveniles were acclimated to the experimental conditions for one week prior to the start of the investigation. Freshwater for the experiment was sourced from tap water, purified using a reverse osmosis (RO) system, and vigorously aerated for 24 hours to remove chlorine before use. Rectangular Styrofoam basins, each with a volume of 16.4 liters (31 cm long x 22 cm wide x 24 cm high), were used as raising units. Each basin was filled with 7 cm of water and equipped with nylon bundles that covered approximately one-fifth of the bottom surface, creating artificial substrates for the eels. A commercial shrimp pellet feed from Grobest Company (Vietnam), with a particle size ranging from 1.2 to 1.7 mm and a crude protein content of 42%, was supplemented with the powder vitamin C (L-ascorbic acid) at dosages of 0, 80, 140, 200, and 260 mg/kg. The vitamin C was dissolved in water and thoroughly mixed with the pellets approximately 15 minutes before feeding the eels. Proximate nutritional components of basal feed used in experiments are presented in [Table 1](#).

EXPERIMENTAL PROCEDURES AND DATA COLLECTION

This study was conducted from July to September 2025 at the Aquaculture and Agriculture Wet Lab, Tra Vinh University, Vietnam. A completely randomized design with three replicates was used over a 60-day period. The main objective of the study was to assess the rearing performance and hematological indices of *M. albus* juveniles under different dosages of dietary vitamin C supplementation. Detailed descriptions of the experiment are provided below:

A total of 1,500 juvenile *M. albus* eels were randomly stocked in 15 rearing basins, with 100 individuals assigned to each basin. Five dietary vitamin C levels (0, 80, 140, 200, and 260 mg/kg) were tested, with each level replicated in three basins. The juveniles were fed the trial diets twice daily at 07:00 and 17:00 until they appeared satiated, approximately 3–4% of their body weight. Two hours after feeding, uneaten feed and waste were removed, and the water in the basins was completely renewed. Key water quality parameters were monitored daily and remained within the optimal range for *M. albus*.^{15,36-38} Water temperature varied from 26.34°C in the morning to 30.68°C in the afternoon, while pH levels ranged from 8.10 to 8.25, as measured with a HANNA portable meter (Model HI98103, Romania). Total ammonia nitrogen (TAN) and nitrite (NO_2^-) levels in the rearing basins were consistently low and stable, remaining below 0.01 mg/L.

Every 15 days during the rearing period, five eels were randomly sampled from each basin (15 eels per dietary vitamin C level) to assess growth performance. Individual body weights were measured using an electric balance with a precision of 0.01 g, while total lengths were measured with a scaled ruler (in mm). At the conclusion of the experiment, the survival rate and feed conversion ratio (FCR) were recorded and calculated. The following formulas were utilized to determine the monitored performance parameters:

Table 1. Proximate nutritional components of basal feed used in experiments.

Protein (%)	42
Lipid (%)	4
Fiber (%)	4
Moisture content (%)	11
Phosphorus (%)	0.9
Lysine (%)	1.6
Ethoxyquin (ppm)	100

Average weight (AW, g) = total weight of 15 eels / 15

Average length (AL, cm) = total length of 15 eels / 15

Weight gain (WG, g) = final weight - initial weight

Length gain (LG, cm) = final length - initial length

Daily weight gain (DWG, g/day) = (final weight - initial weight) / number of rearing days

Daily length gain (DLG, cm/day) = (final length - initial length) / number of rearing days

Specific growth rate in weight (SGR_w, %/day) = ((ln (final weight) - ln (initial weight)) / number of rearing days) × 100

Specific growth rate in length (SGR_L, %/day) = ((ln (final length) - ln (initial length)) / number of rearing days) × 100

Survival rate (%) = (final eel number / initial eel number) × 100

Feed conversion ratio (FCR) = total dry feed fed (g)/total wet weight gain (g)

At the end of the experiment, three eels were randomly collected from each basin (nine eels for each dietary vitamin C level) for hematological examination. The eels were anesthetized using ice. Approximately 0.4 mL of blood was drawn from each eel's caudal vein using a syringe and transferred to EDTA containers (BD Microtainer, UK) to act as an anticoagulant. All hematological determinations were performed according to established fish hematology protocols.^{39,40} Blood samples were examined for hematological indices, including white blood cells (WBC, 10⁹ cells/L), lymphocytes (LYM, 10⁹ cells/L), mid-sized cells (MID; monocytes, eosinophils, and basophils; 10⁹ cells/L), granulocytes (GRAN, 10⁹ cells/L), red blood cells (RBC, 10¹² cells/L), hemoglobin (HGB, g/L), hematocrit (HCT, %), mean corpuscular hemoglobin (MCH, pg), and mean corpuscular hemoglobin concentration (MCHC, g/L). Analyses were performed using a Urit 3000 Vet Plus hematology analyzer (Urit Medical, China).

DATA ANALYSIS

All data were analyzed using SPSS v20.0 (Windows). One-way ANOVA followed by Tukey's post hoc test was used to assess differences among treatments at a significance level of $P \leq 0.05$. Levene's test evaluated variance homogeneity, and percentage data were arcsine-transformed prior to analysis.

RESULTS

From day 15 onward, average weight (AW₁₅₋₆₀), WG, DWG, and SGR_w increased progressively with dietary vitamin C levels ranging from 80 to 260 mg/kg, with significant improvements at levels ≥ 200 mg/kg, except for MW₃₀ ($P \leq 0.05$, Table 2); however, no significant differences were found in all weight growth parameters between the 200 and 260 mg/kg levels ($P \geq 0.05$, Table 2).

The effects of dietary vitamin C levels between 0 and 200 mg/kg on the length growth performance of experimental eels were unclear, as most length growth parameters showed no significant differences within this range ($P \geq 0.05$, Table 3). However, ML₁₅, ML₃₀, ML₆₀, DLG, and SGR_L were significantly higher at 260 mg/kg than at 0 mg/kg ($P \leq 0.05$; Table 3).

Survival remained 100%, and FCR was similar across all tested dietary vitamin C levels ($P \geq 0.05$; Table 4).

Most hematological indices, including WBC, LYM, RBC, HGB, HCT, and MCHC, showed no significant differences among the dietary vitamin C levels tested ($P \geq 0.05$, Table 5). However, MCH values decreased with increasing vitamin C levels, with significant reductions observed at levels ≥ 200 mg/kg ($P \leq 0.05$, Table 5). In contrast, MID and GRAN values showed no consistent trend across the tested vitamin C levels (Table 5).

DISCUSSION

REARING PERFORMANCE

The present study demonstrated that dietary vitamin C (L-ascorbic acid) supplementation markedly improved the weight growth performance of *M. albus* juveniles. This improvement was indicated by increased values of MW₁₅₋₆₀, WG, DWG, and SGR_w at dietary vitamin C levels ranging from 80 to 260 mg/kg. These results align with previous findings in fry (*Anguilla bicolor*) eel reared in cage containers,⁴¹ juvenile tilapia (*Oreochromis karongae*),⁴² and juvenile Waigieu seaperch (*Psammoderus waigiensis*)⁴³ reared in aquaria, indicating that dietary vitamin C supplementation significantly increased weight gain. Vitamin C has been documented to promote fish health and growth through multiple physiological and biochemical mechanisms. From a biological perspective, swamp eels have a carnivorous feeding habit and a high capacity for protein accretion, which may increase their demand for micronutrients in-

Table 2. Initial average weight (IAW), average weight (AW), weight gain (WG), daily weight gain (DWG), and specific growth rate in weight (SGR_w) of *Monopterus albus* juveniles during 60 days of rearing under various dietary vitamin C doses.

Parameters	Dietary vitamin doses (mg/kg)				
	0	80	140	200	260
IAW (g)	5.61±1.53	5.61±1.53	5.61±1.53	5.61±1.53	5.61±1.53
AW ₁₅ (g)	7.73±1.98 ^a	8.20±2.99 ^{ab}	9.58±2.34 ^{bc}	9.67±2.34 ^{bc}	11.04±2.34 ^c
AW ₃₀ (g)	12.15±3.45 ^a	12.75±4.09 ^a	14.22±2.69 ^{ab}	13.77±2.02 ^{ab}	15.96±2.75 ^b
AW ₄₅ (g)	16.93±4.36 ^{ab}	16.00±3.68 ^a	17.43±3.55 ^{ab}	19.13±3.29 ^{bc}	21.25±2.80 ^c
AW ₆₀ (g)	18.92±3.06 ^a	18.61±3.99 ^a	20.97±4.2 ^{ab}	22.61±4.57 ^{bc}	24.14±2.64 ^c
WG (g)	13.33±3.02 ^a	13.00±4.04 ^a	15.33±4.15 ^{ab}	17.33±4.59 ^{bc}	18.47±2.59 ^c
DWG (g/day)	0.22±0.05 ^a	0.22±0.07 ^a	0.26±0.07 ^{ab}	0.28±0.08 ^{bc}	0.31±0.04 ^c
SGR _w (%/day)	2.01±0.29 ^a	1.96±0.37 ^a	2.16±0.37 ^{ab}	2.29±0.35 ^{bc}	2.42±0.18 ^c

Values are shown as mean±SD. Different letters (a, b, c) in the same row indicate a significant difference ($P \leq 0.05$)

Table 3. Initial average length (IAL), average length (AL), length gain (LG), daily length gain (DLG), and specific growth rate in length (SGR_L) of *Monopterus albus* juveniles during 60 days of rearing under various dietary vitamin C doses.

Parameters	Dietary vitamin doses (mg/kg)				
	0	80	140	200	260
IAL (cm)	18.69±1.52	18.69±1.52	18.69±1.52	18.69±1.52	18.69±1.52
AL ₁₅ (cm)	19.27±1.62 ^a	19.15±2.87 ^a	20.95±2.16 ^b	19.89±1.59 ^{ab}	21.02±1.51 ^b
AL ₃₀ (cm)	22.61±2.27 ^a	23.55±2.36 ^{ab}	24.37±1.69 ^{ab}	23.38±1.49 ^b	24.69±1.81 ^b
AL ₄₅ (cm)	25.60±2.208 ^a	25.65±2.01 ^a	26.62±1.89 ^a	25.91±1.37 ^a	26.86±1.50 ^a
AL ₆₀ (cm)	26.97±1.91 ^a	27.11±2.19 ^{ab}	27.77±1.98 ^{ab}	27.86±2.02 ^{ab}	28.63±1.42 ^b
DL (cm)	8.47±1.96 ^a	8.47±2.07 ^a	9.20±2.18 ^a	9.20±1.97 ^a	10.00±1.51 ^a
DLG (cm/day)	0.14±0.03 ^{ab}	0.14±0.04 ^{ab}	0.15±0.03 ^{ab}	0.15±0.03 ^{ab}	0.17±0.02 ^b
SGR _L (%/day)	0.61±0.12 ^a	0.62±0.13 ^{ab}	0.66±0.12 ^{ab}	0.66±0.12 ^{ab}	0.71±0.08 ^b

Values are shown as mean±SD. Different letters (a, b) in the same row indicate a significant difference ($P \leq 0.05$).

Table 4. Survival rates and feed conversion ratio (FCR) of *Monopterus albus* juveniles after 60 days of rearing under various dietary vitamin C doses

Parameters	Dietary vitamin doses (mg/kg)				
	0	80	140	200	260
Survival rates (%)	100	100	100	100	100
FCR	0.57±0.01 ^a	0.54±0.11 ^a	0.57±0.01 ^a	0.57±0.05 ^a	0.58±0.01 ^a

Values are shown as mean±SD. Values with the letter (a) in the same row indicate a significant difference ($P \leq 0.05$).

involved in protein synthesis and tissue repair.^{18,44} It has been shown that vitamin C is vital for collagen synthesis, tissue repair, and bone formation, which helps maintain structural integrity and promote muscle growth.^{1,8,45} Additionally, in intensive aquaculture systems, vitamin C helps mitigate oxidative damage induced by high stocking density, handling stress, and fluctuating environmental conditions.^{2,7,46,47} It also enhances immune function by stimulating leukocyte proliferation, increasing phagocytic activity, promoting lysozyme production, and improving resistance to bacterial pathogens.^{3,48}

Remarkably, the weight growth response stabilized between 200 and 260 mg/kg. Similar growth plateaus at this level have been reported in *Anguilla bicolor* eels⁴¹ and *Labeo rohita* fish,⁴⁹ wherein growth parameters also improved with increasing dietary vitamin C levels up to approximately 200 mg/kg, while no further enhancements were noted at higher levels. The finding suggests that 200 mg/kg may be the optimal dietary level for maximizing weight growth efficiency in *M. albus* juveniles in the current study.

Another observation in this study indicated that dietary vitamin C had a limited effect on length growth in *M. albus* juveniles, as most length-related indices showed no signif-

Table 5. Hematological indices of *Monopterus albus* juveniles after 60 days of rearing under various dietary vitamin C doses

indices	Dietary vitamin doses (mg/kg)				
	0	80	140	200	260
WBC	59.93±5.95 ^a	66.20±10.06 ^a	66.8±4.08 ^a	59.93±14.23 ^a	60.43±4.12 ^a
LYM	24.97±3.45 ^a	20.9±5.00 ^a	27.07±6.93 ^a	30.77±9.62 ^a	23.33±1.31 ^a
MID	6.60±0.90 ^{ab}	8.27±0.60 ^b	6.43±1.53 ^a	5.30±0.40 ^a	6.63±0.46 ^{ab}
GRAN	28.37±5.86 ^{ab}	37.03±5.45 ^b	33.33±9.63 ^{ab}	23.87±5.03 ^a	30.57±4.71 ^{ab}
RBC	1.45±0.19 ^a	1.91±0.36 ^a	1.88±0.59 ^a	1.42±0.19 ^a	1.49±0.12 ^a
HGB	19.87±1.32 ^a	21.8±0.95 ^a	21.97±6.04 ^a	15.57±4.12 ^a	15.37±1.09 ^a
HCT	166.50±2.31 ^a	163.20±5.54 ^a	161.73±3.27 ^a	165.37±1.72 ^a	161.60±1.06 ^a
MCH	83.3±9.19 ^b	71.57±10.97 ^{ab}	73.60±8.32 ^{ab}	65.47±9.02 ^a	64.17±5.12 ^a
MCHC	8.50±1.30 ^a	11.43±2.34 ^a	11.07±2.31 ^a	9.70±0.53 ^a	11.20±1.39 ^a

Values are shown as mean±SD. Different letters (a, b) in the same row indicate a significant difference ($P \leq 0.05$). WBC (white blood cells, 10^9 cells/L), LYM (lymphocytes, 10^9 cells/L), MID (mid-sized cells including monocytes, eosinophils, and basophils, 10^9 cells/L), GRAN (granulocytes, 10^9 cells/L), RBC (red blood cells, 10^{12} cells/L), HGB (hemoglobin, g/L), HCT (hematocrit, %), MCH (mean corpuscular hemoglobin, pg), and MCHC (mean corpuscular hemoglobin concentration, g/L).

icant differences up to 200 mg/kg, with clear improvements observed only at 260 mg/kg compared to the control group. The discrepancy between weight and length responses is consistent with previous studies in *M. albus*²³ and other elongated or eel-like species, such as *Anguilla japonica*.⁴⁸ Swamp eels exhibit significant morphological plasticity, with growth frequently characterized by increases in body mass rather than linear extension, especially in captivity.^{24, 50} Consequently, vitamin C supplementation may preferentially support muscle accretion and connective tissue development rather than skeletal elongation.

The survival rate of *M. albus* juveniles was 100%, and no significant differences in FCR were observed among treatments after the 60-day feeding period. Furthermore, throughout the rearing period, no typical signs of vitamin C deficiency, such as lordosis or scoliosis, were detected in fish fed the control diet,^{10,11,51} indicating that the basal diet probably provided sufficient vitamin C to support survival and normal development of the juveniles, although not optimal growth. Similar results have been reported for juvenile *Psammoperca waigiensis*, in which dietary vitamin C supplementation significantly enhanced growth performance, and survival remained at 100% across supplementation levels of 0–400 mg/kg.⁴³ Likewise, *Anguilla bicolor* fry showed no significant differences in survival between vitamin C-supplemented diets and the control.⁴¹ The FCR exhibited no significant variation among the treatments, suggesting that the tested dietary levels of vitamin C did not adversely affect feed utilization in the experimental *M. albus* juveniles.

HEMATOLOGICAL RESPONSES

In this study, most blood parameters, such as WBC, LYM, RBC, HGB, HCT, and MCHC, did not differ among treatments. This suggests that dietary vitamin C from 0 to 260 mg/kg did not noticeably affect the blood profile of *M. albus* juveniles under experimental conditions. Similar results were reported in *Brycon amazonicus*⁵² and *Oncorhynchus mykiss*,⁵³ in which higher vitamin C levels did not signif-

icantly change hematological values. These findings indicate that once basic vitamin C needs are met, extra supplementation may not further influence baseline blood parameters of swamp eel juveniles. The MCH, however, decreased significantly at dietary vitamin C levels ≥ 200 mg/kg. Similar changes in erythrocyte indices have been reported in matrinxã and rainbow trout fed high vitamin C diets.^{52,54} The reduced MCH at higher vitamin C supplementation levels likely reflects movement in erythrocyte dynamics without impaired oxygen transport, as HGB and HCT levels remained stable. Thus, it may be an adaptive hematopoietic response rather than a pathological effect.^{53,55,56} MID and GRAN counts showed some variability among treatments but lacked a clear dose-dependent pattern with dietary vitamin C and were not accompanied by changes in total WBC or lymphocyte counts. The observed variations are likely within normal physiological limits and do not indicate immune activation.^{1,3,52} Overall, these findings suggest that dietary vitamin C, within the tested range, supports hematological stability in *M. albus* juveniles.

In summary, this study demonstrated that dietary vitamin C (L-ascorbic acid) supplementation significantly increased weight gain in *M. albus* juveniles at levels ≥ 200 mg/kg; however, there was no difference between 200 and 260 mg/kg. In contrast, length growth exhibited a relatively limited response to the vitamin C dosages used. Additionally, while the MCH decreased at higher dietary vitamin C levels, the MID and GRAN values showed no consistent trends, and survival rates remained at 100%. FCR, as well as most hematological indices, remained stable across treatments. These findings suggest that the tested dietary vitamin C range had a minimal impact on hematological indices in trial eels. Overall, a dietary vitamin C supplement at 200 mg/kg is recommended as optimal for rearing *M. albus* juveniles under the study conditions. This study was limited by controlled experimental conditions, a relatively short 60-day duration, and the absence of dose-response modeling to estimate the dietary vitamin C requirement of

the trial eels. Additionally, there was a lack of tissue vitamin C quantification and stress or immune challenge tests, which are needed in future research to better support practical aquaculture applications for *M. albus*.

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ACKNOWLEDGMENTS

We acknowledge the support of time and facilities from Tra Vinh University (TVU) and Ton Duc Thang University for this study.

AUTHORS' CONTRIBUTION

Conceptualization: Huong K. Huynh (Equal), Diep X. Doan (Equal). Methodology: Huong K. Huynh (Equal), Nam K. Ho (Equal), Diep X. Doan (Equal). Investigation: Huong K. Huynh (Equal), Nam K. Ho (Equal), Diep X. Doan (Equal). Writing – original draft: Huong K. Huynh (Equal), Diep X. Doan (Equal). Supervision: Huong K. Huynh (Lead), Diep X. Doan (Equal). Formal Analysis: Nam K. Ho (Lead). Writing – review & editing: Diep X. Doan (Lead).

COMPETING OF INTEREST – COPE

No competing interests were disclosed

ETHICAL CONDUCT APPROVAL – IACUC

The animal experiments adhered to relevant national and international guidelines. Only the *M. albus* juveniles underwent weighing and measuring and were anesthetized using ice for blood sampling, ensuring no harm was caused. After the experiments, the eels were returned to the storage tanks for further research.

INFORMED CONSENT STATEMENT

All authors and institutions have confirmed this manuscript for publication.

DATA AVAILABILITY STATEMENT

All are available upon reasonable request.

Submitted: November 14, 2025 CDT. Accepted: February 02, 2026 CDT. Published: March 08, 2026 CDT.



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REFERENCES

1. Ai Q, Mai K, Zhang C, et al. Effects of dietary vitamin C on growth and immune response of Japanese seabass (*Lateolabrax japonicus*). *Aquaculture*. 2004;242(1–4):489–500. doi:[10.1016/j.aquaculture.2004.08.016](https://doi.org/10.1016/j.aquaculture.2004.08.016)
2. Bae JY, Park GH, Yoo KY, Lee JY, Kim DJ, Bai SC. Re-evaluation of the optimum dietary vitamin C requirement in juvenile eel (*Anguilla japonica*) using L-ascorbyl-2-monophosphate. *Asian-Australas J Anim Sci*. 2012;25(1):98–103. doi:[10.5713/ajas.2011.11201](https://doi.org/10.5713/ajas.2011.11201)
3. Abo-Al-Ela HG, El-Nahas AF, Mahmoud S, Ibrahim EM. Vitamin C modulates the immunotoxic effect of 17 α -methyltestosterone in Nile tilapia. *Biochemistry*. 2017;56:2042–2050. doi:[10.1021/acs.biochem.6b01284](https://doi.org/10.1021/acs.biochem.6b01284)
4. Le KTH, Dinh NT, Nguyen NV. The essential role of vitamin C and E supplementation in enhancing growth, health, and body composition of aquaculture species. *J Agric Dev*. 2025;24(6):33–51.
5. Drouin G, Godin JR, Page B. The genetics of vitamin C loss in vertebrates. *Curr Genomics*. 2011;12(5):371–378. doi:[10.2174/138920211796429736](https://doi.org/10.2174/138920211796429736)
6. Chen GC, Lu DB, Pang Z, Liu QF. Vitamin C intake, circulating vitamin C and risk of stroke: A meta-analysis of prospective studies. *J Am Heart Assoc*. 2013;2(6):e000329. doi:[10.1161/JAHA.113.000329](https://doi.org/10.1161/JAHA.113.000329)
7. Lim C, Lovell RT. Pathology of the vitamin C deficiency syndrome in channel catfish (*Ictalurus punctatus*). *J Nutr*. 1978;108(7):1137–1146. doi:[10.1093/jn/108.7.1137](https://doi.org/10.1093/jn/108.7.1137)
8. Soliman AK, Jauncey K, Roberts RJ. Water-soluble vitamin requirements of tilapia: Ascorbic acid requirement of Nile tilapia. *Aquac Res*. 1994;25(3):269–278. doi:[10.1111/j.1365-2109.1994.tb00690.x](https://doi.org/10.1111/j.1365-2109.1994.tb00690.x)
9. Kaźmierczak-Barańska J, Boguszewska K, Adamus-Grabicka A, Karwowski BT. Two faces of vitamin C—Antioxidative and pro-oxidative agent. *Nutrients*. 2020;12(5):1501. doi:[10.3390/nu12051501](https://doi.org/10.3390/nu12051501)
10. Halver JE. The vitamins. In: Halver JE, ed. *Fish Nutrition*. 2nd ed. Academic Press; 1989:32–102.
11. Sandnes K, Torrissen O, Waagbø R. The minimum dietary requirement of vitamin C in Atlantic salmon (*Salmo salar*) fry using Ca ascorbate-2-monophosphate as a dietary source. *Fish Physiol Biochem*. 1992;10(4):315–319. doi:[10.1007/BF00004480](https://doi.org/10.1007/BF00004480)
12. Rucker RB, Steinberg F. Vitamin C. In: Lennarz WJ, Lane MD, eds. *Encyclopedia of Biological Chemistry*. Elsevier; 2004:367–371. doi:[10.1016/B0-12-443710-9/00741-9](https://doi.org/10.1016/B0-12-443710-9/00741-9)
13. Dawood MAO, Koshio S. Vitamin C supplementation to optimize growth, health and stress resistance in aquatic animals. *Rev Aquac*. 2018;10(2):334–350. doi:[10.1111/raq.12163](https://doi.org/10.1111/raq.12163)
14. Matsumoto S, Kon T, Yamaguchi M, Takeshima H, Yamazaki Y, Mukai T, et al. Cryptic diversification of the swamp eel *Monopterus albus* in East and Southeast Asia. *Ichthyol Res*. 2010;57(1):71–77. doi:[10.1007/s10228-009-0125-y](https://doi.org/10.1007/s10228-009-0125-y)
15. Pedersen PBM, Hansen K, Hounng DTT, Bayley M, Wang T. Effects of salinity on osmoregulation, growth and survival in Asian swamp eel (*Monopterus albus*). *Aquac Res*. 2012;2012:1–12. doi:[10.1111/j.1365-2109.2012.03244.x](https://doi.org/10.1111/j.1365-2109.2012.03244.x)
16. Tian HF, Hu Q, Lu HY, Li Z. Chromosome-scale, haplotype-resolved genome assembly of non-sex-reversal females of swamp eel using long reads and Hi-C data. *Front Genet*. 2022;13:903185. doi:[10.3389/fgene.2022.903185](https://doi.org/10.3389/fgene.2022.903185)
17. Weng WY, Wu T, Chen WQ. Purification and characterization of pepsinogens and pepsins from the stomach of rice field eel (*Monopterus albus*). *Fish Physiol Biochem*. 2011;37(3):543–552. doi:[10.1007/s10695-010-9456-x](https://doi.org/10.1007/s10695-010-9456-x)
18. Mao T, Gan J, Yu Y, Dong L, Zhang L, Zhang T, et al. Evaluation of muscle quality of *Monopterus albus* from different sources. *Food Chem Rev*. 2022;2022:211–222.
19. Hien TTT, Tu NTT, Tu TLC, Lan ML. Replacement of fish meal with soybean meal in diets for Asian swamp eel (*Monopterus albus*). *J Sci Can Tho Univ*. 2019;55(2B):96–103. doi:[10.22144/ctu.jvn.2019.052](https://doi.org/10.22144/ctu.jvn.2019.052)
20. Quyen NTK, Hien HV, Huy H. Value chain analysis in domestic aquaculture: Case study of swamp eel (*Monopterus albus*) in An Giang Province, Vietnam. *Int J Sci Res Publ*. 2019;9(1):638–646. doi:[10.29322/IJSRP.9.01.2019.p8577](https://doi.org/10.29322/IJSRP.9.01.2019.p8577)

21. Nhan HT, Tai NT, Liem PT, Ut VN, Ako H. Effects of different stocking densities on growth performance of Asian swamp eel *Monopterus albus*, water quality, and plant growth of watercress *Nasturtium officinale* in an aquaponic system. *Aquaculture*. 2019;503:96-104. doi:[10.1016/j.aquaculture.2018.12.063](https://doi.org/10.1016/j.aquaculture.2018.12.063)
22. Ou T, Zhu RL, Chen ZY, Zhang QY. Isolation and identification of a lethal rhabdovirus from farmed rice field eels *Monopterus albus*. *Dis Aquat Org*. 2013;106(3):197-206. doi:[10.3354/dao02660](https://doi.org/10.3354/dao02660)
23. Hu Y, Zhang J, He L, et al. Effects of dietary vitamin C on growth, antioxidant activity, and immunity in ricefield eel (*Monopterus albus*). *J World Aquac Soc*. 2020;51(1):159-170. doi:[10.1111/jwas.12636](https://doi.org/10.1111/jwas.12636)
24. Lv W, Yuan Q, Huang W, Sun X, Lv W, Zhou W. Asian swamp eel *Monopterus albus* population structure and genetic diversity in China. *Front Genet*. 2022;13:898958. doi:[10.3389/fgene.2022.898958](https://doi.org/10.3389/fgene.2022.898958)
25. Qu X, Jiang J, Shang X, Cheng C, Feng L, Liu Q. Construction and analysis of gonad suppression subtractive hybridization libraries for rice field eel (*Monopterus albus*). *Gene*. 2014;540(1):20-25. doi:[10.1016/j.gene.2014.02.044](https://doi.org/10.1016/j.gene.2014.02.044)
26. Chew SF, Gan J, Ip YK. Nitrogen metabolism and excretion in the swamp eel, *Monopterus albus*, during 6 or 40 days of estivation in mud. *Physiol Biochem Zool*. 2005;78(4):620-629. doi:[10.1086/430233](https://doi.org/10.1086/430233)
27. Chen H, Liu H, Li R, et al. Blood cell identification and hematological analysis during natural sex reversal in rice field eel (*Monopterus albus*). *Aquaculture*. 2021;538:736543. doi:[10.1016/j.aquaculture.2021.736543](https://doi.org/10.1016/j.aquaculture.2021.736543)
28. Hii YS, Lee MY, Chuah TS. Acute toxicity of the organochlorine insecticide endosulfan and its effects on behaviour and selected hematological parameters of Asian swamp eel (*Monopterus albus*). *Pestic Biochem Physiol*. 2007;89(1):46-53. doi:[10.1016/j.pestbp.2007.02.009](https://doi.org/10.1016/j.pestbp.2007.02.009)
29. Khan KU, Zuberi A, Nazir S, Ullah I, Jamil Z, Sarwar H. Synergistic effects of dietary nano-selenium and vitamin C on growth, feeding, and physiological parameters of mahseer fish (*Tor putitora*). *Aquac Rep*. 2017;5:70-75. doi:[10.1016/j.aqrep.2017.01.002](https://doi.org/10.1016/j.aqrep.2017.01.002)
30. Yadav AK, Sinha AK, Egnen N, Romano N, Kumar V. Potential amelioration of waterborne iron toxicity in channel catfish (*Ictalurus punctatus*) through dietary supplementation of vitamin C. *Ecotoxicol Environ Saf*. 2020;205:111337. doi:[10.1016/j.ecoenv.2020.111337](https://doi.org/10.1016/j.ecoenv.2020.111337)
31. Zehra S, Khan MA. Dietary vitamin C requirement of fingerling *Cirrhinus mrigala* based on growth, feed conversion, protein retention, hematology, and liver vitamin C. *J World Aquac Soc*. 2012;43:648-658. doi:[10.1111/j.1749-7345.2012.00597.x](https://doi.org/10.1111/j.1749-7345.2012.00597.x)
32. Sherif AH, Khalil RH, Talaat TS, et al. Dietary nanocomposite of vitamin C and vitamin E enhanced the performance of Nile tilapia. *Sci Rep*. 2024;14:15648. doi:[10.1038/s41598-024-65507-1](https://doi.org/10.1038/s41598-024-65507-1)
33. Anh PTTA, Sang NT, Nam LH. Effects of dietary vitamin C on growth, survival rate and coefficient of variation of swamp eel (*Monopterus albus* Zuiew, 1793) from 15 to 60 days. *Nha Trang Univ J Fish Sci Technol*. 2021;1:1-8.
34. Ren T, Koshio S, Teshima SI, et al. Optimum dietary level of L-ascorbic acid for Japanese eel (*Anguilla japonica*). *Aquac Nutr*. 2005;11(4):437-443. doi:[10.1111/j.1749-7345.2005.tb00391.x](https://doi.org/10.1111/j.1749-7345.2005.tb00391.x)
35. Ren T, Koshio S, Ishikawa M, et al. Influence of dietary vitamin C and bovine lactoferrin on blood chemistry and non-specific immune responses of Japanese eel (*Anguilla japonica*). *Aquaculture*. 2007;267(1-4):31-37. doi:[10.1016/j.aquaculture.2007.03.033](https://doi.org/10.1016/j.aquaculture.2007.03.033)
36. Portalia N, Sulmartiwi L, Rahardja B. The growth and survival rate in lettuce aquaponic systems (*Lactuca sativa*) of eels at various stocking densities (*Monopterus albus*). *IOP Conf Ser Earth Environ Sci*. 2019;236:012005. doi:[10.1088/1755-1315/236/1/012005](https://doi.org/10.1088/1755-1315/236/1/012005)
37. Lukistyowati I, Tang UM, Putra I, Fauzi M, Suharman I, Rusliadi R, et al. Growth performance and survival rate of Asian swamp eel in biofloc systems with different stocking density. *AACL Bioflux*. 2022;15(2):1013-1020.
38. Yuan Q, Wu C, Yang H, et al. Effects of natural bait types on water quality, feeding, growth, and antioxidant enzyme activity of *Monopterus albus* in recirculating systems. *Front Physiol*. 2024;15:1403391. doi:[10.3389/fphys.2024.1403391](https://doi.org/10.3389/fphys.2024.1403391)
39. Natt PM, Herrick CA. A new blood diluent for counting erythrocytes and leucocytes of chicken. *Poult Sci*. 1952;31:735-738. doi:[10.3382/ps.0310735](https://doi.org/10.3382/ps.0310735)
40. Hrubec TC, Cardinale JL, Smith SA. Hematology and plasma chemistry reference intervals for cultured tilapia (*Oreochromis hybrid*). *Vet Clin Pathol*. 2000;29(1):7-12. doi:[10.1111/j.1939-165X.2000.tb00389.x](https://doi.org/10.1111/j.1939-165X.2000.tb00389.x)

41. Abdana M, Hasri I, Harun, et al. Effects of vitamin C dosage levels on growth and survival rate of sidat fish (*Anguilla bicolor*, McClelland, 1844). *Acta Aquat Aquat Sci J*. 2024;11(1):84-89. doi:[10.29103/aa.v11i1.13858](https://doi.org/10.29103/aa.v11i1.13858)
42. Nsonga AR, Kang'ombe J, Mfitilodze W, Soko CK, Mtethiwa AH. Effect of varying levels of dietary vitamin C on growth, survival and hematology of juvenile tilapia (*Oreochromis karongae*). *Braz J Aquat Sci Technol*. 2009;13(2):17-23. doi:[10.14210/bjast.v13n2.p17-23](https://doi.org/10.14210/bjast.v13n2.p17-23)
43. Luc DM, Masengesho B, Minh-Hoang L. Effects of vitamin C supplementation on growth performance and immune responses of juvenile Waigieu seaperch (*Psammoperca waigiensis*). *Int J Fish Aquat Stud*. 2021;9(3):126-130. doi:[10.22271/fish.2021.v9.i3b.2497](https://doi.org/10.22271/fish.2021.v9.i3b.2497)
44. Vishwanath W, Lilabati H, Bijen M. Biochemical, nutritional and microbiological quality of fresh and smoked mud eel (*Monopterus albus*). *Food Chem*. 1998;61(1-2):153-156. doi:[10.1016/S0308-8146\(97\)00108-8](https://doi.org/10.1016/S0308-8146(97)00108-8)
45. Halver JE, Hardy RW. *Fish Nutrition*. 3rd ed. Academic Press; 2002:144-170.
46. Xu CM, Yu HR, Li LY, et al. Effects of dietary vitamin C on the growth performance, biochemical parameters, and antioxidant activity of coho salmon (*Oncorhynchus kisutch*) postsmolts. *Aquac Nutr*. Published online 2022:6866578. doi:[10.1155/2022/6866578](https://doi.org/10.1155/2022/6866578)
47. Zhu CB, Ren HC, Wu YJ, Yang S, Fei H. Benefits and applications of vitamin C in farmed aquatic animals: A review. *Aquac Int*. 2024;32:1295-1315. doi:[10.1007/s10499-023-01217-1](https://doi.org/10.1007/s10499-023-01217-1)
48. Lin MF, Shiau SY. Dietary L-ascorbic acid affects growth, nonspecific immune responses, and disease resistance in juvenile grouper (*Epinephelus malabaricus*). *Aquaculture*. 2005;244:215-221. doi:[10.1016/j.aquaculture.2004.10.026](https://doi.org/10.1016/j.aquaculture.2004.10.026)
49. Ahmed M, Ferdous Z, Paul M, Rashid MH, Hossain MS. Effect of dietary vitamin C on the growth and survival rate of rohu (*Labeo rohita*). *J Biosci Agric Res*. 2018;16(2):1375-1385. doi:[10.18801/jbar.160218.170](https://doi.org/10.18801/jbar.160218.170)
50. Ayah RH, Syed M, Ridzwan H. Review of factors affecting the Asian swamp eel (*Monopterus albus*). *Curr Trends Biomed Eng Biosci*. 2018;15(3):555915. doi:[10.19080/CTBEB.2018.15.555915](https://doi.org/10.19080/CTBEB.2018.15.555915)
51. Lee C, Lim CE, Gatlin DM, Webster CD. *Dietary Nutrients, Additives, and Fish Health*. John Wiley & Sons; 2015. doi:[10.1002/9781119005568](https://doi.org/10.1002/9781119005568)
52. Affonso EG, Silva EC, Tavares-Dias M, de Menezes GC, de Carvalho CS, Nunes ES. Effect of high levels of dietary vitamin C on the blood responses of matrinxã (*Brycon amazonicus*). *Comp Biochem Physiol A Mol Integr Physiol*. 2007;147(2):383-388. doi:[10.1016/j.cbpa.2007.01.004](https://doi.org/10.1016/j.cbpa.2007.01.004)
53. Adel A, Khara H. The effects of different dietary vitamin C and iron levels on the growth, hematological and immunological parameters of rainbow trout (*Oncorhynchus mykiss*) fingerlings. *Iran J Fish Sci*. 2016;15(2):886-897.
54. Rahimi M, Sudagar M, Ouraji H, Hosseini SA, Taghizadeh V. Effect of vitamin C on growth performance, survival rate, hematological parameters and heat stress response in rainbow trout (*Oncorhynchus mykiss*). *J Vet Res*. 2012;67(4):373-380.
55. Agrawal NK, Mahajan CL. Hematological changes due to vitamin C deficiency in *Channa punctatus*. *J Nutr*. 1980;110(11):2172-2181. doi:[10.1093/jn/110.11.2172](https://doi.org/10.1093/jn/110.11.2172)
56. Witeska M, Kondera E, Bojarski B. Hematological and hematopoietic analysis in fish toxicology—A review. *Animals*. 2023;13(16):2625. doi:[10.3390/ani13162625](https://doi.org/10.3390/ani13162625)