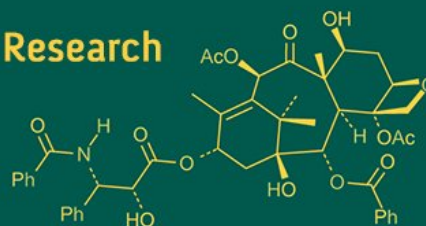


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; 10(6): 1219-1226
www.biochemjournal.com
Received: 09-04-2026
Accepted: 12-05-2026

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Influence of vitamin C and β -glucan on early growth performance of endangered Asian walking catfish, *Clarias magur* Larvae.

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i6o.8878>

Abstract

Poor early growth and inconsistent larval performance remain major constraints in hatchery production of the endangered Indian walking catfish, *Clarias magur*. This study tested the immersion exposure to two natural bioactive compounds, L-ascorbic acid/vitamin C and yeast-derived β -glucan, improved larval growth during the first 30 days after hatching. One-day-old larvae, with a mean initial weight of 2.13 mg, were stocked at 100 larvae per plastic tub (50 L) in a completely randomized design comprising. One control and six treatments group in triplicate for Vitamin C and β -glucan were chosen for the experiment. Vitamin C was tested at 10, 20 and 30 mg L⁻¹ (VC-T1, VC-T2, VC-T3), while β -glucan was tested at 30, 45 and 60 mg L⁻¹ (BG-T1, BG-T2, BG-T3). Treatment solutions were completely renewed every three days to maintain the concentration. After 30 days, all the treatments showed significantly higher final body weight, weight gain, daily weight gain and specific growth rate than the control ($p < 0.001$). The highest responses were recorded in VC-T2, reaching a final weight of 0.255 g and SGR of 15.95% day⁻¹, compared with 0.118 g and 13.37% day⁻¹ in the control. Final length followed a similar pattern, with the highest values in VC-T2 (3.20 $\pm$ 0.10 cm). Fulton's condition factor did not differ significantly among treatments ($p \leq 0.05$), indicating proportional increases in length and weight. These findings suggest that vitamin C immersion at 20-30 mg L⁻¹, may provide a simple compatible and economic approach for improving early growth performance in *C. magur* larvae for hatchery seed production.

Keywords: *Clarias magur*; larval rearing; immersion; vitamin C; β -glucan; specific growth rate; seed production

Introduction

Aquaculture now plays a major role in meeting the growing demand for food and nutritional security, thereby, increasing pressure from overfishing, habitat degradation and exploitation of natural water bodies (FAO, 2024) [11]. In India, freshwater aquaculture, indigenous air-breathing catfishes is one of the major candidate species due to the factors like hardy in nature, well accepted by consumers and suitable for culture under diverse farming conditions. The Indian walking catfish, *Clarias magur* (Hamilton, 1822), is one such high-value native species, particularly valued in eastern and north-eastern part of India.

C. magur occurs naturally in India, Bangladesh and Nepal and is now recognized as taxonomically distinct from *Clarias batrachus* (Ng & Kottelat, 2008). Its accessory respiratory organ allows it to breathe atmospheric air and survive in low-oxygen waters (Munshi, 1961) [24], making the species naturally adapted to shallow, swampy and seasonally stressed freshwater habitats. It is nutritionally rich, with high protein, polyunsaturated fatty acids and micronutrients contents (Borah, 2020) [4], substantiating its strong consumer preference and aquaculture potential.

Nevertheless, natural populations of *C. magur* have descended, and the species is documented as Endangered on the IUCN Red List owing to habitat loss, overfishing, pollution, pesticide exposure and competition from introduced foreign species (*C. gariepinus*) (Vishwanath, 2010) [33]. Modern genome sequencing has further stressed its biological and conservation importance, identifying 23,748 predicted protein-coding genes

That may support future breeding and genetic improvement programmes (Kushwaha *et al.*, 2021) ^[20]. In spite of this promise, large-scale farming of *C. magur* remains limited by unreliable seed availability, high early-stage losses and slow or uneven larval growth in hatcheries. The larval phase is one of the most delicate stages in magur seed production. Poor growth at this stage may result in weak and uneven-sized fry that perform poorly during later nursery rearing (Sahoo *et al.*, 2008) ^[28]. Early mortality, including the commonly reported “fourth-day mortality syndrome”, further reduces seed output (Roy *et al.*, 2019) ^[27]. At the same time, larvae have high nutritional needs though their digestive system is still developing, and suitable feeding procedures are not yet fully systematized (Ferozekhan *et al.*, 2022; Sarma *et al.*, 2025) ^[12, 30]. Recent work on improved magur lines such as “Maha Magur” also identifies larval mortality and poor early growth as major constraints to seed production (Bhusare *et al.*, 2025) ^[3]. Therefore, practical interventions that support early larval growth could improve hatchery seed production efficiency and quality. Natural bioactive compounds such as vitamin C and β -glucan may offer such an approach. During early larval stages, immersion treatment can be useful because larvae may not efficiently consume formulated feeds but can absorb dissolved compounds from the rearing water medium (Meena *et al.*, 2013) ^[21]. B-Glucan, mainly derivative from yeast or algal cell walls, is popularly known as an effective stimulant for innate immune responses and has been interrelated with superior condition and growth in fish, including *Clarias batrachus* (Brown & Gordon, 2001; Misra *et al.*, 2006; Meena *et al.*, 2013) ^[6, 21, 23]. Vitamin C promotes Collagen synthesis, skeletal development, antioxidant defense and proper growth. Deficiency can cause to skeletal defects and reduced growth in fish larvae (Halver *et al.*, 1969; Dawood & Koshio, 2018) ^[7, 15]. Recent investigation also suggests that vitamin C may interact with growth-related signaling pathways, but this needs additional

validation in fish larvae (Sakhawat *et al.*, 2024) ^[29]. The present study tested the immersion exposure of vitamin C or β -glucan to magur larvae, would improve early growth performance. Three different doses of vitamin C and β -glucan were evaluated over a 30-day rearing period. Parameters like, final weight, weight gain, daily weight gain, specific growth rate, final length and Fulton’s condition factor were taken for evaluation. The study aimed to identify a practical immersion regime for supporting early larval growth and hatchery seed production for this endangered catfish species

2. Materials and Methods

2.1. Experimental location and source of larvae

All the experiments were conducted in the wet laboratory of the College of Fisheries, Lembucherra, and Tripura, India. One day old larvae of magur were collected from department of Fish Genetics and Reproduction of College of Fisheries, Lembucherra. The larvae had a mean initial body weight of 2.13 mg and were stocked at a uniform density of 100 larvae per tub, giving a total of 2,100 larvae for the experiment. Before stocking, larvae were handled gently to minimize mechanical stress and were distributed uniformly among experimental tubs.

2.2. Experimental design

The experiment followed a completely randomized design comprising seven groups, one untreated control and six immersion treatments. Each group was maintained in triplicate, giving a total of 21 experimental units. Plastic tubs with a capacity of 50 L were used for rearing, and 100 larvae were stocked in each tub. The treatments consisted of three concentrations of vitamin C and three concentrations of β -glucan with one control group without any treatment were taken. The complete treatment layout, dose level and stocking details are presented in Table 1.

Table 1 Experimental layout showing treatment groups used in the 30-day immersion trial with *Clarias magur* larvae.

Group	Compound	Vit C (mg L ⁻¹)	β -Glucan (mg L ⁻¹)	Larvae/tub
Control	Groundwater only	0	0	100
VC-T1	Vitamin C	10	—	100
VC-T2	Vitamin C	20	—	100
VC-T3	Vitamin C	30	—	100
BG-T1	β -Glucan	—	30	100
BG-T2	β -Glucan	—	45	100
BG-T3	β -Glucan	—	60	100

2.3. Immersion protocol for vitamin C or β -glucan

Treatment solutions were prepared using matured groundwater. Pharmaceutical-grade L-ascorbic acid (Himedia, India) was used at 10, 20 and 30 mg L⁻¹ and dissolved in designated as VC-T1, VC-T2 and VC-T3, respectively. Yeast-derived β -glucan from *Saccharomyces cerevisiae* was used at 30, 45 and 60 mg L⁻¹ and designated as BG-T1, BG-T2 and BG-T3, respectively. The control tubs received groundwater without vitamin C or β -glucan. All tubs were provided with continuous aeration.

To maintain the intended treatment concentrations and reduce the accumulation of metabolic waste, the entire water volume was renewed every third days. During each renewal, tubs were cleaned carefully and refilled with freshly prepared water at the assigned dose. The same water exchange schedule was followed for the control group as

well, assuring that handling conditions remained comparable among all the groups.

2.4. Feeding regime

From day 4 onward, after yolk-sac absorption, larvae in all groups were fed with freshly collected mixed zooplankton twice daily. Before feeding, the plankton was filtered through a 100 μ m nylon mesh to remove large particles, debris and potential predators. Feed was offered ad libitum, and the same feeding schedule and feeding approach were maintained across all tubs to avoid diet-related variation among treatments.

2.5. Growth performance assessment

At the end of the 30-day experimental period, surviving larvae from each tub were sampled for growth assessment.

Before measurement, larvae were anaesthetized using clove oil solution at 50 mg L⁻¹ (Devi and Kamilya, 2019^[8]) to minimize handling stress and larval activity during data collection. Individual body weight was measured to the nearest 0.001 g using a digital analytical balance, and total length was measured to the nearest 0.01 cm using a digital Vernier caliper (Model: 1112-150, Insize India LLP, Pune, Maharashtra).

Growth performance was calculated using standard indices:

Weight Gain (WG g) = $W_f - W_i$	1
Daily Weight Gain (DWG g day ⁻¹) = WG / t	2
Specific Growth Rate (SGR) (% day ⁻¹) = $[(\ln W_f - \ln W_i) / t] \times 100$	3
Condition Factor (CF) = $(W / L^3) \times 100$	4

Where W_f and W_i are final and initial weight, L is final total length, and t = 30 days.

2.6. Water quality monitoring

Water quality was monitored during the 30-day experimental period to characterize the rearing environment to verify and maintain the optimum conditions among the treatments. Measurements were recorded every 10 days interval on days 0, 10, 20 and 30 across all treatments. All the Sampling was carried out at approximately the same time of day, before feeding and water renewal, to minimize temporal variation among the tanks. Water temperature, pH and dissolved oxygen were measured using calibrated

digital instruments. Total ammonia-nitrogen and total hardness were estimated following standard procedures described by APHA (2017).

2.7. Statistical analysis

All experiments were conducted in triplicate, and results are presented as mean $\pm$ standard error (SE). Statistical analyses were performed using IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA). Significant difference among the group were determine using one way ANOVA analysis followed by Games-Howell post hoc test and Tukey's honestly significant difference test was used for pairwise comparison of means. For Fulton's condition factor, where variance heterogeneity was detected using the mean-based Levene test. Graphical representations were generated using GraphPad Prism (version 10.4.1) and Origin (version 9.0) software.

3. Results

3.1. Growth performance

Growth performance of *C. magur* larvae differed markedly among treatments after 30 days of immersion exposure. One-way ANOVA showed significant treatment effects on final body weight, weight gain, daily weight gain, specific growth rate and final total length ($p < 0.001$; Figure 1a-b; Table 2). In contrast, Fulton's condition factor did not differ significantly among groups ($p \leq 0.05$), indicating that treatment-related increases in weight were accompanied by proportional increases in length.

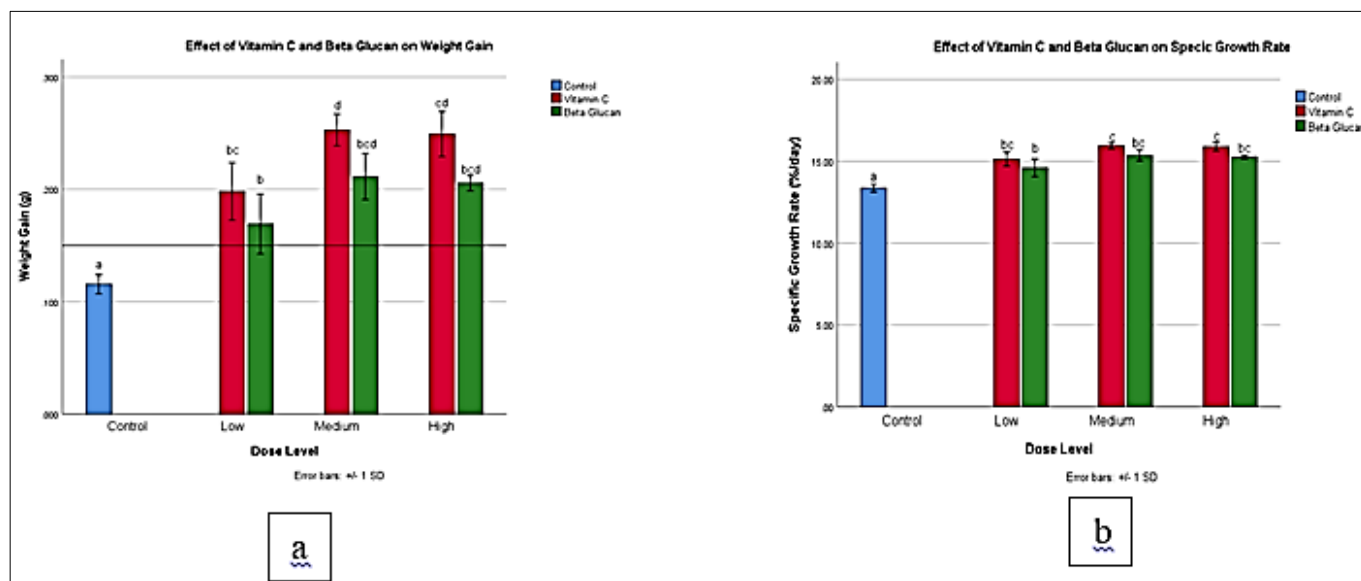


Fig 1: Growth performance of *Clarias magur* larvae after 30 days of immersion treatment with vitamin C and β-glucan. (a) Weight gain and (b) Specific growth rate.

Values are reported as mean $\pm$ SD ($n=3$ replicate tubs). Bars with various letters are significantly different ($p < 0.05$). Low represents 10 mg L⁻¹ (Vitamin C) and 30 mg L⁻¹ (Beta glucan); Medium represents 20 mg L⁻¹ (Vitamin C) and 45 mg L⁻¹ (Beta glucan); and High represents 30 mg L⁻¹ (Vitamin C) and 60 mg L⁻¹ (Beta glucan).

All the vitamin C and β-glucan treatments produced significantly higher final body weight than the control group (Table 2). The control group reached a final body weight of 0.118 ± 0.009 g, whereas treated groups ranged from 0.171 ± 0.027 g in BG-T1 to 0.255 ± 0.014 g in VC-T2. Among all treatments, the highest growth response was observed in

VC-T2, followed by VC-T3. Larvae immersed in VC-T2 achieved the highest final body weight, weight gain, daily weight gain and SGR, with values of 0.255 ± 0.014 g, 0.253 ± 0.014 g, 8.43 ± 0.47 mg day⁻¹ and $15.95 \pm 0.18\%$ day⁻¹, respectively. Relative to the control, in VC-T2 treatment group final body weight increased by approximately 116% and improved SGR by about 2.6 percent.

The β-glucan treatments also improved weight-based growth compared to the control, BG-T1 produced the lowest growth response among the treated groups, with final body weight of 0.171 ± 0.027 g and SGR of $14.60 \pm 0.54\%$ day⁻¹. Higher β-glucan concentrations produced stronger responses, with

BG-T2 and BG-T3 reaching final body weights of 0.214 ± 0.021 g and 0.208 ± 0.007 g, respectively. Overall, the growth response was compound- and dose-specific rather than strictly linear. Vitamin C produced the strongest response at $20\text{--}30$ mg L⁻¹, while β -glucan showed improved performance at $45\text{--}60$ mg L⁻¹.

Final total length followed the same general trend as body weight. The control group recorded the lowest final length of 2.40 ± 0.10 cm, whereas VC-T2 and VC-T3 both reached 3.20 ± 0.10 cm. Length values in VC-T1, BG-T2 and BG-

T3 were also higher than the control, while BG-T1 showed an intermediate response and was not clearly separated from the control based on Tukey grouping. Despite treatment-related differences in length and weight, Fulton's condition factor remained statistically similar among groups, ranging from 0.77 ± 0.01 in VC-T3 to 0.89 ± 0.12 in BG-T3. This suggests that immersion treatments enhanced overall somatic growth without causing a detectable shift in body condition.

Table 2 Growth performance of *Clarias magur* larvae after 30 days of immersion treatment. Values are presented as mean $\pm$ SD (n = 3 replicate tubs). Means in the same column with different superscript letters differ significantly according to Tukey's HSD test ($P < 0.05$).

Group	Final wt (g)	Weight gain (g)	DWG (mg day ⁻¹)	SGR (% day ⁻¹)	Length (cm)	CF
Control	0.118 ± 0.009^a	0.116 ± 0.009^a	3.85 ± 0.28^a	13.37 ± 0.24^a	2.40 ± 0.10^a	0.85 ± 0.04^a
VC-T1	0.200 ± 0.026^{bc}	0.198 ± 0.026^{bc}	6.61 ± 0.85^{bc}	15.13 ± 0.43^{bc}	2.93 ± 0.15^{bc}	0.79 ± 0.03^a
VC-T2	0.255 ± 0.014^d	0.253 ± 0.014^d	8.43 ± 0.47^d	15.95 ± 0.18^c	3.20 ± 0.10^c	0.78 ± 0.03^a
VC-T3	0.251 ± 0.020^{cd}	0.249 ± 0.020^{cd}	8.31 ± 0.67^{cd}	15.90 ± 0.27^c	3.20 ± 0.10^c	0.77 ± 0.01^a
BG-T1	0.171 ± 0.027^b	0.169 ± 0.027^b	5.64 ± 0.89^b	14.60 ± 0.54^b	2.77 ± 0.15^{ab}	0.80 ± 0.01^a
BG-T2	0.214 ± 0.021^{bcd}	0.212 ± 0.021^{bcd}	7.05 ± 0.68^{bcd}	15.35 ± 0.33^{bc}	2.93 ± 0.15^{bc}	0.86 ± 0.17^a
BG-T3	0.208 ± 0.007^{bcd}	0.206 ± 0.007^{bcd}	6.85 ± 0.23^{bcd}	15.26 ± 0.11^{bc}	2.87 ± 0.15^{bc}	0.89 ± 0.12^a

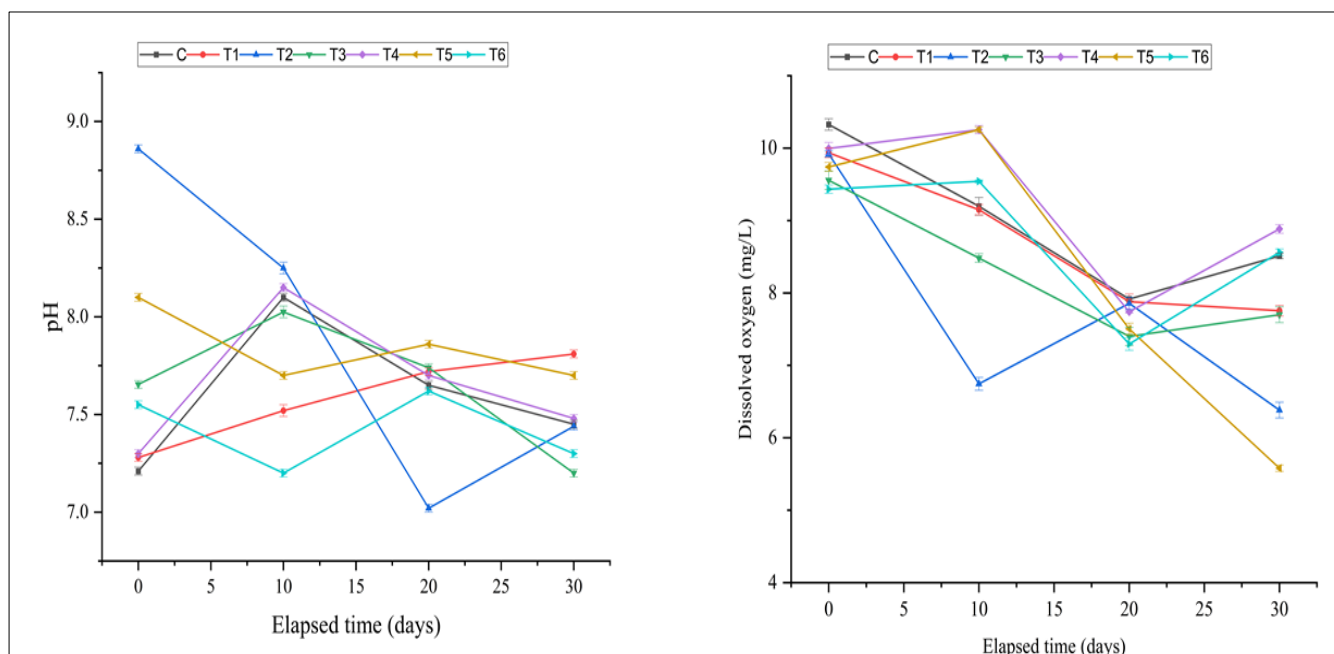
DWG, daily weight gain; SGR, specific growth rate; CF, Fulton's condition factor.

3.2. Water quality

Over the 30-day rearing period, water-quality variables varied by parameter and sampling day, and treatment differences were not consistent across days (Figure 2a–e). Because significant differences were already present at day 0 for several parameters, the water-quality data are best interpreted as reflecting general environmental conditions rather than treatment-driven effects. Across pH, dissolved oxygen, ammonia-nitrogen, nitrite and nitrate, differences between the control and immersion groups appeared sporadically and shifted over time, with no single treatment

showing a sustained or directional pattern. Some parameters differed mainly in the early phase (nitrite and nitrate), others fluctuated throughout (ammonia-nitrogen), and most groups tended to converge toward control values by day 30.

Overall, these results indicate that the observed variation was time- and parameter-dependent rather than attributable to any specific treatment. Collectively, no single water-quality parameter showed a consistent adverse pattern that could explain the improved growth observed in the vitamin C and β -glucan groups.



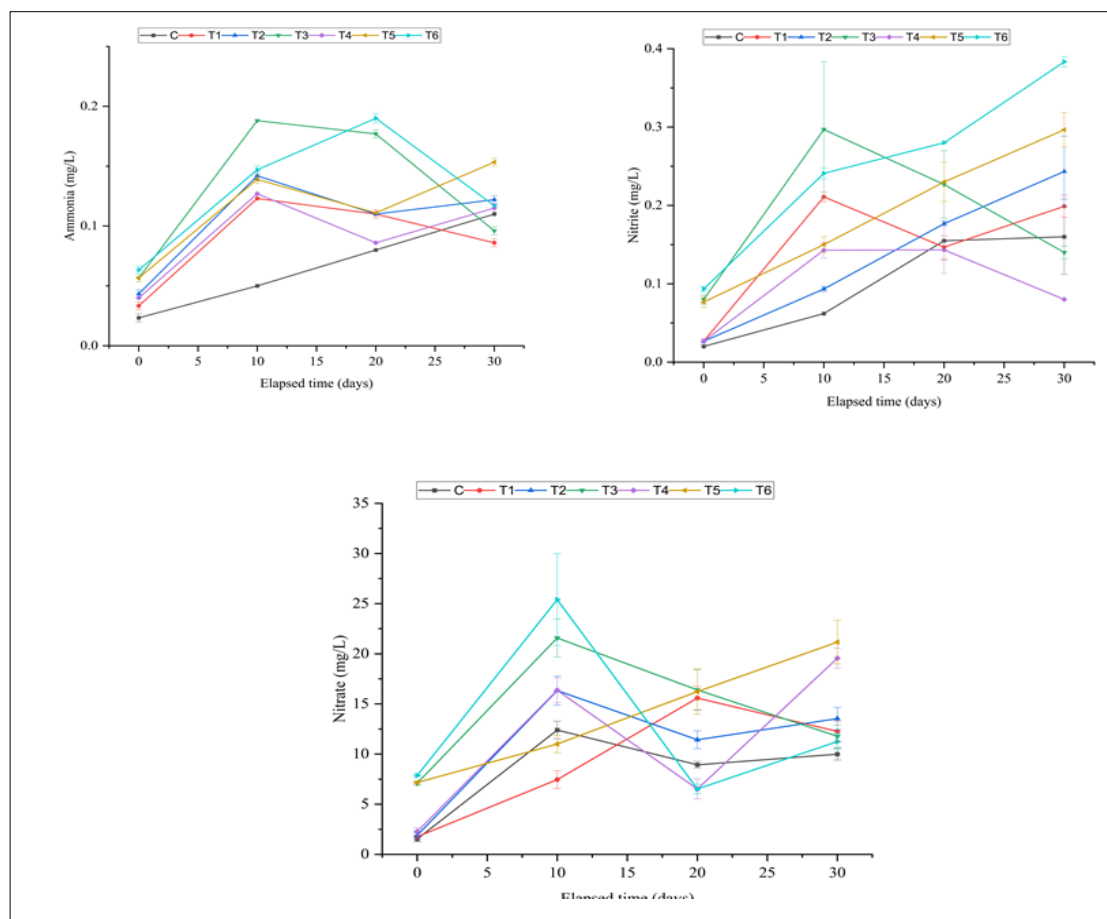


Fig 2: Water-quality dynamics during the 30-day immersion trial with *Clarias magur* larvae. (a) PH, (b) dissolved oxygen, (c) total ammonia-nitrogen, (d) nitrite and (e) nitrate recorded across sampling days in the control, vitamin C and β -glucan treatment groups. Values are presented as mean $\pm$ SD ($n = 3$ replicate tubs). Different letters within the same sampling day indicate significant differences among treatments according to Tukey's HSD test ($p < 0.05$). VC-T1, VC-T2 and VC-T3 represent vitamin C at 10, 20 and 30 mg L⁻¹, respectively; BG-T1, BG-T2 and BG-T3 represent β -glucan at 30, 45 and 60 mg L⁻¹, respectively.

4. Discussion

The present study showed that immersion exposure to vitamin C and β -glucan improved early growth performance of *C. magur* larvae over 30 days experimental period. All treated groups showed higher final body weight, weight gain, daily weight gain and SGR than the control, while final length improved most clearly in the vitamin C and higher concentration of β -glucan treatments. Fulton's condition factor remained unchanged, indicating that the treatments promoted proportional increases in length and weight rather than altering body condition. The strongest response was recorded in the vitamin C treatments, particularly at 20-30 mg L⁻¹, where final body weight was approximately doubled relative to the control. β -Glucan also improved growth, although the response was weaker at 30 mg L⁻¹ and more evident at 45-60 mg L⁻¹. These findings support the hypothesis that immersion delivery of natural bioactive compounds can improve early larval growth in *C. magur*, with the response varying according to compound and dose.

The improved response to vitamin C is biologically feasible as ascorbic acid is an important micronutrient involved in normal growth, collagen synthesis, wound repair, antioxidant protection, stress tolerance and immunological function in aquatic animals (Thuy *et al.*, 2023) [32]. These functions are especially critical during early larval development when tissue formation, skeletal development and oxidative control are still immature and evolving rapidly

(Dawood & Koshio, 2018) [7]. Since most teleost fishes cannot synthesis vitamin C endogenously and hence require an appropriate external supply for normal physiological development and growth (Halver *et al.*, 1969) [15]. Vitamin C supplementation has been shown to improve growth indices in common carp larvae and fry, Nile tilapia and coral trout, often with improved antioxidant or immunological status (Gouillou-Coustans *et al.*, 1998; Imanpoor *et al.*, 2016; Ibrahim *et al.*, 2020; Zhu *et al.*, 2022) [13, 18, 19, 36]. Graded dietary vitamin C enhanced development and feed-utilization indices to an optimum range in red drum juveniles, confirming the concept that vitamin C responses are dose-specific rather than simply linear (Thuy *et al.*, 2023) [32]. Therefore, the strong response observed in VC-T2 and VC-T3 may be associated with improved tissue development, antioxidant protection and nutrient utilization, although these mechanisms were not directly measured in the present trial.

The β -glucan response was also positive but less uniform than that of vitamin C. β -Glucan is generally considered a functional immunostimulant rather than a direct growth promoter, and its activity is linked to recognition by immune receptors, β -glucan-binding proteins and downstream innate immune pathways (Brown & Gordon, 2001; Meena *et al.*, 2013; Hadiuzzaman *et al.*, 2022) [6, 14, 21]. Previous work on fish showed that β -glucan administration through diet, immersion or injection can stimulate immune responses, improve resistance to stress or infection and support

commercial aquaculture health management (Rodrigues *et al.*, 2020)^[26]. Such effects may indirectly support growth by reducing physiological stress and improving general health status, although immune, stress and microbiome endpoints were not measured here (Meena *et al.*, 2013)^[21]. Growth benefits of β -glucan have been documented in *Clarias batrachus*, golden trevally, first-feeding turbot, Atlantic cod larvae and coral trout (Misra *et al.*, 2006; Skjermo *et al.*, 2006; Miest *et al.*, 2016; Do-Huu *et al.*, 2024; Hao *et al.*, 2024)^[9, 16, 22, 23]. The lesser reaction at 30 mg L⁻¹ in this investigation shows that this concentration could have been below the most effective immersion range for *C. magur* larvae, whereas 45–60 mg L⁻¹ gave clear growth responses. This interpretation is consistent with observations indicating β -glucan efficacy is dependent on the source, molecular structure, dose, method of administration, species and developmental stage (Meena *et al.*, 2013; Hao *et al.*, 2024)^[16, 21]. The immersion route is an important practical feature of this study. During early larval development, formulated feed intake can be inconsistent because larvae are small in size, their digestive capacity is still developing and feeding behaviour is not yet fully established (Ferosekhan *et al.*, 2022)^[12]. Immersion can partly overcome this limitation by exposing larvae directly through the rearing water, allowing dissolved compounds to contact external absorptive surfaces such as the integument and gills (Rodrigues *et al.*, 2020)^[26]. In giant gourami, immersion of eggs and larvae in vitamin C improved hatching, growth and larval survival, demonstrating that waterborne vitamin C can be effective during early developmental stages (Aryani *et al.*, 2021)^[2]. Similarly, addition of ascorbic acid and β -1,3-glucan to transport water reduced physiological stress responses and supported survival-related outcomes in tiger grouper under simulated transport conditions (Wu *et al.*, 2020)^[34]. The present findings extend this concept to *C. magur* larvae and suggest that repeated low-dose rearing-water immersion may be compatible with hatchery operations where uniform early exposure and simple application are important. Water-quality results indicate that the treatments interacted with the rearing environment, although these patterns should be interpreted cautiously. In aquaculture systems, pH, dissolved oxygen, ammonia, nitrite, nitrate and hardness are interrelated through respiration, organic matter decomposition, microbial metabolism and nitrogen transformation processes (Boyd & Tucker, 1998; Yusoff *et al.*, 2024)^[5, 35]. In the present study, pH, dissolved oxygen, ammonia, nitrite and nitrate showed parameter- and day-specific differences, but no single variable showed a consistent adverse pattern that could explain the improved growth in treated groups. The significant day-0 differences observed for some water-quality parameters indicate incomplete baseline equivalence among treatment media; therefore, later differences should be interpreted as a combination of initial treatment chemistry and rearing-related change. Ammonia interpretation requires particular caution because total ammonia-nitrogen alone does not define toxicity; the unionized ammonia fraction is more toxic and varies with pH and temperature (Durborow *et al.*, 1997; Hargreaves & Tucker, 2004)^[10, 17]. Nitrite is also relevant because it can impair oxygen transport in fish, especially when water quality and dissolved oxygen are suboptimal (Yusoff *et al.*, 2024)^[35]. Thus, the water-quality results should not be used to claim that vitamin C or β -glucan improved water quality directly. Rather, they show

that growth responses in small-volume larval systems should be interpreted together with the surrounding physicochemical environment.

A major finding of this study is that it evaluates immersion-based application of vitamin C and β -glucan during a sensitive larval stage of an endangered indigenous catfish. Most available work on these compounds has focused on dietary supplementation, immune modulation or juvenile/adult fish, whereas early larval immersion studies remain comparatively limited (Rodrigues *et al.*, 2020; Aryani *et al.*, 2021)^[2, 26]. The strongest practical outcome was the performance of vitamin C at 20–30 mg L⁻¹, which produced the highest growth without altering Fulton's condition factor. This suggests that vitamin C immersion promoted proportional somatic growth rather than simply increasing body mass relative to length. The β -glucan results are also useful, but the non-linear response indicates that concentration and exposure schedule require further refinement before a hatchery recommendation can be made. The present study may be useful baseline information to validate the most effective vitamin C dose under routine hatchery-scale conditions and test whether combined vitamin C and β -glucan immersion provides any additive benefit.

Collectively, the present study demonstrates that repeated immersion exposure to vitamin C or β -glucan can improve early growth of *C. magur* larvae, with vitamin C at 20–30 mg L⁻¹ emerging as the most effective treatment under the tested conditions. This approach provides a practical basis for improving early larval growth, while broader application should await validation under larger hatchery conditions.

5. Conclusion

This study demonstrates that short, repeated immersion exposure to vitamin C and β -glucan can improve early growth performance of *Clarias magur* larvae under controlled hatchery conditions. All treated groups performed better than the control group for major growth indices, with vitamin C at 20–30 mg L⁻¹ producing the strong response in final weight, weight gain, specific growth rate and final length. β -Glucan also supported growth, although its effect was less consistent across doses. The absence of significant differences in Fulton's condition factor suggests that the treatments promoted proportional increases in length and weight rather than altering body condition. Collectively, vitamin C immersion, particularly at 20–30 mg L⁻¹, appears to be a useful early-stage intervention for improving larval growth in *C. magur*. Further studies should validate these findings under hatchery-scale conditions and include survival, physiological and immune-related endpoints.

Credit authorship contribution statement

Funding sources

The authors declare that no funds, grants, or other support were received and work was done by the institution support.

Declaration of competing interest

The authors declare that they have no competing interests among them.

Declaration of generative AI use

In the preparation of this manuscript, generative AI tools (such as ChatGPT developed by OpenAI) were used only to assist in language editing, grammar correction, and

improving the clarity of expression. The use of AI was limited to linguistic refinement and did not involve any data generation, data interpretation, or content creation that would affect the scientific integrity of the work. The authors take full responsibility for the content, accuracy, and originality of the manuscript.

Ethical statement

All experimental procedures involving fish were performed in accordance with the guidelines and policies of the ethical committee of the institute (No. CAU-CF/48/IAEC/2018/05; dated 17/04/2022).

Data availability

Data will be made available on request.

Acknowledgments

The authors would like to thank the Vice Chancellor, Central Agricultural University, Imphal, Manipur, India and Dean, College of Fisheries, Lembucherra, Tripura for providing essential facilities and support to conduct the present study.

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