DAVAO RESEARCH JOURNAL
https://davaoresearchjournal.ph

ORIGINAL RESEARCH ARTICLE

Microalgae-enriched *Artemia salina* enhances growth performance and nutritional value in African catfish (*Clarias gariepinus*) larvae compared to unenriched *Artemia*

Kulwa Mtaki[1], Angelina Michael[2]*, Margareth S. Kyewalyang[3], Matern S. P. Mtolera[3]

[1] *Marine Parks and Reserves Unit, P.O. Box 7565, Dar es Salaam, Tanzania, Kulwa Mtaki: https://orcid.org/0000-0001-6947-5862*
[2]*College of Naturl and Mathematical Sciences, University of Dodoma, P.O Box 338 Dodoma, Tanzania, Angelina Michael: https://orcid.org/0000-0003-3121-9630*
[3]*Institute of Marine Sciences, University of Dar es Salaam, P.O. Box 668, Zanzibar, Tanzania, Matern S. P. Mtolera: https://orcid.org/0000-0003-0850-2454*

*Corresponding author: *onkyangel@yahoo.com*

ABSTRACT

Sole *Artemia* is an incomplete diet for African catfish (*Clarias gariepinus*) larvae due to insufficient essential nutrients. Microalgae is a potential *Artemia* enrichment diet whose cultivation is limited by the high cost of culturing media. The study evaluated the growth performance and nutritional value of *C. gariepinus* larvae fed newly hatched *Artemia salina* nauplii. The *C. gariepinus* larvae in the control group were fed unenriched *Artemia* nauplii, while the treatment group received *Artemia* nauplii enriched with the microalgae *Chlorella vulgaris*. The *C. vulgaris* was batch-cultured using banana stem compost extract (BSCE) as the least-cost medium, and the *Artemia* cysts were hatched according to standard protocols. The *C. gariepinus* larvae were hatched and stocked at a density of 10 larvae/L with three replicates per treatment and fed four times a day for 15 days. Enriched *Artemia* had higher protein and carbohydrate content than unenriched *Artemia* ($p < 0.05$), while the dry matter, lipid, fiber, and ash content were the same in both diets ($p > 0.05$). The protein and lipid content, as well as all growth parameters, were significantly higher in *C. gariepinus* larvae fed enriched *Artemia* than in unenriched *Artemia* ($p < 0.05$). The results indicate that *Artemia* enriched with *C. vulgaris* cultured using BSCE medium is a suitable diet for enhancing the growth and survival of *C. gariepinus* larvae. This information is crucial for the successful production of *C. gariepinus* fish seeds with the ultimate goal of meeting the species' ever-increasing demands.

Keywords: *African catfish, Artemia enrichment, microalgae, nutritional value, survival*

Submitted: 26 Jul 2025
Revised: 07 Aug 2025
Accepted: 20 Aug 2025
Published: 15 Sep 2025

OPEN ACCESS

How to cite: Mtaki, K., Michael, A., Kyewalyang, M. S., and Mtolera, M. S. (2025). Microalgae-enriched *Artemia salina* enhances growth performance and nutritional value in African catfish (Clarias gariepinus) larvae compared to unenriched Artemia*Davao Research Journal*, 16 (3), 39-46. https://doi.org/10.59120/drj.v16i3.432

INTRODUCTION

African catfish (*Clarias gariepinus*) is among the important aquaculture species in Africa, valued for its large size, high gross margin, contributions to human diet, and income, including its use as bait for Nile perch (*Lates niloticus*) fishing (Halasi et al., 2012; Musiba et al., 2014); (Langi et al., 2024). The species is widely cultivated across sub-Saharan Africa, with Nigeria leading as the world's largest producer, followed by significant contributions from Kenya, South Africa, Cameroon, and Mali (FAO, 2024). These countries collectively produce millions of metric tons annually, meeting domestic demand and supporting regional trade (Folorunso et al., 2021). However, high larval mortality rates (~70%) in many African countries remain a major constraint to *C. gariepinus* production, largely due to the larvae's initial dependence on yolk sac reserves and their underdeveloped digestive system, which lacks the enzymes necessary to efficiently utilize formulated feeds (Adewumi, 2015; Gisbert et al., 2022). Consequently, *C. gariepinus* larvae are typically fed live feeds such as brine shrimps (*Artemia*) which provide essential digestive enzymes and are cost-effective, easy to culture, and storable as cysts (Nguyen et al., 2014). *Artemia* are small, planktonic crustaceans widely used in aquaculture for their high protein content, ease of culture, long-term storability as cysts, and capacity to provide exogenous digestive enzymes essential for larval development (Nguyen et al., 2014; Lenz and Browne, 2018). *Artemia* nauplii, the newly hatched larval stage of the *Artemia*, are a staple live feed in aquaculture globally, particularly for fish and crustacean larvae (Joshua et al., 2022). Their small size (400–500 µm), high nutritional value, and ability to hatch on demand from dormant cysts make them ideal for larviculture (Joshua et al., 2022; Lenz and Browne, 2018).

Despite these advantages, *Artemia* alone is nutritionally incomplete for *C. gariepinus* larvae, lacking essential polyunsaturated fatty acids (PUFAs) critical for growth and survival (Ali et al., 2017; Chakraborty et al., 2007). Enriching *Artemia* with microalgae such as Chlorella, enhances its nutritional profile, particularly PUFA content (Ahmadi et al., 2017;

Cheban et al., 2020; Méndez-martínez and Lora-vilchis, 2018). *C. vulgaris* is a unicellular green microalga, recognized for its rich nutrient profile, including proteins, vitamins, and antioxidants, which contribute to its effectiveness as a dietary supplement (Michael and Mtaki, 2024).The primary constraint to widespread adoption of microalgae enrichment is the high cost of commercial cultivation media, which accounts for over 50% of production costs (Michael et al., 2019). Recent studies demonstrate that *C. vulgaris* cultured in cost-effective banana stem compost extract (BSCE) medium significantly improves the PUFA content of enriched *Artemia* (37.2%) compared to commercial media (Mtaki et al., 2023a), potentially benefiting larval survival and growth (Chepkirui-Boit et al., 2011; Keke et al., 2017). However, no studies have evaluated the effects of *Artemia* enriched with *C. vulgaris* cultured in BSCE medium on the growth, survival, and nutritional value of *C. gariepinus* larvae.

This study hypothesizes that there will be no significant differences in the growth performance and nutritional value of *C. gariepinus* larvae fed with unenriched *Artemia* nauplii compared to those fed with *Artemia* enriched with *C. vulgaris* cultured in BSCE medium. To test this hypothesis, the study aimed to compare growth metrics (weight gain, length, survival, condition factor and specific growth rate) of *C. gariepinus* larvae fed with these two diets, and evaluate the proximate composition of larvae from both feeding treatments, thereby assessing the efficacy of BSCE-enriched *Artemia* as a cost-effective feeding strategy for *C. gariepinus* larviculture.

MATERIALS AND METHODS

Cultivation of *Chlorella vulgaris*

The *Chlorella vulgaris* were isolated from freshwater fish ponds with a pH of 8.5, using a standard plating method according to Mtaki et al. (2021). The *C. vulgaris* were batch cultured in the laboratory using a 10% BSCE medium prepared as per Mtaki et al. (2023b). The *C. vulgaris* culturing was carried out in 2 L Erlenmeyer flasks containing 800 ml of the medium and 200 ml of *C. vulgaris* (0.3 × 106 cells ml^{-1}). The environment was maintained at a temperature of 28 ± 1°C using air conditioning, a pH of 9, a light intensity of 5,000 ± 10 lux (measured using a VXLM-636 light meter), 16 hours of light, and continuous aeration. The *C. vulgaris* was harvested during the exponential growth phase and used as an *Artemia* enrichment diet. The proximate composition analysis of *C. vulgaris* revealed that it contained 34.8% crude protein, 36.4% carbohydrate, 13.9% lipid, 4.56% saturated fatty acid, 4.63% monounsaturated fatty acid and 90.74% polyunsaturated fatty acid (Mtaki et al., 2023b).

Hatching and enrichment of *Artemia*

Artemia salina cysts (EG Type, INVE Aquaculture, Belgium) were purchased from a local supplier. The cysts were hatched at a density of 1 g/L in sterile, filtered seawater with a salinity of 30 ppt. The hatching environment was maintained at 28 ± 1°C using air conditioning and provided with vigorous aeration. After 24 hours, the hatched nauplii were collected and thoroughly rinsed with sterilized seawater (30 ppt) to ensure cleanliness. The nauplii were then transferred into 2000 mL enrichment flasks containing BSCE-cultivated *Chlorella vulgaris* in seawater (30 ppt) at a density of 300 nauplii/mL. The nauplii were fed *C. vulgaris* for 24 hours, with the amount adjusted based on the visual transparency of the enrichment medium to ensure complete consumption.Both enriched and unenriched *Artemia* nauplii were sampled, concentrated on a 44-µm mesh filter, and thoroughly rinsed with sterile seawater to remove residual food waste. The cleaned *Artemia* were oven-dried at <40°C and stored at −80°C for subsequent nutritional analysis.

Breeding and hatching of *Clarias gariepinus* larvae

The *Clarias gariepinus* broodstocks (nine females and six males) were obtained from a commercial farm in Dar es Salaam, Tanzania. All male catfish were slaughtered, and their pituitary glands were extracted and injected into female fish. The female fish were put individually into an aerated water tank at 27°C and were stripped after 10 hours by applying slight pressure on the abdomen to collect eggs. Collected eggs were fertilized artificially using normal saline prepared milt, which was obtained from a sacrificed male. The fertilized eggs were incubated in the tank at 27°C with constant aeration for 24 hours. Hatched larvae were collected and transferred to the hatchlings tanks for four days to allow complete absorption of the yolk sac.

Experimental design

On the fourth day after hatching, when the yolk sacs were completely absorbed, the initial body weight of hatched larvae of *C. gariepinus* was measured using an analytical scale (accurate to 0.01 mg). The larvae were then distributed into six 80-liter plastic rearing tanks at a density of 500 individuals per tank. Three tanks received microalgae-enriched *Artemia* nauplii (Treatment 1) while three tanks received unenriched *Artemia* nauplii (Treatment 2), creating a replicated experimental design with three tanks per treatment. The *C. gariepinus* larvae were reared for 15 days following yolk sac absorption. Throughout the experimental period, larvae were fed to satiation four times daily at 08:00, 12:00, 16:00, and 20:00 hours. Feeding was done manually, and satiation was determined based on visual observation of acceptance and refusal of diet. Rearing tanks were supplied with continuous aeration using an electric pump during the experimental period. To maintain good water quality conditions rearing tanks were cleaned by siphoning all uneaten food, faeces and debris daily at 08.00 hours prior to the first feeding. At this time, the dead fish of each replicate were removed and counted. Water was replaced every three days throughout the experiment, with replacement water pre-conditioned in the same environment as the rearing tanks to ensure consistent temperature, dissolved oxygen, and other critical parameters. At the end of the experiment, all surviving fish in each treatment were collected and counted for estimation of survival rate. Also, A total of 16 survived *C. gariepinus* larvae were sampled randomly from each tank at the end of the experiment, oven-dried (<40°C) and sent to the laboratory for nutritional analysis.

Larvae growth and survival rates

Every three days before the first feeding, a sample of 16 *Clarias gariepinus* larvae were taken randomly in every replicate using a scoop net to assess the growth rates (Mtaki et al.2021b). Prior to the beginning of measurement, fish larvae were placed on filter paper to absorb the adhering water. The wet weight of the fish was measured by using an analytical balance (accuracy = 0.01 mg). The total length was determined by measuring the distance from the mouth to the end of the tail fin using a 30-cm ruler. The growth parameters of the fish, such as daily weight gain (DWG), specific growth rate (SGR), survival rate (SR) and weight gain (WG), were calculated using Equations 1, 2, 3 and 4, respectively (Lugert, 2015).

$$\text{DWG (mg day}^{-1}) = \frac{\text{Weight gain (mg)}}{\text{Culturing time (days)}} \quad (1)$$

$$\text{SGR (\% day}^{-1}) = \frac{\ell n \text{ (Final weight)- } \ell n \text{ (Initial weight)}}{\text{Culturing time (days)}} \times 100 \quad (2)$$

$$\text{SR (\%)} = \frac{\text{Number of fish harvested}}{\text{Number of fish stocked}} \times 100 \quad (3)$$

$$\text{WG (mg)} = \text{Final weight (mg)} - \text{Initial weight (mg)} \quad (4)$$

Length-weight relationship and condition factor

The length-weight relationship (LWR) of *Clarias gariepinus* larvae was analysed by using the equation: $W = aL^b$ (Pauly, 1993). The values of constants a and b were obtained by logarithm transformation of the equation to obtain a formula: Log W = b log L + log a through linear regression, as suggested by LeCren (1951).

Where: W = total weight of the fish in grams (g) L= total length of fish in centimetres (cm) a = exponent describing the rate of change of weight with length (intercept) b = weight at unit length (slope), indicating isometric growth when equal to 3 and allometric growth when significantly different from 3.

The condition factor of the fish larvae was also assessed by using the equation:

$K = 100\ W/L^3$ (Pauly, 1983)
where K = condition factor
W = the weight of the fish in grams (g)
L = the total length of the fish in centimetres (cm).

Chemical analysis

Sampled dietary treatment and catfish larvae were analysed for crude protein, crude fat, crude fiber, ash and moisture content. The AOAC's (Association of Official Analytical Chemists) standard methods were used to analyse dry matter (ID 930.15) and ash (942.05) contents (A.O.A.C, 1990). Crude protein (CP) in the individual sample was determined using the Kjeldahl method (ID 954.01). Ether extract (EE, ID 920.39) was used to determine fat contents in the samples. Crude fiber (CF) and carbohydrate in the dietary treatments were analysed using acid/alkali hydrolysis and the anthrone method respectively, as described by Allen (1989).

Water quality parameters

Water quality parameters (pH, dissolved oxygen, temperature) were monitored daily between 8:30 and 9:00 hours. Temperature and pH were read using a pH meter (HI 8424 HANNA instruments, USA), while dissolved oxygen (DO) was determined using a DO meter (HI 98193 HANNA instruments, USA). The un-ionised ammonia (NH3) and nitrite level were analysed every three days by using phenol method. The water quality parameters in all treatments were within desirable ranges for the growth and survival of the experimental fish (Allen, 1989). Water temperature values ranged from 23.1 to 25.8° C, DO from 3 mg L^{-1} to 6.01 mg L^{-1}, pH from 8.88 to 9.44, nitrite from 0.03 to 0.08 mg L^{-1} and NH_3 from 0.02 to 0.06 mg L^{-1}.

Data analysis

Collected data were checked for normality and homogeneity using Shapiro-Wilk's and Levene's tests, respectively, prior to their statistical analysis using R software (4.3.3). The DWG, condition factor, SGR and WG were analysed using an independent *t*-test, while LWR was analysed using a student's *t*-test. Nutritional values data were analysed using an independentt-test for normally and Mann Whitney for not normally distributed data. Results were presented as mean ± standard error (SE) and were declared statistically different when $p \leq 0.05$.

RESULTS

Larvae growth and survival

Fish larvae demonstrated a similar growth trend with a gradual increase throughouth the exeperimental period (Figure 1). As it is shown in Figure 1, the *Clarias gariepinus* larvae fed *C. vulgaris* enriched *Artemia* nauplii consistently maintained higher body weights compared to the unenriched group from day 6 onwards. There was no statistical difference in *C. gariepinus* initial weight between enriched and unenriched diets. However, the growth trajectory showed a divergent during the experimental period, with the enriched diet group showing accelerated weight that became increasingly pronounced over time.

The growth performance parameters of *C. gariepinus* larvae in both dietary treatments are shown in Table 1. The daily weight gain (DWG), final weight, weight gain (WG), and specific growth rate (SGR) were all significantly higher ($p < 0.05$) in larvaefed with *C. vulgaris* enriched *Artemia* compared to the unenriched treatment. The enriched diet resulted in larvae achieving 160.7 ± 1.2 mg final body weight while the unenriched group attained 131.9 ± 1.3 mg as the final weight.

The length-weight relationship (LWR) analysis revealed important insights into growth patterns of the *C. gariepinus* between the two dietary treatments (Figure 2 and Figure 3). Both treatments showed positive allometric growth patterns, but with different magnitudes. The *C. gariepinus* larvae fed enriched *Artemia* nauplii (Figure 2) exhibited a mild positive allometry, with a 'b' value of 3.18, indicating a slight deviation from isometric growth (b = 3). In contrast, the larvae fed unenriched *Artemia* nauplii (Figure 3) showed more pronounced positive allometric growth with a 'b' value of 3.5. The LWR for larvae fedthe enriched diet (b = 3.18) did not differ significantly from the isometric 'b' value of 3, whereas the LWR for those fed the unenriched diet (b = 3.5) showed a statistically significant variation. However, both groups showed strong correlation coefficient ($R^2 > 0.90$) indicating consistent growth patterns across individuals within the dietary treatment. Despite these growth differences, the condition factor remained statistically similar between treatments (Table 1, $p = 0.84$). On the other hands, the survival rate (SR) was higher ($p < 0.01$) in *C. gariepinus* fed enriched (98.8%) compared to those fed unenriched (96.5%) diet.

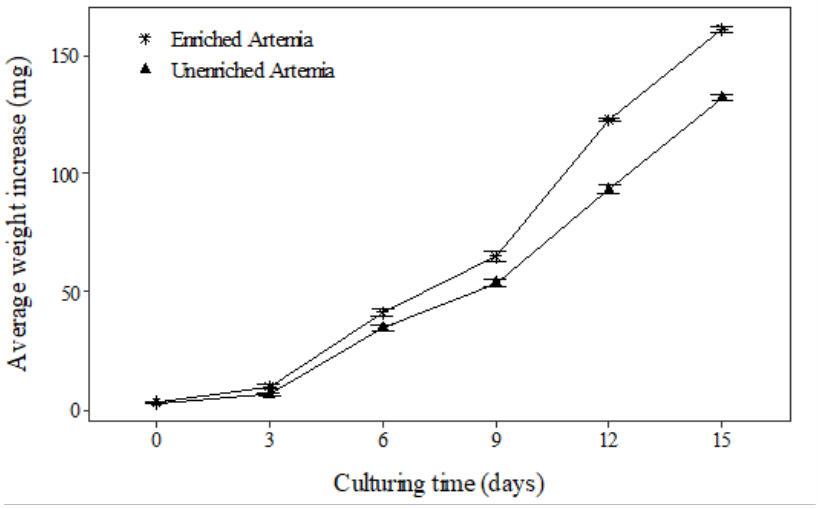

Figure 1. Growth rate of *Clarias gariepinus* fed enriched and unenriched *Artemia* nauplii.

Table 1. Growth performance of *Clarias gariepinus* larvae fed either enriched or unenriched *Artemia* nauplii.

Parameters	Dietary treatments	
	Enriched *Artemia*	Unenriched *Artemia*
Initial body weight (mg)	3.1 ± 0.1	3.0 ± 0.1
Final body weight (mg)	160.7 ± 1.2^{a}	131.9 ± 1.3^{b}
Weight gained (mg)	157.7 ± 1.3^{a}	128.8 ± 1.3^{b}
Daily weight gain (mg day^{-1})	10.5 ± 0.1^{a}	8.6 ± 0.1^{b}
Specific growth rate (% day^{-1})	26.4 ± 0.3^{a}	25.1 ± 0.3^{b}
Condition factor	1.1 ± 0.03	1.1 ± 0.07
Survival rate (%)	98.8 ± 0.2^{a}	96.5 ± 0.3^{b}

Means in the same row with different letter were statistically different

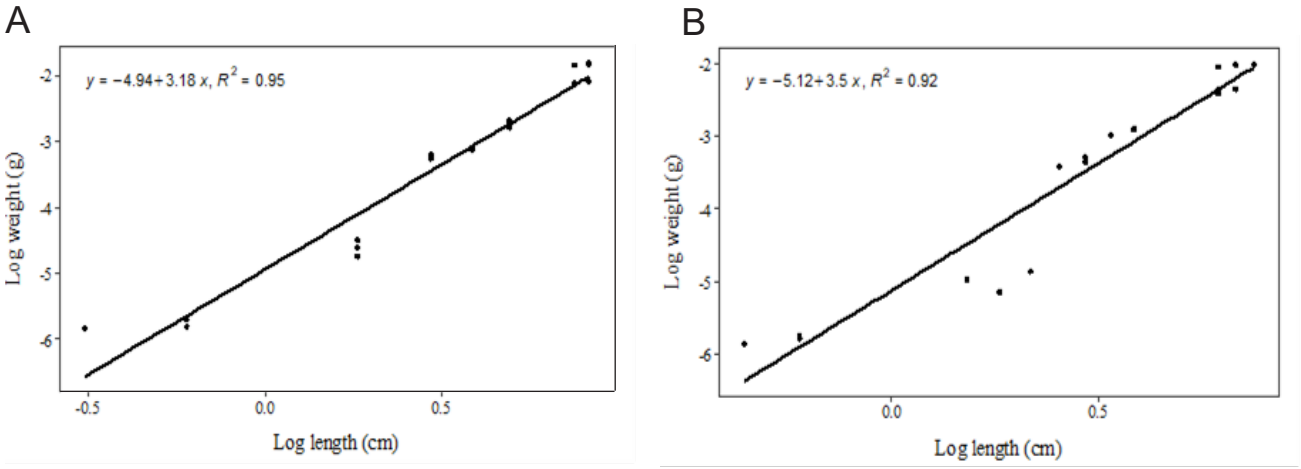

Figure 2. Length-weight relationships: (A) *Clarias gariepinus* larvae fed on enriched Artemia, and (B) *C. gariepinus* larvae fed on unenriched *Artemia* nauplii.

Nutritional value of dietary treatments and fish larvae

Nutritional values of dietary treatments and *Clarias gariepinus* larvae are presented in Table 2. The CP and EE differed statistically ($p < 0.05$) in both diets and *C. gariepinus* larvae while carbohydrates differed ($p = 0.003$) only in diets. The CP and EE were higher in enriched diets (51.3% CP and 12.4% EE) and *C. gariepinus* fed it (67.7% CP and 22.5% EE) than unenriched diet (41.9% CP and 9.3% EE) and *C. gariepinus* fed it (61.7% CP and 21% EE). Carbohydrate was also higher in enriched (21.6%) than unenriched (6.8%) diet. There were no statistical differences ($p > 0.05$) in DM, ash and CF between dietary treatments and among *C. gariepinus* larvae.

Table 2. Nutritional values (% dry matter) of experimental diets and *Clarias gariepinus* larvae.

Parameters	Dietary treatments		*Clarias gariepinus* larvae	
	Enriched *Artemia*	Unenriched *Artemia*	Enriched *Artemia*	Unenriched *Artemia*
Dry matter	91.7 ± 1.5	88.6 ± 0.4	99.9 ± 0.5	99.8 ± 0.1
Ash content	12.5 ± 0.3	11.1 ± 0.9	18.6 ± 0.1	18.1 ± 0.01
Crude protein	51.3 ± 1.3[a]	41.9 ± 1.9[b]	67.7 ± 0.5[a]	61.7 ± 0.2[b]
Crude fiber	3.5 ± 0.2	3.3 ± 0.2	0.4 ± 0.01	0.1 ± 0.004
Carbohydrate	21.6 ± 2.3[a]	6.8 ± 0.4[b]	-	-
Lipid content	12.4 ± 1.2[a]	9.3 ± 0.4[b]	22.5 ± 0.3[a]	21.0 ±0.01[b]

Means in the same row with different letters were statistically different

DISCUSSION

Nutritional values

The *Chlorella vulgaris*-enriched *Artemia* diet (51% CP, 12% EE) and unenriched diet (42% CP, 9.3% EE) met the 35–50% CP and 8–15% EE ranges required for *C. gariepinus* larvae growth and survival (Abdel-Aziz et al., 2021; Hamre et al., 2020; Méndez-martínez et al., 2018). The enriched diet's CP was closer to the optimal 55–56% for enhanced growth and protein utilization (Chepkirui-Boit et al., 2011; Gisbert et al., 2022) surpassing the 41–47% CP reported in other microalgae-enriched studies (Hamre et al., 2020; Méndez-martínez et al., 2018)). Larvae fed enriched *Artemia* nauplii exhibited higher CP (67%) and EE (23%) compared to those fed unenriched *Artemia* (62% CP, 21% EE), matching the 67.7% CP reported for Asian catfish larvae by Evangelista et al. (2005) but differing in EE from other studies due to experimental diet variations (Keke et al., 2017; Okomoda et al., 2019). These differences likely stem from the use of *C. vulgaris* in BSCE medium, enhancing nutrient transfer (Yamasaki-granados et al., 2013).

The enriched *Artemia* diet had higher dry matter (91.7 ± 1.5% vs. 88.6 ± 0.4%) and ash content (12.5 ± 0.3% vs. 11.1 ± 0.9%) than the unenriched diet, with larvae showing similar trends (99.9 ± 0.5% vs. 99.8 ± 0.1% dry matter; 18.6 ± 0.1% vs. 18.1 ± 0.01% ash). Crude fiber was comparable (3.5 ± 0.2% vs. 3.3 ± 0.2% in diets; 0.4 ± 0.01% vs. 0.1 ± 0.004% in larvae), but carbohydrates were significantly higher in the enriched diet (21.6 ± 2.3% vs. 6.8 ± 0.4%), suggesting enhanced energy availability for larval growth (Okomoda et al., 2019). Enriching *Artemia* with *C. vulgaris* in BSCE medium significantly improved CP, EE, dry matter, ash, and carbohydrate content, outperforming unenriched diets and other enrichment studies. This cost-effective approach optimizes nutrient assimilation and supports superior growth and survival of *C. gariepinus* larvae in aquaculture.

Growth performance

The larvae of *Clarias gariepinus* fed enriched *C. vulgaris*-*Artemia* nauplii showed significantly higher survival rate (98%) compared to those fed unenriched *Artemia* nauplii (96%), signifying the nutritional advantage of the enriched diet. The enriched *Artemia's* enhanced nutritional profile, with elevated crude protein (51.3%, close to the optimal 55% for catfish larvae (Mir et al., 2020), lipids, and carbohydrates, likely improved larval resilience by supporting metabolic processes and immune function during the critical early developmental stages. This survival rate aligns closely with the 97.7% reported by Ngupula et al. (2014) and surpasses the 75% noted by Evolubi et al. (2016), with differences likely attributable to variations in experimental diet quality. The improved survival complements enhanced growth metrics, reinforcing the efficacy of *C. vulgaris* enrichment in optimizing aquaculture outcomes.

Larvae fed *C. vulgaris*-enriched *Artemia* nauplii exhibited significantly higher specific growth rate (SGR), weight gain (WG), and daily weight gain (DWG) compared to those fed unenriched *Artemia*, attributed to the enriched diet's superior nutritional profile, including elevated levels of crude protein, carbohydrates, and lipids. SGR is a pivotal metric for assessing feed efficiency in *C. gariepinus* larvae. It quantifies the daily percentage increase in body weight, reflecting the larvae's ability to convert nutrient into biomass, thus serving as an indicator of both growth performance and feed quality (Lugert et al., 2016). Higher SGR values in this study highlight the enhanced nutritional efficacy of the enriched diet, optimizing early development. Variations in growth performance observed between *C. gariepinus* larvae likely stem from differences in the experimental diets' nutritional quality (Abaho et al., 2016; Evangelista et al., 2005). However, the SGR of 26.4% day^{-1} was lower than the 29.9% day^{-1} reported by Vandecan et al. (2011) but higher than the 14.3% day^{-1} by (hepkirui-Boit et al. (2011), likely due to differences in husbandry practices (Onura et al., 2018).

The length-weight relationship data in this study showed that, *C. gariepinus* larvae fed with unenriched *Artemia* exhibited positive allometric growth, becoming stouter as they grew larger. Conversely, larvae fed *C. vulgaris*-enriched *Artemia* showed a slight isometric growth, indicating symmetrical development (Riedel et al., 2007). These differences are likely due to the superior nutritional quality of enriched *Artemia*, particularly its higher levels of essential fatty acids like DHA and EPA, which promote efficient tissue development (Gümüş et al., 2021). Supporting these findings, Kamaszewski et al. (2014), reported that the high palatability of unenriched Artemia drives increased ingestion rates, resulting in greater biomass accumulation, even with reduced levels of essential nutrients. This explains the heavier weight observed in our larvae fed unenriched *Artemia*, as compensatory feeding likely prioritized energy storage over proportional growth. Conversely, enriched *Artemia* supports more balanced development promoting efficient nutrient use, resulting in proportional growth rather than excessive weight gain (Chepkirui-Boit et al., 2011; Gümüş et al., 2021).

The condition factor is a metric that reflects ecological and biological parameters, including fish health, gonad development, and environmental suitability for growth (Alam et al., 2014). This index is influenced by multiple variables such as sex, maturity stage, food availability, feeding frequency, seasonal variations, and stress levels (Khristenko and Kotovska, 2017). A condition factor greater than one indicates good health (Mtaki et al., 2021; Michael and Mramba, 2024). In this study, both larval groups exhibited condition factors greater than one (1.1), demonstrating that the experimental feeds maintained healthy growth conditions. These values were comparable to the condition factor of 1.0 reported by Bwala et al. (2018) for catfish larvae fed oviparous nauplii, confirming that neither feed type negatively impacted larval health. However, these values were lower than the 1.49

reported by Ngupula et al. (2014) for larvae fed Moina micrura, likely due to variations in rearing conditions (Khristenko and Kotovska, 2017).

CONCLUSION

Feeding *Clarias gariepinus* larvae with *Chlorella vulgaris*-enriched *Artemia* significantly enhanced growth performance, survival rate, specific growth rate, and weight gain compared to unenriched *Artemia*. The enriched diet's superior nutritional profile, including higher crude protein, ether extract, and carbohydrate content, supports its use as an effective live starter food. These findings provide valuable insights for hatchery operators to optimize larval growth and survival, meeting the demand for *C. gariepinus* seeds and advancing aquaculture development.

ACKNOWLEDGMENT

Authors wish to express their gratitude to Swedish International Development Cooperation Agency (SIDA) for financial support through Bilateral Marine Sciences Program with Institute of Marine Sciences (IMS), University of Dar es Salaam. We are also grateful to Mr. Tibakula Mihayo Tibakula, Mr. Livinus Renatus Bitumbe and Mr. Yoakim Eustack Komba for their help during data collection and Dr. Peter R. Ruvuga for his assistance in language check.

AUTHOR CONTRIBUTIONS

Conceptualization, data curation, formal analysis and drafting-KM, Methodology, writing and review-AM, Review and editing-MSK, Fund acquisition, review and editing- MSPM.

FUNDING SOURCE

The study was funded by Swedish International Cooperation Agency (Sida) through 2015-2020 Bilateral Marine Science Program (grant no.51170071).

DECLARATION

Informed consent statement

The experiment conducted of this research was approved by the university.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

Abaho, I., Bwanika, G., Walekhwa, P., Arinaitwe, A. V. I., and Kwetegyeka, J. (2016). Fatty acid profiles and growth of African catfish (*Clarias gariepinus*, Burchell, 1822) larvae fed on freshwater rotifer (*Brachionus calyciflorus*) and *Artemia* as live starter feeds. *International Journal of Fisheries and Aquatic Studies*, 4(1), 189–196.

Abdel-Aziz, M. F. A., Hassan, H. U., Yones, A. M., Abdel-Tawwab, Y. A., and Metwalli, A. A. A. T. (2021). Assessing the effect of different feeding frequencies combined with stocking density, initial weight, and dietary protein ratio on the growth performance of tilapia, catfish and carp. *Scientific African*, 12, e00806. https://doi.org/10.1016/J.SCIAF.2021.E00806

Adewumi, A. A. (2015). Growth performance and survival of *Clarias gariepinus* hatchlings fed different starter diets. *Pelagia Research Library European Journal of Experimental Biology*, 5(3), 1–5.

Ahmadi, A., Mozanzadeh, M. T., andAgh, N. (2017). Effects of enriched *Artemia* with Saccharomyces cerevisiae and *Chaetoceros gracilis* on growth performance, stress resistance and fatty acid profile of Litopenaeus vannamei postlarvae. *International Journal of Fisheries and Aquatic Studies*, 5(2), 669–673.

Alam, M. M., Rahman, T., and Parween, S. (2014). Morphometric characters and condition factors of five freshwater fishes from Pagla river of Bangladesh. *International Journal of Aquatic Biology*, 2(1), 14–19.

Ali, S. S. R., Syamadayal, K. A., Praveena, P. E., Nandakumar, S., Jagabatula, and Syamadayal, J. (2017). Effect of dietary fructooligosaccharide supplementation on growth, body composition, hematological and immunological parameters of Asian seabass (*Lates calcarifer*). *Aquaculture International*, 25(2), 837–848. https://doi.org/10.1007/s10499-016-0081-2

Allen, S. (1989). Analysis of vegetation and other organic materials. In *Chemical analysis of ecological materials* (Second edi, pp. 46–60). Blackwell. Scientific Publications, Oxford London Edinburgh, Boston Melbourne.

A.O.A.C. (1990). "*Association of Official Agricultural hemists*" (1990): *Official methods of analysis*. (15th ed.). A.O.A.C., Benjamin Francklin Station, Washington. D. C., USA.

Bwala, R., Salie, K., and Van Stappen, G. (2018). Ovoviviparously produced *Artemia* nauplii are a suitable live food source for the larvae of the African catfish (*Clarias gariepinus:* Burchell, 1822). *Aquaculture Research*, 49(10), 3319–3328. https://doi.org/10.1111/ARE.13795

Chakraborty, D. R., Chakraborty, K., and E.V, Radhakrishnan. (2007). Variation in Fatty Acid Composition of *Artemia salina* Nauplii Enriched with Microalgae and Baker ' s Yeast for Use in Larviculture. *Journal of Agricultural and Food Chemistry*, 55, 4043–4051.

Cheban, L., Khudyi, O., Prusińska, M., Duda, A., Khuda, L., Wiszniewski, G., Kushniryk, O., and Kapusta, A. (2020). Survival , proximate composition , and proteolytic activity of *Artemia salina* bioencapsulated with different algal monocultures. *Fisheries & Aquatic Life*, 28, 205–215. https://doi.org/10.2478/aopf-2020-0025

Chepkirui-Boit, V., Ngugi, C. C., Bowman, J., Oyoo-Okoth, E., Rasowo, J., Mugo-Bundi, J., and Cherop, L. (2011). Growth performance, survival, feed utilization and nutrient utilization of African catfish (*Clarias gariepinus*) larvae co-fed *Artemia* and a micro-diet containing freshwater atyid shrimp (*Caridina nilotica*) during weaning. *Aquaculture Nutrition*, 17(2). https://doi.org/10.1111/j.1365-2095.2009.00737.x

Evangelista, A. D., Fortes, N. R., and Santiago, C. B. (2005). Comparison of some live organisms and artificial diet as feed for Asian catfish *Clarias macrocephalus* (Günther) larvae. *Journal of Applied Ichthyology*, 21(5), 437–443.

Evolubi, O. O. C., Absalom, K. V., RUMA, G. A., Damshit, M., and Uja, A. I. (2016). Survival and growth performance of *Clarias gariepinus* (clariidae) fry on different diets in aerated and survival & growth of *Clarias gariepinus* using different fried diets. *FUW Trends in Science & Technology Journal*, 1(2), 466–470.

FAO. (2024). *The State of World Fisheries and Aquaculture* 2024. *Blue Transformation in Action*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd0683en

Folorunso, E. A., Rahman, M. A., Sarfo, I., Darko, G., and Olowe,

O. S. (2021). Catfish farming: A sustainability study at Eriwe fish farming village in southwest Nigeria. *Aquaculture International*, 29(2), 827–843. https://doi.org/10.1007/s10499-021-00662-0

Gisbert, E., Luz, R. K., Fernández, I., Pradhan, P. K., Salhi, M., Mozanzadeh, M. T., Kumar, A., Kotzamanis, Y., Castro-Ruiz, D., Bessonart, M., and Darias, M. J. (2022). Development, nutrition, and rearing practices of relevant catfish species (Siluriformes) at early stages. *Reviews in Aquaculture*, 14(1), 73–105. https://doi.org/10.1111/raq.12586

Gümüş, E., Yılayaz, A., Kanyılmaz, M., Gümüş, B., and Balaban, M. (2021). Evaluation of body weight and color of cultured European catfish (*Silurus glanis*) and African catfish (*Clarias gariepinus*) using image analysis. *Aquacultural Engineering*, 93, 102147. https://doi.org/10.1016/j.aquaeng.2021.102147

Halasi, G., Hyuha, T. S., A., A., F., M., and Nabbika, M. R. (2012). Economic analysis of fish farming in Mbale-sub region , eastern Uganda Literature Summary. *Third RUFORUM Biennial Meeting*, 505–510.

Hamre, K., Erstad, B., de Kok, J., Norberg, B., and Harboe, T. (2020). Change in nutrient composition of *Artemia* grown for 3–4 days and effects of feeding on-grown Artemia on performance of Atlantic halibut (*Hippoglossus hippoglossus*, L.) larvae. *Aquaculture Nutrition*, 26(5), 1542–1554. https://doi.org/10.1111/ANU.13101

Joshua, W. J., Kamarudin, M. S., Ikhsan, N., Yusoff, F. M., and Zulperi, Z. (2022). Development of enriched *Artemia* and *Moina* in larviculture of fish and crustaceans: A review. *Latin American Journal of Aquatic Research*, 50(2), 144–157.

Kamaszewski, M., Ostaszewska, T., Prusińska, M., Kolman, R., Chojnacki, M., Zabytyvskij, J., Jankowska, B., and Kasprzak, R. (2014). Effects of *Artemia* sp. Enrichment with essential fatty acids on functional and morphological aspects of the digestive system in Acipenser gueldenstaedtii larvae. *Turkish Journal of Fisheries and Aquatic Sciences*, 14(4), 929–938.

Keke, U., Arimoro, F. O., Ayanwale, V., and Agbikimi, I. O. (2017). Rotifer (*Brachionus Calyciflorus*) Could Compete Favourably With Artemia Nauplii As Alternative Starter for African Catfish (*Clarias gariepinus*). *Applied Science Research Journal*, 4(2), 41–58.

Khristenko, D. S., and Kotovska, G. O. (2017). Length-Weight Relationship and Condition Factors of Freshwater Bream *Abramis brama* (Linnaeus, 1758) from the Kremenchug Reservoir, Middle Dnieper. *Turkish Journal of Fisheries and Aquatic Sciences*, 17, 71–80. https://doi.org/10.4194/1303-2712-v17

Langi, S., Maulu, S., Hasimuna, O. J., Kaleinasho Kapula, V., and Tjipute, M. (2024). Nutritional requirements and effect of culture conditions on the performance of the African catfish (*Clarias gariepinus*): A review. *Cogent Food & Agriculture*, 10(1), 2302642. https://doi.org/10.1080/23311932.2024.2302642

Lenz, P. H., and Browne, R. A. (2018). Ecology of artemia. In *Artemia biology* (pp. 237–254). CRC Press. https://www.taylorfrancis.com/chapters/edit/10.1201/9781351069892-10/ecology-artemia-petra-lenz-robert-browne

Lugert, L., V. (2015). *Modelling the growth of turbot in marine Recirculating Aquaculture Systems* (RAS). Selbstverlag des Instituts für Tierzuch und Tierhaltung der Christian-Albrechts-Universität zu Kiel).

Lugert, V., Thaller, G., Tetens, J., Schulz, C., and Krieter, J. (2016). A review on fish growth calculation: Multiple functions in fish production and their specific application. *Reviews in Aquaculture*, 8(1), 30–42. https://doi.org/10.1111/raq.12071

Méndez-martínez, Y., and Lora-vilchis, M. C. (2018). Nutritional effect of *Artemia* nauplii enriched with *Tetraselmis suecica* and *Chaetoceros calcitrans* microalgae on growth and survival on the river prawn *Macrobrachium americanum* larvae. *Aquaculture International*, 26, 1001–1015. https://doi.org/10.1007/s10499-018-0264-0

Méndez-martínez, Y., Lora-Vilchis, M. C., García-Guerrero, M. U., Lora-Vilchis, M. C., Martínez-Córdova, L. R., Arcos-Ortega, F. G., Alpuche, J. J., and Cortés-Jacinto, E. (2018). Nutritional effect of *Artemia* nauplii enriched with *Tetraselmis suecica* and *Chaetoceros calcitrans* microalgae on growth and survival on the river prawn *Macrobrachium americanum* larvae. *Aquaculture International*, 26(4), 1001–1015. https://doi.org/10.1007/s10499-018-0264-0

Michael, A., Kyewalyanga, M. S., and Lugomela, C. V. (2019). Biomass and nutritive value of Spirulina (*Arthrospira fusiformis*) cultivated in a cost-effective medium. *Annals of Microbiology*, 69(13), 1387–1395. https://doi.org/10.1007/s13213-019-01520-4

Michael, A., and Mramba, R. P. (2024). Comparative growth performance of Nile tilapia (*Oreochromis niloticus*) sex groups intank culture: A hormone-free approach for sustainable aquaculture in Dodoma, Tanzania. *Davao Research Journal*, 15(4), 6–18.

Michael, A., and Mtaki, K. (2024). Optimizing Growth Conditions and Biomass Accumulation for *Chlorella vulgaris* of the Western Indian Ocean, Tanzania. *International Journal of Biological and Chemical Sciences*, 18(6), 2066–2077.

Mir, I. N., Srivastava, P. P., Bhat, I. A., Jaffar, Y. D., Sushila, N., Sardar, P., Kumar, S., Muralidhar, A. P., and Jain, K. K. (2020). Optimal dietary lipid and protein level for growth and survival of catfish *Clarias magur* larvae. *Aquaculture*, 520, 734678. https://doi.org/10.1016/j.aquaculture.2019.734678

Mtaki, K., Kyewalyanga, M. S., and Mtolera, M. S. P. (2021). Supplementing wastewater with NPK fertilizer as a cheap source of nutrients in cultivating live food (*Chlorella vulgaris*). *Annals of Microbiology*, 71(7), 1–13. https://doi.org/10.1186/s13213-020-01618-0

Mtaki, K., Kyewalyanga, M. S., and Mtolera, M. S. P. (2023a). Nutritional values of *Artemia salina* (brine shrimp) enriched with microalgae *Chlorella vulgaris* grown in banana stem compost extract medium. *Journal of Applied Aquaculture*, 00(00), 1–15. https://doi.org/10.1080/10454438.2023.2293112

Mtaki, K., Kyewalyanga, M. S., and Mtolera, M. S. P. (2023b). Replacing expensive synthetic media with banana stem compost extract medium for production of *Chlorella vulgaris*. *Applied Phycology*, 4(1), 34–43. https://doi.org/10.1080/26388081.2022.2140073

Mtaki, K., Mchele, S., John, A., and Mtolera, M. S. P. (2021). Hybrids production as a potential method to control prolific breeding in tilapia and adaptation to aquaculture climate-induced drought. *Aquaculture and Fisheries, December 2020*, 0–5. https://doi.org/10.1016/j.aaf.2021.04.005

Musiba, M. J., Ngupula, G. W., Kashindye, B. B., Elison, M., Shoko, A. P., Ndikumana, J., and Zziwa, E. (2014). Performance of locally formulated feeds for rearing of African catfish in Tanzania. *African Crop Science Journal*, 22(0), 979–986.

Ngupula, G. W., Shoko, A. P., Musiba, M., Ndikumana, J., and Zziwa, E. (2014). Performance of *Artemia* Shell-Free Embryos, *Moina* Micrura and Phytoplankton on Larvae of Reared *African Catfish*. *African Crop Science Journal*, 22, 875–881.

Nguyen, D. T., Vangansbeke, D., & De Patrick, C. (2014). Solid artificial diets for the phytoseiid predator *Amblyseius swirskii*. *BioControl*, 57, 719–727. https://doi.org/10.1007/s10526-014-9607-6

Okomoda, V. T., Aminem, W., Hassan, A., and Martins, C. O. (2019).

Effects of feeding frequency on fry and fingerlings of African catfish *Clarias gariepinus*. *Aquaculture*, 511 (March). https://doi.org/10.1016/j.aquaculture.2019.734232

Onura, N., Callen, Broeck, V. den, Wim, Nevejan, Nancy, Muendo, Patricia, Stappen, V., and Gilbert. (2018). Growth performance and intestinal morphology of African catfish (*Clarias gariepinus*, Burchell, 1822) larvae fed on live and dry feeds. *Aquaculture*, 489(2017), 70–79. https://doi.org/10.1016/j.aquaculture.2018.01.046

Riedel, R., Caskey, L. M., and Hurlbert, S. H. (2007). Length-weight relations and growth rates of dominant fishes of the Salton Sea: Implications for predation by fish-eating birds. *Lake and Reservoir Management*, 23(5), 528–535. https://doi.org/10.1080/07438140709354036

Vandecan, M., Diallo, A., and Mélard, C. (2011). Effect of feeding regimes on growth and survival of *Clarias gariepinus* larvae: Replacement of *Artemia* by a commercial feed. *Aquaculture Research*, 42(5), 733–736. https://doi.org/10.1111/j.1365-2109.2010.02709.x

Yamasaki-granados, S., García-guerrero, M., Vega-villasante, F., Universitario, C., Costa, D., Guadalajara, U. De, Melaque, S. P. De, Acuicultura, P. De, and Investigaciones, C. De. (2013). Experimental culture of the river prawn Macrobrachium americanum larvae (Bate , 1868), with emphasis on feeding and stocking density effect on survival. *Latin American Journal of Aquatic Research*, 41(4), 793–800.