Jurnal Akuakultur Indonesia
Research Article
ISSN: 1412-5269
EISSN: 2354-6700
Vol. 25 No. 2, July 2026
DOI: 10.19027/jai.25.2.305-314

Evaluation of dietary manganese (Mn) supplementation on the growth performance of African catfish *Clarias gariepinus*

Evaluasi suplementasi mangan (Mn) dalam pakan terhadap kinerja pertumbuhan ikan lele *Clarias gariepinus*

Muhammad Agus Suprayudi, Gestiana Arsy Prastiwi, Ichsan Ahmad Fauzi, Dedi Jusadi, Mia Setiawati, Julie Ekasari, Talita Shofa Adestia[*]

Department of Aquaculture, Faculty of Fisheries and Marine Science, IPB University, Bogor, West Java 16680, Indonesia
Corresponding author: talitashofa@apps.ipb.ac.id

(Received December 18, 2025; Revised January 27, 2025; Accepted June 26, 2026)

ABSTRACT

Manganese (Mn) is an essential trace mineral involved in enzymatic activity, metabolism, and antioxidant defense in fish. This study evaluated the effects of dietary Mn supplementation on growth performance, feed efficiency, protein utilization, and survival of African catfish (*Clarias gariepinus*). Experimental diets were formulated with graded levels of Mn (0, 15, 30, and 45 mg/kg feed) and fed to fish for 60 days. Dietary Mn supplementation significantly improved growth performance compared to the control diet (P<0.05). Fish fed 45 mg/kg Mn exhibited the highest final weight (87.14 ± 2.05 g) compared to the control (64.90 ± 3.41 g). Along with a higher specific growth rate (3.58 ± 0.05% per day vs 3.09 ± 0.09% per day) average daily gain (1.28 ± 0.04 g/day vs 0.91 ± 0.06 g/day)/ feed intake was also significantly higher at 45 mg/kg (1071.81 ± 12.84 g) compared to the control (931.62 ± 15.99 g). However, feed conversion ratio and protein efficiency ratio were not significantly affected (P>0.05). Survival rate remained high and did not differ significantly among treatments. In conclusion, dietary Mn supplementation positively influences growth performance, feed efficiency, and protein utilization in African catfish, with 45 mg/kg feed identified as the most effective dose under the conditions of this study. These findings highlight the importance of adequate trace mineral inclusion in catfish feed formulation.

Keywords: catfish, manganese, growth, feed additive

ABSTRAK

Mangan (Mn) merupakan mineral mikro esensial yang berperan penting dalam aktivitas enzimatik, metabolisme, dan sistem pertahanan antioksidan pada ikan. Penelitian ini bertujuan untuk mengevaluasi pengaruh suplementasi Mn dalam pakan terhadap performa pertumbuhan, efisiensi pakan, pemanfaatan protein, dan tingkat kelangsungan hidup ikan lele Afrika (*Clarias gariepinus*). Pakan percobaan diformulasikan dengan beberapa tingkat suplementasi Mn, yaitu 0, 15, 30, dan 45 mg/kg pakan, dan diberikan selama 60 hari pemeliharaan. Hasil penelitian menunjukkan bahwa suplementasi Mn dalam pakan secara signifikan meningkatkan performa pertumbuhan dibandingkan dengan perlakuan kontrol (P<0,05). Suplementasi Mn dalam pakan secara signifikan meningkatkan kinerja pertumbuhan dibandingkan kontrol (P<0,05). Ikan yang diberi 45 mg/kg Mn menunjukkan bobot akhir tertinggi (87,14 ± 2,05 g) dibandingkan kontrol (64,90 ± 3,41 g), serta laju pertumbuhan spesifik yang lebih tinggi (3,58 ± 0,05%/hari vs 3,09 ± 0,09%/hari) dan pertambahan bobot harian (1,28 ± 0,04 g/hari vs 0,91 ± 0,06 g/hari). Konsumsi pakan juga secara signifikan lebih tinggi pada dosis 45 mg/kg (1071,81 ± 12,84 g) dibandingkan kontrol (931,62 ± 15,99 g). Namun, rasio konversi pakan dan rasio efisiensi protein tidak menunjukkan perbedaan yang signifikan (P>0,05). Tingkat kelangsungan hidup tetap tinggi dan tidak berbeda nyata antar perlakuan. Secara keseluruhan, suplementasi Mn memberikan pengaruh positif terhadap performa pertumbuhan, efisiensi pakan, dan pemanfaatan protein ikan lele Afrika, dengan dosis 45 mg/kg pakan diidentifikasi sebagai dosis paling efektif pada kondisi penelitian ini. Temuan ini menegaskan pentingnya pemenuhan kebutuhan mineral mikro secara optimal dalam formulasi pakan ikan lele.

Kata kunci: ikan lele, mangan, pertumbuhan, aditif pakan

INTRODUCTION

Catfish (*Clarias gariepinus*) is a freshwater commodity with high demand, offering a substantial market. Production in Indonesia reached 1,171,367 tons in 2024 and 1,137,807 tons in 2023. Catfish production continues to increase annually, reaching 1.61% (KKP, 2024). FAO (2022) reported that catfish production in 2020 reached 1.25 million tons, accounting for 2.5% of inland aquaculture production. Efforts to significantly increase production include intensive cultivation (Pamaharyani *et al.,* 2024). One essential factor in intensive cultivation is feed, also protein is one of the costliest components in feed formulations and plays a major role in determining overall feed expenses (Octaviani *et al.,* 2024; Son *et al.,* 2024). Feed significantly impacts aquaculture production, accounting for approximately 40-91.2% of total production costs (Suprayudi *et al.,* 2012; Suprayudi, 2018).

The nutrient composition of the feed directly affects fish growth. Fish feed contains macronutrients (protein, fat, carbohydrates, water) and micronutrients (vitamins, minerals). Minerals include macrominerals phosphorus (P), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chlorine (Cl), sulfur (S), and microminerals selenium (Se), manganese (Mn), nickel (Ni), zinc (Zn), silicon (Si), iodine (I), copper (Cu), cobalt (Co), molybdenum (Mo), fluorine (F), aluminum (Al), vanadium (V), chromium (Cr) (Prabhu *et al.,* 2019). Manganese (Mn), a micromineral, can influence fish growth, metabolism, and reproductive performance (Musharraf & Khan, 2021).

Manganese (Mn) is a transition element in group 7, period 4 of the periodic table, with an atomic number of 25 and an isotopic number of 55 (RSC, 2024). Sources of Mn come from organic and inorganic compounds. Mn supplementation in the form of inorganic compounds uses organic salts, one of which is Manganese (II) Sulfate ($MnSO_4$), and organic Mn forms include Glycine Manganese (Mn-Gly), Mn-Proteinate, Mn-Methionine (Prabhu *et al.,* 2019). The role of Mn in fish feed is as a cofactor for enzymes and an integral part of metalloenzymes (Hayat *et al.,* 2026). Manganese (Mn) is an essential trace mineral that function both as an enzymatic cofactor and as integral component of several metalloenzymes involved in cellular metabolism. As an enzyme activator, Mn binds reversibly to enzymes, facilitating substrate binding and stabilizing reaction intermediates. This catalytic role is particularly important for transferases and glycosyltransferases, which participate in the synthesis of cartilage extracellular matrix components such as proteoglycans and glycosaminoglycans (Musharraf & Khan, 2021; Jiang *et al.*m 2017; Baj *et al.,* 2023). In addition, Mn serves as a structural component of several metalloenzymes, including arginase, pyruvate carboxylase, superoxide dismutase, and decarboxylase (Leach, 2022; Nguyen *et al.,* 2024; Hayat *et al.,* 2025).

Among this enzymes, manganese superoxide dismutase (MnSOD) plays a particularly important role as the primary antioxidant enzyme in mitochondria. MnSOD catalyzes the conversion of superoxide radicals generated during oxidative phosphorylation into less reactive molecules, thereby protecting lipids, proteins, and other cellular components from oxidative damage while maintaining efficient energy production (Nyarko-Danquah *et al.,* 2020). Maintaining an appropriate dietary Mn level is therefore essential for normal physiological function and growth in fish. Both Mn deficiency and excessive Mn supplementation can impair fish performance, leading to reduced growth, skeletal abnormalities, cataract formation, oxidative stress, and inflammatory responses (Mmanda, 2025; Wang etal., 2022; Kumar *et al.,* 2024).

Manganese (Mn) is an essential trace mineral in aquaculture nutrition that plays a fundamental role in regulating growth, metabolism, skeletal development, and antioxidant defense in fish. Its biological functions are primarily attributed to its role as an enzymatic cofactor and as structural component of several metalloenzymes involved in key physiological processes. As a cofactor, Mn activates enzymes that regulate metabolic pathways and tissue formation, thereby supporting efficient nutrient utilization and normal growth. One of its most important functions is the activation of glucosyltransferases, which catalyze the synthesis of proteoglycans and glycosaminoglycans, the major constituents of the extracellular matrix in cartilage and bone (Tseng *et al.,* 2025; Lall & Kaushik, 2021). Adequate Mn availability is therefore essential for skeletal development, particularly during the larval and juvenile stages when rapid bone formation occurs. Insufficient Mn intake has been associated with skeletal deformities, including scoliosis and lordosis, which subsequently impair growth performance (Tseng *et al.,* 2025). Excess

Mn can disrupt the physiological function of fish, affecting their metabolism and health, thus impacting their growth and survival (Watanabe *et al.,* 1997; Ali *et al.,* 2021; Lv *et al.,* 2025).

Research on Mn requirements for various fish species varies. Liang *et al.* (2015) stated that yellow catfish require 5.5–6.4 mg/kg of feed, carp and rainbow trout require 12–13 mg/kg of feed, Atlantic salmon require 7.5–10.5 mg/kg of feed, and tilapia require 7 mg/kg of feed (Watanabe *et al.,* 1997). According to Prabhu *et al.* (2016), the highest dose of Mn added to Atlantic salmon feed was 106 mg/kg, while the highest dose for American catfish was 63 mg/kg. Research by Thabet *et al.* (2021) showed that adding manganese oxide nanoparticles to African catfish at 1.2–2.4 mg/kg of feed can affect their growth performance. Beyond skeletal health, Mn critically supports growth through its function in the mitochondrial antioxidant system.

Manganese (Mn) also plays a critical role in antioxidant defense as the essential cofactor of manganese superoxide dismutase (MnSOD), the primary mitochondrial enzyme responsible for detoxifying superoxide radicals produced during aerobic metabolism. Adequate dietary Mn enhances MnSOD activity, thereby reducing oxidative damage to lipids, proteins, and other cellular components while maintaining mitochondrial function and energy production. In coho salmon, dietary Mn levels of approximately 16.8 – 25.8 mg/kg have been reported to maximize hepatic MnSOD activity and improve antioxidant capacity (Yu *et al.,* 2024; Liu *et al.* 2023). This protective effect becomes particularly important under environmental or nutritional stress, when excessive reactive oxygen species (ROS) are generated. In contrast, inadequate Mn intake results in elevated oxidative stress, as indicated by increased malondialdehyde concentrations, causing cellular damage in metabolically active tissue such as the liver and muscle. Consequently, more energy is diverted toward cellular repair and maintenance rather than growth, ultimately reducing growth performance and feed utilization efficiency (Xu *et al.,* 2023).

This study aimed to evaluate the effects of dietary manganese (Mn) supplementation on the production performance of African catfish (*Clarias gariepinus*). Specifically, it examined the effects of different dietary Mn inclusion levels on growth performance, as indicated by weight gain and specific growth rate, as well as feed utilization efficiency through parameters such as feed conversion ratio (FCR). The findings are expected to provide insights into the optimal dietary Mn level for improving the growth performance and feed efficiency of African catfish.

MATERIALS AND METHODS

Experimental diets and design

The research was conducted at the Fish Nutrition and Feed Technology Wet Laboratory, Faculty of Fisheries and Marine Sciences, IPB University, in Dramaga District, Bogor Regency, West Java. Proximate analysis was conducted at the Fish Nutrition Proximate Laboratory using method outlined by Association of Official Analytical Chemistry (AOAC, 2012), while water quality analysis was conducted to meet the quality standards (SNI 7550:2009) at the Aquaculture Environment Laboratory, Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University.

This study used a completely randomized design (CRD) with four treatments and three replications for each treatment.

Mn 0 = Feed without Mn mineral supplementation (0 mg/kg)

Mn 15 = Feed supplemented with Mn mineral supplementation (15 mg/kg)

Mn 30 = Feed supplemented with Mn mineral supplementation (30 mg/kg)

Mn 45 = Feed supplemented with Mn mineral supplementation (45 mg/kg).

The raw materials were sieved using a fine mesh sieve (approximately 250 µm to ensure uniform particle size, then weighed according to the formulated diet and mixed using a laboratory-scale horizontal feed mixer. The ingredients were blended until a homogeneous mixture was obtained, after which the feed was pelletized using a laboratory-scale floating feed extruder commonly used for aquafeed production. The pellets were subsequently dried in an oven at 60°C for four hours. The feed was stored in airtight containers at room temperature. The results of the proximate analysis of each dietary treatment are presented in Table 2.

Fish maintenance

The experimental species used in this study was African catfish (*Clarias gariepinus*) with a total length of 10–11 cm. The fish originated from broodstock of BBPBAT Sukabumi, Indonesia and were cultured in Dramaga, Bogor Regency, West Java, Indonesia. Prior to stocking, the fish were acclimatized to the experimental conditions for seven days prior to the start of the feeding trial. During the acclimatization period, fish were fed a commercial diet (PF100). A gradual transition to the experimental diets was conducted on days 6-7 by overlapping the commercial feed with the formulated control diet used in this study to ensure adaptation. The experiment was conducted using 12 aquaria measuring 50×40×35 cm^3, with each aquarium stocked with 10 fish weighing 10.15 ± 0.02 g. Stocking was carried out after acclimatization upon arrival and an initial feeding period during which the fish were confirmed to be in healthy condition. The fish were then fasted prior to sampling and grading. After sampling and grading, the rearing trial was conducted for 60 days. Fish were fed three times daily at 08:00, 14:00, and 20:00 to apparent satiation. Fish were anesthetized using clove oil (eugenol) at a concentration of 50 mg/L prior to handling and sampling procedures to minimize stress and ensure animal welfare during the experiment. Also, the biomass weighing of all fish was performed on days 15, 30, 45, and 60 of the rearing period.

Table 1. Experimental diet formulation.

Ingredient (%)	Treatment			
	Mn0	Mn15	Mn30	Mn45
Poultry meat meal	5.00	5.00	5.00	5.00
Meat bone meal	8.99	8.99	8.99	8.99
Soy bean meal	28.81	28.81	28.81	28.81
Corn gluten meal	5.09	5.09	5.09	5.09
Cassava chips	5.00	5.00	5.00	5.00
Pollard	19.11	19.11	19.11	19.11
Wheat flour	20.00	19.97	19.95	19.93
Mineral mix Mn free	1.70	1.70	1.70	1.70
Vitamin mix	1.70	1.70	1.70	1.70
Polymethylolcarbamide	0.20	0.20	0.20	0.20
Fish oil	1.70	1.70	1.70	1.70
Crude palm oil	1.70	1.70	1.70	1.70
Monocalcium phosphate	1.00	1.00	1.00	1.00
Organic Mn (5%)	0	0.03	0.06	0.09

Table 2. Proximate analysis of experimental diets.

Composition	Treatment			
	Mn0	Mn15	Mn30	Mn45
Moisture (%)	8.95	9.16	9.23	8.84
Ash (%)	8.20	8.23	8.25	8.35
Crude fiber (%)	3.00	3.32	3.22	3.06
Fat (%)	5.88	5.12	5.25	5.12
Protein (%)	31.45	31.48	31.31	31.24
NFE (%)*	42.51	42.69	42.74	43.39
GE (kcal/kg)**	439.34	433.19	433.75	435.21
C/P (kcal/kg)***	13.97	13.76	13.85	13.93
Total (%)	**100**	**100**	**100**	**100**

*Wet Nitrogen Free Extract (NFE) =). **Gross Energy Composition (GE) was calculated based on protein = 5.64 kcal/g protein, fat = 9.44 kcal/g fat, and carbohydrate/NFE = 4.11 kcal/g carbohydrate (Watanabe, 1997). ***C/P = calorie/protein.

Water quality

Water quality management was carried out by partial water exchange of 20% every three days during the first 15 days of rearing, 50% every three days during the subsequent 15 days, and 80% every three days until the end of the experimental period. Water temperature and pH were measured daily, dissolved oxygen (DO) was measured every seven days, and total ammonia nitrogen (TAN) and nitrite were measured every 15 days. During the rearing period, water quality parameters ranged as follows: temperature 28.2–30.5°C (optimum 28–3°C) , pH 6.2–7.3 (7.5–8.5), DO 3.4–4.6 mg/L (optimum 4–8 mg/L), TAN 0.1–0.2 mg/L (optimum 0.1–0.4 mg/L), nitrite 0.01–0.06 mg/L (<0.25 mg/L), and nitrate 0.1–0.2 mg/L (<0.5 mg/L) (Syahrul *et al.,* 2023).

Research parameter

According to Stickney and Gatlin (2022), growth performance in aquatic organisms is commonly assessed using parameters that describe developmental changes throughout their life cycle, particularly during the early growth stages when feed efficiency and overall development are most critical. In this study, the evaluated experimental parameters consisted of feed conversion ratio (FCR), survival rate (SR), specific growth rate (SGR), feed intake (FI), average daily gain (ADG), and protein efficiency ratio (PER).

Feed conversion ratio (FCR)

Feed conversion ratio (FCR) is defined as the amount of feed required to produce 1 kg of fish biomass. FCR was calculated using the following formula (Goddard, 1996):

$$FCR = \frac{FI}{Wt - W0}$$

Note:
FCR = Feed conversion ratio
FI = Total feed intake (g)
Wt = Final weight (g)
Wo = Initial weight (g)

Survival rate (SR)

Survival rate (SR) was calculated using the following formula (Effendie, 2002):

$$SR\ (\%) = \frac{N_t}{N_0} \times 100$$

Note:
SR = Survival rate (%)
Nt = Number of fish at the end of the experiment (fish)
No = Number of fish at the beginning of the experiment (fish)

Specific growth rate (SGR)

Specific growth rate (SGR) represents the average increase in fish weight based on the weighing of samples from each treatment. SGR was calculated using the following formula (Huissman, 1987):

$$SGR = \left(\frac{(\text{Ln } Wt - \text{Ln } W0)}{t}\right) \times 100$$

Note:
SGR = Specific growth rate (%)
t = Rearing period (day)
Wt = Average final weight (g)
Wo = Average initial weight (g)

Feed intake (FI)

Total feed intake (TFI) refers to the total amount of feed provided throughout the rearing period.

Average daily gain (ADG)

Average daily gain (ADG) can be calculated using the following formula:

$$ADG = \frac{W_t - W_0}{t}$$

Note:
ADG = Average daily gain (g/day)
Wt = Final body weight (g)
Wo = Initial body weight (g)
t = Time (day)

Protein efficiency ratio (PER)

Protein efficiency ratio (PER) was calculated using the following formula (Hepher, 1988):

$$PER = \frac{W_t - W_0}{f \times \%\text{feed protein}} \times 100$$

Note:
PER = Protein efficiency ratio
Wt = Final biomass (g)
Wo = Initial biomass (g)
f = Total amount of feed provided to the fish during the study (g)

Data analysis

The obtained data were processed using Microsoft Excel 2019 and analyzed using analysis of variance (ANOVA). Differences among treatments were determined based on ANOVA results at a 95% confidence level. When the F-test indicated significant differences, further comparison was conducted using Duncan's multiple range test.

RESULT AND DISCUSSION

Growth Performance

The growth performance of African catfish (*Clarias gariepinus*) fed diets supplemented with different doses of manganese (Mn) was evaluated over a 60-day rearing period. The results showed significant differences (P<0.05) among treatments for several growth parameters, indicating that Mn supplementation in the diet affected the growth of African catfish. The growth performance data of fish fed diets containing different Mn doses are presented in Table 3.

Growth performance of African catfish was assessed based on the difference between initial individual body weight (W_0) and final individual body weight (W_t). Based on one-way ANOVA results, all treatments supplemented with manganese (Mn) exhibited significantly higher growth performance (P<0.05) compared to the control. Final biomass (B_t), final individual weight (W_t), average daily gain (ADG), and specific growth rate (SGR) in all Mn-supplemented treatments were significantly higher (P<0.05) than those of the control group. In contrast, feed conversion ratio (FCR) and protein efficiency ratio (PER) did not differ significantly (P>0.05) among Mn-supplemented treatments. Significant differences (P<0.05) were observed for total feed intake (FI) in the treatments supplemented with 30 and 45 mg/kg Mn. Other parameters, including initial biomass (B_0), initial individual weight (W_0), and survival rate (SR), showed no significant differences (P>0.05) among treatments. Based on these results, dietary supplementation with manganese at a dose of 45 mg/kg feed resulted in the best growth performance.

Discussion

The growth performance of African catfish over a 60-day rearing period showed significant differences (P<0.05) between treatments receiving dietary manganese (Mn) supplementation and the control treatment without Mn addition. Fish fed diets supplemented with Mn at doses of 15, 30, and 45 mg/kg feed exhibited better growth performance than those fed the Mn-free diet. The best growth performance was observed in the treatment supplemented with 45 mg/kg Mn, which resulted in a 34.26% increase in final body weight compared to the control. According to Lall (2022), manganese is an essential mineral required by fish to support optimal growth and feed efficiency.

Table 3. Catfish Growth Performance.

Parameter	Treatment Mn (g/kg)			
	Mn 0	Mn 15	Mn 30	Mn 45
B0 (g)	101.59 ± 0.21^a	101.56 ± 0.14^a	101.62 ± 0.16^a	101.543 ± 0.25^a
Bt (g)	606.42 ± 60.79^d	704.99 ± 32.91^c	783.48 ± 30.81^b	871.37 ± 20.54^a
W0 (g)	10.16 ± 0.02^a	10.16 ± 0.02^a	10.16 ± 0.02^a	10.14 ± 0.03^a
Wt (g)	64.90 ± 3.41^d	75.58 ± 1.25^c	81.13 ± 2.08^b	87.14 ± 2.05^a
SR (%)	93.33 ± 5.77^a	93.33 ± 5.77^a	96.67 ± 5.77^a	100.00 ± 0.00^a
FI (g)	931.62 ± 15.99^c	940.12 ± 12.71^c	964.71 ± 7.89^b	1071.81 ± 12.84^a
ADG (g/day)	0.91 ± 0.06^d	1.09 ± 0.02^c	1.18 ± 0.04^b	1.28 ± 0.04^a
SGR (%)	3.09 ± 0.09^d	3.35 ± 0.03^c	3.46 ± 0.04^b	3.58 ± 0.05^a
FCR	1.69 ± 0.12^b	1.47 ± 0.02^a	1.37 ± 0.03^a	1.39 ± 0.03^a
PER	1.73 ± 0.23^b	2.04 ± 0.14^a	2.24 ± 0.11^a	2.30 ± 0.05^a

*Initial biomass (B0), final biomass (Bt), initial weight (W0), final weight (Wt), survival rate (SR), feed intake (FI), average daily gain (ADG), specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER).
**Different letters in the same row indicate significant differences in each treatment (P<0.05).

Final individual body weight (W_t) and final biomass (B_t) increased significantly in Mn-supplemented treatments, with the highest values observed at the Mn dose of 45 mg/kg feed. This result was supported by the average daily gain (ADG) and specific growth rate (SGR), which reached the highest values of 1.28 ± 0.04 g/day and 3.58 ± 0.05%, respectively. The observed growth enhancement may be attributed to the role of Mn as a cofactor for several enzymes involved in metabolic and physiological process. Mn-dependent glycosyltransferase plays a critical role in the synthesis of proteoglycans, which are essential for cartilage and bone formation, thereby supporting structural growth.

Manganese (Mn) supports fish growth through its involvement in several enzymes systems that regulate nutrient metabolism, skeletal development, and antioxidant defense. As a structural component of metalloenzymes, Mn is required for the activity of arginase, which participate in amino acid metabolism and the urea cycle, thereby promoting efficient protein utilization and nitrogen metabolism (Viegas *et al.,* 2020; Taskozhina *et al.,* 2024). Mn also serves as a cofactor for glycosyltransferases involved in the synthesis of proteoglycans and glycosaminoglycans, which are essential components of the bone and cartilage extracellular matrix and are therefore critical for normal skeletal development (Tseng *et al.,* 2025). In addition, Mn activates pyruvate carboxylase, a key enzyme in gluconeogenesis that supports energy production from non-carbohydrate substrate and contributes to overall metabolic efficiency (Liu *et al.,* 2023).

Another important function of Mn is its role as a structural component of manganese superoxide dismutase (MnSOD), the primary mitochondrial antioxidant enzyme that scavenges reactive oxygen species (ROS). By limiting oxidative damage and preserving cellular function, Mn reduces the energy required for stress responses, allowing more nutrients and energy to be directed toward tissue growth and development (Ren *et al.,* 2023). Together, these physiological functions explain the positive relationship between adequate dietary Mn supplementation and improved growth performance in aquaculture species. Collectively, this mechanism contributes to improve metabolic efficiency, which may explain the enhanced growth performance observed in Mn-supplemented fish. Improved enzymatic activity can ultimately enhance fish growth performance (Watanabe *et al.,* 1997; Hayat *et al.,* 2025; Lall, 2022).

Increasing dietary Mn supplementation enhanced the total feed intake (TFI) of African catfish, suggesting that Mn may play a physiological role in regulating appetite and feeding behavior. Manganese is an essential trace mineral involved in the activation of various enzymes related to metabolism. Improved metabolic efficiency may contribute to enhanced growth performance, which is consistent with the findings of Suprayudi *et al.* (2023), where the trace minerals such as selenium support metabolic processes and promote fish growth. The observed increase in feed intake is consistent with findings by Assan *et al.* (2021), who reported that optimal levels of dietary n can promote feeding activity and improve nutrient utilization in fish, indicating that Mn plays a role in stimulating fish appetite.

The increased total feed intake (TFI) observed in this study likely reflects improved metabolic activity, physiological status, and appetite regulation associated with dietary Mn supplementation. Greater feed consumption may have contributed to the increases in biomass and individual body weight by providing a higher nutrient supply, while Mn-dependent metabolic processes likely enhanced nutrient utilization. These improvements in nutrient intake and utilization were further reflected in feed efficiency, as indicated by the feed conversion ratio (FCR) and protein efficiency ratio (PER). The lowest FCR value was observed in the treatment supplemented with 45 mg/kg Mn (1.39 ± 0.03), indicating that less feed was required to produce one kilogram of biomass compared to the control treatment. Meanwhile, PER reached the highest value (2.30 ± 0.05), indicating efficient conversion of dietary protein into body tissue (Hepher, 1988). This result is further supported by the role of Mn in facilitating protein synthesis and muscle tissue repair through its involvement in enzymes such as arginase (Baj *et al.,* 2023).

In contrast, survival rate (SR) was not significantly affected by dietary Mn supplementation ($P>0.005$), although the highest survival was recorded in fish fed the diet containing 45 mg/kg Mn. The lack of significant differences suggest that all experimental diets supplied sufficient Mn to meet the minimum physiological requirement for survival, whereas additional Mn primarily improved metabolic efficiency, leading to enhanced growth performance and nutrient utilization. This response may be associated with the activity of manganese-dependent superoxide dismutase (MnSOD), which protects mitochondria from oxidative damaged by scavenging reactive oxygen species (Musharraf & Khan, 2021; Lall, 2022). However, survival in cultured fish is also strongly influenced by environment conditions, particularly water quality. Factors such as dissolved oxygen concentration and temperature fluctuations can affect habitat suitability and fish survival, potentially masking the effect of dietary treatments on SR (Skoglund *et al.,* 2022; Park *et al.,* 2024).

Increasing dietary Mn doses significantly enhanced growth rate, feed efficiency, and protein utilization, highlighting the importance of fulfilling trace mineral requirements in fish diets. The growth trend depicted in the growth graph continue to rise, indicating that the optimal Mn dose for African catfish growth had not yet been fully achieved. Based on orthogonal polynomial analysis of ADG in relation to dietary Mn supplementation, the optimal dose was estimated at 66.11 mg/kg feed, corresponding to an ADG of 1.31 g/day. Thabet *et al.* (2021) reported that effective Mn doses for African catfish ranged from 1.2 to 2.45 mg/kg feed. However, their study used manganese oxidative nanoparticles, an inorganic form of Mn. Although inorganic Mn generally has lower bioavailability than organic Mn, the nanoparticle form used in that study has smaller particle size, which enhances bioavailability and accelerates absorption in the digestive tract compared to conventional organic Mn (Lall & Kaushik, 2021). Therefore, the higher Mn doses required in this study using organic Mn can be explained by differences in chemical form and bioavailability between organic Mn and inorganic Mn nanoparticles.

CONCLUSION

Dietary supplementation of manganese (Mn) in the feed formulation significantly affected growth rate, feed efficiency, and protein utilization in African catfish (*Clarias gariepinus*). Feeding Mn at a dose of 45 mg/kg resulted in a 34.26% increase in final body weight (Wt) compared to the control treatment, indicating a substantial improvement in growth performance.

ACKOWLEDGEMENTS

The author gratefully acknowledges the Department of Aquaculture, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, for its support.

REFERENCES

Ali Z, Yousafzai AM, Sher N, Muhammad I, Nayab GE, Aqeel SAM, Shah ST, Aschner M, Khan I, Khan H. 2021. Toxicity and bioaccumulation of manganese and chromium in different organs of common carp (*Cyprinus carpio*) fish. Toxicology Reports 8: 343–348.

AOAC. 2012. Official method of analysis of the association analytical chemist 15th edition. Washington.

Assan D, Huang Y, Mustapha UF, Addah MN, Li G, Chen H. 2021. Fish Feed Intake, Feeding Behavior, and the Physiological Response of Apelin to Fasting and Refeeding. Front Endocrinol (Lausanne) 15: 798903.

Baj J, Flieger W, Barbachowska A, Kowalska B, Flieger M, Forma A, Teresiński G, Portincasa P, Buszewicz G, Radzikowska-Büchner E, Flieger J. 2023. Consequences of Disturbing Manganese Homeostasis. International Journal of Molecular Sciences, 24: 14959.

Effendie MI. 2002. Biologi Perikanan. Yogyakarta, Indonesia: Yayasan Pustaka Nusatama.

Goddard S. 1996. Feed Management in Intensive Aquaculture. New York, United States: Springer New York.

Hayat R, Shah SZH, Fatima M, Ali W, Farooq A. 2025. Manganese supplementation in aquafeed: Current knowledge, research gaps, and future prospects for growth and health optimization. Journal of Trace Elements in Medicine and Biology 93: 127813.

Hayat R, Shah SZH, Fatima M, Hussain SM, Ashraf S, Ali W. 2025. Dietary manganese requirement of *Cirrhinus mrigala* juveniles. Journal of Trace Elements in Medicine and Biology 89: 127639.

Hepher.1988. Nutrition of Pond Fishes. Cambridge (US): Cambridge University

Huissman EA. 1987. *Principles of Fish Production* (p. 187). Netherland (NL): Department of Fish Culture and Fisheries, Wageningen Agricultural University.

Jiang WD, Tang RJ, Liu Y, Wu P, Kuang SY, Jiang J, Tang L, Tang WN, Zhang YA, Zhou XQ, Feng L. 2017. Impairment of gill structural integrity by manganese deficiency or excess related to induction of oxidative damage, apoptosis and dysfunction of the physical barrier as regulated by NF-κB, caspase and Nrf2 signaling in fish. Fish & Shellfish Immunology 70: 280–292.

Kumar N, Thorat ST, Kochewad SA, Reddy KS. 2024. Manganese nutrient mitigates ammonia, arsenic toxicity and high temperature stress using gene regulation via NFkB mechanism in fish. Scientific Reports 14: 1273.

Lall SP, Kaushik SJ. 2021. Nutrition and metabolism of minerals of fish. Animals 11: 1–41.

Lall SP. 2022. The minerals. In Hardy RW, Kaushik SJ. *Fish Nutrition 4th edition*. London: Academic Press. pp. 469–554.

Leach, R. 2022. *Manganese in enteral and parenteral nutrition*. In Bulletin of the New York Academy of Medicine.

Liang JJ, Wang S, Han B, Tian LX, Yang HJ, Liu YJ. 2015. Dietary manganese requirement of juvenile grass carp (*Ctenopharyngodon Idella* Val) based on growth and tissue manganese concentration. Aquaculture Research 46: 2991–2998.

Liu D, Li L, Zhang Q, Yu H. 2023. Effect of dietary manganese on the growth performance, lipid metabolism, and antioxidant capacity in the post-larval Coho salmon (*Oncorhynchus kisutch*). Animals (Basel) 13: 1310.

Lv WH, Fan W, Mette S, Xiao-Ying T, Xiao-Lei W, An-Gen Y, Chonng-Chao Z, Yu-Feng S, Zhi L. 2025. Interaction between dietary zinc (Zn) and manganese (Mn) on growth performance, intestinal health and lipid metabolism in yellow catfish. Aquaculture 596: 741809.

[KKP] Kementerian Kelautan dan Perikanan. 2024. Laporan Kinerja Direktorat Jenderal Perikanan Budidaya Tahun 2024. Jakarta (ID): KKP RI.

Mmanda FP. 2025. Importance of Minerals and Their Bioavailability in Boosting Aquaculture: A Systematic Review. Aquaculture, Fish and Fisheries 5: c70067.

Musharraf M, Khan MA. 2021. Dietary manganese requirement of fingerling Indian major carp, *Labeo rohita* (Hamilton) estimated by growth, tissue manganese concentration and hepatic manganese-superoxide dismutase activity. Aquaculture 540: 736734.

Nguyen NA, Forstater JH, McIntosh JA. 2024. Decarboxylation in Natural Products Biosynthesis. JACS Au. 4: 2175–2745.

Nyarko-Danquah I, Pajarillo E, Digman A, Soliman KFA, Aschner M, Lee E. 2020. Manganese Accumulation in the Brain via Various Transporters and Its Neurotoxicity Mechanisms. Molecules 25: 5880.

Octaviani A, Suprayudi MA, Setiawati M, Fauzi IA. 2024. Evaluation of food digestibility in Nile tilapia fish *Oreochromis niloticus* given NSP enzymes and organic chromium. Jurnal Akuakultur Indonesia 24: 136–147.

Park J, Jang S, Lee H, Gou J, Song I. 2024. Evaluation of fish habitat suitability based on stream hydrodynamics and water quality using SWAT and HEC-RAS linked simulation. Scientific Reports 14.

Pamaharyani LI, Ilham, Zaidy AB. 2024. The use of different carbon sources to maintain water quality and growth performance of sangkuriang catfish (*Clarias gariepinus*) in the biofloc aquaculture system. Journal of Applied Aquaculture 1–18.

Prabhu PAJ, Schrama JW, Kaushik SJ. 2016. Mineral requirements of fish: a systematic review. Reviews in Aquaculture 8: 172–219.

Prabhu PAJ, Silva MS, Kroeckel S, Holme MH, Ornsrud R, Amlund H, Lock EJ, Waagbo R. 2019. Effect of levels and sources of dietary manganese on growth and mineral composition of post-smolt atlantic salmon fes low fish meal, plant-based ingredient diets. Aquaculture 512: 734287.

Ren H, Wang Q, Jin X, Gao G, Mei J, Qi G, He Z, Yang S. 2023. Molecular cloning and expression profiles of MnSOD and CAT genes from the turbot *Scophthalmus maximus*. Israeli Journal of Aquaculture – Bamidgeh 75: 1–11.

[RSC] Royal Society of Chemistry. 2024. *Manganese*. Periodic Table. Available at: https://periodic-table.rsc.org/element/25/manganese [September 27th, 2024].

Skoglund, S., Whitlock, R., Petersson, E., Palm, S., & Leonardsson, K. 2022. From spawner habitat selection to stock-recruitment: Implications for assessment. Ecology and Evolution 12. https://doi.org/10.1002/ece3.9679

[SNI] Standar Nasional Indonesia. 2009. Produksi ikan nila (*Oreochromis niloticus* Bleeker) kelas pembesaran di kolam air tenang. https://pesta.bsn.go.id/produk/detail/8279-sni75502009. [September 28th, 2024].

Son J, Lee WD, Kim CH, Kim H, Hong EC, Kim HJ. 2024. Effect of Dietary Crude Protein Reduction Levels on Performance, Nutrient Digestibility, Nitrogen Utilization, Blood Parameters, Meat Quality, and Welfare Index of Broilers in Welfare-Friendly Environments. Animal (Basel) 14: 3131.

Stickney R, Gatlin D. 2022. Aquaculture: An introductory text 4th edition. CAB International.

Suprayudi MA, Edriani G, Ekasari J. 2012.

Quality evaluation of fermented products of various local agroindustrials by-products: the effect on digestibility and growth performance of common carp juvenile. Jurnal Akuakultur Indonesia 11: 1–10.

Suprayudi MA. 2018. *Peran ilmu nutrisi ikan dan kemandirian bahan pakan local dalam mendukung produksi akuakultur yang berkelanjutan* [Oration IPB]. Bogor (ID): Institut Pertanian Bogor.

Suprayudi MA, Amanullah MR, Jusadi D, Nasrullah H, Latif AY. 2023. Dietary selenium peptide supplementation for increasing the growth of African catfish *Clarias gariepinus*. Jurnal Akuakultur Indonesia 22: 80–86.

Syahrul, Supriyono E, Nirmala K, Lideman. 2023. Growth and quality performances of seaweed (*Kappaphycus alvarezii*) with different combinations of temperature and light parameters. IOP Conference Series: Earth and Environmental Science 1221: 1–8.

Taskozhina, G., Batyrova, G., Umarova, G., Issanguzhina, Z., & Kereyeva, N. 2024. The Manganese–Bone Connection: Investigating the Role of Manganese in Bone Health. Journal of Clinical Medicine 13: 4679.

Thabet SR, Abdel-Galil MAA, Osman AS, Ahmed NS, Mousa MA. 2021. Impact of dietary manganese oxide nanoparticles on biochemical parameters of *Clarias gariepinus*. Assiut Veterinary Medical Journal 67: 118–126.

Tseng Y, Dominguez D, Sivagurunathan U, Zamorano MJ, Philip AJP, Izquierdo M. 2025. Effects of the dietary supplementation of manganese on growth, skeletal development, oxidative stress and bone metabolism related genes in gilthead seabream (*Sparus aurata*) larvae. Aquaculture 594: 741439.

Viegas MN, Salgado MA, Aguiar C, Almeida A, Gavaia P, Dias J. 2020. Effect of Dietary Manganese and Zinc Levels on Growth and Bone Status of Senegalese Sole (*Solea senegalensis*) Post-Larvae. Biological Trace Element Research 199: 2012–2021.

Watanabe T, Kiron V, Satoh S. 1997. Trace minerals in fish nutrition. Aquaculture 151: 185–207.

Wang X, Liu BL, Gao XQ, Fang YY, Zhang XH, Cao SQ, Zhao KF, Wang F. 2022. Effect of long-term manganese exposure on oxidative stress, liver damage and apoptosis in grouper *Epinephelus moara* ♀ × *Epinephelus lanceolatus* ♂. Frontiers in Marine Science 9.

Xu JJ, Jia BY, Zhao T, Tan XY, Zhang DG, Song CC, Song YF, Zito E, Luo Z. 2023. Influences of five dietary manganese sources on growth, feed utilization, lipid metabolism, antioxidant capacity, inflammatory response and endoplasmic reticulum stress in yellow catfish intestine. Aquaculture 566: 739190.

Yu L, Li L, Yu H, Yuan Z, Ma C, Wu X, Kong W. 2024. Effects of dietary manganese supplementation on the growth performance, tissue manganese content and antioxidant capacity of coho salmon (*Oncorhynchus kisutch*) post-smolts. Aquaculture Reports 34: 101924.