Available online at sjuoz.uoz.edu.krd

Science Journal of University of Zakho
Vol. 13, No.1 pp33–39January-March,2025

p-ISSN: 2663-628X
e-ISSN: 2663-6298

DIETARY SILICA NANOPARTICLE AMELIORATES THE GROWTH PERFORMANCE AND MUSCLE COMPOSITION OF STINGING CATFISH, *Heteropneustes fossilis*

Partha Sarathi Das[1], Md Fazle Rohani[2*], Basim. S. A. Al Sulivany[3], Salman Shahriar Nibir[2], Runa Akther Juthi[1], Abdus Satter[1], Md Sazzad Hossain[2*], and Shameeran Salman Ismael[4],

[1]Department of Fisheries, Bangamata Shiekh Fojilatunnesa Mujib Science and Technology University, Jamalpur, Bangladesh.
[2]Department of Aquaculture, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh.
[3]Department of Biology, College of Science, University of Zakho, Zakho, Duhok, Kurdistan Region, Iraq.
[4]Department of Medical Laboratory Sciences, College of Health Sciences, University of Duhok, Duhok, Kurdistan Region,- Iraq.

*Corresponding author email: rohani_aq@bau.edu.bd
*Corresponding author email: sazzadbau@bau.edu.bd

Received: 27 Sep. 2024 Accepted:30 oct. 2024 Published: 05 Jan. 2025 https://doi.org/10.25271/sjuoz.2025.13.1.1394

ABSTRACT:

Silica nanoparticles (Si-NPs) are increasingly prevalent in various industrial applications, potentially impacting aquaculture. The study investigated the effects of dietary Si-NPs on growth performance and its repercussions on muscle compositions in Stinging catfish, *Heteropneustes fossilis (H. fossilis)*. In this study, four isonitrogenous diets containing Si-NPs (0, 1, 2, and 3 mg/kg) were fed to juvenile *H. fossilis* for 60 days. Several growth indices (weight gain, WG; percent weight gain, %WG; length gain, LG; and specific growth rate, SGR), feed utility parameters (feed conversion ratio, FCR; feed conversion efficiency, FCE; and protein efficiency ratio, PER) and survival rate was assessed at the end of the feeding trial. This study showed significant effects of Si-NPs (2 mg/kg) in the growth and muscle composition of *H. fossilis*. However, Si-NPs did not significantly affect the feed utility of *H. fossilis*. The findings of this study recommended that Si-NPs can be effectively supplemented into the diets of *H. fossilis* for better production.
KEYWORDS: Silica nanoparticle; feed; growth; muscle composition; Stinging catfish.

1. INTRODUCTION

Aquaculture is one of the fastest-growing and most influential animal protein sectors globally (Naylor *et al.*, 2021; Hoseini & Al Sulivany, 2024). Particularly for developing Asian and African nations like Bangladesh, this expanded industry has been shown to contribute significantly to food security (Chan *et al.*, 2019). Among the inputs for aquaculture feed accounts for nearly 60-70% of the total production costs which quality must be met to ensure a sustainable production (Akter *et al.*, 2021). Quality feed is the prerequisite for successful aquaculture operations, and it significantly influences the production and profitability of this sector (Singha *et al.*, 2021; Al Habbib & Al Sulivany, 2013). Nowadays, the sustainability of aquaculture is a great challenge due to the ceiling price of the feed ingredients that reduce the profitability of this emerging sector (Daniel *et al.,* 2018). To overcome this significant problem, nutritionists and aquaculturists from all over the world have introduced several strategies such as feed additives, including probiotics (Rohani *et al.*, 2022a; Islam *et al.,* 2021; Jahan *et al.,* 2021); prebiotics (Rohani *et al.*, 2019a; Islam *et al.*, 2020); seaweed (Siddik *et al.,* 2023); micronutrients (Rohani *et al.*, 2019b; Rohani *et al.,* 2022b; Rohani *et al.,* 2023) and nanoparticles (Ghafarifarsani *et al.,* 2024).

Nanoparticles (NPs) are a promising supplement in fish feed, offering a range of benefits for aquaculture. (Sarkar *et al.,* 2022). They have been studied for their potential to enhance the bioavailability and absorption of nutrients, thereby playing a significant role in improving the growth and health of farmed fish species. (Misra *et al.,* 2023). By increasing the bioactivity of molecules, particularly micronutrients, NPs can improve aquaculture productivity (Shah & Mraz, 2020). Additionally, it can allow for the tissue-specific application of disease treatments without compromising human health (Jennings *et al.*, 2016). Because of their large specific surface area, NPs can be used as feed additives because they help both terrestrial and aquatic animals absorb micronutrients from the intestine into the bloodstream (Khosravi-Katuli *et al.*, 2017; Pieszka *et al.*, 2019). Application of Silica nanoparticles (Si-NPs) in the production of animals, including fish, is gaining popularity due to their exceptional optical properties, adsorption capacity, low toxicity, biocompatibility, thermal stability, and low production cost (Bitar *et al.,* 2012; Priyadarsini *et al.*, 2018).It has been reported that Si-NPs improve fish welfare by making medication administration easier and lowering the chance of disease outbreaks, even in cases of extreme crowding (Khosravi-Katuli *et al.*, 2017). Furthermore, studies have shown that Si-NPs are helpful for treating wastewater (Jarvie *et al.*, 2009), managing the microbial load (Huang *et al.*, 2015), and promoting the growth of aquatic species (Bashar *et al.,* 2021).

Stinging catfish (*Heteropneustes fossilis*) along with other catfish species, play a significant role in global aquaculture (Ali *et al.*, 2018). This species is considered a good source of protein with some medicinal benefits (Rahman *et al.*, 2014). With excellent suitability in different aquaculture systems (Mahmud *et al.*, 2017), tanks (Ahamed *et al.*, 2023), and recirculatory and bio-flock systems (Sohel et al., 2023) the importance of this species has increased. Despite the remarkable potential of Si-NPs in aquaculture, there is very limited information regarding their role in important farmed species, such as *H. fossilis*. Therefore, the current study was carried out to investigate the effects of dietary Si-NPs on growth performance, feed utilization, and muscle composition in *H. fossilis*.

* Corresponding author

2. MATERIALS AND METHODS

Ethical Issues:

The Bangladesh Agricultural University Research System's ethical committee reviewed and approved the experimental design and implementation (Code Number: BAU-FoF/2023/005). The fish were fed, handled, and sacrificed according to the animal welfare and ethical committee's established regulations.

Experimental Fish:

Stinging catfish fry, weighing 1.00 g (± 0.10 g) from the same breeding stock, were procured from Reliance Hatchery Ltd., Mymensingh, Bangladesh. There was no sign of diseases and/or abnormalities. After collection, the fry was acclimatized for 7 days in the experimental system. Fish were fed a controlled diet, and an oxygen supply was kept consistent during the acclimation period. After 7 days, fish were randomly assigned to the replication tanks at a density of 94 per cubic meter (15 fish per 160 L tank).

Physicochemical Parameters:

The water quality parameters in the aquaculture tanks were evaluated using various instruments and a multimeter. These parameters included temperature (24.3°C), pH (6.3), electrical conductivity (453 µS/cm), total dissolved solids (290 ppm), turbidity (3.4 NTU), dissolved oxygen (5.9 mg/L), total hardness (238 mg/L), 5-day biological oxygen demand (2.7 mg/L), and total alkalinity (135 mg/L).

Experimental Design:

Four diets with graded Si-NPs (0, 1, 2 and 3 mg/kg) were fed to *H. fossilis*. A static aquaria system with 20 rectangular glass tanks (0.64m × 0.5m × 0.5m) was developed in the Wet Laboratory, Faculty of Fisheries, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh. Five replications for each dietary treatment were used. Fifteen fry of uniform body weight (1.00 ± 0.10 g) and length (5.59 ± 0.14 cm) were randomly stocked in each tank. The fish were fed for 60 days. Twenty-four hours of continuous aeration and a water depth of 0.4m were maintained throughout the feeding trial. The overview of the experimental design is presented in the following figure:

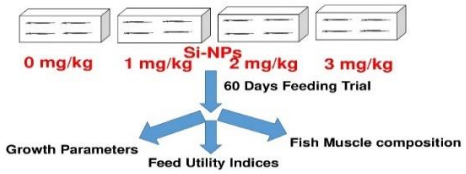

Figure: Overview of experimental design

Diet Formulation and Feeding Trial

Highly pure Si-NPs composed of more than 98% of silicon dioxide (SiO_2), 0.08% Al_2O_3, 0.05% Fe_2O_3, and CaO, 0.5% K_2O, and 0.10% TiO_2, were imported from Canada and activated in Fish Nutrition Laboratory of Department of Aquaculture, BAU. Feed was formulated with locally available ingredients, including fish meal, mustard oil cake, soybean meal, rice bran, wheat bran, molasses, vitamins and minerals premix, etc. Protein level was maintained at 30% for the experimental fishes. Four different dosages of Si-NPs were added to diets, namely 0 mg/kg (T0, control), 1 mg/kg (T_1), 2 mg/kg (T_2), and 3 mg/kg (T_3). The proximate composition analysis of the formulated diets (Table 1) was carried out in the Fish Nutrition Laboratory, Department of Aquaculture, Bangladesh Agricultural University, Mymensingh, by following standard procedures (AOAC, 2005). Pellet feed was made with the help of a pelletizer and kept in air-tight poly bags at -20°C until further use, following a 4-day drying period. The diets were provided at 5% of the body weight, having two times feeding frequency (9 am and 5 pm) for 60 days. Fish were sampled bi-weekly to monitor the growth and adjust the daily ration

Table 1: The inclusion level of Si-NPs and proximate composition of the formulated diets

Name of Items	T_0	T_1	T_2	T_3
Silica NP (mg)	0	1	2	3
Moisture (%)	13.85	13.3	12.91	13.16
Crude Lipid (%)	5.89	6.24	6.35	5.95
Crude Protein (%)	30.04	30.11	30.18	30.01
Ash (%)	8.27	9.2	9.23	9.55
Crude Fiber (%)	5.23	5.47	5.15	5.21
Carbohydrate (%)	35.86	34.22	33.68	33.17

Growth and Feed Utilization Parameters:

At the end of the feeding trial, growth indices were calculated according to the following formulae (Kari *et al.,* 2023; Al Sulivany *et al.,* 2024):

1. Weight gain (g) = Final weight (g) − Initial weight(g)
2. Percent weight gain (%) = (Weight gain (g))/ (Initial weight (g)) × 100
3. Specific growth rate (% per day) = (Ln (final weight) − Ln (initial weight))/ (study period (day)) × 100.
4. Daily growth coefficient (% per day) = (final weight $(g)^{0.33}$ − initial $weight(g)^{0.33}$)/ (study period (day)) × 100
5. Condition factor = (final weight (g))/ (final length (cm)^3)
6. Survival rate (%) = (final number)/ (initial number) × 100

Feed utilization parameters were calculated from the following formulae (Roslan *et al.,* 2024):

7. Food conversion ratio = (dry feed fed (kg))/ (live weight gain (kg))
8. Food efficiency ratio = (live weight gain (kg))/ (dry feed fed (kg)
9. Protein efficiency ratio = (total weight gain (g))/ (protein intake (g))

Fish Muscle Composition:

At the end of the feeding trial, five fish from each replication were caught by a dip net, killed by a sharp blow on the head, and dissected by scissors to determine the proximate composition of the muscle (Adineh *et al.,* 2024). The contents of crude protein, crude lipid, moisture, and ash were calculated following AOAC (2005). The total nitrogen content was determined using the micro-Kjeldahl analysis (method 945.01) and multiplied by the conversion factor (6.25) to translate it into the total crude protein content. Crude fat, ash, and moisture content were estimated by Soxhlet extraction (method 920.39C), by calcination in a muffle furnace at 550°C for 5 h (method 942.05), and by drying in a hot-air oven at 105◦C (method 950.01), respectively. The crude fiber

content (only for feed samples) was estimated with Fiber Tech (Tulin equipment, India) following the calcination in a muffle furnace.

Statistical Analysis:

The data were analyzed using R-Studio (RStudio Team, 2022) and presented as mean ± SD. The significance of various levels of Si-NPs on the measured responses was ascertained using a one-way ANOVA. To specify the differences among the treatments, a multiple-range test of Tukey at a 5% significance level was performed. $p < 0.05$ was considered to be statistically significant.

3. RESULTS

Growth Performance and Feed Efficiency:

This study evaluated the effects of different level of dietary Si-NPs on growth parameters. The results showed significant differences between the groups in various growth metrics (Table 2). For final weight, significant differences were observed, with T_2 achieving the highest value (8.88 ± 0.481 g), significantly higher than T_0 (6.85 ± 0.248 g) ($p < 0.01$). T_3 and T_1 had final weight of 8.29 ± 0.6 g and 7.35 ± 0.342 g, respectively, indicating dose-dependent effects. The final length also followed a similar pattern, with T_2 having the longest length (12.19 ± 0.352 cm), significantly greater than T_0 (10.77 ± 0.208 cm) ($p < 0.01$). T_3 and T_1 showed intermediate increases (11.68 ± 0.307 cm and 11.27 ± 0.271 cm, respectively).

Survival rate, T_2 had the highest rate (93.33%), followed by T_0 (90%) and T_1 (80%), while T_3 showed a significant drop (70%) ($p < 0.01$). In terms of weight gain, T_2 demonstrated the most substantial increase (7.6 ± 0.495 g), significantly greater than T_0 (5.68 ± 0.255 g) ($p < 0.01$). T_3 (7.03 ± 0.596 g) and T_1 (6.12 ± 0.339 g) also showed marked improvements. The SGR was significantly higher in T_2 (3.22 ± 0.108%), followed by T_3 (3.13 ± 0.119%) and T_1 (2.98 ± 0.077%), with the control showing the lowest value (2.95 ± 0.077%) ($p < 0.05$). Daily weight gain mirrored these trends, with T_2 having the highest value (0.13 ± 0.008 g), significantly greater than T0 (0.09 ± 0.004 g) ($p < 0.01$). T_3 and T_1 had daily weight gain of 0.12 ± 0.01 g and 0.1 ± 0.006 g, respectively. On the other hand, the condition factor in the control (0.55 ± 0.016) had the highest value, with a significant decrease in T_1 (0.51 ± 0.018) and T_2 (0.49 ± 0.023) ($p < 0.01$), although T_3 showed a slight recovery (0.52 ± 0.01).

Furthermore, the percent weight gain was the highest value in T_2 (593.47 ± 45.796%), followed by T_3 (555 ± 45.611%), with T_0 showing the lowest value (489.06 ± 27.346%) ($p < 0.05$). T_1 exhibited a moderate improvement (497.33 ± 27.323%).

The food conversion ratio for T_0 averaged 1.94 ± 0.065, while the values for T_1, T_2, and T_3 were 2.03 ± 0.082, 2.05 ± 0.134, and 2.03 ± 0.126, respectively, with no statistically significant differences observed ($p = 0.3999$). Similarly, the food conversion efficiency showed no substantial variation between groups, with T_0 recording a mean of 0.52 ± 0.017, and T_1, T_2, and T_3 yielding 0.49 ± 0.02, 0.49 ± 0.033, and 0.49 ± 0.029, respectively ($p = 0.3902$). Likewise, protein conversion efficiency remained consistent across treatments, with T_0 displaying a mean of 1.72 ± 0.057 and T_1, T_2, and T_3 showing means of 1.64 ± 0.066, 1.63 ± 0.109, and 1.65 ± 0.096, respectively ($p = 0.3902$).

Table 2: The effects of Si-NPs on growth performance and feed efficiency of *H. fossilis* after 60 days of feeding trial

Growth parameters	Control (T_0)	T_1	T_2	T_3	p-values
Initial Weight (g)	1.16 ± 0.027	1.16 ± 0.014	1.16 ± 0.015	1.16 ± 0.014	0.3116
Initial Length (cm)	5.42 ± 0.104	5.43 ± 0.096	5.42 ± 0.117	5.44 ± 0.115	0.3212
Final Weight (g)	6.85 ± 0.248^{b}	7.35 ± 0.342^{b}	8.88 ± 0.481^{a}	8.29 ± 0.6^{a}	<0.01
Final Length (cm)	10.77 ± 0.208^{c}	11.27 ± 0.271^{bc}	12.19 ± 0.352^{a}	11.68 ± 0.307^{ab}	<0.01
Survival Rate (%)	90b	80c	93.33a	70d	<0.01
Weight Gain (g)	5.68 ± 0.255^{b}	6.12 ± 0.339^{b}	7.6 ± 0.495^{a}	7.03 ± 0.596^{a}	<0.01
Length Gain (cm)	5.35 ± 0.187^{c}	$5.66 \pm 0.282b^{c}$	6.39 ± 0.329^{a}	5.96 ± 0.307^{ab}	<0.01
Specific growth rate (%)	2.95 ± 0.077^{b}	2.98 ± 0.077^{b}	3.22 ± 0.108^{a}	3.13 ± 0.119^{ab}	<0.05
Daily weight gain (g)	0.09 ± 0.004^{b}	0.1 ± 0.006^{b}	0.13 ± 0.008^{a}	0.12 ± 0.01^{a}	<0.01
Condition factor	0.55 ± 0.016^{a}	0.51 ± 0.018^{b}	0.49 ± 0.023^{b}	0.52 ± 0.01^{ab}	<0.01
Percent weight gain	489.06 ± 27.346^{b}	497.33 ± 27.323^{b}	593.47 ± 45.796^{a}	555 ± 45.611^{ab}	<0.05
Feed parameters					
Food conversion ratio	1.94 ± 0.065	2.03 ± 0.082	2.05 ± 0.134	2.03 ± 0.126	0.3999
Food conversion efficiency	0.52 ± 0.017	0.49 ± 0.02	0.49 ± 0.033	0.49 ± 0.029	0.3902
Protein conversion efficiency	1.72 ± 0.057	1.64 ± 0.066	1.63 ± 0.109	1.65 ± 0.096	0.3902

★ Results are presented as mean ± SD. Means in the same row with different superscript letters are significant ($p < 0$.

Muscle Composition of H. Fossilis

Table 3 presents the proximate muscle composition of Stinging catfish after a 60-day feeding trial with diets supplemented with varying concentrations of Si-NPs. The moisture content analysis showed significant differences between treatments, with T_0 having the highest moisture content (78.09 ± 0.005%) and T_1 the lowest (77.28 ± 0.005%). T_2 and T_3 exhibited intermediate moisture levels of 77.54 ± 0.005% and 77.86 ± 0.005%, respectively ($p < 0.001$). Regarding crude lipid content, T_2 recorded the highest value (3.33 ± 0.005%), significantly higher than T_0 (3.15 ± 0.005%) and the other groups. T_1 and T_3 had lower lipid levels of 2.88 ± 0.005% and 2.92 ± 0.025%, respectively ($p < 0.001$).

The crude protein content was significantly affected by Si-NP supplementation, with T_1 and T_2 showing the highest values (15.33 ± 0.025% and 15.32 ± 0.005%, respectively), while T_0 and T_3 exhibited lower protein levels at 14.88 ± 0.005% and 14.46 ± 0.005%, respectively ($p < 0.001$). For ash content, T_1 had the highest value (2.95 ± 0.03%), significantly greater than T_0 (2.23 ± 0.015%) and the other groups. T_0, T_2, and T_3 showed similar ash contents of 2.23 ± 0.015%, 2.21 ± 0.0075%, and 2.27 ± 0.008%, respectively ($p < 0.001$). Furthermore, the crude fiber content increased with higher Si-NP doses, with T_3 having the highest value (1.58 ± 0.005%) and T_0 the lowest (1.26 ± 0.01%). T_1 and T_2 exhibited intermediate values of 1.39 ± 0.005% and 1.46 ± 0.005%, respectively ($p < 0.001$). Similarly, carbohydrate content showed significant differences across treatments, with T_3 exhibiting the highest level (0.91 ± 0.01%), while T_0, T_1, and T_2 had carbohydrate contents of 0.41 ± 0.005%, 0.16 ± 0.005%, and 0.14 ± 0.005%, respectively ($p < 0.001$). These results demonstrate that dietary Si-NP supplementation significantly influences the muscle composition of *H. fossilis*, particularly affecting moisture, lipid, protein, ash, fiber, and carbohydrate contents in a dose-dependent manner.

Table 3: Final muscle composition of *H. fossilis* after 60 days of feeding trial

Treatments	T_0	T_1	T_2	T_3	Significance
Moisture	78.09 ± 0.005^a	77.28 ± 0.005^d	77.54 ± 0.005^c	77.86 ± 0.005^c	<0.001
Crude lipid	3.15 ± 0.005^b	2.88 ± 0.005^c	3.33 ± 0.005^a	2.92 ± 0.025^c	<0.001
Crude protein	14.88 ± 0.005^c	15.33 ± 0.025^a	15.32 ± 0.005^a	14.46 ± 0.005^c	<0.001
Ash	2.23 ± 0.015^b	2.95 ± 0.03^a	2.21 ± 0.0075^b	2.27 ± 0.008^b	<0.001
Crude fiber	1.26 ± 0.01^d	1.39 ± 0.005^c	1.46 ± 0.005^b	1.58 ± 0.005^a	<0.001
Carbohydrate	0.41 ± 0.005^b	0.16 ± 0.005^c	0.14 ± 0.005^c	0.91 ± 0.01^a	<0.001

★ Results are presented as mean ± SD. Means in the same row with different superscript letters are significant ($p < 0.05$)

4. DISCUSSION

Nanoparticles, as a part of nanotechnology, have become very popular in the aquaculture industry in the very recent years due to their positive role regarding the growth, immunity, disease resistance and overall well-being of several farmed aquaculture species (Khalefa *et al*., 2024; Mahboub *et al.,* 2024). Sever-al nanoparticles are used in different aquatic animals throughout the globe. The application of Si-NPs has significantly improved the growth of stinging catfish in the current study. Many studies have demonstrated that the provision of Si-NPs in the diet remarkably enhanced the growth performance of farmed fish species, including rohu, *Labeo rohita* (Murshed *et al.,* 2023) and Nile tilapia, *Oreochromis niloticus* (Bashar *et al.,* 2021). This growth increment could be attributed to the nutrient-carrying capacity of Si-NPs that may play a role in the better digestion and absorption of essential nutrients through controlled encapsulation and enhance their availability to the associated fish species (Bahabadi *et al.,* 2017). In addition, NPs are crucial in improving gut microbial activity, which may contribute to better nutrient utilization (Onuegbu *et al.,* 2018). However, a specific investigation is required with Si-NPs. Moreover, enhanced nutrient digestibility, especially protein digestibility, by dietary Si-NPs could also contribute to the growth increment in the current fish species (Bashar *et al.,* 2021). Fish primarily obtain their metabolic energy from protein, specifically amino acids (Walton & Cowey, 1982; Wu *et al.*, 2020). Lipids are stored in fish liver and muscles as a backup source if no adequate energy is found through protein (Kim *et al*., 2012; Zhang *et al*., 2019). Si-NPs undoubtedly increase digestibility and absorption of nutrients, including proteins and lipids (Bashar *et al*., 2021). However, higher levels of Si-NPs could negatively affect the growth performance of fish due to toxicity (Rashidian *et al.,* 2023).

In the current study, dietary Si-NPs significantly enhanced the muscle protein concentration in Stinging catfish. Asad *et al.* (2023) and El-Shenawy *et al.* (2019) also observed protein increment in the muscle of *Labeo rohita* and *Oreochromis niloticus*, respectively, due to the incorporation of iron (Fe) nanoparticles in the diet. This may be a result of the enhanced protein adsorption ability of nanoparticles that can enhance protein linking, which results in enhanced protein retention in the fish muscle (Asad *et al*., 2023). Dietary Si-NPs likely also improved the muscle lipid level in the current study. Similar results have also been found in *Clarias batrachus* (Akter *et al.,* 2018), and *Labeo rohita* (Asad *et al*., 2023) due to the provision of Fe-NPs in their diet. This could be attributed to the lipoprotein binding ability of nanoparticles in the blood, which resulted in higher lipid metabolism as well as enhanced lipid retention in the fish muscle (Asad *et al.,* 2023).

CONCLUSION

In summary, dietary Si-NPs positively ameliorate the growth performance and fish muscle composition of Stinging catfish, and the best result was observed at 2 mg/kg Si-NPs. This level of Si-NPs can be effectively recommended as an important dietary supplementation for the better production of Stinging catfish as well as feed manufacturing companies associated in the preparation of fish feed. However, further investigations are recommended to determine the role of dietary Si-NPs on digestive enzyme activities, immune status and disease resistance of the host fish species.

Acknowledgements:

Bangladesh Agricultural University Research System (BAURES) are gratefully acknowledged for providing a grant to the corresponding author (MS Hossain) to conduct this study.

Author Contributions

P.S.D., was responsible for investigation, data analysis, and writing. M.F.R., Methodology, formal analysis, writing –editing, supervision, B.S.A.A.S., contributed in writing and resources, S.S.N., investigation and data curation. R.A.J., formal analysis. A.S., contributed investigation and resources. M.S.H., writing, and editing; and S.S.I. assisted with writing. All authors read and approved the final manuscript.

Funding

Nil

REFERENCES

Adineh, H., Yousefi, M., Al Sulivany, B. S. A., Ahmadifar, E., Farhangi, M. & Hoseini, S. M. (2024). Effects of dietary yeast, *Saccharomyces cerevisiae*, and Costmary, *Tanacetum balsamita*, essential oil on growth performance, digestive enzymes, biochemical parameters, and disease resistance in Nile tilapia, *Oreochromis niloticus*. *Aquaculture Nutrition*, Article ID 1388002, 11. https://doi.org/10.1155/2024/1388002

Ahamed, M. T., Siddique, M. A. B., Akter, S., Nahiduzzaman, M., Rahman, M. H. & Haque, M. A. (2023). Culture suitability of stinging catfish *Heteropneustes fossilis* in homestead tank: Selection of suitable stocking size. *Archives of Agriculture and Environmental Science*, 8(3):319324.https://doi.org/10.26832/24566632.2023.080307

Al Habbib, O. A. M & Al Sulivany, B. S. A. (2013). Effect of omega-3 and multivitamins on aluminum-induced changes in serum and tissue enzyme activities in rats, *Science Journal of University of Zakho*, 1(1): 65-71. https://sjuoz.uoz.edu.krd/index.php/sjuoz/article/view/38/16

Al Sulivany, B. S. A., Gali Romani, F. A. M., Mohammed, D. A. & Khaleefah, R. S. (2024). Winter dietary protein impacts on growth performance of *Cyprinus carpio*, *Egyptian Journal of Aquatic Biology and Fishers*, 28(5): 701-716. DOI: 10.21608/ejabf.2024.380406

Akter, S., Jahan, N., Rohani, M. F., Akter, Y., & Shahjahan, M. (2021). Chromium supplementation in diet enhances growth and feed utilization of striped catfish (*Pangasianodon hypophthalmus*). *Biological Trace Element Research,* 199: 4811-4819. https://doi.org/10.1007/s12011-021-02608-2

Akter, N., Alam, M. J., Jewel, M. A. S., Ayenuddin, M., Haque, S. K., & Akter, S. (2018). Evaluation of dietary metallic iron nanoparticles as feed additive for growth and physiology of Bagridae catfish *Clarias batrachus* (Linnaeus, 1758). *International Journal of Fisheries and Aquatic Studies*, 6(3): 371-377.

Ali, A., Rahman, M. R., Alam, M. J., Nishat, A. A., Fazla Rabbi, M., Haque, M. A., Islam, R., Azam, M. R., & Ullah, M. A. (2018). Production of Stinging catfish (*Heteropneustes fossilis*) in different stock-ing densities with GIFT (*Oreochromis niloticus*) and Thai sharpunti (*Barbonymus gonionotus*) in ponds. *Journal of Fisheries and Life Science*, 3(1): 9-15.

AOAC. (2005). Official Methods of Analysis. eds W. Horwitz and G. W. Latimer (W. Horwitz & G. Latimer (eds.)). Association ofOfficial Analytical Chemists (AOAC) International.

Asad, F., Qam er, S., Shaheen, Z., Jamal, R., Bano, S., Nadeem, A., Batool, N., & Anwar, N. (2023). Dietary effects of iron and iron oxide nanoparticles on growth, muscle composition and hematological aspects of *Labeo rohita*. *University of Sindh Journal of Animal Sciences*, 7(2): 1-8.

Bahabadi, M. N., Delavar, F. H., Mirbakhsh, M., Niknam, K., & Johari, S. A. (2017). Assessment of antibacterial activity of two different sizes of colloidal silver nanoparticle (cAgNPs) against *Vibrio harveyi* isolated from shrimp *Litopenaeus vannamei*. *Aquaculture International*, 25: 463-472. doi: 10.1007/s10499-016-0043-8

Bashar, A., Hasan, N. Al, Haque, M. M., Rohani, M. F., & Hossain, M. S. (2021). Effects of dietary silica nanoparticle on growth performance, protein digestibility, hematology, digestive morphology, and muscle composition of Nile tilapia, *Oreochromis niloticus*. *Frontiers in Marine Science*, 8: 1-14. https://doi.org/10.3389/fmars.2021.706179

Bitar, A., Ahmad, N. M., Fessi, H., & Elaissari, A. (2012). Silica-based nanoparticles for biomedical applications. *Drug Discovery Today*, 17(19-20): 1147-1154. https://doi.org/10.1016/J.DRUDIS.2012.06.014

Chan, C. Y., Tran, N., Pethiyagoda, S., Crissman, C. C., Sulser, T. B., & Phillips, M. J. (2019). Prospects and challenges of fish for food security in Africa. *Global Food Security*, 20: 17-25. https://doi.org/10.1016/j.gfs.2018.12.002

Daniel, N. (2018). A review on replacing fish meal in aqua feeds using plant protein sources. *International Journal of Fisheries and Aquatic Studies*, 6(2): 164-179.

El-Shenawy, A. M., Gad, D. M. & Yassin, S. A. (2019). Effect of iron nanoparticles on the development of fish farm feeds, *Alexandria Journal of Veterinary Sciences*, 60(1): 102-115.

Ghafarifarsani, H., Hoseinifar, S. H., Raeeszadeh, M., Vijayaram, S., Rohani, M. F., Van Doan, H., & Sun, Y. Z. (2024). Comparative effect of chemical and green zinc nanoparticles on the growth, hematology, serum biochemical, antioxidant parameters, and immunity in serum and mucus of Goldfish, *Carassius auratus* (Linnaeus, 1758). *Biological Trace Element Research*, 202: 1264-1278. https://doi.org/10.1007/s12011-023-03753-6

Hoseini, S. M. & Al Sulivany, B. S. A. (2024). Copper and microplastic exposure affect the gill gene expression of common carp during saltwater challenge. *Science Journal of University of Zakho*, 12(3): 382-387. https://doi.org/10.25271/sjuoz.2024.12.3.1335

Huang, S., Wang, L., Liu, L., Hou, Y., & Li, L. (2015). Nanotechnology in agriculture, livestock, and aquaculture in China. A review. *Agronomy for Sustainable Development*, 35(2): 369-400. https://doi.org/10.1007/S13593-014-0274-X/TABLES/6

Islam, M. M., Rohani, M. F., Rahman, M. H., Tandra, T. S., Alam, M., & Hossain, M. S. (2020). Suitability and efficacy of potato as prebiotic compound on the growth performance of rohu (*Labeo rohita*). *Journal of Agriculture, Food and Environment*, 1(1): 20-25.

Islam, S. M. M., Rohani, M. F., & Shahjahan, M. (2021). Probiotic yeast enhances growth performances of Nile tilapia (*Oreochromis niloticus*) through morphological modifications of intestine. *Aquaculture Reports*, 21: 100800. https://doi.org/10.1016/j.aqrep.2021.100800.

Jahan, N., Islam, S. M. M., Rohani, M. F., Hossain, M. T., &Shahjahan, M. (2021). Probiotic yeast enhances growth performances of rohu (*Labeo rohita*) through upgrading hematology, and intestinal microbiota and morphology. *Aquaculture,* 545:737243.https://doi.org/10.1016/j.aquaculture.2021.737243

Jarvie, H. P., Al-Obaidi, H., King, S. M., Bowes, M. J., Lawrence, M. J., Drake, A. F., Green, M. A., & Dobson, P. J. (2009). Fate of silica nanoparticles in simulated primary wastewater treatment. *Environmental Science and Technology*, 43(22): 8622-8628.

https://doi.org/10.1021/ES901399Q/SUPPL_FILE/ES901399Q_SI_001.PDF.

Jennings, S., Stentiford, G. D., Leocadio, A. M., Jeffery, K. R., & Metcalfe, J. D., *et al*. (2016). Aquatic food security: insights into challenges and solutions from an analysis of interactions between fisheries, aquaculture, food safety, human health, fish and human welfare, economy and environment. *Fish and Fisheries*, 17(4): 893-938. https://doi.org/10.1111/faf.12152

Kari, Z. A., Rohani, M. F., Davies, S. J., &Wei, L. S. (2023). Effect of fish meal substitution with Black Soldier Fly (*Hermetia illucens*) on growth performance, feed stability, blood biochemistry, liver and gut morphology of Siamese fighting (*Betta splendens*). *Aquaculture Nutrition,* Article ID 6676953. https://doi.org/10.1155/2023/6676953

Khalefa, H. S., AbuBakr, H. O., Aljuaydi, S. H., Kotp, Y. H., Al-Mokaddem, A. K., & Abdel-Moneam, D. A. (2024). Aquatic assessment of the chelating ability of Silica-stabilized magnetite nanocomposite to lead nitrate toxicity with emphasis to their impact on hepatorenal, oxidative stress, genotoxicity, histopathological, and bioaccumulation parameters in *Oreochromis niloticus* and *Clarias gariepinus*. *BMC Veterinery Reserach*, 20(1): 262. DOI: 10.1186/s12917-024-04094-9.

Khosravi-Katuli, K., Prato, E., Lofrano, G., Guida, M., Vale, G., & Libralato, G. (2017). Effects of nanoparticles in species of aquaculture interest. *Environmental Science and Pollution Research,* 24(21): 17326-17346. https://doi.org/10.1007/S11356-017-9360-3

Kim, K. D., Lim, S. G., Kang, Y. J., Kim, K. W., &Son, M. H. (2012). Effects of dietary protein and lipid levels on growth and body composition of juvenile far eastern catfish, *Silurus asotus*. *Asian-Australasian Journal of Animal Sciences*, 25(3): 369-374. https://doi.org/10.5713/ajas.2011.11089

Mahboub, H. H., Gad, W. M., Aziz, E. K., Nasr, M. A., Fahmy, E. M., Mansour, D. M., Rasheed, N., Ali, H. S., Ismail, S. H., & Abdel Rahman, A. N. (2024). Silica nanoparticles alleviate the immunosuppression, oxidative stress, biochemical, behavioral, and histopathological alterations induced by *Aeromonas veronii* infection in African catfish (*Clarias gariepinus*). *Fish Physiology and Biochemistry*, 50(2): 767-783. doi: 10.1007/s10695-023-01274-6.

Mahmud, Y., Rahman, K., Ahamed, S., Rashidul Hasan, K., & Hossain, M. (2017). Adaptability of polyculture of stinging Catfish (*Heteropneustes fossilis*) in seasonal water bodies of greater northern region, Bangladesh. *International Journal of Fisheries and Aquatic Studies*, *5*(1): 433-439. www.fisheriesjournal.com

Misra, V. K., Gupta, S., Singh, C. P., Singh, S., & Kumar, A. (2023). Nanoencapsulation of nutrients in fish feed : Enhancing bioavailability, absorption, and health benefits for farmed fish. *Biological Forum*, 15(5a): 632-639.

Murshed, S., Rahman, M. H., Mahruf, B., Najmunnahar, Mostakima, S., & Hossain, M. S. (2023). Impact of silica nanoparticles on the digestibility and growth efficiency of rohu (*Labeo rohita*). *Journal of Agriculture, Food and Environment*, 4(4): 24-30.

Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., ...; & Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature*, 591(7851): 551-563.

Onuegbu, C. U., Aggarwal, A., & Singh, N. B. (2018). ZnO nanoparticles as feed supplement on growth performance of cultured African catfish fingerlings. *Journal of Scientific and Industrial Research*, 77: 213-218.

Pieszka, M., Bederska-łojewska, D., Szczurek, P., & Pieszka, M. (2019). The membrane interactions of nano-silica and its potential application in animal nutrition. *Animals,* 9(12): 1041. https://doi.org/10.3390/ANI9121041

Priyadarsini, S., Mukherjee, S., & Mishra, M. (2018). Nanoparticles used in dentistry: A review. *Journal of Oral Biology and Craniofacial Research*, 8(1): 58–67. https://doi.org/10.1016/J.JOBCR.2017.12.004

Rahman, S., Monir, M. S., & Mou, M. H. (2014). Culture potentials of stinging catfish shing (*Heteropneustes fossilis*) under different stocking densities in northern region of Bangladesh. *Treands in FIsheries Research*, 3(3): 1-6.

Rashidian, G., Mohammadi-Aloucheh, R., Hosseinzadeh-Otaghvari, F., Chupani, L., Stejskal, V., Samadikhah, H., Zamanlui, S., Multisanti, C. R., & Faggio, C. (2023). Long-term exposure to small-sized silica nanoparticles (SiO2-NPs) induces oxidative stress and impairs reproductive performance in adult zebrafish (*Danio rerio*). *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, 273: 109715. https://doi.org/10.1016/j.cbpc.2023.109715.

Rohani, M. F., Rahman, M. S., Sarker, S., Rana, M. M., & Hossain, M. S. (2019a). Efficacy of whole wheat flour as prebiotic compound on the growth performance and survival rate of catla (*Catla catla*). *International Journal of Fisheries and Aquatic Studies*, 7(5): 394-399.

Rohani, M. F., Das, M., & Hossain, M. S. (2019b). Effect of dietary vitamin E on growth and survival rate of the giant freshwater prawn, *Macrobrachium rosenbergii*. *Bangladesh Journal of Fisheries*, 31(1): 49-54.

Rohani, M. F., Bristy, A. A., Hasan, J., Hossain, M. K., & Shahjahan, M. (2022b). Dietary Zinc in association with vitamin E promotes growth performance of Nile Tilapia. *Biological Trace Element Research*, 200: 4150-4159. https://doi.org/10.1007/s12011-021-03001-9

Rohani, M. F., Islam, S. M. M., Hossain, M. K., Ferdous, Z., Siddik, M. A. B., Nuruzzaman, M., Padeniya, U., Brown, C., & Shahjahan, M. (2022a). Probiotics, prebiotics and synbiotics improved the functionality of aquafeed: upgrading growth, reproduction, immunity and disease resistance in fish. *Fish and Shellfish Immunology*, 120: 569-589. https://doi.org/10.1016/j.fsi.2021.12.037

Rohani, M. F., Tarin, T., Hasan, J., Islam, S. M. M., & Shahjahan, M. (2023). Vitamin E supplementation in diet ameliorates growth of Nile tilapia by upgrading muscle health. *Saudi Journal of Biological Sciences*, 30(2): 103558. https://doi.org/10.1016/j.sjbs.2023.103558

Roslan, N. A., Sukri, S. A. M., Wei, L. S., Shahjahan, M., Rohani, M. F., Yea, C. S., Kabir, Y. A., Guru, A., Who, K. W., Kallem, P., & Kari, Z. A. (2024). Replacement of fishmeal by fermented spent coffee ground: Effects on growth performance, feed stability, blood biochemistry, liver, and intestinal morphology of African catfish (*Clarias gariepinus*). *Aquaculture Reports*, 36: 102073.

RStudio Team. (2022). RStudio: Integrated Development Environment for R. http://www.rstudio.com

Sarkar, B., Mahanty, A., Gupta, S. K., Choudhury, A. R., Daware, A., & Bhattacharjee, S. (2022). Nanotechnology: A next-generation tool for sustainable aquaculture. *Aquaculture*, 546: 737330. https://doi.org/10.1016/j.aquaculture.2021.737330

Shah, B. R., & Mraz, J. (2020). Advances in nanotechnology for sustainable aquaculture and fisheries. *Reviews in Aquaculture*,12(2):925942.https://doi.org/10.1111/RAQ.12356

Siddik, M. A. B., Francis, P., Rohani, M. F., Azam, M. S., Mock, T. S., & Francis, D. S. (2023). Seaweed and seaweed based functional metabolites as potential modulators of

growth, immune and antioxidant responses, and gut microbiota in fish. *Antioxidants*, 12(12): 2066. 10.3390/antiox12122066

Singha, K. P., Shamna, N., Sahu, N. P., Sardar, P., Harikrishna, V., Thirunavukkarasar, R., Chowdhury, D. K., Maiti, M. K., & Krishna, G. (2021). Optimum dietary crude protein for culture of genetically improved farmed tilapia (GIFT), *Oreochromis niloticus* (Linnaeus, 1758) juveniles in low inland saline water: Effects on growth, metabolism and gene expression. *Animal Feed Science and Technology*, 271, 114713. https://doi.org/10.1016/j.anifeedsci.2020.114713

Sohel, A. M., Shahjahan, M., Hossain, M. K., Sumi, K. R., Hossain, M. S., Abdul Kari, Z., Tahiluddin, A. B., & Téllez-Isaías, G. (2023). Effects of multispecies probiotics on growth, hematology, and gut health of Stinging catfish (*Heteropneustes fossilis*) in biofloc system.*Water,*15(14):2519.https://doi.org/10.3390/W15142519

Walton, M. J., & Cowey, C. B. (1982). Aspects of intermediary metabolism in salmonid fish. *Comparative Biochemistry and Physiology Part B: Comparative Biochemistry*, 73(1):5979.https://doi.org/10.1016/03050491(82)90201-2

Wu, W., Ji, H., Yu, H., Sun, J., & Zhou, J. (2020). Effect of re-feeding dietary containing different protein and lipid levels on growth performance, body composition, digestive enzyme activities and metabolic related gene expression of grass carp (*Ctenopharyngodon idellus*) after overwinter starvation. *Aquaculture*, 523: 735196. https://doi.org/10.1016/j.aquaculture.2020.735196

Zhang, H., Luo, Y., Lu, D. L., Jiao, J. G., Li, L. Y., & Qin, J. G., *et al*. (2019). Diacylglycerol oil reduces fat accumulation and increases protein content by inducing lipid catabolism and protein metabolism in Nile tilapia (*Oreochromis niloticus*). *Aquaculture*, 510: 90-99. doi: 10.1016/j.aquaculture.2019.05.035