Review Article

Impact of Biogenic Selenium Nanoparticles on Growth, Survival Rate and Immune Response of Nile Tilapia – A Systematic Review

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ABSTRACT

Background: Aquaculture is a vital sector in global food production, with Nile tilapia (Oreochromis Niloticus) being a widely cultivated and consumed fish species due to its adaptability and economic importance. However, challenges such as inadequate farming practices, poor feed quality, and disease outbreaks impact its production and sustainability. Selenium nanoparticles (Se-NPs) have emerged as potential dietary supplements in aquaculture due to their antioxidant and immune-boosting properties.

Methods: This systematic review summarized findings from 16 peer-reviewed studies published between 2018 and 2024 to investigate the effects of Se-NPs on the fish's overall health and disease resistance. It highlights different synthesis methods, optimal supplementation levels, and their impact on fish survival, immune system, and growth performance.

Results: The findings revealed that Se-NPs, particularly at concentrations around 1 mg/kg, significantly enhance tilapia health and productivity while minimizing toxicity risks. However, the effects of 1.5 mg/kg and above are understated. In a nutshell, Se-NPs at optimal levels of around 1 mg/kg improve fish's health, immunity, and growth, thus being a promising dietary supplement in aquaculture. However, the effects of higher concentrations (≥1.5 mg/kg) are unknown and require further research to establish their safety and efficacy.

Conclusion: Se-NPs promise to enhance Nile tilapia's growth performance, immune response, and overall health in aquaculture. Therefore, incorporating Se-NPs into fish diets can improve survival rates and better nutrient absorption, addressing common farming challenges. However, there is a need for further research to optimize the use of Se-NPs, ultimately promoting sustainable practices and food security in aquaculture.

Keywords: *Aquaculture, Nile tilapia, Selenium nanoparticle, Survival rate.*

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INTRODUCTION

Aquaculture farming of aquatic organisms has become crucial in global food production while providing significant employment opportunities, including regular feeding and stocking practices to achieve sustainable aquaculture. It has a rich history in ancient civilizations and has evolved from simple to advanced fish farming methods for growing food demand and combating environmental stresses[1-2].

About 20 million people are employed in aquaculture globally; concurrently, over 500 species are farmed by the industry, in which Asia dominates with 89% of production and has become one of the fastest-growing food industries globally[1-2]. In 2009, aquaculture accounted for 45% of global fish production and contributed significantly to the fish supply for human consumption[3]. However, the output of catch fisheries worldwide hit a record 96.4 million tons in 2018[4]. This growth trajectory is expected to continue due to rising global populations and increasing demand for seafood as a quality protein source. Currently, more than half of the seafood consumed worldwide comes from aquaculture[5].

Nile tilapia (Oreochromis niloticus) is a widely cultivated fish species globally, primarily due to its adaptability, fast growth rates, and high market demand[6]. This freshwater fish is native to Africa and the Levant and has become a staple in aquaculture due to its ability to thrive in various environmental conditions. Nile tilapia is particularly valued for its mild flavour, nutritional benefits, and

role in food security, making it a critical source of protein for millions of people worldwide. Its cultivation supports local economies and provides employment opportunities, particularly in developing countries. Intensive tilapia farming is practiced due to its adaptability to various environments[7]. Furthermore, inadequate farming practices contribute to the challenges of agriculture. Many farmers lack access to quality feeds and seeds, hindering growth rates and overall fish health. Low-quality feed inputs can lead to poor growth performance and increased disease susceptibility[8].

Nanoparticles are ultrafine materials with dimensions ranging from 1 to 100 nanometers, with unique properties due to their small size and high surface area[9]. These properties enable nanoparticles to interact effectively with biological systems, making them valuable in various fields, including medicine, agriculture, and aquaculture. Se-NPs have gained attention for their potential health benefits, particularly in enhancing growth and immune responses in aquatic species. Selenium is an essential trace element critical in various biological functions, including anti-oxidant defence and immune system support[10]. In aquaculture, Se-NPs demonstrated improved growth performance and nutrient absorption in fish species like Nile tilapia and Catla catla. For instance, a study indicated that a diet supplemented with 1.5 mg/kg of Se-NPs resulted in a 208% weight gain and a 100% survival rate in Catla catla[11].

Additionally, Se-NPs have been linked to enhanced immune parameters and reduced oxidative stress in fish, demonstrating their potential as a dietary supplement in aquaculture[12]. Therefore, this systematic review evaluated the effectiveness of Se-NPs in aquaculture, explicitly focusing on their impact on the growth, survival rate, and physiological parameters of Nile tilapia to provide a comprehensive analysis of their potential role in enhancing fish health and ensuring the safety of Nile tilapia.

METHODOLOGY

Sources and Search Strategy

Electronic databases, including ScienceDirect, PubMed, and Google Scholar, were thoroughly searched. The keywords used were **'Selenium nanoparticles'**, **'Nile tilapia'**, **'Aquaculture'**, **'Fish health'**, **'Growth performance'**, '**Immune response'**, '**Disease resistance**, and **'Selenium supplementation'** combined with Boolean operators ('AND' and 'OR') to enhance the search efficiency. A combination of MeSH terms **('Nanoparticles' and 'Nile tilapia')** was used in PubMed. Filters were applied to restrict results to studies published between 2018 and 2024, focusing on original research findings.

Study Selection

The authors screened the articles by thoroughly examining titles and abstracts to eliminate all duplicates. The duplicates were automatically removed using EndNote software to ensure accuracy. The authors then obtained and independently reviewed full-text articles of potentially relevant papers for final inclusion. Discounts or disagreements were resolved through productive discussions and mutual consensus among the authors.

Eligibility Criteria

The study encompassed peer-reviewed publications documenting the impacts of Se-NPs or a combination with other additives. Furthermore, only the publications with clear and well-defined methodologies and characterization for assessing the effects of the Se-NPs were included. Additionally, the inclusion criteria specified that only studies published in English were eligible. Articles that were pre-prints or unpublished, as well as those in languages other than English, were excluded.

Risk of Bias Criteria

The Cochrane Risk of Bias (RoB-2) tool was used to evaluate the studies on the primary outcome measures of the survival rate of Nile tilapia. The tool evaluates the following five key domains of bias: arising from the **'randomization process'** due to deviations from intended interventions, **'missing outcome data', 'measurement of the outcome**, and **'selection of the reported result'**.

Each domain produced an algorithmic judgement based on *"low risk"*, *"some concerns"*, or "high risk of bias", which results in an overall risk of biased judgement.

Data Analysis

Data synthesis was carried out by summarizing the findings from the included studies, focusing on the effectiveness of Se-NPs and their effect on the growth performance, survival rate and physiological parameters of Nile Tilapia. The synthesis process involved comparing the results of different studies, identifying trends, and drawing conclusions based on the collective evidence. Due to variations in experimental duration and sample size, the obtained data were normalized by calculating daily weight gain and survival rate and determining the percentage gain relative to the control to ensure comparability.

Ethical Considerations

The ethical considerations adhered to the principles outlined in the Declaration of Helsinki, confirming that all the studies included were conducted with respect for animals (Nile Tilapia) and that ethical standards were maintained during the research process.

RESULTS

Studies Selection

The electronic search strategy yields 292 research articles. Only peer-reviewed research articles published in journals were considered. After removing duplicates, 211 research articles were obtained. Of these, 186 publications were excluded after title and abstract reviews because they did not report on the effect of Se-NPs on Nile tilapia (Figure-1).

The remaining 16 articles were critically reviewed, and every section of the research articles was closely scrutinized. Subsequently, 16 relevant research articles were chosen to be included in this systematic review as shown in Table-1.

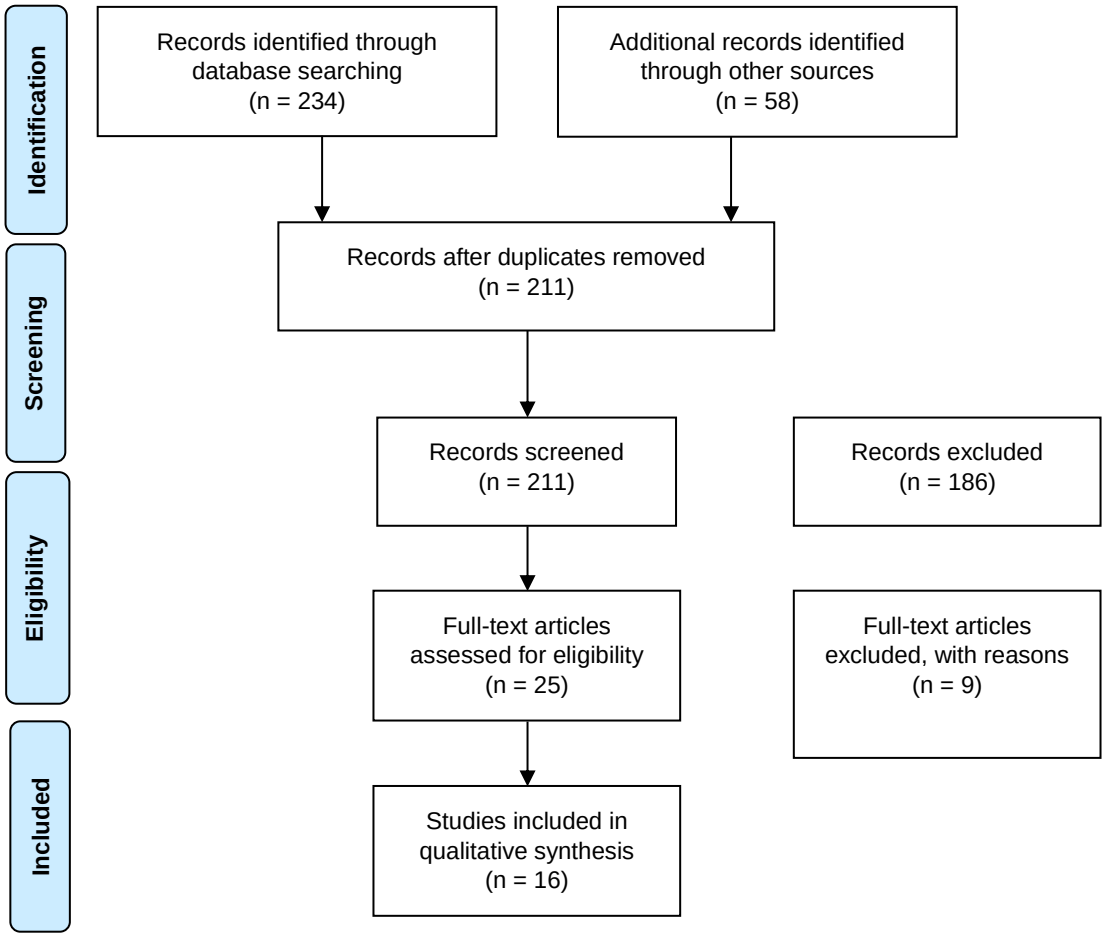

Figure-1 PRISMA flowchart showing the screening of studies using databases

Risk of Bias Assessment

ROB assessment for the 16 studies on the primary outcome is reported using the RoB-2 tool and exhibited in the form of a traffic light plot showing the low risk (green), red (High risk) and yellow (some concerns) are represented in Figure-2. Thirteen of the total 16 studies had a low risk of bias arising from the sample size utilized. Two studies algorithmically scored as having a high risk of biasness with the randomization process.

Only one study has shown some concerns. Most studies exhibited low risk of bias in reporting results, whereas a few embraced high risks and some problems. The overall risk of bias assessment was carried out in a way that yielded some concerns, if any, of the bias domains comprised of no information. If two bias domains contained some problems, then the overall risk of bias also showed some concerns.

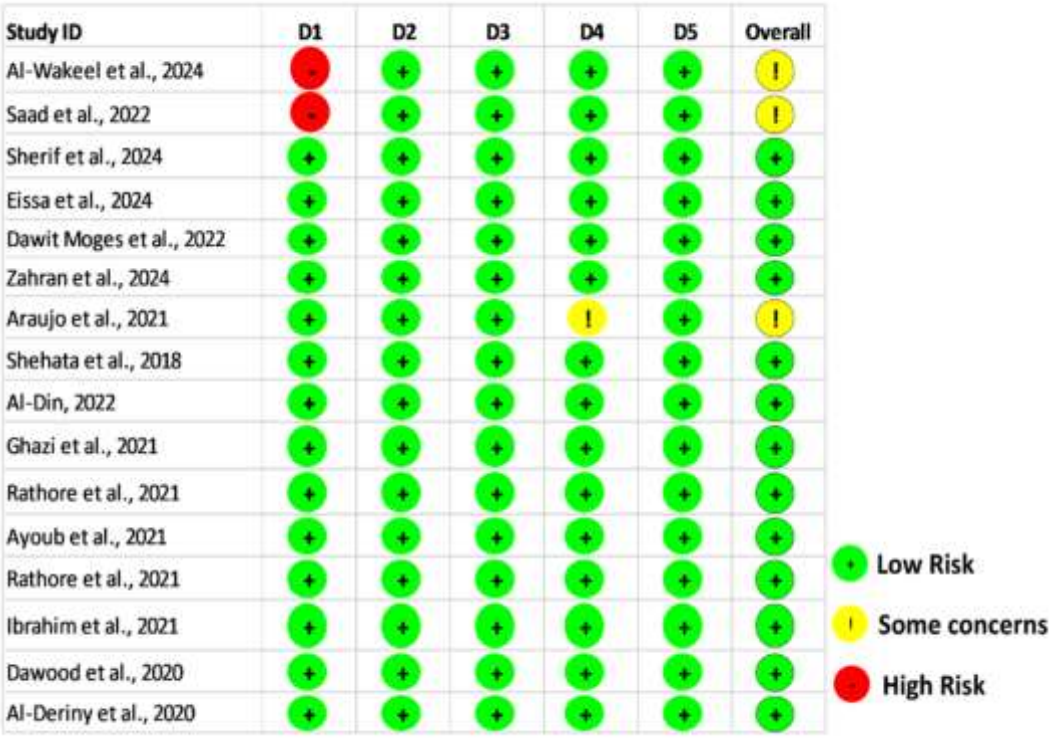

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Figure-2 Traffic light plot for the risk of bias assessment using Cochrane risk of bias RoB-2 tool. Red and green colours correspond to high and low risk of bias, respectively. Yellow is showing some concerns. D1 Randomization process, D2 Deviations from the intended interventions, D3 Missing outcome data, D4 Measurement of the outcome, D5 Selection of the reported result.

Overview of Reviewed Studies

This systematic review synthesized findings from 16 studies published between 2018 and 2024, assessing the impact of Se-NPs on growth, immune response, and disease resistance of Nile tilapia (Oreochromis niloticus). These studies show various experimental designs, with different concentrations, sample sizes and exposure durations of Se-NP.

The total sample size across the studies ranged from 10 to 120 tilapia per tank as indicated in Figure-3, with various selenium nanoparticle concentrations and experimental durations. The outcomes measured included growth performance, immune function, disease resistance, and biochemical indicators.

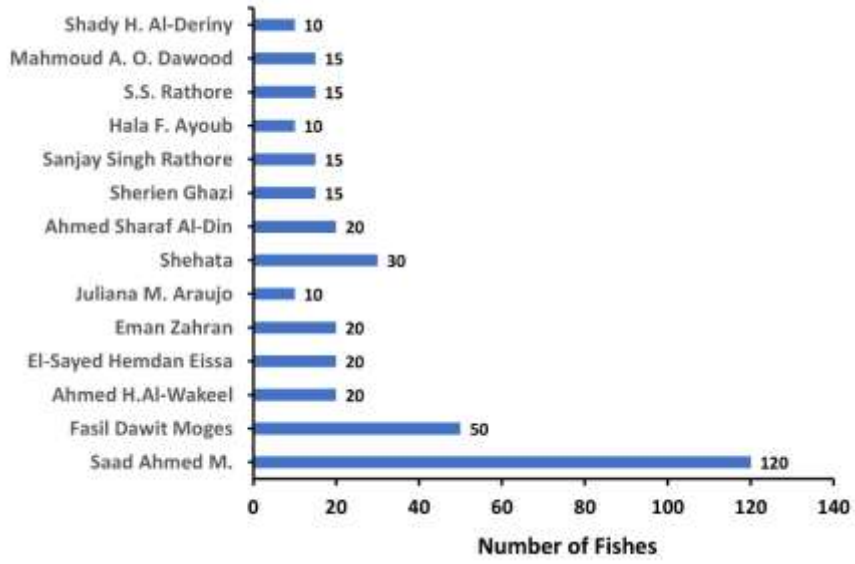

Figure-3 Different studies showing the number of experimental fishes used per tank

Synthesis of Selenium Nanoparticles

Se-NP can be synthesized through biological, chemical, and physical methods shown in Figure-4, among which biological synthesis involves using biological agents for example, microalgae like Pediastrum boryanum and bacteria like Bacillus subtilis. Chemical synthesis involves using sodium selenite, whereas high-energy ball milling contributes to the physical synthesis of Se-NPs. The comparison of particle sizes from various synthesis methods reveals distinct ranges that highlight the effectiveness and characteristics of each approach.

Green synthesis methods yield nanoparticles with sizes averaging 77 nm to 150 nm, indicating a relatively larger size range when compared to other methods. In contrast, physical synthesis produces smaller nanoparticles of about 40 nm, whereas chemical synthesis results in particles measuring approximately 52.61 nm, which is also smaller than many green-synthesized nanoparticles. Overall, the data indicate that green synthesis can produce a broader range of particle sizes. In contrast, physical and chemical synthesis yield smaller nanoparticles, as shown in Figure-5, which may influence their application in aquaculture.

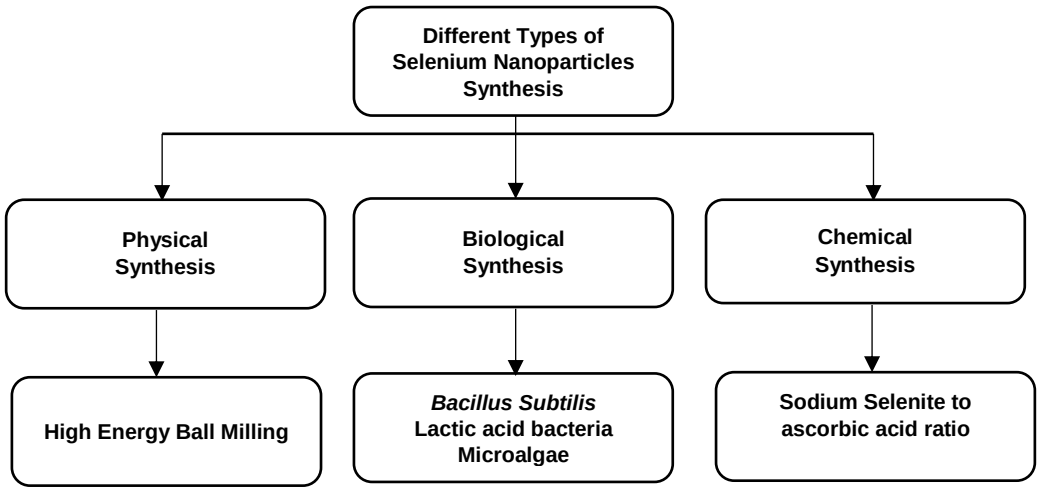

Figure-4 The flow diagram showing the different methods of Synthesizing Selenium Nanoparticles

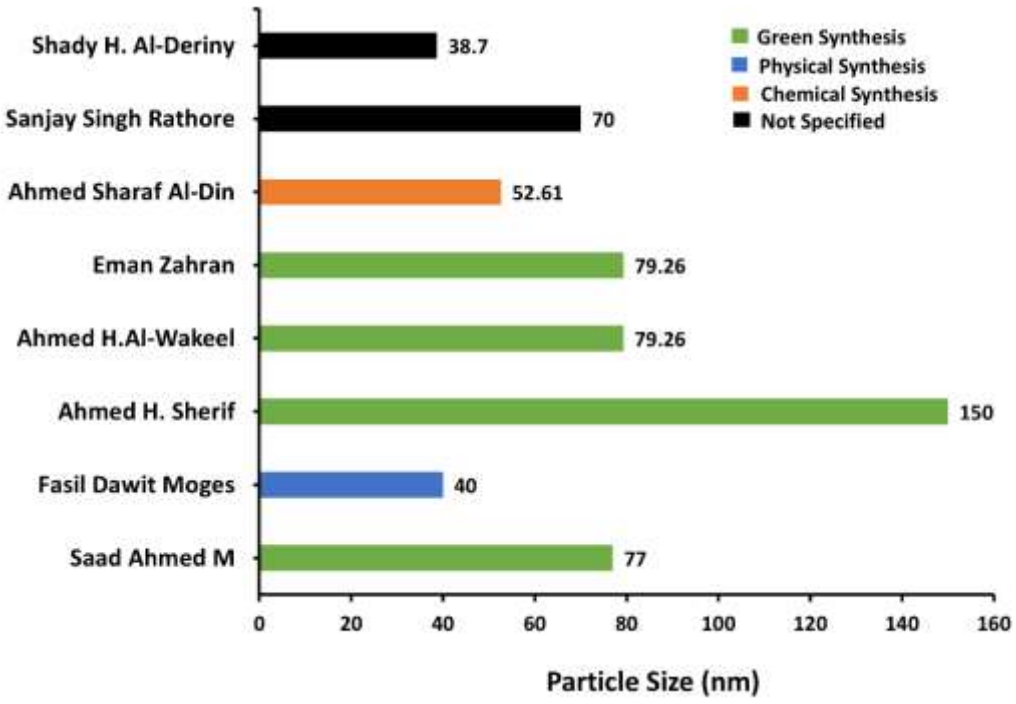

Figure-5 Particle size of Se-NPs with different synthesis methods

Impact of Different Concentrations of Se-NPs on the Survival and Growth rate of Nile Tilapia

The survival rate graph for Nile tilapia exposed to varying concentrations of Se-NPs provides an understanding of the impact of different concentrations of nanoparticles on fish health. The survival rate of Nile tilapia in response to varying concentrations of Se-NPs has been investigated across multiple studies.

The findings indicate that the optimal concentration for enhancing survival rates is 1 mg/kg, while both lower (0.5 mg/kg) and higher (2 mg/kg) concentrations yield less favourable outcomes. At 0.5 mg/kg, the Se-NPs resulted in moderate growth performance and survival rate of approximately 90%.

Table-1 Study Characteristics

Author/ Year	Objectives	Nanoparticle Synthesis	Particle Size	Experimental period	Key Findings
Al-Wakeel et al., 2024[13]	Examination of the influence of Se-NPs on growth performance, serum biochemical and immunological parameters of Nile tilapia	Microalgae	79.26 nm	8 weeks	Green-synthesized Se-NPs at 0.75 mg/kg and 1.5 mg/kg enhanced growth performance, and immune responses in Nile tilapia without inducing toxicity or inflammation
Saad et al., 2022[14]	Reduction of pathogenic bacterial load and heavy metal accumulation in Nile tilapia	Biosynthesis (Bacillus subtilis AS12)	Average size of 77 nm	2 weeks	Bio-Se-NPs mitigated heavy metal toxicity and bacterial infections. Concentration-dependent efficacy was observed, with 3–5 µg/mL being optimal

Sherif et al., 2024[15]	Evaluation of the impact of Se-NPs on nutritional quality and growth performance of Nile tilapia	High Energy Ball Milling	30–50 nm	2 weeks	Se-NPs enhance growth and nutritional quality at optimal doses (1 mg/kg). Over-supplementation (2 mg/kg) may lead to toxicity and reduced performance
Dawit Moges et al., 2022[16]	Investigation of the mitigation of mycotoxin in Nile tilapia by the treatment of Se-NPs.	*Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus*	Ranging between 100 and 200 nm	4 weeks	Addition of Se-NPs improved the antioxidant status, significantly in a free Aflatoxin diet. On the other hand, continuous feeding with the aflatoxin contaminated feed with or without nanoparticle addition fish could not recover normal physiological parameter
Eissa et al., 2024[17]	Investigation of the impacts of Se-NPs particles on immune response and growth of Nile tilapia infected by *Aspergillus favus*	Chemical (sodium selenite and ascorbic acid)	Not Specified	60 days	Se-NPs at 1.0 mg/kg diet provide an optimal balance for boosting Nile tilapia's growth performance, immunity, digestive enzyme activity, and histological health, particularly under stress conditions such as *Aspergillus flavus* infection
Zahran et al., 2024[18]	Investigation of the impact of P. boryanum-derived biosynthesized Se-NPs on immune response, biochemical parameters, genes expression, and intestinal health on Nile tilapia	(Microalgal-fabricated) *P. boryanum* powder	79.26 nm	8 weeks	Se-NPs supplementation positively improves intestinal barrier integrity and overall gut health, especially at the 1.5 mg/kg. At a dose of 1.5 mg/kg, Se-NPs significantly enhanced the expression of IL-8 and interleukin and IL-1β genes, indicating enhanced immune defense system
Araujo et al., 2021[19]	Production of Se loaded chitosan nanoparticles and investigation of controlled release properties	Ionotropic gelation method	633-nm	2 weeks	Selenium-loaded chitosan nanoparticles have proven to be an efficient and sustainable delivery method for selenium supplementation in aquaculture and is a promising alternative to traditional selenium sources for enhancing the health and productivity of Nile tilapia
Shehata et al., 2018[20]	Evaluation of the effect of dietary supplementation of Se, Cu and their combination on growth performance, and body composition of Nile tilapia	Not specified	Not specified	15 weeks	No significant growth or health improvement was observed of nanoparticles as compared to control diet
Al-Din, 2022[21]	Evaluation of the effects nano-Se at concentration of 0, 0.5, and 1mg per kg of feed on growth performance and overall health of Nile tilapia	Chemical	38.45 - 66.78nm.	10 weeks	Nano-Se supplementation increased hematological profile and reduced protein content and negatively impacted growth performance, feed efficiency, and enzymes in both sexes, with no significant sex-based interactions
Ghazi et al., 2021[22]	Investigation of the synergistic effects of Se-NP and ZnO-NP on growth performance, haemato-biochemical parameters, immune and oxidative stress responses, and intestinal morphology of Nile tilapia.	Not Specified	Not Specified	60 days	Synergistic supplementation of Se-NPs and ZnO-NPs improves growth, feed efficiency, and immunity

Rathore et al., 2021[23]	Examination of the efficacy of dietary nano-selenium to strengthen nutrition physiology, immune response, disease resistance and antioxidant system in monosex Nile tilapia before and after *A. hydrophilia* infection	Not Specified	70 nm	90 days	Nano-Se significantly enhanced growth, feed utilization, hematological parameters, serum biochemistry, immune responses (e.g., lysozyme and immunoglobulin activity), and antioxidant markers (e.g., catalase, glutathione peroxidase). The survival rate after a challenge with *Aeromonas hydrophila was* highest in this group. These findings suggest 1 mg/kg Nano-Se as an optimal dose for improving health and productivity in Nile tilapia
Ayoub et al., 2021[24]	Evaluation of the effects of different levels of C. colocynthis extract and synthesized Se nanoparticles on Nile tilapia	Citrullus colocynthis extract and synthesized Selenium nanoparticles	Not Specified	4 weeks	Supplementation of C. colocynthis extract and Nano-Se in N. tilapia Diet can activate the non-specific immunity and increase antioxidants enzymes which may then decrease mortality by enhancing protection against pathogens and stressors
Rathore et al., 2021[25]	Investigation of the effects of Se nano-particle on growth performance, immune-regulated selenoproteins and its bioaccumulation and assimilation in Nile tilapia	Not Specified	Average particle size of <80 nm	90 days	Findings suggestedthat the incorporation of nano-Se could be more effective for growth and immune-regulation of selenoproteins in Nile tilapia
Ibrahim et al., 2021[26]	Comparison between bulk and nanoparticles of selenium form as supplementation in Nile tilapia on growth, health and immune response of Nile tilapia	Not Specified	Not specified	84 days	Se improved performance of growth and immune response and oxidative stress. Se-NPs demonstrated relatively better absorption efficiency than Bulk-Se, and is recommended to use it at concentration of 0.4 or 0.8 mg kg^{-1} diet as supplement in tilapia commercial feed
Dawood et al., 2020[27]	Investigation of the impact Nano Se, VE and combination of both on growth performance, immune-related gene expression and oxidative status of Nile tilapia	Lactic Acid Bacteria	100–500 nm	8 weeks	Supplements of Nano Se or/and Vitamin E has also stimulated the oxidation status of Nile tilapia. Dietary supplements upregulated TNF-α and IL-1β gene expression, which could improve immune response in Nile tilapia
Al-Deriny et al., 2020[28]	Evaluation of the influence of (Se-NPs) or/and spirulina (SP) on the growth, immunity, and oxidation resistance of Nile tilapia.	Not Specified	38.7 nm	60 days	Dietary Se-NPs or/and Spirulina improved the growth, immune response, and oxidation status. Based on the measured parameters, the combination of both Se-NPs and Spirulina is highly recommended for the welfare of Nile tilapia

At 1 mg/kg concentration, Se-NPs demonstrated the highest survival rate (>95%) and growth performance, whereas at 2 mg/kg concentration, fishes exhibited the lowest growth performance and survival rates, indicating potential toxicity or adverse effects at higher concentrations.

In a nutshell, Se-NPs at 1 mg/kg Se-NPs appear optimal for the growth of Nile tilapia, as shown in Figure-6. It is essential to consider that excessive selenium can lead to toxicity, suggesting a need for careful dosage management in aquaculture practices.

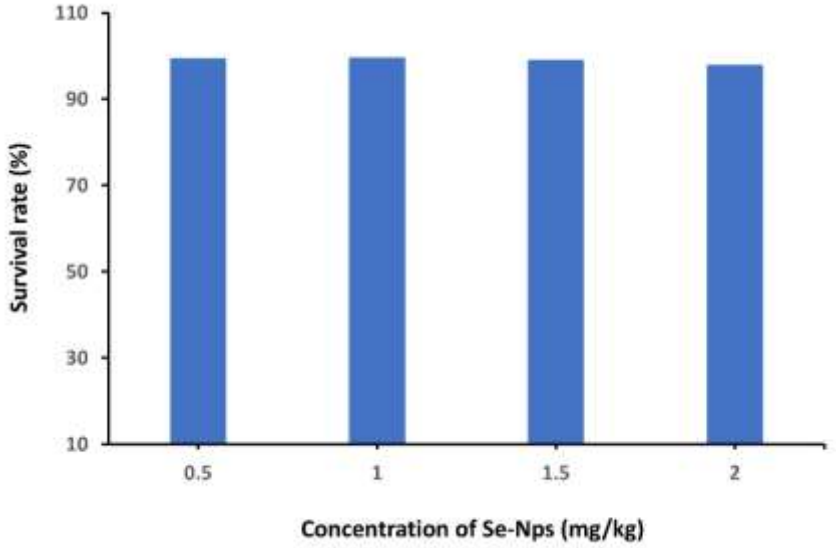

Figure-6 Survival rate per day on different concentration of Se-NPs

Similarly, Nile tilapia's growth performance when fed Se-NPs at varying concentrations highlights significant differences in weight and length gain, relative growth rate (RGR) and specific growth rate (SGR) (Figure-7). A 0.5 mg/kg Se-NPs dosage resulted in moderate growth, with a RGR and SGR. Similarly, the 1 mg/kg Se-NPs group demonstrated the improved growth performance, indicating it to be the optimal concentration for Nile tilapia. The synergistic effect of Se-NPs with other supplements suggests that nano selenium can be used to improve the growth and overall health of the fish. 1.5 mg/kg showed no significant additional benefit compared to the 1 mg/kg diet, which might indicate a plateau or diminishing returns in growth. In contrast, the 2 mg/kg of Se-NPs group demonstrated reduced growth, suggesting potential toxicity at higher concentrations. In conclusion, 1mg/kg of Se-NPs appears optimal in Nile tilapia's growth, whereas higher concentrations may lead to toxicity.

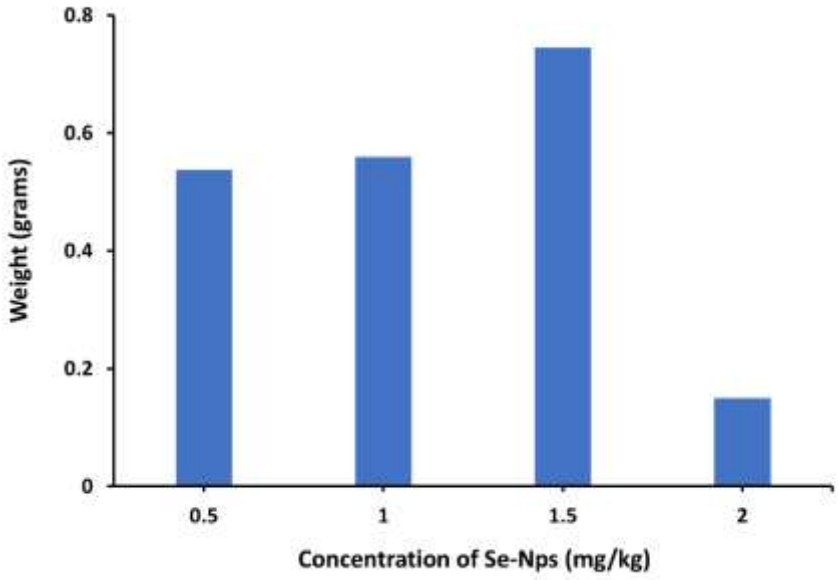

Figure-7 Growth rate of Nile tilapia per day on different concentration of Se-NPs

Impact of Se-NP Concentration on the Immune System of Nile Tilapia

Se-NPs were demonstrated to enhance the immune response in Nile tilapia exposed to various stressors. Se-NP supplementation at 0.75 and 1.5 mg/kg significantly increased innate immune parameters, including IgM and lysozyme levels, compared to the control. These findings suggest that Se-NPs can effectively boost Nile tilapia's immune function and infection resistance. In the reviewed studies, as the concentration of Se-NPs increases from 0.5 to 2, there is a noticeable decrease in Malondialdehyde (MDA) percentage, indicating reduced oxidative stress in Nile tilapia. In contrast, the activities of anti-oxidant enzymes such as Glutathione Peroxidase (GPx), Catalase (CAT), and Superoxide Dismutase (SOD) show significant increases, suggesting enhanced anti-oxidant defence mechanisms. Additionally, lysozyme activity improves substantially from 52.80% at 0.5 concentration to 80% at 2mg/kg concentrations, NPs on immune response and oxidative stress mitigation, indicating an enhanced immune
response.

Se-NPs at the 1.5 mg/kg concentration significantly upregulate intestinal interleukin 8 (IL-8) gene transcription and interleukin 1 beta (IL-1β). Furthermore, supplementation with Se-NPs, particularly at 1.0 mg/kg, improved immune resistance against Aspergillus flavus infection. Table-2 shows the influence of Se NPs on oxidative stress and immunological response markers (MDA, GPx, SOD, CAT, and lysozyme) as reported in many studies. This may helps to understand the trends and variations in Se NP efficacy, providing insight into their role in fish health improvement and aflatoxin detoxification.

At a concentration of 1 mg/kg fish feed, Se-NPs increased the antibacterial activity, oxidative burst, phagocytic activity, and cytokine expression, which suggests the reduction of immune suppression and improving resistance to infections such as Streptococcus agalactiae.

Table-2 Effect of Se-NPs on Oxidative Stress and Immune Biomarkers in Nile Tilapia

Parameters	Se-NPs Concentration (mg/kg)				
	0	0.5	1	1.5	2
MDA (nmol/l)	1.45±0.005	1.47±0.38	1.565±0.505	2.23±0.14	1.03±0.04
SOD (IU/L)	13.606±1.985	16.67±2.69	17.22±2.92	14.02±0.18	21.36±0.13
CAT (IU/L)	13.475±2.155	16.315±3.175	16.915±3.815	12.76±0.28	22.68±0.33
GPx (IU/L)	19.515±3.685	21.631±2.195	21.7±1.02	23.52±0.49	22.07±0.51
Lysozyme (µg/ml)	1.28±0.03	2.08±0.17	2.05±1.02	2.23±0.31	2.25±0.03

The values are represented as mean±standard deviation

Impact of Selenium Nanoparticles in Mitigating Metal Ions in Nile Tilapia

The incorporation of Se-NPs in the diet of Nile tilapia has shown promising effects on growth performance when challenged with heavy metals like cadmium (Cd) and mercury (Hg). The presence of Se-NPs mitigated the negative impacts of these heavy metals, reducing their accumulation in fish tissues by up to 87% as shown in Figure-8. Significant weight gain of up to 52% compared to controls demonstrates a clear benefit in growth performance.

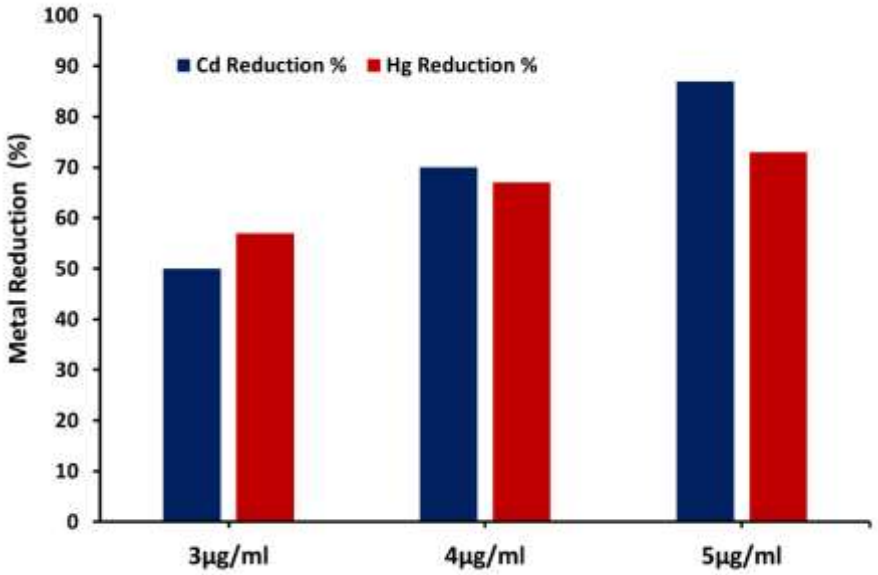

Figure-8 Se-NPs reduces metals accumulation in Nile tilapia

DISCUSSION

This review evaluates the efficacy of Se-NPs in enhancing Nile tilapia's growth, survival rate, and immune response and assessed the potential role of Se-NPs in mitigating stress factors and improving overall fish health. By analyzing 16 peer-reviewed studies, this review provides insights into optimal dosage, synthesis methods, and their effects on various physiological parameters of Nile tilapia. It was reported in several studies that the synthesis of nanoparticles plays a crucial role in determining their size and purity. Chemical synthesis involves reducing high-valence selenium compounds, such as sodium selenite, using reducing agents like ascorbic acid or glutathione[29-30]. Studies show that the chemical synthesis of Se-NPs includes stabilizers to prevent clumping, such as Spirulina polysaccharides[31]. Even though the chemical method is widely used, it raises environmental concerns.

In contrast, physical synthesis, such as pulsed laser ablation, produces nanoparticles without chemical contamination, resulting in particles with high surface purity[32]. The growth of fish and other aquatic animals depends on several factors, including proper management, optimal temperature, salinity, and a nutritionally balanced diet that enhances overall health and growth performance. Several studies have investigated the role of Se-NPs at different concentrations in improving the growth and survival of various aquatic species.

In Asian seabass (Lates calcarifer), dietary supplementation with 4 mg/kg Se-NPs significantly improved growth performance and feed efficiency[33]. Similarly, in red sea bream (Pagrus major), supplementation with 1 mg/kg Se-NPs enhanced growth rates and feed utilization efficiency[34]. In common carp (Cyprinus carpio), Se-NP supplementation at 0.7–1 mg/kg improved growth performance, muscle composition, and anti-oxidant enzyme activity, highlighting its role in metabolic regulation[35]. Other nanoparticles, like silver and copper, have been found to enhance the immune response in fish but may induce oxidative stress, which may lead to a potential negative impact[36-37]. Se-NPs, when combined with other nanoparticles like zinc, further improved growth performance and immune responses, showing higher phagocytic activity and anti-oxidant enzyme levels[38].

Se-NPs offer a promising effect in mitigating the negative impact of heavy metals in Nile tilapia, indicating a similar impact to chitosan and silica

nanoparticles, which are also beneficial for mitigating heavy metal effects[39-40]. Se-NPs provide a unique combination of growth promotion and immune system enhancement, positioning them as a superior choice for aquaculture applications focused on these aspects. However, integrating Se-NPs with other nanoparticles could potentially leverage their respective strengths in a comprehensive aquaculture strategy.

Nanoparticles like phosphorus, iron and zinc are also known to improve the growth of Nile tilapia[41-43]. Se-NPs still have a better advantage because they enhance the immune response much more than other nanoparticles. This suggests that even though different kinds of nanoparticles play a part in aquaculture development, Se-NPs are better for enhancing resistance against disease and resilience of the fish. Recent studies have demonstrated synergistic effects when using Zn-NPs and Se-NPs in Nile tilapia diets. Both nanoparticles may combine to enhance growth performance, blood health, and immune responses compared with using either nanoparticle alone. More studies collectively suggest that selenium nanoparticles have synergistic effects when combined with other supplements, such as zinc oxide nanoparticles or vitamin-E[22]. Studies directed explicitly towards the synergistic effects between iron and selenium nanoparticles are limited; thus, it may be a subject for further research.

CONCLUSION

This systematic review highlights the potential benefits of Se-NPs as dietary supplements for Nile tilapia. It positively influence growth performance, immune response, anti-oxidant defence, and disease resistance, with optimal supplementation levels at around 1 mg/kg. However, higher concentrations may lead to diminishing benefits or adverse effects, indicating the need for careful dosage management. Future research should focus on higher concentrations and long-term studies to assess the sustainability, bioaccumulation, and environmental impact of Se-NPs in aquaculture. Comparative studies with other nanoparticle-based supplements and traditional selenium sources would provide further insights into their effectiveness and safety.

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None.

Author Contributions
Bushra Anzar and **Fariha Ibrahim** contributed to the study conception, design, and data interpretation. **Ayesha Ali** was involved in data collection and statistical analysis. **Fariha Ibrahim** and **Ayesha Ali** assisted in literature review and manuscript drafting. All authors reviewed and approved the final version of the manuscript.

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None.

Conflict of Interests
None.

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