Selenium Nanoparticles in Aquaculture

Subjects: Biology
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Balanced aquafeed is the key factor for enhancing the productivity of aquatic animals. In this context, aquatic animals require optimal amounts of lipids, proteins, carbohydrates, vitamins, and minerals. The original plant and animals' ingredients in the basal diets are insufficient to provide aquafeed with suitable amounts of minerals. Concurrently, elements should be incorporated in aquafeed in optimal doses, which differ based on the basal diets' species, age, size, and composition. Selenium is one of the essential trace elements involved in various metabolic, biological, and physiological functions. Se acts as a precursor for antioxidative enzyme synthesis leading to high total antioxidative capacity. Further, Se can enhance the immune response and the tolerance of aquatic animals to infectious diseases. Several metabolic mechanisms, such as thyroid hormone production, cytokine formation, fecundity, and DNA synthesis, require sufficient Se addition. The recent progress in the nanotechnology industry is also applied in the production of Se nanoparticles. Indeed, Se nanoparticles are elaborated as more soluble and bioavailable than the organic and non-organic forms. In aquaculture, multiple investigations have elaborated the role of Se nanoparticles on the performances and wellbeing of aquatic animals.

Keywords: nanotechnology ; physiological function ; aquaculture

1. Introduction

Nanotechnology is a growing technology with high potential for application in the aquaculture industry [1]. Nanoengineered minerals (<100 nm) are well recognized in aquafeed due to their high solubility, active surface, and functionality [2]. Nano minerals are characterized by higher surface area affinity, higher solubility, thermal resistance, low toxicity, slow excretion rate, and sustained release [3]. Accordingly, nanominerals can beneficially affect animals' metabolic, physiological, and biological functions [4]. Selenium (Se) particles are one of the microelements involved in various tasks in the entire body of aquatic animals [1][5]. The targeting role of Se is to protect cells from oxidation through the formation of antioxidative defenses [6]. Se also acts as a cofactor in the formation of selenoproteins involved in the catalysis of hydroperoxide [7]. Besides, Se contributes to the metabolism of the thyroid gland, reproduction, and development of body tissues [8]. Initially, Se has organic and non-organic forms with low bioavailability, solubility, and adherence properties [9][10]. Thus, introducing Se nanoparticles in the aquafeed industry is highly recommended to maximize aquatic animals' health status and productivity.

Se nanoparticles are well investigated with high potential as a growth promotor, antioxidative, and immunostimulant agent in aquaculture [11][12]. Multiple studies reported the necessity of including Se nanoparticles for enhancing the growth performance, physiological, and health status in aquatic animals [5][13][14]. Due to the low margin between the benefits and the toxicity, Se nanoparticles have to be included in aquafeed based on a dose-specific manner. Excessive levels of dietary Se (>20–30 mg/kg) are hazardous to most animals, including livestock and fish [15]. The novel Se nanoparticles are characterized by their low toxicity and high functionality [1]. Markedly, the inclusion of Se nanoparticles led to enhancement in aquatic animals' growth, performance, and productivity [10][16][17].

2. Selenium Sources

Microelements are required at adequate levels and forms to contribute to several metabolic, physiological, and biological functions in the entire body of the organisms [18][19]. Zinc, copper, and selenium are among these microelements which should be fortified in fish diets to guarantee optimum growth and wellbeing [20]. A particular focus has been given to selenium (Se) due to its crucial role in antioxidative capacity, male reproduction, anti-carcinogenesis, thyroid metabolism, and muscle development [4]. Se is firstly introduced to the scientific community in 1818 by Jacob Berzelius and has two primary forms (organic and non-organic) [1]. The inorganic Se includes selenite (Se^{4+}), selenide (Se^{2-}), and selenate (Se^{6+}), while the organic form of Se such as yeast-Se [21]. Se functionality depends on its form, and organic Se is more bioavailability than inorganic Se sources [9][22][23]. However, organic and inorganic Se sources are less water soluble, permeable, and bioavailable for metabolic and physiological functions [1]. The low surface adherence aptitudes lower its activity in the animal's body. Regarding the advanced steps that have been investigated in applying nanotechnology in several fields, including medication, food, and feed preparation [24], Se nanoforms are suggested as an active source for aquafeed [12]. Se nanoforms are more biologically available with fewer amounts making them less toxic and highly effective [25]. Further, Se nanoforms have a wide surface area that is possibly responsible for their functionality and permeability [11].

3. The Role of Selenium Nanoparticles on the Performance of Aquatic Animals

The growth performance of aquatic animals depends on several factors such as well management, water quality, vaccination, and temperature [26] (**Table 1**). Besides, nutritionally balanced aquafeed is another vital factor associated with improving the feed digestibility and thereby the health condition and growth performance of finfish species [27]. Optimum feed formulations should contain both macro and microelements to fulfill the basic requirements of finfish species. Over or low levels of these elements cause impaired metabolic and physiological functions and led to malnutritional features. Nutritionally, Se can stimulate growth hormone production, leading to high growth performance in fish [12]. Se bind with deiodinase enzyme, which is required for thyroid hormone regulation [28]. Fish, in the same way as other vertebrates, have a pituitary gland involved in the secretion of thyroid hormones that stimulate the secretion of growth hormones [8]. In this regard, Khan et al. [29] elucidated that *Tor putitora* fed dietary Se nanoparticles showed increased growth hormone levels. Asian seabass (*Lates calcarifer*) fed dietary nano Se at 4 mg/kg showed enhanced growth performance in a feeding trial that lasted for six weeks [30]. In another trial that lasted for four weeks, Asian seabass-fed nano Se at 4 mg/kg showed enhanced growth and survival rates. The inclusion of dietary Se nanoparticles at 3 mg/kg in the diets of early weaning gilthead seabream (*Sparus aurata*) improved larval and growth performance [31]. The authors stated that the role of Se nanoparticles in improving larval growth is related to bone mineralization and the prevention of skeleton anomalies. Dawood et al. [32] also reported that red sea bream (*Pagrus major*) fed dietary nano Se at 1 mg/kg had enhanced growth performance and feed utilization. The authors correlated the enhanced growth performance with the role of Se nanoparticles in activating the protease, thereby feed utilization. In several feeding trials that lasted for 4 to 8 weeks, Nile tilapia (*Oreochromis niloticus*) fed dietary nano Se at 1–2 mg/kg showed enhanced growth performance and feed utilization [25][33][34][35][36]. Notably, Abd El-Kader et al. [37] and Abd El-Kader et al. [38] reported that European seabass (*Dicentrarchus labrax*) fed Se nanoparticles at 0.5–1 mg/kg had enhanced growth performance and feed efficiency. The authors attributed enhance growth performance of European seabass to the role of nano Se in the upregulation of Insulin-like growth factor 1 (*IGF-1*) gene expression. In a feeding trial that lasted for 70 days, Khan et al. [29] and Khan et al. [39] reported that Mahseer fish displayed increased growth performance. Kumar et al. [40] and Kumar et al. [41] stated that *Pangasinodon hypophthalmus* treated with Se nanoparticles at 1–2 mg/kg had enhanced growth performance. Further, rainbow trout (*Oncorhynchus mykiss*) fed dietary Se nanoparticles at 2 mg/kg for 60 days had enhanced growth performance and feed utilization [42]. In a nine-week feeding trial, Goldfish (*Carassius auratus*) fed dietary Se nanoparticles at 0.6 mg/kg and enhanced weight gain, specific growth rates, and *IGF-1* gene expressions [43]. Jahanbakhshi et al. [43] elucidated the enhanced growth performance of Goldfish to the role of Se nanoparticles in improving ghrelin hormone and improving feed utilization. In common carp (*Cyprinus carpio*), Saffari et al. [44] and Ashour et al. [45] reported that the inclusion of dietary nano Se at 0.7–1 mg/kg resulted in improved growth performance and feed utilization. Rohu (*Labeo rohita* Hamilton) fed dietary Se nanoparticles at 0.3 mg/kg for 120 days had enhanced growth performance [46]. Liu et al. [47] reported that Grass carp (*Ctenopharyngodon idella*) fed dietary Se nanoparticles at 0.6–0.9 mg/kg for ten weeks had enhanced growth performance and survival rate. On the other hand, rainbow trout (*O. mykiss*) fed dietary Se nanoparticles at 1 mg/kg had no marked effects on the growth performance [48].

Se nanoparticles can enhance the growth performance of aquatic animals. The role of Se nanoparticles is probably attributed to the effect of Se in activating the digestive enzymes and enhancing the integrity of intestinal villi [45]. It should be noted that Ghazi et al. [55] reported enhanced intestinal morphometry, villi length, and goblet cells number in Nile tilapia fed Se nanoparticles. This study confirms that Se nanoparticles have a notable role in improving intestinal health, leading to high feed utilization and thereby improved growth performance. Further, the Se nanoform has active antibacterial potential that may inhibit the growth of pathogenic microorganisms in the intestines of aquatic animals. Accordingly, the beneficial bacteria can perform more effectively in digesting the nutrients through the secretion of digestive enzymes. The enhancement in the growth performance of fish is also explained by Ibrahim et al. [5], who indicated that Nile tilapia-fed dietary Se nanoparticles (0.4–0.8 mg/kg) showed enhanced growth performance and feed efficiency. The authors also confirmed that Se nanoparticles caused a positive impact on the intestinal histomorphological features. Increased villi length and width, a high number of goblet cells, and marked villi branching and integrity were also seen in Nile tilapia fed Se nanoparticles. Indeed, Se acts as a precursor for synthesizing selenoproteins involved in high protein levels in the intestinal villi, leading to increased digestive enzyme activity, thereby high feed utilization, metabolic function, and growth performance. Markedly, the nano form of Se is more efficient in enhancing the feed utilization in the entire body of fish associated with Se nanoparticles' active surface and its small sizes that allow the particles to function with low amounts. Obviously, the inclusion of Se nanoparticles is recommended at 0.15–4 mg/kg depending on the fish species, feeding duration, and experimental conditions (**Table 1**).

Table 1. The effects of selenium nanoparticles on the performances of aquatic animals.

Species	Dose	Duration	Effects	References
Asian seabass (*Lates calcarifer*)	**4 mg/kg**	**6 weeks**	• Growth performance and immune response (↑) • Alanine aminotransferase (ALT) and aspartate transaminase levels (AST) (↓) • Liver superoxide dismutase (SOD), glutathione peroxidase (GPx), and catalase (CAT) (↔)	**Longbaf Dezfouli, et al.** [30]
Asian seabass (*Lates calcarifer*)	**4 mg/kg**	**4 weeks**	• Growth performance, digestive enzymes, and lysozyme activity (↑) • Serum levels of ALT, AST, ALP, and LDH (↔) • Serum levels of glucose, cholesterol, triglyceride, protein indices, immunoglobulin, IgM, C3, and ACH50 indexes (↓)	**Deilamy Pour et al.** [14]
Gilthead seabream (*Sparus aurata*; Linnaeus, 1758)	**3 mg/kg**	**24 days**	• Larval growth and bone mineralization and prevention of skeleton anomalies (↑)	**Izquierdo, et al.** [31]
Red seabream (*Pagrus major*)	**1 mg/kg**	**45 days**	• The growth performance, feed efficiency, protease activity, hematocrit, and biological antioxidant potential (↑) • Reactive oxygen metabolites, cholesterol, and triglycerides (↓)	**Dawood, et al.** [32]
Red seabream (*Pagrus major*)	**1–2 mg/kg**	**45 days**	• Alternative complement pathway, nitro blue tetrazolium activity (NBT), total serum protein, CAT, serum bactericidal activity, serum lysozyme activity, and amounts of skin mucus secretions as well as stress resistance against low salinity stress (↑)	**Dawood, et al.** [49]
Nile tilapia (*Oreochromis niloticus*)	**1 mg/kg**	**8 weeks**	• Growth performance, feed utilization, GPx, SOD, CAT, NBT, lysozyme, and phagocytosis activities, liver, and spleen *TNF-α* and *IL-1β* expressions upregulated (↑) • Malondialdehyde (MDA) (↓)	**Dawood, et al.** [25]
Nile tilapia (*Oreochromis niloticus*)	**1 mg/kg**	**60 days**	• Growth performance, feed efficiency, immunoglobulin M, SOD, and tumor necrosis factor-alpha (*TNF-α*) (↑) • Heat shock protein 70 (*HSP70*) (↓)	**Al-Deriny, et al.** [33]

Species	Dose	Duration	Effects	References
Nile tilapia (*Oreochromis niloticus*)	**1–2 mg/kg**	**4 weeks**	• Serum lysozyme, respiratory burst activities, antioxidant enzymes, and resistance against *Aeromonas sobria* (↑)	**Ayoub, et al. [34]**
Nile tilapia (*Oreochromis niloticus*)	**1 mg/kg**	**4 weeks**	• Growth indices, phagocytic, lysozyme activities, phagocytic index, *IGF-1*, *TNF-α*, *IL-1β*, *CAT* genes, resistance against cadmium toxicity (↑)	**Abu-Elala, et al. [35]**
Nile tilapia (*Oreochromis niloticus*)	**1 mg/kg**	**60 days**	• Growth performance, intestinal morphometry, villi length, and goblet cells number hemoglobin, red blood cells, globulin, phagocytic activity, phagocytic index, lysozyme activity, immunoglobulin M, SOD, and CAT (↑) • FCR and MDA (↓)	**Ghazi, et al. [36]**
European Seabass (*Dicentrarchus labrax*)	**0.5–1 mg/kg**	**90 days**	• Growth performance, feed efficiency, Hb, PCV, RBCs, WBCs, total serum protein globulin, phagocytic index, phagocytic, lysozyme activities, SOD, CAT, *GH*, *IGF-1*, *IL-8*, and *IL-1β* (↑) • MDA and *HSP70* (↓)	**Abd El-Kader et al. [38] and Abd El-Kader et al. [37]**
Mahseer fish (*Tor putitora*)	**0.68 mg/kg**	**70 days**	• Growth performance, red blood cell count, hemoglobin level, hematocrit values, lysozyme activity, serum growth hormone levels, tissue total protein content, and GPx (↑)	**Khan et al. [29] and Khan et al. [39]**
Pangasinodon hypophthalmus	**1–2 mg/kg**	**60 days**	• Growth performance, antioxidative status, immunity, and neurotransmitter enzyme activity (↑)	**Kumar et al. [40]**
Pangasinodon hypophthalmus	**1–2 mg/kg**	**72 days**	• Thermal tolerance (↑)	**Kumar et al. [50]**
Pangasinodon hypophthalmus	**1–2 mg/kg**	**60 days**	• Resistance against *Aeromonas veronii* biovar *sobria* (↑)	**Kumar and Singh [17]**
Pangasinodon hypophthalmus	**1–2 mg/kg**	**95 days**	• CAT, glutathione-s-transferase (GST), and GPx (↑)	**Kumar et al. [51]**
Pangasianodon hypophthalmus	**0.5 mg/kg**	**2 months**	• Growth performance, anti-oxidative status, acetylcholine esterase, NBT, total immunoglobulin, myeloperoxidase, globulin, and high-temperature resistance (↑) • Serum cortisol, lipid peroxidation in the liver, gill, and kidney, blood glucose, *HSP70* in gill and liver (↓)	**Kumar, et al. [41]**

Species	Dose	Duration	Effects	References
Rainbow trout (*Oncorhynchus mykiss*)	**1 mg/kg**	**8 weeks**	• GPx (↑) • The survival rate, growth performance, feed utilization, and body composition (↔)	**Kohshahi, et al.** [48]
Rainbow trout (*Oncorhynchus mykiss*)	**2 mg/kg**	**-**	• Percentage of egg hatching (↑)	**Mahdave Jehanabad, et al.** [16]
Rainbow trout (*Oncorhynchus mykiss*)	**2 mg/kg**	**60 days**	• Growth parameters, RBC, hemoglobin, hematocrit, and resistance against sublethal ammonia stress (↑) • WBC (↔)	**Nazer, et al.** [42]
Caspian roach (*Rutilus caspicus*)	**1 mg/kg**	**28 days**	• Resistance to malathion stress (↑)	**Zahmatkesh, et al.** [52]
Goldfish (*Carassius auratus*)	**0.6 mg/kg**	**9 weeks**	• Weight gain, specific growth rates (SGR), mucosal immunity, ghrelin, and *IGF-1* genes expressions (↑) • FCR (↓)	**Jahanbakhshi et al.** [43]
Goldfish (*Carassius auratus*)	**1 mg/kg**	**60 days**	• Male semen quality and GPx (↑)	**Seyedi, et al.** [53]
Common carp (*Cyprinus carpio*)	**0.7 mg/kg**	**8 weeks**	• Growth performance, liver GPx, SOD, and CAT activities (↑) • MDA, AST, alanine transaminase, and lactate dehydrogenase activity (↓)	**Saffari, et al.** [44]
Common carp (*Cyprinus carpio*)	**1 mg/kg**	**8 weeks**	• Growth performance, GPx, SOD, total protein, globulin, serum high-density lipoprotein (HDL) (↑) • Albumin, MDA, AST, and alanine transaminase (ALT) activities (↓) • Feed efficiency (↔)	**Ashouri et al.** [45]
Rohu (*Labeo rohita* Hamilton)	**0.3 mg/kg**	**120 days**	• Growth performance, respiratory burst, lysozyme, SOD, acetylcholine esterase activity, myeloperoxidase activities, resistance *Aeromonas hydrophila* (↑) • Lactate dehydrogenase and alkaline phosphatase activities (↓)	**Swain, et al.** [46]
Crucian carp (*Carassius auratus* gibelio)	**0.5 mg/kg**	**30 days**	• GPx in plasma and liver (↑)	**Zhou et al.** [22]

Species	Dose	Duration	Effects	References
Grass carp (*Ctenopharyngodon idella*)	**0.6–0.9 mg/kg**	**10 weeks**	• Growth performance, survival rate, liver fatty acid oxidation, and triglyceride hydrolyses genes (*PPARα*, *CPT1*, *ATGL*, and *LPL*) and high-density lipoprotein cholesterol (↑) • Serum triglyceride and total cholesterol, ALT, and AST (↓)	**Liu et al. [47]**
Whiteleg shrimp (*Litopenaeus vannamei*)	**0.15 mg/kg**	**56 days**	• Growth performance (↑) • FCR (↓)	**Karamzadeh et al. [13]**

Variation in the treated fish compared to controls: (↑), significantly increases; (↓), significantly decreased; (↔), no significant change.

4. Antioxidative Capacity of Selenium Nanoparticles

Aquaculture activity is threatened with various stressors involved in reducing the health status of aquatic animals [54]. Aquatic animals suffer from biotic and abiotic stressors which impair their biological and physiological functions. Stressors disrupt the antioxidative balance due to the high generation of reactive oxygen metabolites (ROS), hydrogen peroxide, and peroxide radicals [55]. These free radicals induce lipid peroxidation and led to DNA and cell damage. Severe oxidative stress is the precursor for several antioxidative responses such as superoxide dismutase (SOD), catalase (CAT), glutathione-S-transferase (GST), and peroxidase (GPx) [56]. Se is known for its role in forming selenoproteins that help synthesize glutathione peroxidase enzymes [7]. More specifically, Se nanoparticles are noted to upregulate the expression of GPx by forming selenophosphate [8]. Therefore, Se nanoparticles are suggested as a powerful antioxidative agent in aquaculture.

Longbaf Dezfouli et al. [30] reported that Asian seabass-fed dietary Se nanoparticles (4 mg/kg) showed improved antioxidative capacity (SOD, CAT, and GPx). Further, Dawood et al. [32] reported that red sea bream-fed dietary Se nanoparticles (1–2 mg/kg) had enhanced CAT. Besides, Dawood et al. [25] stated that Nile tilapia-fed dietary Se nanoparticles (1 mg/kg) had enhanced GPx, SOD, and CAT. Additionally, Al-Deriny et al. [33] reported that Nile tilapia-fed Se nanoparticles (1 mg/kg) had activated SOD. In another study by Ghazi et al. [36], Nile tilapia treated with Se nanoparticles (1 mg/kg) had enhanced SOD and CAT and reduced malondialdehyde levels (MDA). In European Seabass, Abd El-Kader et al. [37] and Abd El-Kader et al. [38] illustrated high SOD and CAT and low MDA levels in fish treated with Se nanoparticles (0.5–1 mg/kg). Mahseer fish fed dietary Se nanoparticles (0.68 mg/kg) had enhanced GPx activity. Markedly, *P. hypophthalmus* fed dietary Se nanoparticles (1–2 mg/kg) for 95 days had enhanced CAT, GST, and GPx [51]. Kohshahi et al. [48] indicated that rainbow trout-fed Se nanoparticles (1 mg/kg) had enhanced GPx activity. Seyedi et al. [53] reported that Goldfish fed Se nanoparticles (1 mg/kg) for 60 days had enhanced GPx. Saffari et al. [44] and Ashouri et al. [45] reported that common carp-fed dietary Se nanoparticles (0.7–1 mg/kg) had enhanced SOD, CAT, and GPx and reduced MDA levels. Furthermore, rohu fish fed Se nanoparticles (0.3 mg/kg) [46] and Crucian carp [22] fed 0.5 mg Se nanoparticles/kg showed enhanced SOD and GPx, respectively.

It is evident that Se nanoparticles can enhance the antioxidative capacity of aquatic animals through the activation of SOD, CAT, GST, and GPx enzymes. In addition, Se nanoparticles reduced lipid peroxidation through the reduction of MDA levels.

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