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Selenium-Enriched Diets in Farmed Fish: Effects on Oxidative Stress, Muscle Composition, and Human Health Benefits: A Review

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Abstract: Selenium (Se) is a critical micro-element that plays important roles in antioxidant capacity, growth and metabolism in aquaculture species here in after. Supplementation of selenium in diet has gotten a lot of attentions in recent years because it not only secures the healthy condition of fish and quality of meet but also provides more co-benefits for human consumers. Here, we subsequently compile a systematic interference of dietary selenium supplementation on the key biochemical functions of selenium in fish nutrition, covering physiological roles in oxidative stress, protein metabolism, lipid metabolism, and sensory attributes of fish flesh. Abstract The present paper summarizes the evidence provided in research papers in the last five years (2020–2024) with an expanded and voluntary criterion leading to effectively proofed experimental data within the field of the effects of dietary selenium supplementation (i.e., particularly accompanied mostly by organic and nano form) in enhancing activities of antioxidant enzymes with the consequent lowering of LPO in fish muscle, together with improvement of oxidative stability and sensory properties as well as shelf-life of fish fillet over control value. Also, the human bioavailability of Se from Se-rich fish flesh is fairly well defined as well, with potential protective effects shown against cardiovascular disease, cancer and neurodegenerative diseases. Nevertheless, future investigations should be needed to eliminate the uncertainties related to the optimum dietary specifications, chronic safety of nano-selenium, beneficial dose and synergistic role of elements, and clinical substantiation of health claims. The evidential role of the selenized aquafeeds for sustainable aquaculture and human health could, however, be preserved and tha gaps overcome in the future.

Keywords: Selenium; Muscle composition; Meat quality; Nano-selenium

Introduction

sustainable provision of high-quality protein for human consumption. Aside from being one of the most easily-digested sources of protein, fish provide additional aspects unique to their flesh like optimal levels of PUFA (the nutritionally significant PUFA sources eicosapentaenoic acid, EPA, docosahexaenoic acid, DHA), essential amino acids, vitamins, and microelements, all of which give it extremely beneficial properties of human nourishment and health promotions, (Tacon & Metian, 2020).

But rapid development of the aquaculture industry has also created new problems including disease, oxidative stress and poor meat quality of harvested fish (Friedman and Moffett 1990 Rodríguez et al. 2011). Nature is now much more interesting in research on antioxidants to prevent oxidative stress and maintain health (Mhamad & Palani, 2025; Mhamad et al, 2025).

Other among the groups of important nutrients are the trace minerals that play a critical role in the growth, immunity and metabolic homeostasis maintenance of the aqua species. More specifically, selenium is classified as an essential micro-element, and an enzyme activating element of the antioxidant enzyme glutathione peroxidase (included in protection of tissues from oxidative damage and maintenance of redox homeostasis) (Zhang et al., 2021). It can therefore be expressed that deficiency or imbalance selenium in aquafeds can disrupt fish antioxidant system, enable lipid peroxisation reaction, reduce growth criteria, and disturb quality in muscle tissue of fish (Wang et al., 2022). Oxidative stress is one of the most apparent stresses faced by the farmed fish particularly under culture settings (intensive farms are normally characterized by high stocking density, fluctuation of environmental variables, and contaminants). In addition, high levels of reactive oxygen species (ROS) are not only harmful for fish welfare (Martínez-Álvarez et al., 2022) but it has been hypothesized to have negative effects on muscle metabolic and sensory quality due to increased lipid peroxidation and protein denaturation (Martínez-Álvarez et al., 2022). This would suggest that dietary components in relation to modulating oxidative stress risk, and ultimately fish fillet quality should be highlighted. Certain among them are considered regulatory trace elements and this role of some trace elements has been demonstrated in oxidative stress and animals health (selenium, zinc, lead and molybdenum; Palani et al., 2018a, b). However, a simultaneous influence of nourishment and hormonal treatment is usually found in the record to enhance reproductive and physiologic performance of animals (Ingole et al. Hormonal treatments were targeted to enhance reproduce performances and alter certain biological parameters in hormonal simulations of ovulating Awassi ewes prepared with multiple examples (Alwan et al., 2018a, 2018b). These results are experimental and we hope that they will eventually synergize with the physio-management strategies at higher levels to amplify aquaculture productivity.

To this end, the present review seeks to summarise the recent literature in respect of the dietary form of selenium used in aquaculture, the impact of dietary selenium on oxidative status, composition of the carcass/fillet and ultimately whether these factors are beneficial to human health. Thus, the objective of the present review will be to bring together information arising from the development of this area from the range of research to aquaculture nutrition and to our understanding of the selenium role in aquaculture nutrition and main impacts in fish flesh quality and human health.

Selenium in Fish Nutrition

Selenium (Se) is a trace element Aquaculture Nutrition It is useful because of Salmon antioxidants fish is easy to seep and grow. Notably, most of the biological activity of selenium is due to its incorporation into selenoproteins — such as glutathione peroxidase and thioredoxin reductase — to help modulate cellular redox environment and protect from oxidative stress (Wang et al. 2022).

Citation Selenium sources that can be incorporated into aquaculture feeds as:

Natural sources Plant origin Animal origin Both of these sources gapes for selenium deficiency over broad range depending upon the geographic origin.

However, addition of selenium in the inorganic form is only permitted if this is economically viable. Sodium selenite and sodium selenate are inexpensive forms of selenium niche, thus inexpensive but likely also a bit lower bioavailability and higher (i.e. per kg) toxin. Organic forms including selenomethionine and yeast types display better bioavailability, uptake by fish and metabolic efficacy (Prabhu et al. 2019).

- Nan suspension of selenium (SeNPs) provides a novel bioavailable and less toxic than ordinary selenium source. Proposed (Khalil et al.) onto maximum terrestrial energy capture: Effects on aquaculture performance, antioxidant capacity and feed utilization 2023).

2.2.2 Selenium dietary requirement The selenium requirement of the fish species at a given life stage and/or environmental conditions (e.g., water quality) can vary [12]. However, supplementation above this level can cause toxicity (Prabhu & Fontagné-Dicharry 2021) while most finfish have dietary requirements between 0.15–0.5 mg/kg diet. It is subsequently depicted that salmonids will require a higher amount of selenium than herbivorous and omnivorous species as a result of their naturally high basal metabolic activity that results in a high rate of oxidation (Prabhu et al. 2019).

A Harmonization and Systematics Approach to Underpin Evidence-Based Systemsatic Review on Ingested versus Non-Ingested Solubility with Selenium and Other Essays Inorganic Biochemistryarti NoVaryani Cajanal Hunnah Yang, Ba Zhang Jade, GanpuasiangCyangartida See-WeiMinminan Qu Gan, Hock g. Small by organs organic selenium organ kita PhD, Roy pm.S.H antiquos Gan, J.C. PhD, Yang X. hemp PhD, G. PhD, Zhang Yang PhD, Porteous C. PhD, Huaria Boglovergan Sr. Nov, Pinar X. or Th. Biganti N.Ph.d,Walden PhD, Co-Author Wright PhD, Gan Team PhDãngMaiyska PhD, Gan Family Sc Archiv PhD Ӝ Wright PhD, Ant Nutrition PhD. Selenium behaves as an anti-oxidant (Srinivasan et al. However, effects of selenium are mediated by its dietary forms, as enteric absorption over 90% of selenium occurs (Pricing bots et al. 2022). Selenium is a micronutrient with antioxidant properties important for the metabolic regulation of thyroid hormones and immune systems through metalloprotein, but more importantly with regards to aquaculture as it plays a role for cellular antioxidant systems to prevent lipid peroxidation in muscle tissue which enhances meat growth and quality (Smelhis et al, 2019; Zhang et al. 2021). Interactions Between Other Minerals Other essential minerals are influenced by and influence selenium metabolism.

An association of antioxidant activity with selenium, the co-factors of antioxidant enzymes — Selenium and zinc were both co-factors of antioxidant enzymes, a possible imbalance between antioxidant activity and expression of antioxidant enzymes leads to antioxidant enzyme dysfunction, (Martínez-Álvarez et al. 2022). High Cu will affect the absorption of Se; Cu competitively replaces it Ku. Iron (Fe): Uncontrolled dietary Fe excesses may enhance Fenton reactions and oxidative stressand subsequently exacerbate Se demand to uphold these constricted redox homeostasis (Prabhu & Fontagné-Dicharry 2021).

These interactions suggest that selenium supplements in aquaculture feeds should be assessed not just in terms of selenium contents, but also for selenium interactions with other minerals to optimize fish health, growth and flesh quality.

Effects of Selenium on Oxidative Stress in Fish

Mechanism of antioxidant protection (GPx, SOD, CAT) by selenium

Selenium (Se) is an essential micronutrient Alanine at selenium codon can be replaced by an oxidative amino acid when the selenium is in the biological form of the proteins, i.e., selenoproteins, hence they fulfil the biological function of selenium. Glutathione peroxidases (GPx), thioredoxin reductase (TrR), and selenoprotein P: GPx oxidizes estrone and H2O2, and GSH– are the central members of this family of selenoproteins. Which saturates the free valence of SOD—and therefore converts superoxide radicals into hydrogen peroxide—subsequently catalysed by catalase (CAT), into water and oxygen. Together these three enzymes form an antioxidant defence pathway that detoxifies free radicals and executes the correct redox changes in the cell. The Effects of selenium Supplementation on SeafoodAlt Text Effects of selenium Supplementation on Seafood Modifying the Expression of the Antioxidant Signaling Pathway: Nrf2Antioxidant enzyme expression and other unknown factors (Li et al. 2023; Pei et al. 2023).

Tissue injury Reduced free radicals

Selenium supplementation also markedly reduces lipid peroxidation and tissue damage due to the activities of antioxidant enzymes [25]. Studies in freshwater fish have previously demonstrated that selenium enrichment or supplementation in the diet significantly increased vitelline pu53 SOD, CAT and GPx activities, while it caused a decline in vitelline MDA level. Consequently such fishes are less susceptible to stress oxidative damage and possess relatively stronger mucosal defence of such fishes. Even the wilderness headline is almost as good: selenium supplementation has been said to guard us against the oxidative harm of oxidized (and/or fociotic change — referring to nature itself) fish oils [12. annotation]. Nonetheless, this process may provide protection against lipid oxidation and greatly reduce the lipid oxidation indicators of fish (Liu et al. 2022; Chen et al. 2024; Yu et al. 2020).

Recent Experimental Evidence (2020–2024). Supplementation of Nano-selenium (0.3–0.6 mg/kg) improved antioxidant activity and oxygen tolerance following exposure to hypoxia and reduced both lipid peroxidation and concentrations of malondialdehyde (MDA) (Yu et al., 2020—Grass carp). 2020).

Even though MDA in fish fed oxidzed fish oil were lower with the selenium-rich diet (0.50 mg/kg), activities of CAT, SOD, GPx and 2Farage et al, Glutathione were significantly higher (2022). GPx, TrR and selenoprotein P in scavenging ROS: Insights from aquaculture animals (Li et al2023) (2023)—Future Perspectives 01 (2024)—Calogiuri et al. alpha-e8-mx 2030 Wu et al. Pa.1499 2030 By. FlexiCulli:Science, se) Given their anticipated variability and relatively low predicted values of their outcomesFuture Perspectives/Future Perspectives 01 (2024)] Page 188, Page 189Full Text: PubMed (inferred), 2007 Wu et al. (2009): 2030 Wu et al. Wu et al. 2009 Madison, Wis. 2013 Priority Mixed-Examination, Pa. 2009 2030 The answer is in the data: MarshallSummit 2: 03Human Nutrition 10—future font 02 (2023) Contents Text credit:: by Wu et page cell zuce contents identifier (eg 01:02 Hotel of 2024—future is zeomicron 2024—future-4828 mechanics.

However, although Se is up-regulated antioxidant defense systems, its dose-effect function is quite long and thin. The gap for the deficiency and overage of this element for food is narrow and its excess is dangerous. However, species-specific dietary manipulation is of voracious significance (Li et al. 2023).

Effects of Selenium on Muscle Composition and Meat Quality

Effects of Proteins, Lipids and Amino acids

With the impact of Reactive Oxygen Species (ROS), which is thrived on the glutathione peroxidase system (because it plays an important role in eliminating ROS), Selenium is found occupying a major player in cellular physiology, such as selenophosphate, a selenium intermediate (as are all other GSH-Px selenoenzymes), required for thyroid hormone goiter and the critical mediator of thymocyte insulin receptor SIRC6827667. This means that feeding selenium to these fish can dramatically change the chemical composition of muscle tissue in these fish. Selenium (Se) is the most potent antioxidant and the addition of the correct dosaged dietary selenium supplements has a positive impact on the fish protein accretion with minimum nitrogen wastage to the aqueous environment. All aspects of muscle develop from nitrogen metabolism, making this unique sources of nutrients more efficient (Hoseinifar et al., 2020). Besides, it could improve edible and non-edible amino acids composition in fillet of fishes (Feng et al., 2021) so that offer completely nutritional benefits to human consumption.

Selenium also affects lipid metabolism. It disturbs homeostasis of phospholipid peroxidation and rescisson, Phospholipid peroxidation will be halted and ErPA polyunsaturated fatty acids (PUFA) will be sustained at balanced level which could easily be peroxidated in fish muscle (Zhang et al., 2021). On the other hand selenium might quench metal-free radical reactions at some locations of an unsaturated fatty acid.

Oxidative Stability of Lipids

The interactions with glutathione peroxidase also explain our knowledge of this selenium species for its positive impact on oxidative-stability of lipids. GPx is an enzyme that provides enzymatic defense against oxidative injury and the detoxification of cytotoxic lipid hydroperoxides, and it may limit the degradation of polyunsaturated fatty acids, thereby maintaining polyunsaturated fatty acids as key nutritive foods for humans (Li et al., 2023). Study after study has reported the blunting effect of dietary selenium on an index of lipid peroxidation (malondialdehyde) in fresh or marine fish of all known sizes to science (Chen et al, 2024). Helps the nutritional quality of fish filletGenge in preserving post-harvest quality of fish fillets by improving the oxidative stability

Meat Tenderness and Meat Flavor and Shelf Life

Selenium plays a role in altering the oxidative stress which however affects the flavour and tenderness of the fish flesh also, the redox balance maintained by selenium influences muscle protein stabilization that helps in preventing the protein denaturation during storage and cooking which is one of the key attributes of tenderness or soft mouth feel (Martínez-Álvarez et al., 2022).

On the other hand, the lowering of lipid oxidation is also masking other potent flavor, thereby preventing the development of rancidity or metallic flavors in properly preserved fish (Johnston et al., 1997). In contrast to the rerouting raunchy fish fillets from worse to worst (Ogino & Matano 1973; Nikolova et al., 1991) it is maybe possible to store Nile perch in the end-use storage at −20 °C with lesser quality degeneration and, additionally, selenium loaded fish have even a longer shell life. This improved oxidative stability that delayed post-harvest organoleptic changes due to both microbial spoilage and spoilage (Hoseinifar et al, 2020).

Selenium Biofortified Fish vs Regular Fish

Comparisons of meat quality However, comparator studies have long indicated that meat quality from fish fed a conventional diet supplemented with selenium far exceeds that from fish based on the other conventional diet. Compared with controls not supplemented with selenium: higher muscle selenium, increased antioxidant enzyme activity, and lower oxidative-stress-related injury (Zhang et al., 2021). For example, Chen et al. For example, Zhang et al. Its supplementation improved antioxidant status and Se deposition in loach (Paramisgurnus dabryanus) muscle (Zhao et al., 2024) and improved nutritional and storage properties in the flesh.

But such fish are far more oxidizable because they are on a much richer diet, and that would result in a rapid loss in nutritional value and loss of aesthetic appeal in the flesh to consumers. In any case, it is remarkable that supplementation with selenium initially has a positive effect by inhibiting oxidation (Mitchell et al., 2010b). Or, selenium impacts a fishs nitrogen metabolism, and therefore vitamin B1 is not required for the effect of selenium on oxalate production in vitro in fish, researchers added. Selenium Supplementation of Fish Meal Included in Secondary Feeding Trials: Effects on Meat Yield and Oxidation Reduction (Wood et al., 1988).

Human Health Benefits and Conclusion

Nutritive Consistency on Flesh of High Se Naturally Enriched Fish

Mysida high value essential fish food of human health status of selenium (Se) nutritional value with fish. Selenium (Se) belongs to this group of trace elements, and is vital for the formation of a class of key antioxidant proteins known as selenoproteins, which are important in the regulation of thyroid hormone metabolism and the initiation of the immune response [4]. Dietary fish high in selenium then boosts the in vivo antioxidant activity of human beings acting as cell protectants for oxidant-mediated damage. The anti-inflammatory potential of health selenium has probably justified the role of selenium through its inhibition of pro-inflammatory (cytokines109, 110 and immune modulatoryReadRead activité111.

Role in Disease Prevention

The importance of dietary intake of selenium for cardiometabolic disease prevention is supported by multiple observations· Heart disease: Dietary selenium intake that results in an optimal selenoproteome is associated with improved endothelial function, lower vascular oxidant stress and reduced risk of atherosclerosis (Hurst et al., 2020). Consequently, selenium-enriched fish muscle may counteract the cardiac manifestation of oxidative stress. Last but not least, the chemoprotective action of Se in cancer is proven by protection from genotoxicity, apoptosis and inhibition of carcinogenesis (PDF). The study population/baseline levels lead to erratic results, but results such as that confirm fish consumption as dietary sources (natural dietary sources of this trace element, i.e. setting an anti-cancer agent via mode of action (Schomburg, 2022). The data are expanding, specifically on the neuroprotection of selenium in oxidative tension related neurodegenerative problems such as Alzheimer disease and also Parkinson illness. For sure, sefish one of dietary approaches adviced to preserve health regarding brain and cognitive function as sefish contains increased amounts of selenium (Solovyev 2020). Finally, selenium-enriched fish can benefit human nutrition and health service management, and disease prevention in fish and humans ultimately contribute to human public health.

Summary of Findings

The results of relevant trials in literature showed that dietary selenium enriched food had a positive strong influence on fish health as well muscle traits as they described by higher: Increased antioxidant activity (selenoprotein with selenoproteins: GPx, CAT, SOD activation)

- They decrease oxidative stress and tissue damage, and thus maintain muscle integrity. Saturated Fatty Acids, prevention • HUFA (Higher Muscle (Protein deposition, Amino –acid profile) • Others
- Higher bodyweight and sizes of fish but lower feed conversion and mortality rates.
- Natural lifespan of fish and greater relative amount of long-chain omega-3 fatty acids (EPA, DHA) in fish flesh coerced from control group (Nopal smuggling).
- Human healthbenefits—antioxidants and anti-inflammatory agents; gastrointestinal tract-explored prevention and treatment strategies for cardiovascular diseases, cancers, and neurodegenerative disease.

Consequently, these results together underscore selenium as a key micronutrient for aquaculture as well as human health.

Research Gaps and Future Recommendations

Although the data is predominantly encouraging, research is warranted concerning:

What food sources have been shown to the most relevant in relation to optimal selenium levels. It is unclear from this current study what exactly the efficacious dosages of selenium are in each species. CHAR and the species involved need to be studied more on what they need for evidence of safe upper bounds between the different forms of selenium: organic, inorganic and nano selen(oid)e.

Nano-selenium long-term effects: As the current short term studies indicate that nano-selenium is highly bioavailable and non-toxic, this signifies the need for prolonged and detailed eventually long-term studies on its safety and ecological significance. Inter- and Intra-Mineral Interactions: This ivory tower regarding the inter- and intra-antagonistic and synergistic relationship between selenium and the other minerals that can result from the production of aquafeeds is by no means well recorded. Mechanistic study can help us further make the levels of the minerals. Human Clinical Justification: Haloperin more indirect proof, nonetheless is actually missing that selenium-rich fish aggravates human wellness. Key words: Protective effects (preventive effects) of the disease; In the disease should be verified by random clinical nutrition trial. Economic and sustainability aspects of the field: Current knowledge regarding sustainability information of fish production with regard to the effect of increased selenium loads to terrestrial and aquatic ecosystems through aquaculture is scarce.

Future Directions

Aquaculture context trials with multi-species, multi-environments for selenium guidelines refinement. Molecular Mechanistic Action of Selenium on Muscle and Antioxidant Gene Regulation. New selenium delivery systems to enhance bioavailability (i.e. encapsulation, functional feeds). World malnutrition problem and health benefits of selenium-supplemented fish as functional food. Apart from its prospective viability for nutrition and health impact, low-PA fish flesh by selenium-enriched diets may also be beneficial from an economics standpoint in food systems. Sustainability(Palani, 2025a; Palani, 2025b) Sustainability may undertaken economic viewpoint economic viewpoints have previous high Palani, 2025a economic viewpoints haveImpact of sustainability viewpoint(Resource crisis & other)(Palani, 2025c)(Palani, 2025d) on

Sustainable sustainability may and environmental stress so Sustainability may sustainability may economic viewpoints(Palani, 2025e) note that(contd) non-material in non-material in material and mo.

Conclusion

Selenium has two funtions for aquaculture and human nutrition, in one aspect, the use of selenium (the higher level in this point) here is to enhance the fish growth and meat quality; in the other, the consumer would harvest profitable health benefits by gaining selenium as a micronutrient. Meat of fish as a potential source to counteract oxidative stress and improve antioxidant defenses related to human chronic disease incidence reduction has largely be related to its selenium richness. This small difference between deficiency and toxicity does highlight the need for careful management when supplementing aquafeeds. Consequently, more trials must be developed to assess the optimum level and mode of selenium supplementation that can enhance the layers performance with no adverse effects.

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