



Plant-Derived Dietary Antioxidants for Mitigating Oxidative Stress in Cultured Fish: Mechanisms, Experimental Evidence, and Practical Limitations

Yuli Andriani^{1*}, Rusky Intan Pratama¹

¹ Department of Fisheries, Faculty of Fisheries and Marine Sciences,
Universitas Padjadjaran, Indonesia.

Corresponding author | Yuli Andriani Email: yuli.andriani@unpad.ac.id

Abstract

Oxidative stress is an important concern in cultured fish because environmental, nutritional, and physiological challenges can disturb cellular redox regulation and contribute to molecular damage. Plant-derived dietary antioxidants have been investigated as potential feed additives to support antioxidant defenses and improve fish health. This narrative review examines major plant-derived antioxidant compounds and preparations, their proposed mechanisms of action, experimental evidence from finfish feeding trials, and limitations affecting their practical application. Relevant publications were evaluated through a targeted narrative approach, with emphasis on antioxidant enzyme activities, oxidative damage indicators, growth, immune responses, and stress tolerance. Feeding trials have reported changes in superoxide dismutase, catalase, glutathione-related indicators, and malondialdehyde following supplementation with selected plant-derived compounds and ingredients. However, responses were not uniform across studies. Some treatments reduced lipid peroxidation without increasing antioxidant enzyme activities, whereas others changed enzymatic defenses without significantly affecting malondialdehyde. Improvements in growth or disease-related outcomes were also not consistently associated with reduced oxidative damage. These differences were influenced by ingredient preparation, dietary inclusion level, fish species, and experimental conditions. Practical application is further complicated by variation in ingredient composition, losses of active compounds during feed processing, uncertain bioavailability, and limited information on long-term safety and commercial-scale performance. The available evidence indicates that selected plant-derived dietary antioxidants may support oxidative stress management under specific conditions, but their effectiveness cannot be generalized across ingredients or fish species. Future investigations should integrate ingredient characterization, appropriate dose evaluation, feed-processing stability, and complementary indicators of oxidative damage to establish more reliable recommendations for aquaculture feeds.

Keywords:

Oxidative stress; Fish nutrition; Phytogetic feed additives; Antioxidant defenses; Aquaculture.

1. Introduction

Reactive oxygen species (ROS) are continuously generated during cellular metabolism and participate in physiological processes, including intracellular signaling and responses to environmental changes. However, disturbances in the regulation of oxidant production and antioxidant defenses may result in oxidative stress, which can affect redox signaling and cause molecular damage. Excessive oxidative reactions may modify lipids, proteins, and nucleic acids, potentially impairing cellular functions. The biological effects of ROS therefore depend on their chemical properties, concentrations, cellular locations, and regulation by endogenous antioxidant systems (Sies & Jones, 2020; Sies, 2020).

Oxidative stress is relevant to aquaculture because cultured fish may encounter environmental and physiological conditions that affect cellular redox balance. Temperature fluctuations, inadequate water quality, high stocking density, contaminants, and pathogen exposure have been associated with changes in oxidative status in aquatic organisms. Although fish possess enzymatic and non-enzymatic antioxidant defenses, prolonged or intense stress may exceed their capacity to maintain redox balance. These concerns have encouraged research into nutritional strategies intended to support antioxidant regulation and physiological resilience in cultured fish (Hu et al., 2025).

Dietary supplementation with plant-derived ingredients is one approach investigated for this purpose. Plants contain bioactive constituents, including phenolic compounds, carotenoids, and other substances with antioxidant-related properties. Depending on their chemical characteristics and biological availability, these compounds may participate in oxidative reactions or influence endogenous antioxidant defenses. Their use in aquaculture feeds has been examined through plant powders, extracts, processing by-products, and purified compounds. For example, Oh et al. (2022) reported changes in antioxidant enzyme activities, growth performance, and resistance to *Streptococcus iniae* infection in juvenile black rockfish (*Sebastes schlegelii*) receiving diets supplemented with ginger processing residue.

Nevertheless, the potential benefits of plant-derived dietary antioxidants cannot be generalized across ingredients or fish species. Differences in composition, preparation, inclusion level, feeding duration, and experimental conditions may influence the responses observed. Moreover, changes in antioxidant enzyme activities do not necessarily demonstrate reduced oxidative damage because these measurements represent different aspects of cellular redox regulation. Previous reviews have summarized natural antioxidant sources, mechanisms, and applications in aquaculture (Hu et al., 2025; Kawsar et al., 2026). A focused examination of individual feeding trials remains useful for distinguishing changes in antioxidant defenses from evidence of oxidative protection and identifying the conditions under which dietary supplementation may provide measurable benefits.

This narrative review examines plant-derived dietary antioxidants used in cultured finfish, with emphasis on their sources, proposed mechanisms, and experimental evidence related to oxidative stress mitigation. It considers antioxidant defenses and oxidative damage indicators alongside growth, feed utilization, immune responses, and stress tolerance. Particular attention is given to inconsistent findings and limitations involving ingredient preparation, dietary inclusion levels, bioavailability, and feed processing. The review aims to clarify what current experimental evidence supports and where additional research is required before practical recommendations can be established.

2. Materials and Methods

2.1. Literature identification

This article was developed as a narrative literature review of plant-derived dietary antioxidants and their potential roles in mitigating oxidative stress in cultured finfish. Relevant publications were identified through targeted, iterative searches of accessible scientific literature and bibliographic records. The literature examined included original feeding trials, review articles, and studies addressing biochemical mechanisms relevant to oxidative stress and antioxidant regulation.

Search terms were adapted to the topics being investigated and included combinations of fish, finfish, aquaculture, dietary antioxidants, plant extracts, phytogetic additives, oxidative stress, antioxidant enzymes, and lipid peroxidation. Targeted searches also used the names of individual ingredients and compounds, including curcumin, ginger, moringa, tea polyphenols, quercetin, and other relevant plant-derived substances. Publication records were checked against publisher information and accessible article texts, including PubMed and PubMed Central records where available.

Priority was given to literature published between 2016 and October 2026, while earlier publications were considered when necessary to explain established biochemical concepts or document relevant experimental findings.

2.2. Literature selection and organization

Original studies involving dietary supplementation with plant-derived materials in cultured finfish were prioritized for evaluating biological responses. Relevant treatments included plant powders, extracts, processing by-products, and purified plant-derived compounds. Studies were particularly relevant when they reported antioxidant defense indicators, oxidative damage markers, responses to defined stress challenges, or associated changes in growth, feed utilization, and immune function.

Studies involving crustaceans, mollusks, or other non-fish organisms were not used as primary evidence of dietary effects in cultured fish. Similarly, studies limited to chemical antioxidant assays or direct treatment of harvested fish products were not considered evidence of physiological protection following dietary supplementation. Such publications were considered only when they provided relevant background information. The literature was organized by antioxidant sources, proposed mechanisms, experimental outcomes, and practical considerations.

2.3. Evidence evaluation and narrative synthesis

The literature was examined using a thematic and critical narrative approach. Particular attention was given to fish species, ingredient preparation, dietary inclusion levels, feeding duration, experimental conditions, and the indicators used to assess antioxidant responses. Antioxidant enzyme activities were distinguished from indicators of molecular oxidative damage. Where reported, significant, non-significant, and inconsistent findings were considered. No quantitative meta-analysis was performed. The review presents a qualitative synthesis of selected publications rather than an exhaustive assessment of all available studies.

3. Results and Discussion

3.1. Oxidative stress and antioxidant defense in cultured fish

3.1.1. Reactive oxygen species and oxidative stress

Reactive oxygen species include chemically distinct oxygen-derived species, such as the superoxide anion radical, hydrogen peroxide, and hydroxyl radical. These species differ in reactivity, biological targets, and physiological roles. ROS arise during aerobic metabolism, including mitochondrial electron transport and enzyme-mediated reactions. Their production is not necessarily harmful, as certain ROS participate in cellular signaling. Oxidative stress may develop when redox regulation is disrupted sufficiently to impair signaling or promote molecular damage (Sies & Jones, 2020; Sies, 2020).

Oxidative damage can affect polyunsaturated lipids, proteins, and nucleic acids. The presence of ROS alone does not establish oxidative stress; effects must be interpreted in relation to cellular conditions, antioxidant regulation, and evidence of molecular damage (Murphy et al., 2022). In fish, oxidative disturbances may affect tissues including gills and liver. Assessment requires complementary indicators rather than reliance on a single biochemical measurement (Oliveira et al., 2024).

3.1.2. Aquaculture-related oxidative stressors

Environmental and husbandry conditions can alter oxidative status in cultured fish. Temperature changes, low dissolved oxygen, elevated ammonia, contaminants, high stocking density, and disease-related challenges may affect metabolism and antioxidant regulation; responses vary with species, exposure, and tissues (Oliveira et al., 2024).

Jia et al. (2022) investigated largemouth bass (*Micropterus salmoides*) at different stocking densities in an integrated rice–fish system for 90 days. The highest-density treatment showed poorer growth and changes in physiological and oxidative indicators compared with lower densities. Santana et al. (2022) reported effects of pesticide exposure on antioxidant defense and biotransformation systems in fish, varying with exposure and biomarkers. These observations do not establish equivalent effects for other species or stressors.

3.1.3. Endogenous antioxidant defense systems

Fish possess interconnected enzymatic and non-enzymatic systems contributing to cellular redox regulation. Superoxide dismutase (SOD) catalyzes dismutation of superoxide into hydrogen peroxide and oxygen, while catalase (CAT) and glutathione-dependent peroxidases (GPx) contribute to peroxide removal. Their activities should not be treated as independent indicators of protection (Sies, 2020; Oliveira et al., 2024).

Reduced glutathione (GSH) participates in peroxide reduction and is converted to oxidized glutathione (GSSG), which can be reduced back using NADPH. GSH/GSSG balance can inform redox status but depends on sampling and methods. The contribution of dietary compounds likewise cannot be established solely from their chemical radical-scavenging ability.

3.1.4. Indicators of oxidative damage and antioxidant responses

Enzyme activities and molecular damage indicators provide distinct information. An increase in SOD, CAT, or GPx may represent adaptation to oxidant exposure, while a decrease

can occur under different physiological conditions. Neither direction alone proves protection (Sies, 2020; Oliveira et al., 2024).

Malondialdehyde (MDA) is commonly associated with lipid peroxidation, whereas protein carbonyls and oxidized nucleic acids reflect other classes of modifications. The thiobarbituric acid-reactive substances (TBARS) assay is not specific for MDA, and total antioxidant capacity depends on assay principles. Comparisons between studies require attention to tissue, life stage, analytical method, and experimental context (Murphy et al., 2022).

3.2. Plant-derived antioxidants and their mechanisms of action

3.2.1. Major classes of plant-derived antioxidants

Plant-derived antioxidant-associated compounds include phenolic substances, carotenoids, tocopherols, and other secondary metabolites. Polyphenols include flavonoids, with quercetin classified as a flavonol; chlorogenic acid is a hydroxycinnamic-acid derivative, and curcumin a phenolic curcuminoid. Chemical structure affects solubility, stability, and possible biological actions (Hu et al., 2025). Whole plant powders and extracts must be distinguished from purified compounds because they contain additional nutritional and non-nutritional constituents.

3.2.2. Direct antioxidant-related chemical mechanisms

Phenolic compounds may participate in electron-transfer or hydrogen-atom-transfer reactions and interact with transition metals. Such activities depend on reaction conditions and cannot establish the same effect following ingestion. Digestion, metabolism, and tissue exposure must be considered before attributing fish responses to direct radical scavenging.

3.2.3. Modulation of endogenous antioxidant defenses

Dietary plant compounds may alter antioxidant enzyme activity, glutathione-related responses, and expression of redox-associated genes. Armobin et al. (2023) evaluated quercetin at 200, 400, and 600 mg/kg for 60 days in common carp. SOD and MDA responses differed from CAT and GPx patterns, showing that supplement-associated modulation does not uniformly increase antioxidant enzyme activities.

3.2.4. Nrf2–Keap1 signaling and regulatory pathways

Nuclear factor erythroid 2-related factor 2 (Nrf2) participates in transcriptional regulation of responses to oxidative and electrophilic challenges, and Kelch-like ECH-associated protein 1 (Keap1) contributes to regulation of Nrf2 stability (Hu et al., 2025).

Ma et al. (2024) investigated dietary tea polyphenols at 0, 40, 80, 120, 160, and 200 mg/kg in grass carp during 60 days of feeding followed by a three-day *Flavobacterium columnare* challenge. The authors reported improved gill histopathology and changes in antioxidant enzyme activities and expression of genes related to Nrf2/Keap1 at 120 mg/kg. Accessible evidence supports an association but not proof that the complete activation sequence was established or that tissue protection was exclusively mediated by this pathway.

3.2.5. Relationships with inflammatory and immune responses

Oxidative stress, inflammation, and immunity are related but distinct. Ma et al. (2024) reported changes in gill antioxidant, inflammatory, and apoptotic indicators following bacterial challenge, while Armobin et al. (2023) reported altered immune indicators in quercetin-

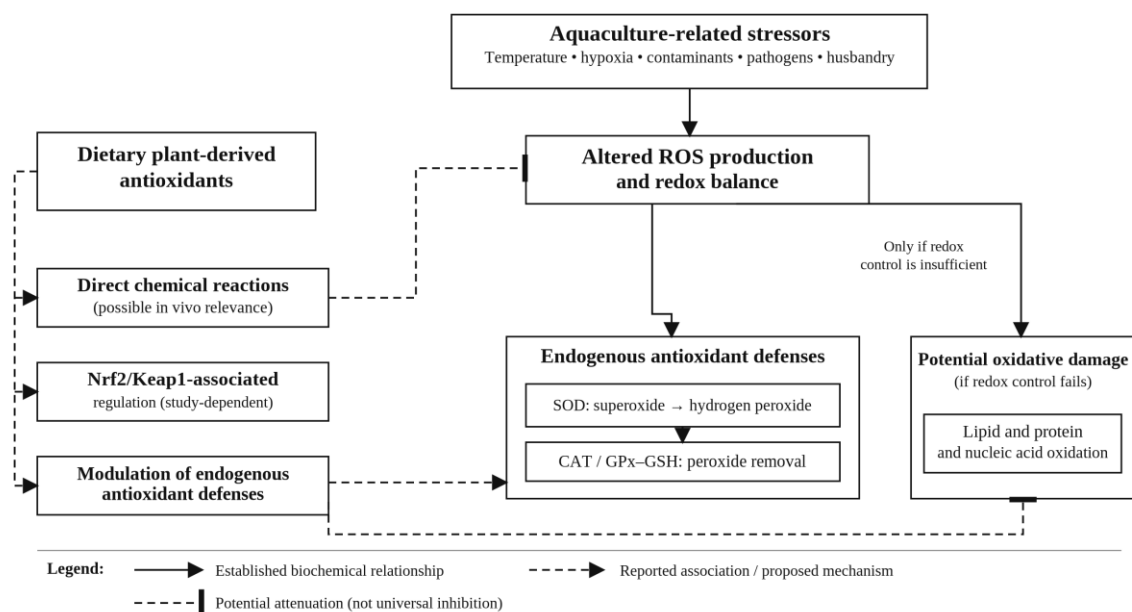
supplemented carp. Such measurements do not establish that immune changes were caused exclusively by antioxidant mechanisms (Sies & Jones, 2020).

Table 1. Major plant-derived antioxidant compounds and preparations investigated in cultured fish

Compound/preparation	Chemical class/source	Reported mechanism or response	Fish evidence	Reference
Curcumin	Phenolic curcuminoid; turmeric	Antioxidant enzymes, MDA; dose-dependent response	Tilapia feeding trial	Amer et al. (2022)
Quercetin	Flavonol; plant-derived purified compound	SOD, CAT, GPx and MDA responses differ	Carp feeding trial and heat challenge	Armobin et al. (2023)
Chlorogenic acid	Hydroxycinnamic-acid derivative	Lower hepatic MDA at 120 mg/kg; enzymes not uniformly increased	Largemouth bass feeding trial	Xia et al. (2024)
Tea polyphenols	Phenolic mixture; <i>Camellia sinensis</i>	Nrf2/Keap1-associated gene expression; not proof of complete activation	Grass carp infection challenge; abstract level	Ma et al. (2024)
Grape seed extract	Mixed polyphenols; grape seed	Context-dependent oxidative responses	Senegalese sole feeding trial	Xavier et al. (2021)
Ginger residue	Complex Zingiber officinale fraction	Antioxidant enzyme and glutathione changes	Black rockfish feeding trial	Oh et al. (2022)
Moringa preparations	Fermented/nonfermented leaf–seed mixtures	Preparation-dependent antioxidant and physiological responses	Tilapia feeding trial	Nassar et al. (2024)
Basil extraction fraction	Supercritical fluid-extraction-derived fraction	Dose-dependent effects; higher levels potentially unfavorable	Rainbow trout feeding trial	Magara et al. (2022)

Note. Mechanisms proposed from chemical properties are not equivalent to demonstrated in vivo causality; mixed preparations should not be treated as purified compounds.

Figure 1. Conceptual framework of oxidative stress regulation and potential effects of plant-derived dietary antioxidants in cultured fish



Solid arrows represent established biochemical relationships or general physiological processes. Dashed connections denote potential mechanisms or study-specific associations, and blunt-ended connections indicate possible attenuation. These links do not imply universal causal effects across fish species or dietary treatments.

3.3. Plant-derived antioxidant sources in fish feeds

3.3.1. Spices and rhizomes

Turmeric (*Curcuma longa*) and ginger (*Zingiber officinale*) are among the plant materials examined in fish nutrition. Studies have used purified curcumin, nanoparticle formulations, botanical extracts, and processing residues; these preparations are not chemically or nutritionally interchangeable. Abdel-Ghany et al. (2023) compared curcumin formulations in Nile tilapia, while Xavier et al. (2021) included curcumin extract in Senegalese sole diets.

Ginger contains gingerols and related phenolic compounds. Oh et al. (2022) investigated ginger residue remaining after juice extraction at dietary levels of 0.25–1% during an eight-week feeding trial in juvenile black rockfish. The material was a processing residue, not a purified compound.

3.3.2. Leaves and phenolic-rich plant materials

El-Kassas et al. (2022) investigated moringa (*Moringa oleifera*) leaf powder at 5% and 10% in Nile tilapia diets. Nassar et al. (2024) evaluated fermented and non-fermented mixtures of moringa leaves and seeds at 5% and 10%. Differences in preparation may involve multiple nutritional and phytochemical changes and cannot be attributed to one compound.

Tea (*Camellia sinensis*) provides catechins and related phenolics. Ma et al. (2024) used a tea polyphenol preparation rather than whole leaf powder in grass carp diets, illustrating why botanical origin does not establish equivalence of inclusion levels.

3.3.3. Fruit- and seed-derived extracts and selected phenolic compounds

Xavier et al. (2021) evaluated grape seed extract in Senegalese sole postlarvae; results from such extracts should not be generalized to whole grape seeds. Armobin et al. (2023) evaluated purified quercetin in common carp, and these results cannot establish the effects of whole fruits or vegetables containing quercetin. Fruit peel sources identified only by in vitro antioxidant activity were not treated as evidence of dietary physiological efficacy.

3.3.4. Plant processing by-products

Ginger residue (Oh et al., 2022) and a fraction derived from the supercritical fluid extraction of basil (*Ocimum basilicum*; Magara et al., 2022) illustrate processing-derived dietary materials. The basil fraction was tested at 0.5%, 1%, 2%, and 3% in rainbow trout over 30 days. These fractions should not be described as equivalent to intact plant powder.

3.3.5. Factors affecting ingredient characteristics

Botanical identity, plant part, extraction, fermentation, drying, and feed manufacture can alter ingredient composition. Inclusion percentages for crude powders cannot be equated with doses of concentrated extracts or pure compounds. The differences observed between fermented and non-fermented moringa (Nassar et al., 2024) and in basil-processing fractions (Magara et al., 2022) reinforce the need for ingredient characterization. Availability of local plant materials alone cannot establish economic or nutritional suitability.

3.4. Experimental evidence of effects on fish health and performance

3.4.1. Changes in antioxidant defense and oxidative damage

Feeding trials show that plant-derived supplementation may alter antioxidant regulation and oxidative damage, but these outcomes do not always agree. Amer et al. (2022) reported higher SOD and lower MDA after curcumin supplementation in Nile tilapia, with CAT and GSH showing more favorable responses at intermediate levels.

Xia et al. (2024) evaluated chlorogenic acid at 0, 60, 120, 180, and 240 mg/kg for eight weeks in largemouth bass. Hepatic MDA was significantly lower at 120 mg/kg than in the control, while GPx activity was lower in supplemented groups; CAT and SOD decreased at selected levels. In the detailed reported comparisons, hepatic GSH and total antioxidant capacity did not differ significantly. Changes in gene expression were not uniformly significant and do not demonstrate complete Nrf2 pathway activation.

Khalafalaa et al. (2025) examined a formulated herbal essential-oil blend in Nile tilapia for 72 days. Selected doses changed SOD and CAT, whereas MDA did not differ significantly ($p = 0.6547$). Araujo et al. (2025) studied a polyphenol-rich plant ingredient at 0.01% and 0.05% in Atlantic salmon diets over 100 days. Despite substantial processing losses, three of four monitored polyphenols were detected in tissues, and liver and muscle MDA were significantly lower, while growth did not differ significantly. Collectively, these studies support interpreting enzyme activity and molecular damage separately.

3.4.2. Growth performance and feed utilization

Armobin et al. (2023) reported higher final weight, weight gain, and specific growth rate in carp receiving 400 and 600 mg/kg quercetin, and lower feed conversion ratios in supplemented groups. Amer et al. (2022) found more favorable growth responses at 200–400 mg/kg curcumin than at higher concentrations. Nassar et al. (2024) reported different growth outcomes between fermented and non-fermented moringa, and the 10% non-fermented treatment did not significantly improve final body weight compared with control. Xavier et al. (2021) found selected improvements in Senegalese sole growth after botanical extract supplementation. Improved growth cannot by itself establish an antioxidant-mediated mechanism.

3.4.3. Immune function and disease resistance

Oh et al. (2022) reported higher survival after *Streptococcus iniae* challenge in black rockfish given 0.75% or 1% ginger residue. Nassar et al. (2024) reported differences in immune parameters and disease-related outcomes in tilapia receiving moringa preparations. Armobin et al. (2023) measured immune indicators during heat stress and should not be described as a bacterial challenge study. Ma et al. (2024) reported gill-associated changes following *Flavobacterium columnare* challenge. Immune biomarkers, pathogen-challenge survival, and oxidative damage represent different types of evidence.

3.4.4. Responses under environmental and physiological stress

Xavier et al. (2021) observed condition-dependent responses to extracts in Senegalese sole: some treatments produced unfavorable oxidative indicators under standard rearing but influenced selected indicators more favorably after thermal challenge. Armobin et al. (2023) found that quercetin and heat exposure affected MDA, but the diet-by-stress interaction for

MDA was not significant, unlike interactions for selected antioxidant enzymes. Effects under heat, pathogen, or dietary oxidative challenge should not be generalized across stressors.

3.4.5. Variability and inconsistencies across studies

Responses depend on species, ingredient form, duration, dose, biomarkers, and experimental conditions. Magara et al. (2022) reported favorable selected antioxidant-defense responses at 0.5% basil extraction fraction, whereas higher inclusion levels impaired several enzyme and glutathione-related indicators; at 3%, liver and kidney MDA exceeded control values. Khalafalaa et al. (2025) reported survival of 100% in control and 30 mL/kg groups versus 80% at 240 mL/kg, alongside non-significant differences in MDA ($p = 0.6547$). The multi-component formulation does not permit attribution of effects to one botanical compound.

Across trials, lower oxidative damage may occur without increased enzyme activity or growth, while improved enzyme activity may occur without decreased damage. Statistical inference must also consider the experimental unit, controls, and interaction tests. These observations do not provide a universal dose or efficacy estimate.

Table 2. Experimental evidence of plant-derived dietary antioxidants in cultured finfish

Species / preparation	Dose / duration	Design / markers	Key findings	Reference
Nile tilapia; curcumin	0, 200, 400, 600, 800 mg/kg diet; 10 weeks	Basal control; SOD, CAT, GSH, MDA; growth; bacterial challenge	MDA decreased; SOD increased; growth and selected defense responses more favorable at intermediate doses; higher levels showed adverse inflammatory signals.	Amer et al. (2022)
Common carp; quercetin	0, 200, 400, 600 mg/kg; 60 days	Control + heat stress; enzymes, MDA, growth	Dose-related changes; diet-by-stress interaction for MDA not significant.	Armobin et al. (2023)
Largemouth bass; chlorogenic acid	0, 60, 120, 180, 240 mg/kg; 8 weeks	Hepatic MDA, SOD, CAT, GPx, GSH, T-AOC	MDA reduced significantly at 120 mg/kg; GPx decreased; CAT/SOD decreased at selected doses; GSH and T-AOC not significant in detailed comparisons.	Xia et al. (2024)
Black rockfish; ginger residue	0, 0.25, 0.5, 0.75, 1% diet; 8 weeks	Antioxidant enzymes; growth; <i>S. iniae</i> challenge	Selected enzymes increased; postchallenge survival higher at 0.75–1%.	Oh et al. (2022)
Nile tilapia; moringa mixtures	0, 5%, 10% fermented/unfermented; 30 days	Growth, immune and redox indices; <i>A. hydrophila</i> challenge	Fermentation-dependent effects; some detailed significance comparisons require caution.	Nassar et al. (2024)
Grass carp; tea polyphenols	0, 40, 80, 120, 160, 200 mg/kg; 60 days	Gills; <i>F. columnare</i> 3-day challenge	120 mg/kg associated with improved gill-related outcomes and Nrf2/Keap1 expression changes (abstract evidence).	Ma et al. (2024)
Senegalese sole; botanical extracts	Curcumin 46 g/kg premix; green tea/grape seed 12 g/kg premix each; 25 days	Normal/thermal challenge; oxidative indices; growth	Condition-dependent responses, including oxidative damage under some normal conditions. Reported doses are expressed	Xavier et al. (2021)

Species / preparation	Dose / duration	Design / markers	Key findings	Reference
			per kg of micronutrient premix, not per kg of complete diet.	
Rainbow trout; basil F1-BEO	0, 0.5, 1, 2, 3% diet; 30 days	Liver/kidney antioxidant indicators; MDA	0.5% favorable in some responses; higher concentrations impaired indices; 3% increased tissue MDA.	Magara et al. (2022)
Nile tilapia; essential-oil blend	0, 30, 60, 120, 240 mL/kg; 72 days	SOD, CAT, MDA, growth and survival	MDA not significant ($p = 0.6547$); survival 100% control and 30 mL/kg versus 80% at 240 mL/kg.	Khalafalaa et al. (2025)
Atlantic salmon; polyphenol-rich ingredient	0, 0.01, 0.05% ingredient; 100 days	Feed processing; tissue polyphenols; liver/muscle MDA; growth	Processing losses; tissue detection; MDA decreased significantly; growth not significant.	Araujo et al. (2025)

Note. Percentages, mg/kg, mL/kg, and g/kg micronutrient premix refer to different dose bases and are not interchangeable. Absence of statistical significance should not be treated as equivalence.

3.5. Practical limitations and research gaps

3.5.1. Dose selection and potential adverse effects

Suitable doses depend on material composition, species, and conditions. Amer et al. (2022) found favorable growth and selected immune responses at 200–400 mg/kg curcumin, although higher doses remained associated with reduced MDA and also showed increased selected inflammatory and apoptosis-related indicators. A single favorable biomarker does not establish overall safety.

Richter et al. (2003) examined moringa leaf meal as partial dietary protein replacement in tilapia: diets replacing 20% or 30% of dietary protein showed poorer growth, with phytate, saponins, phenolics, and fiber discussed as possible contributors. This is not evidence of an antioxidant toxicity threshold. The lower survival at the highest level of the essential-oil blend tested by Khalafalaa et al. (2025) likewise raises a dose- and formulation-specific tolerability concern without identifying the mechanism.

3.5.2. Bioavailability and feed-processing stability

Araujo et al. (2025) evaluated inclusion of 0.01% and 0.05% of a polyphenol-rich plant ingredient, not equivalent quantities of purified polyphenols. Extrusion led to substantial losses, although selected compounds were detected in salmon tissues and tissue MDA decreased. Hernández et al. (2014) evaluated oxidative stability of extruded feeds containing rosemary extract or thyme essential oils under storage conditions. Protection of feed lipids during storage must be distinguished from antioxidant protection of fish after ingestion.

3.5.3. Ingredient variability, safety, and standardization

Whole plant materials, extracts, and purified compounds differ in bioactive concentrations, nutrients, fiber, and potential antinutritional factors. Fermentation can alter several characteristics simultaneously (Nassar et al., 2024). Botanical origin alone does not establish safety. Reproducible studies should document identity, plant part, processing conditions, inclusion basis, composition, and where possible measured levels of proposed active compounds in the finished feed.

3.5.4. Research gaps and practical implications

The principal gaps are limited comparability of assays and doses, insufficient paired measurement of oxidative damage and endogenous defense, limited tracking of compounds through manufacture and tissues, and few long-term commercial validation studies. Research relevant to tropical aquaculture should integrate chemical characterization, processing and storage stability, appropriate dose evaluation, complementary biomarkers, and performance under realistic farming conditions. Economic benefits should be demonstrated rather than inferred from plant availability.

4. Conclusion

Plant-derived dietary antioxidants have the potential to support oxidative stress management in cultured fish through their effects on endogenous antioxidant defenses and other redox-related processes. Experimental feeding trials have reported improvements in antioxidant-related biomarkers and reductions in oxidative damage under certain conditions. However, these responses are not consistent across studies and depend on factors such as fish species, ingredient preparation, dietary inclusion level, feeding duration, and exposure to environmental or physiological stressors.

The available evidence also indicates that changes in antioxidant enzyme activities should not be interpreted independently of oxidative damage indicators. Similarly, improvements in growth, feed utilization, or immune responses do not necessarily demonstrate that these benefits are mediated by antioxidant mechanisms. Although several regulatory pathways have been proposed, their contributions require further confirmation through appropriately designed experiments.

Practical application remains limited by variations in ingredient composition, bioavailability, stability during feed processing and storage, and insufficient information on long-term safety and performance under commercial farming conditions. Future research should combine ingredient characterization, appropriate dose evaluation, complementary oxidative stress biomarkers, and species-specific feeding trials. Such approaches would provide a stronger basis for determining effectiveness and practical suitability in aquaculture feeds.

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