JOURNAL OF MARINE SCIENCES & ENVIRONMENTAL TECHNOLOGIES
Vol. 9, Issue No. 1 (June-2023)
DOI: https://doi.org/10.59743/jmset.v9i1.75

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Effects of Plant Essential Oil Used as Feed Supplements in Aquaculture on Immune Response, and Antioxidant Status of Finfish: A Review

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آثار الزيوت العطرية النباتية المستخدمة كمكملات غذائية في تربية الأحياء المائية على الاستجابة المناعية، وحالة مضادات الأكسدة للأسماك الزعنفية: مراجعة

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Received: 22 February 2023; Revised: 01 April 2023; Accepted: 12 April 2023

Abstract

To meet the needs of the world's population for protein, aquaculture production is rising daily. Aquatic animals, on the other hand, are vulnerable to a variety of farming stresses that result in poor development performance, decreased output, and, eventually, high mortality rates. Antibiotics and chemotherapies are still widely used in some areas to manage biotic stresses. Aside from the obvious advantages, continuous antibiotic use promotes bacterial resistance, degrades bacterial populations, and accumulates these chemicals in the aquatic environment. To avoid the direct and indirect effects on aquatic ecology and human health, environmentally friendly were utilized instead. Among these feed additives, plant essential oils get attention. Since essential oils contain several bioactive components with potent antibacterial, antioxidative, and immunostimulant properties, in aquatic animals. In this article, we examined recent research on the use of plant essential oils as feed additives for several species of mostly commercial fish species. According to the available researches, we deduced that plant essential oils may be applied to aquaculture. The findings demonstrated that herbal essential oils are intriguing alternatives to antibiotics, with significant effects on antioxidative, and immunostimulant responses. We believe that plant essential oils can have synergistic effects, and future research should explore this idea.

***Keywords**: Plant essential oils, Immunostimulation, Antioxidative, Aquaculture, Fish, feed additive*.

الملخص

لتلبية احتياجات سكان العالم من البروتين، يزداد إنتاج تربية الأحياء المائية يوميًا. من ناحية أخرى، فإن الحيوانات المائية معرضة لمجموعة متنوعة من ضغوط الزراعة التي تؤدي إلى ضعف الأداء التنموي، وانخفاض الإنتاج، وفي نهاية المطاف، ارتفاع معدلات الوفيات. لا تزال المضادات الحيوية والعلاجات الكيميائية تستخدم على نطاق واسع في بعض المناطق لإدارة الضغوط الحيوية. بصرف النظر عن المزايا الواضحة، فإن الاستخدام المستمر للمضادات الحيوية يعزز المقاومة البكتيرية، ويقوض التجمعات البكتيرية، ويراكم هذه المواد الكيميائية في البيئة المائية. لتجنب الآثار المباشرة وغير المباشرة على البيئة المائية وصحة الإنسان، تم استخدام مواد صديقة للبيئة بدلاً من ذلك. من بين هذه المضافات العلفية، تحظى الزيوت العطرية النباتية بالاهتمام. نظرًا لأن الزيوت الأساسية تحتوي على العديد من المكونات النشطة بيولوجيًا مع خصائص قوية مضادة للجراثيم ومضادات الأكسدة ومنبهات المناعة، في الحيوانات المائية. في هذه المقالة، قمنا بفحص الأبحاث الحديثة حول استخدام الزيوت الأساسية النباتية كمضافات علفية لعدة أنواع

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ISSN (Online): 2706-9966

من أنواع الأسماك التجارية في الغالب. وفقًا للأبحاث المتاحة، استنتجنا أنه يمكن استخدام الزيوت العطرية النباتية في تربية الأحياء المائية. أظهرت النتائج أن الزيوت العطرية العشبية هي بدائل مثيرة للاهتمام للمضادات الحيوية، مع تأثيرات كبيرة على مضادات الأكسدة والاستجابات المناعية. نعتقد أن الزيوت العطرية النباتية يمكن أن يكون لها تأثيرات تآزريه، ويجب أن تستكشف الأبحاث المستقبلية هذه الفكرة.

الكلمات الدالة: الزيوت النباتية العطرية، التحفيز المناعي، مضادات الأكسدة، تربية الأحياء المائية، الأسماك، المضافات العلفية.

1. Plant Essential Oils as Immunostimulators

The immune system is made up of several humoral and cellular components that protect the body from foreign toxins (Biller-Takahashi and Urbinati, 2014). Immuno-stimulation is a phenomenon in which an organism's immune response is increased ahead of time so that when an extraneous material enters the body, it must contend with a more powerful immune system. The innate response is the first defensive action and a significant part of the immunity system, and it includes phagocytosis, cytokine production, the release of inflammatory mediators, and antigen production by monocytes, macrophages, basophil granulocytes, neutrophils, eosinophil mast cells, natural killer (NK) cells, and dendritic cells. Phagocytosis is a non-specific immunological line in fish that uses bactericidal and lysozyme activities to tolerate infections. The acquired response makes use of antibodies/immunoglobulins (Ig), B cells (plasma cells), and T-cells. Lymphocytes mediate cellular and humoral immune responses in fish, and the kidney, spleen, thymus, and liver are the principal lymph organs. Other than phytochemicals, studies have shown that a wide range of items successfully boost the immune response in finfish (Mohamed *et al*., 2018; Bilen *et al*., 2020; and Makled *et al*., 2020). Studies have shown that a wide range of phytochemicals successfully boost the immune response in finfish (Mohamed *et al*., 2018; Bilen *et al*., 2020; and Makled *et al*., 2020). Phytochemicals are generally thought to be harmless to fish, humans, and the environment (Chakraborty, 2011). As a result, immunostimulation with phytochemicals is especially essential since it has the potential to replace or reduce the usage of antibiotics or drugs with negative side effects. The research on the immunity of cultured finfish with dietary administration of phytochemicals are shown in Table (1).

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Table 1. Effects of dietary plant essential oils supplementation in fish immune response and serum biochemistry.

Plant essential oil	Fish species	Dose and duration	Pathogen challenge	Notable results immune response	References
Encapsulated combination of carvacrol and thymol	Rainbow trout (*Oncorhynchus mykiss*) 8.4 ± 0.1g	2.0 and 3.0 g kg^{-1} for 45 day	-	↑ lymphocytes ↔ Survival	Ahmadifar *et al*. (2011)
Canola Oil	Yellowtail kingfish (*Seriola lalandi*) 95.6 ± 0.1g	100% ,50% for 34 days	-	↓ plasma cholesterol	Bowyer *et al*. (2012)
Carvacrol and thymol	Rainbow trout (*Oncorhynchus mykiss*) 113.0± 10.4 g	1 g/kg for 8 weeks	-	↑ Lysozyme and total complement	Giannenas *et al*. (2012)
Lippia alba	Silver catfish 22.93 ± 0.75 g	0.25, 0.5, 1.0 or 2.0 mL kg^{-1} for 60 day	-	↔ blood ↓ parameters glucose	Saccol *et al*. (2013)
Black cumin seed oil (*Nigella sativa*)	Rainbow trout (*Oncorhynchus mykiss*) 18±0.2 g	0.1%, 0.5% and 1% for 14 days	-	↑ lysozyme ↑ antiprotease ↑ total protein ↑myeloperoxidase ↑ bactericidal activity ↑ IgM titers	Awad *et al*. (2013)
Peanut Oil	Mozambique Tilapia Juveniles (*Oreochromis mossambicus*) 6.36±0.19 g	50% and 100% for 60 days	-	↔ hematological, immunological parameters	Demir *et al*. (2014)

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Table 1. Cont.

Oregano	Yellowtail Tetra (Astyanax altiparanae) 1.46±0.09 g	0.0, 0.5, 1.0, 1.5, 2, and 2.5 g/kg for 90 day	-	↔blood glucose and liver glycogen levels	de Moraes França Ferreira *et al*. (2014)
carvacrol and thymol	Great sturgeon *(Huso huso)* 43.6 ± 1.6 g	1, 2, and 3 g kg^{-1} for 60 day	-	↑ lymphocytes ↔ Red and white blood cells. ↔ Survival rates	Ahmadifar *et al*. (2014)
Origanum vulgare	Nile tilapia (*O. niloticus*) 50 ± 5 g	2.5 %, 5% and 10% for 8 week	*Vibrio alginolyticus*	↑ Improve immunity. ↑ survival rates	Abdel-Latif & Khalil (2014)
Linseed oil	Darkbarbel catfish *Pelteobagrus vachelli* 0.99 ± 0.01 g	0, 2 and 4% for 46 days	*Edwardsiella ictaluri*	↔ immune response	Li *et al*. (2014)
Sweet Orange Peel (*Citrus sinensis*)	Mozambique tilapia (*Oreochromis mossambicus*) 0.91 ± 0.03 g	0.1%, 0.3%, and 0.5% for 90 day	*Streptococcus iniae*	↑ Improve immunity.	Ümit Acar *et al*. (2015)
1,8-cineole, carvacrol or pulegone	Rainbow trout (*Oncorhynchus mykiss*)	0.5, 1, and 1.5% for 60 days	-	↔ Liver or kidney histological alterations	Sönmez *et al*. (2015)
Lime basil	Red drum (*Sciaenops ocellatus*) 17.75 ± 0.1 g	0, 0.25, 0.5, 1.0, and 2.0 g/kg for 7 week		↑ lysozyme ↓ NBT	Sutili *et al*. (2016)
Peanut Oil	Sea bream *Diplodus vulgaris* 10.37 ± 0.25 g	50%and 100% for 8weeks		↔Hemoglobin, MCH, total protein, albumin, and globulin	Kesbiç *et al*. (2016)

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Table 1. Cont.

Citrus limon peels essential oil	Mozambique tilapia (*Oreochromis mossambicus*) 12.87 ± 0.18 g	0.5%, 0.75% and 1% for 60 days	*Edwardsiella tarda*	↑ NBT ↑ WBC ↑ lysozyme ↑ myeloperoxidase	Baba *et al*. (2016)
Clove Basil (*Ocimum gratissimum*) and ginger (*Zingiber officinale*)	GIFT Tilapia 1.84 ± 0.52 g	0.5%, 1.0% and 1.5% for 55 days	*Streptococcus agalactiae*	↑ Thrombocytes, total leukocytes, lymphocytes and neutrophils. ↑ phagocytic activity	Brum *et al*. (2018)
oregano (*Origanum onites* L.) essential oil	Rainbow trout (*Oncorhynchus mykiss)* 26.05 ± 0.15 g	0.125, 1.5, 2.5 and 3.0 mL kg^{-1}) for 90 days	*Lactococcus garvieae*	↑ lysozyme ↓ mortality	Diler et al., (2017)
Citrus limon peel essential oil	(Labeo victorianus) fingerlings 21.0 ± 2.4 g	10, 20, 50 and 80 g kg−1 for14 days	*Aeromonas hydrophila*	↑ haemato-immunological parameters ↑Resistance against *A. hydrophila*	Ngugi *et al*. (2016)
Ocimum basilicum oil	Nile-tilapia (*Oreochromis niloticus*) 20±2 g	0.25, 0.5 and 1% of basil oil /kg diet for 42 days	*Aeromonas hydrophila*	↑ non-specific immune response	El-Ashram *et al.* (2017)
Grape *Vitis vinifera* seed oil	Rainbow trout *Oncorhynchus mykiss* 30 g	250 mg, 500 mg, 1,000 mg kg^{-1} feed for 60 days	-	↑ Improve immunity. ↑ survival rates	Arslan *et al*. (2018)

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Table 1. Cont.

essential oil extracts from lemongrass (*Cymbopogon citratus*) and geranium (*Pelargonium graveolens*)	*Oreochromis niloticus*. Fish 3.04 ± 0.003 g	200 and 400 mg kg^{-1} for 12 weeks	*Aeromonas hydrophila*	↑ lysozyme, and total immunoglobulins; IgM Resistance against *A. hydrophila*	Al-Sagheer *et al*. (2018)
Origanum essential oil	*Tilapia zillii* 180 ± 10.2 g	1 g kg^{-1} for 15 days	*Vibrio anguillarum*	↑ Improve immunity. ↑ survival rates	Mabrok and Wahdan (2018)
centary oil (*Hypericum perforatum*)	common carp (Cyprinus carpio) 3.07±0.02 g	5 and 10 g kg^{-1} for 60 days		↑ serum biochemical parameters	ÜMİT Acar (2018)
Mentha piperita essential oil	*Colossoma macropomum* (Serrasalmidae) 36.0 ± 7.7 g	0.5%, 1.0% and 1.5% kg^{-1} For 30 days	*Aeromonas hydrophila*	↑ respiratory activity ↔ leukocytes ↔ lysozyme	Ribeiro *et al*. (2018)
Soybean Oil	Nile tilapia (*Oreochromis niloticus*) 425.33 ± 32.37 g	15.00; 30.00; 45.00 and 60.00 g kg^{-1} for 50 days	-	↑ survival ↑ hematological variables	Godoy *et al*. (2019)

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Table 1. Cont.

Ocimum basilicum essential oil	Nile tilapia (*Oreochromis niloticus*) 12.13 ± 0.11 g	0.25; 0.5; 1.0 and 2.0 kg.diet^{-1} for 45 days	*Aeromonas hydrophila*	↑ hematological variables ↓ plasma triglycerides ↓ glucose ↓ hepatic glycogen ↓ alanine ↓ aminotransferase ↑ plasma total proteins ↑ Lysozyme post-infection. ↔ survival	de Souza *et al*. (2019)
Mentha piperita	Nile tilapia (*Oreochromis niloticus*) 5 g	0.075%; 0.125%; 0.25% for 50 days.	*Streptococcus agalactiae*	↔ hematological parameters ↑ Total plasmatic protein	de Souza Silva *et al.* (2019)
Thymus vulgaris Essential Oil	Rainbow trout (*Oncorhynchus mykiss*) 10g	0.5 mg kg $^{-1}$ feed for 2 months	*Aeromonas hydrophila*	↑ immune responses ↑ disease resistance	Zargar *et al*. (2019)
Ocimum basilicum oil	pirarucu juveniles (*Arapaima gigas*) 7.56 kg m^{-3}per tank	0.5; 1.0; and 2.0 mL kg diet^{-1} over 48 days	-	↓ plasma urea ↑ Albumin and total proteins. ↔ glucose, cortisol, and acid uric	Chung *et al*. (2020)
Geranium (*Pelargonium graveolens*) essential oil	common carp, *Cyprinus carpio* 35.24 ± 0.20 g	400 mg kg^{-1} for for 60 days	-	↑ immune responses	Rahman *et al*. (2020)

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Table 1. Cont.

Aloysia triphylla	Nile tilapia (*Oreochromis niloticus*) 10.79 ± 0.02 g	(0.25, 0.50, 1.00 and 2.00 mL kg diet^{-1}) for 45 days.	-	↑ haematocrit ↑ erythrocytes ↑ intestinal lipase ↑ alkaline ↑ protease ↑ plasma alanine aminotransferase ↑ albumin ↑ globulin ↑ lysozyme ↓ intestinal amylase ↓ plasma glucose triglycerides	de Souza *et al*. (2020)
Rosemary essential oil	Young great sturgeon (*Huso huso*) 130.94 ± 5.28 g	0.01, 0.1, 1 and 2% for 8 weeks	-	↑ Improve immunity ↓ hemoglobin	Ebrahimi *et al*. (2020)
Bitter lemon (C. limon) peels	Nile tilapia (*Oreochromis niloticus*) 16.42 ± 0.059 g	0.75% and 1% for 60 day	-	↓ immune response	Mohamed *et al*. (2021)
Oregano *Origanum vulgare* L. essential oil	koi carp, *Cyprinus carpio* 15.6 ± 3.3 g	500 mg/kg, 1500 mg/kg, and 4500 mg/kg for 8 weeks.	*Aeromonas hydrophila*	↑ lysozyme ↑ complement C3 ↑ complement C4 ↑ Resistance against *A. Hydrophila* challenge. ↓ TNF-α ↓ TGF-β	Zhang *et al*. (2020)

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Table 1. Cont.

clove oil	Nile tilapia (*Oreochromis niloticus*) 35±1.32g	1.5 and 3% for 4 weeks	*Streptococcus iniae*	↑ blood phagocytic ↑ bactericidal ↑ lysozyme ↑ respiratory burst	Abdelkhalek *et al*. (2020)
Bergamot (Citrus. bergamia) peel oil	Nile tilapia (*Oreochromis niloticus*) 2.57 ± 0.06 g	0.5%, 1.0%, and 2.0% for 8 weeks		↑ haemoglobin and haematocrit	Kesbiç *et al*. (2020)
Oregano *Origanum vulgare* L. essential oil	Common carp (*Cyprinus carpio* L.) 20.3±0.8 g	5, 10, 15, and 20 g/kg diet for 2 months	*Aeromonas hydrophila*	↑ lysozyme ↑ phagocytic ↑ IL-1β ↑IL-10	Abdel-Latif *et al*., (2020)
	Sea bass (*Dicentrarchus labrax*) 80.83 ± 2.11 g	100 and 200 ppm for 60 days	-	↑ serum biochemical indices	Dinardo *et al*. (2020)
Menthol Essential Oil	Nile tilapia (*Oreochromis niloticus*) 31.11 ± 1.14 g	0.25% for 30 days	-	↑ Hb, PCV, RBCs, and WBCs. ↑ Total protein, Albumin, and globulin. ↑ IFN-γ ↓ IL-8 and IL-1β ↓ Lysozyme and phagocytic.	Dawood *et al*. (2020)

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Table 1. Cont.

Corn oil, tea oil, olive oil, rice oil and Sunflower oil	Hybrid grouper (♀ *Epinephelus fuscoguttatus* × ♂ *E. lanceolatus*). 15.09 ± 0.01 g	5% for 8 weeks	-	↑serum lipoproteins, cholesterol, triglycerides and the activity of liver lipid-metabolizing enzymes	Yan *et al*. (2021)
Hot pepper (Capsicum sp.) oil	rainbow trout (Oncorhynchus mykiss) 7.20 ± 0.57g	1‰ 2‰,4‰ and 6‰ for 60 days		↑serum biochemical parameters, ↓ serum liver enzymes, glucose, cholesterol and triglyceride	Parrino *et al*. (2020)
Rosemary essential oil	Young great sturgeon (*Huso huso*) 130.94 ± 5.28 g	0.01, 0.1, 1 and 2% for 8 weeks		↑ immune response	Ebrahimi *et al*. (2020)
Oregano Origanum vulgare L. essential oil	Nile tilapia (*Oreochromis niloticus*) 11.5 ± 0.4 g	1, or 2 mL/kg for 12 weeks	-	↑ Hemoglobin, red blood cells, and (WBCs). ↑ MPO ↓ lysozyme ↓ phagocytic	Shourbela *et al*. (2021)
Nigella sativa oil	Nile tilapia (*Oreochromis niloticus*) 50 ± 0.2 g	7% ml/kg diet for 14 days	*Aeromonas hydrophila* and *Pseudomonas fluorescens*	↑ IL-1β ↓ CYP1A	Hal and El-Barbary, (2021)
Ginger (*Zingiber officinale)* essential oil	Nile tilapia (*Oreochromis niloticus*) 7.78 ± 0.10 g	0.5,1.0, 1.5 and 2.0 mL kg diet $^{-1}$) for 60 days	-	↑ leukocytes ↑ hematological values ↑ plasma cholesterol	Chung *et al*. (2021)

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Table 1. Cont.

Rapeseed oil	large yellow croaker *Larimichthys crocea* 36.02 ± 0.58 g	50% and 100% for 2 weeks		-	↓ IL10 ↑ TNFα ↑ IL1β	Mu *et al.* (2020)
Menthol Essential Oil	Nile tilapia (*Oreochromis niloticus*) 15.11 ± 0.06 g	0.1%, 0.2%, 0.3%, and 0.4% for 8 weeks		-	↑ lysozyme ↑ phagocytic	Magouz *et al.* (2021)
Lippia sidoides essential oil	Tambaqui *Colossoma macropomum* 14.02 ± 1.00 g	0.625 and 1.25 g/kg	For 60 days	*Aeromonas hydrophila*	↑respiratory activity of leukocytes	Monteiro *et al.* (2021)
Ocimum gratissimum essential oil		1.25 and 5.0 g/kg			↔ immune response	
Zingiber officinale essential oil		1.25 and 5.0 g/kg				
thyme essential oil	Rainbow trout (*Oncorhynchus mykiss*) 20.77 ± 0.08 g	1% for 30 days		-	↑ lysozyme ↑ ACH50 ↑ TNF-α ↑ TGF-β	Ghafarifarsani *et al.* (2021)
Thymol and carvacrol	Nile tilapia (*Oreochromis niloticus*) 8.00 ± 0.01 g	300 mg/kg for 8 weeks.		*Streptococcus agalactiae*	↑ Antibacterial effect.	Ning et al., (2021)
sweet orange and lemon essential oils	Nile tilapia (*Oreochromis niloticus*) 16.42±0.059 g	1‰, 3‰, 0.75‰ for 60 days		-	↑ phagocytic ↑ phagocytic index ↑ lysozyme	Mohamed *et al.* (2020)

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Bitter Orange (*Citrus aurantium*) essential oils	Common Carp Juveniles (*Cyprinus carpio*) 1.94 ± 0.05 g	0.25, 0.50, 1, and 1.5% for 60 days	-	↑ immune response gene levels TNF-α, IL-8 and IL-1ß	Acar *et al*. (2021)
Neem oil	*Labeo bata* 48.47 ± 1.09 g	0.5% and 1%, for 90 days		↓ serum glucose, ↓ plasma protein ↓ lipid profile	Jana *et al*. (2021)
(carvacrol, oregano, 1,8 cineol, thymol, pinene, pinene β, limonene, and propylene glycol) oils	Nile tilapia (*Oreochromis niloticus*) 19.6 ± 0.51 g	0.25, 0.5 and 1 ml kg $^{-1}$ for 60 days		↑ Lysozyme activity ↑ phagocytic	Magouz *et al*. (2022)
Palm (*Phoenix dactylifera* L.) SEED Essentail Oil	Rainbow trout (*Oncorhynchus mykiss*) 5,77 ± 0,01 g	0.5, 1, and 2% for 45 days	-	↑ Phagocystic ↑ NBT ↑ MPO	Gaballah (2019)
Black Mustard Seeds (*Brassica nigra*) Oil Nettle Seed (*Urtica dioica*) OiL	Rainbow trout (*Oncorhynchus mykiss*) 22,39±0,1	%0,5; %1 and %2 for 60 days	*Aeromonas hydrophila*	↑Lysozyme ↑potential killing activity ↑Myeloperoxidase ↑IL gene expression ↑survival rate	Lakwani (2021

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Table 1. Cont.

White mustard (*Sinapis alba*) Oil	Rainbow trout (*Oncorhynchus mykiss*) 25.77 ± 0.13 g	0.5, 1, and 1.5% of diet for 9 weeks	*Aeromonas hydrophila* and *Yersinia ruckeri*	↓Respiratory burst ↓potential killing activity ↑Lysozyme and ↑myeloperoxidase ↑ Cytokine gene expression ↔ survival against *A. hydrophila* ↑ survival against *Y. ruckeri*	Salem *et al.* (2022)
Flax seed (*Linum usitatissimum*) Oil				↑Respiratory burst ↑potential killing activity ↑Lysozyme and ↑myeloperoxidase ↑ Cytokine gene expression ↔ survival against *A. hydrophila* ↑ survival against *Y. ruckeri*	
savory (*Satureja hortensis*) essential oil	Caspian roach (*Rutilus caspicus*) 2.29 ± 0.07 g	100, 200, or 400 mg/kg for 60 days		↑serum total immunoglobulin , lysozyme , and (ACH50)	Ghafarifarsani *et al.* (2022)
thyme essential oil	common carp (*Cyprinus carpio*) 20.46 ± 0.07 g	10 g , 20 g for 60 days		↑ (WBC) (Hb) and (MCHC)	Ghafarifarsani *et al.* (2022)
Dracocephalum kotschyi essential oil	Rainbow trout (*Oncorhynchus mykiss*) 55 ± 5.6 g	0.2, 0.25 and 0.3 mg/kg for 60 days	*Aeromonas hydrophila*	↑ Plasma [ACH50], IgM, lysozyme, total protein and total albumin. ↑ mucus (protease activity, IgM and lysozyme activity)	Hafsan *et al.* (2022)
thyme essential oil	Rainbow trout (*Oncorhynchus mykiss*) 11.92 ± 0.06 g	1% and 2% for 60 days		skin mucus total Ig, total protein level, and ACH50, protease, and lysozyme	Yousefi *et al.* (2022)
summer savory (Satureja hortensis) oil	common carp 25.35±0.13 g	1% for 21 days		↑ ACH50 ↑Lysozyme ↑immunoglobulin	Jalil *et al.* (2022)

Symbols: ↑ indicates increase, ↓ indicates decrease, ↔ indicates no change.
Abbreviations: ALP Alkaline phosphatase**, ALT** Alanine aminotransferase, **AST** Aspartate aminotransferase, **C3** Complement 3, **C4** Complement 4, **GIFT** Genetically improved farmed tilapia, **Ig** Immunoglobulin, **IgG** Immunoglobulin G, **IgM** Immunoglobulin M, **IRGE** Immune-related gene expression, **LYS** Lysozyme, **MPO** Myeloperoxidase, **WBC** White blood cell

ISSN (Print): 2413-5267
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2. Plant Essential Oils as Antistress Agents

The survival of an animal is dependent on its internal balance and compatibility with its surroundings (Cengiz, 2001). When an animal's internal balance is steady and compatible with its surroundings, it lives under normal conditions. Stress, on the other hand, is an animal's reaction to an abnormal situation (Cengiz, 2001). In fish, stress causes a variety of physiological changes in systems such as metabolism, immunity, behavior, gene expression, protein synthesis, endocrine, and so on (Tort, 2011). Stress in aquaculture can lead to illness susceptibility, growth retardation, and reproduction interference (Pickering, 1993). Furthermore, fish may get stressed in farm conditions due to handling, transportation, excessive stocking density, and poor water quality (Bilen *et al*., 2013; Elbesht 2020).

Because some Plant essential oils may exert a direct antioxidant impact in addition to helping the fish's antioxidant system, plant essential oils are effective feed additives for fish under farm circumstances to cope with stress (Yu *et al*., 2017; Ahmadifar *et al*., 2019; and Bhattacharjee *et al*., 2020). Table (3) summarizes recent investigations on the antioxidant capacity of dietary Plant essential oils supplementation in finfish.

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Table 2. Effects of dietary Plant essential oils supplementation on antioxidant status in fish

Plant essential oil	Fish species	Dose and duration	Stress - Toxicant	Notable results	References
Lippia alba	Silver catfish *(Rhamdia quelen)*	*L. alba* in water ($10\ \mu L\ L^{-1}$) 5, 6 and 7 h	Hyperoxia	↑ LPO in the brain ↓ GST in the brain ↓ liver LPO, GST , CAT and SOD ↓ LPO in the gills	Azambuja *et al.* (2011)
Carvacrol and thymol	Rainbow trout (*Oncorhynchus mykiss*) 113.0± 10.4 g	1 g/kg for 8 weeks	-	↑ nitric oxide and catalase	Giannenas *et al.* (2012)
Lippia alba	*Silver catfish (Rhamdia quelen)*	0.25, 0.5, 1.0 or 2.0 mL kg^{-1} for 60 days	-	↔ LPO ↑ SOD ↑ CAT ↑ GPx ↑ GST	Saccol *et al.* (2013)
Linseed oil	Darkbarbel catfish *Pelteobagrus vachelli*	0, 2 and 4% for 46 days	Ammonia stress	↔ SOD ↔ CAT ↔ GPX ↔ MDA	Li *et al.* (2014)
Sage (*Salvia officinalis*) oil Mint (*Mentha spicata*) oil Thyme (*Thymus vulgaris*) oil	Rainbow trout (*Oncorhynchus mykiss*)	500, 1,000 and 1,500 mg kg^{-1} for 60 days	-	↑ SOD ↑ G6PD ↑ GPx ↓ CAT ↓GST ↓GR	Sonmez *et al.* (2015)

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Table 2. Cont.

oregano (*Origanum onites* L.) essential oil	Rainbow trout (*Oncorhynchus mykiss)* 26.05 ± 0.15 g	0.125, 1.5, 2.5 and 3.0 mL kg^{-1}) for 90 days	*Lactococcus garvieae*	↔SOD ↑ CAT	Diler *et al.* (2017)
Mentha piperita essential oil	*Colossoma macropomum* (Serrasalmidae)	0.5%, 1.0% and 1.5% kg^{-1} For 30 days	-	↑ CAT ↓ SOD ↓ GPx ↑ LPO	Ribeiro *et al.* (2018)
Grape *Vitis vinifera* seed oil	Rainbow trout *Oncorhync hus mykiss*	250 mg, 500 mg, 1,000 mg/kg feed for 60 days	-	↑ Improve antioxidant enzyme activities	Arslan *et al.* (2018)
Oregano	Nile tilapia (*Oreochromis niloticus*) 13.21 ± 1.71 to 14.24 ± 1.18 g	0.0, 1.0, and 2 mL/kg for 10 weeks	density	↑ increased antioxidant	El-Hawarry *et al.*, (2018)
essential oil extracts from lemongrass (*Cymbopogon citratus*) and geranium (*Pelargonium graveolens*)	*Oreochromis niloticus*. Fish 3.04 ± 0.003 g	200 and 400 mg kg^{-1} for 12 weeks	*Aeromonas hydrophila*	↑ CAT ↓ MDA	Al- Sagheer et al., (2018)
geranium *(Pelargonium graveolens)* essential oil	common carp, *Cyprinus carpio*	400 mg kg^{-1} for 60 days	profenofos (PFF) hepato-renal toxic.	↑ MDA ↓ CAT ↓ SOD ↓ GSH	Abdel Rahman *et al.* (2020)
Oregano *Origanum vulgare* L. essential oil	koi carp, *Cyprinus carpio*	500 mg/kg, 1500 mg/kg, and 4500 mg/kg for 8 weeks.	-	↑ SOD ↑ GPx ↓ MDA	Zhang *et al.* (2020)

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Table 2. Cont.

clove oil	Nile tilapia (*Oreochromis niloticus*)	1.5 and 3% for 4 weeks	-	↑ MDA ↑ GPx ↔ SOD	Abdelkhalek *et al.* (2020)
Rapeseed oil	large yellow croaker *Larimichthys crocea*	50% and 100% for 2 weeks	-	↓ total ant oxidative capacity	Mu *et al.* (2020)
Oregano *Origanum vulgare* L. essential oil	Common carp (*Cyprinus carpio* L.)	5, 10, 15, and 20 g/kg diet for 2 months	-	↑ SOD ↑ CAT ↓ MDA	Abdel-Latif *et al.* (2020)
	Sea bass (*Dicentrarchus labrax*)	100 and 200 ppm for 60 days	-	↑ total ant oxidative	Dinardo *et al.* (2020)
sweet orange (*Citrus sinensis*) and lemon (*Citrus limon*) essential oils	Nile tilapia (*Oreochromis niloticus*)	1‰, 3‰, 0.75‰ for 60 days	-	↑ SOD ↑ CAT	Mohamed *et al.* (2020)
Oregano *Origanum vulgare L.* essential oil	Nile tilapia (*Oreochromis niloticus*)	1, or 2 mL/kg for 12 weeks	different stocking densities	↑ GR ↑ NO ↓ SOD	Shourbela *et al.* (2021)
Menthol Essential Oil	Nile tilapia (*Oreochromis niloticus*)	0.1%, 0.2%, 0.3%, and 0.4% for 8 weeks	Ammonia challenge	↑ SOD ↑ CAT ↑ GPx ↓ MDA	Magouz *et al.* (2021)
Thymol and carvacrol	Nile tilapia (*Oreochromis niloticus*)	300 mg/kg for 8 weeks.	-	↑ SOD ↓ MDA	Ning *et al.* (2021)

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Table 2. Cont.

Menthol essential oil	Nile tilapia (*Oreochromis niloticus*)	0.25% for 60 days	-	↑ SOD ↑ CAT ↑ GPx	Dawood *et al.* (2020)
Bitter lemon (*C. limon*) peels	Nile tilapia (*Oreochromis niloticus*) 16.42 ± 0.059 g	0.75% and 1% for 60 day	-	↓ SOD ↓ CAT	Mohamed *et al.* (2021)
Neem oil	*Labeo bata*	0.5% and 1%, for 90 days	-	↓ SOD ↓ CAT	Jana *et al.* (2021)
Blend of liquid essential oils containing (carvacrol, oregano, 1,8 cineol, thymol, pinene, pinene β, limonene, and propylene glycol)	Nile tilapia (*Oreochromis niloticus*) 19.6 ± 0.51 g	0.25, 0.5 and 1 ml kg^{-1} for 60 days	-	↑ SOD ↑ CAT	Magouz *et al.* (2022)
Thyme essential oil	common carp (*Cyprinus carpio*) 20.46 ± 0.07 g	10 g , 20 g for 60 days		↑serum and liver (CAT), (SOD), (GPx), (GR) and (MDA)	Ghafarifarsani *et al.* (2022)
Thyme essential oil	Rainbow trout (*Oncorhynchus mykiss*) 11.92 ± 0.06 g	1% and 2% for 60 days		↑ (CAT), (GR), (GPx) and (SOD) ↓MDA	Yousefi *et al.* (2022)
Savory (*Satureja hortensis*) essential oil	Caspian roach (*Rutilus caspicus*) 2.29 ± 0.07 g	100, 200, or 400 mg/kg for 60 days	salinity stress	↑ SOD, CAT, MDA	Ghafarifarsani *et al.* (2022))

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

Table 2. Cont.

Cinnamon *Cinnamomum cassia* essential oils	silver catfish (*Rhamdia quelen*) 6.62 ± 0.28 g	1.0 mL for 60 days		↑ SOD	Bandeira Junior *et al.* (2022)
Summer savory (Satureja hortensis) oil	common carp 25.35±0.13 g	1% for 21 days	exposed to pretilachlor herbicide	↑ (SOD ↑ (GPX)	Jalil *et al.* (2022)
Palm (*Phoenix dactylifera* L.) SEED Essentail Oil	Rainbow trout (*Oncorhynchus mykiss*) 5,77 ± 0,01 g	‰0,5, ‰1, ‰2 for 45 days	-	↔ SOD	Gaballah (2019)
White mustard (*Sinapis alba*) Oil Flax seed (*Linum usitatissimum*) Oil	Rainbow trout (*Oncorhynchus mykiss*) 25.77 ± 0.13 g	0.5, 1, and 1.5% of diet for 9 weeks	-	↑ SOD ↑ CAT ↑ GST ↓ LPO	Salem *et al.* (2022)

Symbols: ↑ indicates increase, ↓ indicates decrease, ↔ indicates no change.
Abbreviations: CAT Catalase, **SOD** superoxide dismutase, **GPx** Glutathione peroxidase, **GR** Glutathione reductase, **GSH** Glutathione, **GST** Glutathione s-transferase, **LPO** Lipid peroxidation, **MDA** Malondialdehyde.

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

3. Overview of the use of Plant essential oils in aquaculture

In this paper, discovered that Plant essential oils have a high potential for usage as feed additives in aquaculture. According to the studies examined (Tables 1-3), Plant essential oils are more beneficial in immunostimulation improvement in fish than in boosting antioxidant status, as some studies indicated antioxidant status retardation following Plant essential oils supplementation. Antioxidant status retardation may be ascribed to the Plant essential oils supplement dosage. As seen in Table 1, studies show that typically used rather high amounts of Plant essential oils. Furthermore, various other parameters, including as the chemical nature of the substances in the feed, water pH, water temperature, genetic characteristics, the threshold of the substance for a specific species, and so on, influence palatability (Kasumyan and Dving, 2003). Or negatively alter feed palatability (Serrano *et al*., 2011; and Omnes *et al*., 2017). Palatability is especially crucial for carnivorous fish because their meals typically do not contain herbal compounds; hence, certain Plant essential oils may limit absorption (Lall and Tibbetts, 2009). To avoid such unfavorable results, future research should take the above-mentioned possibilities into account while selecting the Plant essential oils and the dose of administration.

Plant essential oils provide enormous beneficial effects in aquaculture by improving appetite, microbial balance, immune responses, antioxidative capacity, and disease resistance of aquatic animals. At the same time, plant essential oils provide growth-promoting and feed utilization effects. A comprehensive review indicates that the primary determinants of Plant essential oils efficacy in aquatic animals are the oil's source, concentration, and duration of administration. This review article clearly illustrates that herbal EOs have beneficial effects on aquatic animals' performances, and can feasibly replace antibiotics and chemotherapies for clean, healthy, and sustainable aquaculture. Hence, further studies on fish physiology are also required to determine and quantify the effects of botanical Plant essential oils concentrations on adaptive immune response, antioxidative status, and disease resilience. Furthermore, further research plans are needed in this direction, coupled with comprehensive studies using advanced methods to investigations the effects of Plant essential oils on targeted fish species. Additional research is also required to investigate the possibility of combining Plant essential oils with other feed additives (e.g., probiotics and prebiotics) and comparing their effects to antibiotics.

In terms of immunostimulation and antioxidant status, none of the reviewed studies (Tables 2 and 3) reported adverse effects. It is clear from the presented tables that Plant essential oils are potent antioxidant and immunostimulatory substances that can be used in aquaculture. However, we have observed that only a small fraction of the studies utilized more than one Plant essential oil but we think that combinations of Plant essential oils may exhibit synergistic effects that can possibly result in more beneficial results.

4. Conclusion

To summarize, the use of phytochemicals as feed additives is currently a hot field in aquaculture and has received a lot of attention in recent years. There is sufficient data to infer that dietary

ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

phytochemical supplementation increases finfish development, boosts the immunological response, and improves antioxidant status. However, we believe that additional research should be conducted to evaluate the potential synergistic effects of mixed phytochemicals. Furthermore, more extensive research is required to assess the industrial applicability of phytochemicals on a bigger scale.

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ISSN (Print): 2413-5267
ISSN (Online): 2706-9966

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