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APPLICATION DEVELOPMENT ON *BRASSICA* SPECIES IN AQUACULTURE – A REVIEW

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Abstract

***Brassicaceae* family are traditional, medicinal and nutritional value plants. *Brassicaceae* family produces valuable components to provide different types of beneficial effects for humans and animals such as anti-oxidant, antimicrobial, anticancer, anti-scurvy, anti-inflammatory, anti-hyperglycemic, anti-tumor, anti-diabetes, anti-stomach diseases, and anti-cardiac. This review mainly focuses to observe *Brassicaceae* family response in aquatic animals and provides some information collected from literature analysis regarding the development of aquaculture applications like *Brassicaceae* family plants used as a supplement to enhance nutritional value, replacement of fish meal, antimicrobial activity against pathogens, immunomodulatory effects, antioxidant, and growth activity of aquatic animals. This literature review analysis is helpful to enlighten for future research and development on the application in the aquaculture sector.**

Key words: *Brassica* sp., antimicrobial, antioxidant, immune system, growth, aquaculture

Brassicaceae family can be present approximately on the entire land surface of the globe, but the family is not present in the Antarctica region, and also not present in several areas in the tropics i.e. the Congo basin, northeast Brazil, tropical Australasia, and maritime Southeast Asia. *Brassicaceae* family species are important agricultural crops; some plants are considered indigenous. The economic importance of *Brassicaceae* family plants like cauliflower, broccoli, kale, cabbage, rape, brown mustard, turnip, and rutabaga is high (Schmidt and Bancroft, 2011). Iran's annual vegetable production reaches 30 m tons. Of this amount, almost 800 tons are allocated to broccoli. The United States is the 3rd largest producer of broccoli in the world, with California leading in US production (90%) (Van Hayek, 1911; Schulz, 1936; Azarashkan et al., 2022). *Brassicaceae* (*Cruciferae*) is one of the biggest angiosperm families belonging to the order Brassicales. It includes 12–15 groups with 338–360 genera and 3709 species spread all around the world in the entire continents excluding Antarctica (Al-Shehbaz, 1973, 1984; Appel and Al-Shehbaz, 2003; Al-Shehbaz, 2006). *Brassica* spp. is generally categorized into three different varieties: coles, mustards, and rapeseed. The coles are leafy and stalk vegetable category incorporated in cauliflower (*Brassica oleracea*), broccoli (*B. oleracea*), cabbage (*B. oleracea*), tronchuda (*B. oleracea*), Brussels sprouts (*B. oleracea*) and kale (*B. oleracea*) and reported to be a most vital source of folates and vitamin C (Dias, 2019). The *Brassica* species are classified into different types such as Asian mustard (*B. juncea*), black mustard (*B. nigra*), white mustard (*B. alba*), Ethiopian mustard (*B. carinata*), rapeseed (*B. rapa*), oilseed rape (*B. napus*), and canola (*B. napus*), which are crucial, economically vital oilseed crops (Rahman et al., 2018). *Brassica napus* is the oil seed crops such as rapeseed or canola, including turnip, Chinese cabbage, and pak choi. *Brassica napus* is one of the significant oil crops after maize and oil palm (Beszterda and Nogala-Kałucka, 2019). Numerous researchers and taxonomists classified the *Brassicaceae* family into various tribes; the *Brassicaceae* family contains annuals, biennials, and also herbaceous perennials. *Brassicaceae* family plants and herbs have the least percentage (5%) of characteristically woody such as *Crambоxylon* spp., *Parolinia* spp., *Zilla spinosa*, *Heliophila scandens, Vella* spp., *Faresetia somalensis*, etc. (Franzke et al., 2011). In addition, canola and *Brassica napus* are this family's major significant oil crops (Alagoz and Toorchi, 2018). Different wild *Brassica* species are a vital source of food in the Mediterranean diet, some studies suggested the nutritional and medicinal effects of the edible wild plants concerning cultivated crops (Malfa et al., 2020; Raeeszadeh et al., 2021 a, b). *Brassica* vegetables have played potent various biological responses such as antibacterial, antiviral, and anticancer activity for the non-specific immune system (Chauhan et al., 2016). Anti-nutritional effects cause different activities such as growth retardation, poor egg production, goiter, and liver damage in animals that have been studied for glucosinolates (GLSs) (Griffiths et al., 1998; Cartea and Velasco, 2008).

Wild *Brassica* species contain numerous beneficial bioactive compounds, and in adaptation to challenging environmental conditions plants directly synthesize secondary metabolites as a chemical defense mechanism (Sánchez-Mata et al., 2012; Vijayaram et al., 2022). *Brassica* species contain a high quantity of flavonols with quercetin, and isorhamnetin as the major aglycones, they are frequently acylated with various hydroxycinnamic acids (Nielsen et al., 1993). *Brassica* vegetable sources contain a high quantity of vitamins like vitamin C, folic acid, tocopherols, and carotenes (Ghafarifarsani et al., 2022 a, b; Kurilich et al., 2002). *Brassica* species is the potential source to produce the rich level of minerals such as calcium (Ca), iron (Fe), phosphorus (P), chlorine (Cl), sulfur (S), potassium (K), and strontium (Sr) (Kmiecik et al., 2007). In addition, *Brassica* species have potential hyperaccumulators in soil-polluted heavy metals such as nickel, zinc, and cadmium as well as *Brassica* species capable of aggregating and tolerating the heavy metals (Devi, 2017). Generally, *B. nigra* species known as black mustard are universally produced and consumed plant species; these species are utilized in different ways like fodder crop, oilseed crop, industrial oil, salad crop, green manure, and green vegetables (Thomas et al., 2012). Black mustard contains different kinds of components such as amino acids, fatty acids, minerals, oligosaccharides, glucosinolates, anti-nutritional factors, and several phenolic compounds as well as the plant species have numerous positive effects like immunomodulatory, antioxidant, antithrombotic, anti-inflammatory, antifungal, antibacterial, anticonvulsant and antidiabetic effects (De Zoysa and Waisundara, 2021; Ghafarifarsani et al., 2021; Ajdari et al., 2022; Ghafarifarsani et al., 2022 c, d, e, 2023).

Lakwani et al. (2022) pointed out that a *Brassica* sp. supplement of 1–2% is supportive to increase the intestinal immunity in rainbow trout for 30 days trial period. Numerous studies described that the incorporation of rapeseed oil supportive to partially replaced fish oil is used to enhance the growth performance of diverse fish species namely red sea bream (*Pagrus major*), yellowtail kingfish (*Seriola lalandi*), chinook salmon (*Oncorhynchus tshawytscha*), rainbow trout (*Oncorhynchus mykiss*), Atlantic salmon (*Salmo salar*) and common carp (*Cyprinus carpio*) (Drew et al., 2007; Huang et al., 2007, 2008; Bowyer et al., 2012; Ghafarifarsani et al., 2022 c, d, 2023). *Brassica* species produced glucosinolates present in rapeseed (*Brassica* spp.) meal and mustard oil cake, and potential significant protein sources in fish feed. *Brassica* species are the alternative development of fish nutrition supplements and they have noticeably improved aquaculture development (Naylor et al., 2009). Various types of plant protein sources were examined to replace fish meal in turbot nutrition (Fournier et al., 2004; Bonaldo et al., 2011; Nagel et al., 2012 a; Yousefi et al., 2022 a, b, c). Kasiga (2018) reported examining the composition and digestibility of carinata (*B. carinata*) meal to hybrid striped bass (*Morone chrysops* × *M. saxatilis*). Carinata meal contains 48% crude protein (which is 98.9% digestible) and different types of components similar to leucine but more arginine, histidine, methionine, threonine, tryptophan, and cysteine. Amino acid level is high compared to solvent-extracted (SE) soybean meal (SE-SBM) with hulls (National Research Council, 2011). Mzengereza et al. (2021 a) reported that dietary supplementation of carinata meal at 20.5 kg/kg (60 days) noticeably enhanced immunity, growth, digestive enzymes, nutrient digestibility, feed utilization capability, and stress resistance activity of red sea bream. Additionally, numerous studies reported the potential importance of camelina oil as a lipid source in aquaculture and livestock sectors (Hixson and Parrish, 2014; Betancor et al., 2018; Toyes-Vargas et al., 2020; Raeeszadeh et al., 2021 a). Dietary incorporation of camelina produces vital components such as sinapine, phytic acid glucosinolates (GSL), and condensed tannins are providing a beneficial response in rainbow trout (Schuster and Friedt, 1998; Matthäus and Zubr, 2000; Russo and Reggiani, 2012). Canola meal and its products have provided beneficial responses like growth and feed utilization of salmonids (Mwachireya et al., 1999; Thiessen et al., 2003, 2004) and also canola meal concentration level increases to improve the performance of fish species (Collins et al., 2012, 2013). Canola meal protein is the most successful protein supplement in aquatic animals such as rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792), high-value crustaceans such as mitten crab, and shrimp species (Cruz-Suarez et al., 2001; Suárez et al., 2009; Luo et al., 2011; Nagel et al., 2012 b; Slawski et al., 2012; Adem et al., 2014; Turchini et al., 2019). Canola meal (19.02%) can replace less than 30% of soybean meal without compromising on growth and feed conversion in juvenile hybrid tilapia (*Oreochromis niloticus* × *Oreochromis aureus*) (Zhou and Yue, 2010). Red cabbage (*B. oleracea* L. var. *Capitata* f. *rubra* DC.) contains more vitamins, minerals, and antioxidant levels compared to other cabbage. Red cabbage supplement is more helpful to enhance the growth, and resistance power of tilapia species (Taufik, 2012). This review provides some information collected from literature analysis regarding the development of aquaculture applications like *Brassica* species used as a supplement to enhance nutritional value, replacement of fish meal, antimicrobial activity against pathogens, immunomodulatory effects, antioxidant, and growth activity of aquatic animals.

Applications of *Brassica* species

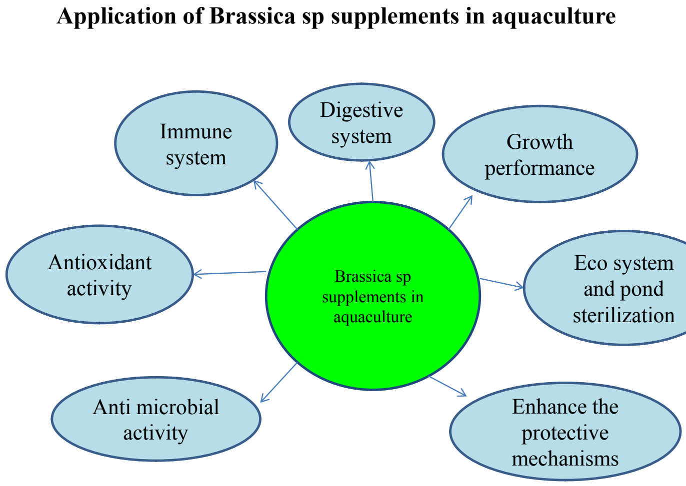

Figure 1. Role of *Brassica* sp. in aquatic animals

Table 1. Effect of broccoli on growth in aquaculture

Brassica sp. scientific name	Local name	Phytochemical components of *Brassica* sp.	Aquatic animals Local/scientific name	Response	Reference
1	2	3	4	5	6
Brassica rapa L. and *Brassica oleracea*	Pak choi and kailan	Polyphenols, phenolic acids, flavonoids, carotenoids (zeaxanthin, lutein, β-carotene), alkaloids, tannins, saponins, anthocyanins, phytosterols chlorophyll, glucosinolates, phytosteroids, terpenoids, glycosides, vitamin	Tilapia (*Oreochromis* sp.)	↑ FCR and SGR value	Ariadi et al. (2020)
Brassica oleracea	Cabbage		Nile tilapia (*Oreochromis niloticus*)	↑ Body weight, final weight gain, growth rate, feed conversion ratio	Oke et al. (2017)
Brassica nigra	Black mustard		Rainbow trout (*Oncorhynchus mykiss*)	↑ Intestinal immunity	Lakwani et al. (2021)
Brassica carinata	Ethiopian mustard		Hybrid striped bass (*Morone saxatilis*)	↑ Concentration of essential amino acids	Kasiga et al. (2021)
Camelina	Siberian oilseed		Red seabream (*Pagrus major*)	Maintain growth, digestive enzymes, immunity, stress resistance and feed utilization	Mzengereza et al. (2021 a, b)
Camelina high-oil residual camelina meal	Siberian oilseed		Rainbow trout (*Oncorhynchus mykiss*)	↑ Glucosinolate level ↓ Feed intake	Buller et al. (2016)
			Rainbow trout (*Oncorhynchus mykiss*)	No adverse effects on growth performance	Pan et al. (2011)
Brassica napus	Rapeseed		Rainbow trout (*Oncorhynchus mykiss*)	↑ Overall growth ↓ Feed intake	Kaiser et al. (2021)
Camelina	Siberian oilseed		Rainbow trout (*Oncorhynchus mykiss*)	↑ Overall growth	Koskela et al. (2021)
Brassica oleracea	Red cabbage		Nile tilapia (*Oreochromis niloticus*)	↑ Growth and survival range	Nasution (2021)
Brassica napus	Rapeseed		GIFT (juvenile genetically improved farmed tilapia)	23.2% is suitable level to enhance growth, feed utilization and physiological function	Wu et al. (2021)
Canola oil	Turnip		Pacific white shrimp (*Litopenaeus vannamei)*	100% replacement of fish meal	Gia Vo et al. (2021)

Table 1 – contd.

1	2	3	4	5	6
Brassica rapa L.	Pak choi		Nile tilapia (*Oreochromis niloticus*)	Maintain the level of ammonia, nitrate and nitrite in fish ponds	Febriani et al. (2018)
Brassica napus, Camelina sativa and *Brassica carinata*	Canola, camelina and Ethiopian mustard		Rainbow trout fingerlings (*Oncorhynchus mykiss*)	↑ Growth performance	Bullerwell et al. (2016); Anderson et al. (2018)
Brassica juncea L.	Samhong mustard		Nile tilapia (*Oreochromis niloticus*)	↑ Growth performance and removal of nutrients from fish farm water	Deswati et al. (2020)
Brassica oleracea, *B. napus* and *B. juncea*	Broccoli, cole and potherb mustard		Shrimp *Limpenaeus vannamei*	Suitable model to enhance shrimp quality and ecological development of shrimp pond	Ni et al. (2020)

Table 2. Broccoli and its systemic effects in aquatic animals

Scientific name	Local name	Aquatic animals Local/scientific name	Response	Reference
Brassica oleracea	Red cabbage	Nile tilapia (*Oreochromis niloticus*)	↑ Detoxification metabolism of fish	Villa-Cruz et al. (2009)
Brassica oleracea	Broccoli	Nile tilapia (*Oreochromis niloticus*)	Novel protective agents against water pollutants	Davila et al. (2010)
Brassica oleracea	Red cabbage	Common carp (*Cyprinus carpio*)	↑ Nutrient efficiency, growth performance, and hematological parameters	Kadhim et al. (2022)
Brassica oleracea	Red cabbage	Nile tilapia (*Oreochromis niloticus*)	↑ Cellular and humoral immunity	Pisuttharachai et al. (2020)

Antimicrobial activity

Brassica species contain volatile sulfur compounds originating from S-alk(en)yl-L-cysteine sulfoxide, as well as glucosinolates. Sulfur compounds are commonly present in two families: the *Brassicaceae* and the *Lilliaceae* (Kyung and Lee, 2001). *Brassica* species cabbage (*B. tolerance*) extract showed potential antimicrobial response (Sherman and Hodge, 1936). *B. rapa* seeds showed potential antimicrobial response against *Salmonella paratyphi*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Escherichia coli*, and *Klebsiella pneumonia* (Muluye et al., 2015; Danlami et al., 2016). Researchers pointed out that *Brassica* species like radish root, kale leaves, and mustard seeds showed antimicrobial action against *Bacillus subtilis*, *Staphylococcus aureus*, *Salmonella typhimurium*, *S. aureus*, *Enterobacter faecalis*, *Moraxella catarrhalis*, *Listeria monocytogenes* and *Escherichia coli* (Ayaz et al., 2008; Beevi et al., 2009; Engels et al., 2012).

Immune system response

Brassica species and their components like tocopherol, ascorbic acid, canolol, carotenoids (lutein and carotene), phenolic acids (gallic acid, caffeic acid, sinapic acid, ferulic acid, and 3,4-di-hydroxybenzoic acid), and flavonoids (rutin, quercetin, and kaempferol) showed antioxidant activity to protect the immune system by neutralizing free radicals (Dua et al., 2014; Salehi et al., 2021; Grygier, 2022). Dietary incorporation of *B. oleracea* powder (0.5 g/100 g) noticeably enhanced feed utilization and nonspecific immune diseases in Nile tilapia (Oke et al. 2017; Raeeszadeh et al., 2022 a). Black mustard (*B. nigra*) supplement at 1–2 g/kg dosage for 30 days provides beneficial effects to improve immune response, pro- and anti-inflammatory responses in the intestine, and disease resistance against *Aeromonas hydrophila* in rainbow trout (Lakwani et al., 2022). Dietary incorporation of carinata 30% is improving palatability and overall nutrient value in sunshine bass; carinata supplements contain high iron contents and are useful to enhance the hemoglobin content of red blood cells (Kasiga and Brown, 2019; Raeeszadeh et al., 2022 b).

Antioxidant activity

Brassica species contain high antioxidant activity; numerous studies pointed out that different species of *Brassica* such as *B. rapa*, *B. oleracea*, *B. napus*, and *B. juncea* extract showed antioxidant activity (Raeeszadeh et al., 2022 a, b). The antioxidant activity was measured by *in vitro* methods based on the use of free radicals scavenging (Costa et al., 2005; Gawlik-Dziki, 2008; Miglio et al., 2008; Lemoine et al., 2010; Cogo et al., 2011; Liang et al., 2019; Ninh Le et al., 2019). Arora and Vig (2015) reported that *B. rapa* dichloromethane extract showed antioxidant activity by the inhibition of hydroxyl radicals responsible for oxidative damage to DNA at 1000 g/ml concentration by phenylethylbrassinin and 3-phenylpropionitrile by *in vivo* methods. *B. fruticulosa* subsp. *fruticulosa* leaf hydroalcoholic extract has phytochemical and antioxidant properties. The plant extract is non-toxic and potentially safe for shrimp larvae and is also a potential health-promoting factor in aquatic animals (Cavò et al., 2022). Aqueous and ethanolic extracts of broccoli showed the potential antioxidant activity of different reactive oxygen species/free radicals by *in vitro* conditions. Broccoli is a source of natural antioxidants or nutraceuticals with the possible function to reduce oxidative stress with consequent health benefits (Bidchol et al., 2011; Raeeszadeh et al., 2022 a). Aqueous and ethanolic extracts of cauliflower have effective antioxidant activity by various *in vitro* assays such as DPPH scavenging, $ABTS^{+}$ scavenging, $DMPD^{+}$ scavenging, Cu^{2+}-Cu^{+} reducing power assays, ferric thiocyanate method, Fe^{3+}-Fe^{2+} and superoxide anion radical scavenging, hydrogen peroxide scavenging, and metal chelating activity. The antioxidant results compared standard antioxidant compounds α-tocopherol (a natural antioxidant) and Trolox (the water-soluble analog of tocopherol) (Qaderi Forough et al., 2017). Cauliflower contains natural antioxidants and potential use for food additives or pharmaceutical applications (Köksal and Gülçin, 2008).

Growth response

Dietary incorporation of rapeseed oil was applied to examine the production and growth parameters of rainbow trout and the study results indicate no changes in final weight, weight gain, hepatosomatic index, or viscerosomatic index compared to fish meal and fish oil-based diet (Caballero et al., 2002; Drew et al., 2007; Turchini et al., 2013; Kaiser et al., 2021). The dietary additive of pak choi (*B. rapa* subsp. *chinensis*) supplement is a noticeable improvement of significant growth ratio of 3.15% and a feed conversion ratio at 1.21 of tilapia compared to the kalian plant in the aquaponic system (Ariadi et al., 2020; Raeeszadeh et al., 2022 b). Dietary additives of camelina oil are utilized to replace fish oil. Camelina oil contains limited fatty acids, eicosapentaenoic acid (EPA), and docosahexaenoic acids (DHA) which are helpful to maintain growth and sustain health performance in red seabream (*Pagrus major*). A camelina diet supplement is a successful effective method for the growth development of aquatic animals (Mzengereza et al., 2021 b). Dietary supplementation of red cabbage liquid organic supplement had a noticeable effect to improve growth performance at 2.84–3.90% per day and survival range from 88 to 92% in tilapia. Red cabbage liquid supplement was supportive to enhance growth performance and decreased mortality rate in tilapia (*Oreochromis niloticus*) (Nasution, 2021). Dietary supplementation of rapeseed meal at 23.2% noticeably improved physiological function, feed utilization, flesh quality, and growth performance of improved farmed tilapia (GIFT); the higher concentration of rapeseed diet (46.4%) can reduce growth action, damaged liver function, and suppress the immune function of tilapia. Appropriate quantity of the supplement helps to improve growth performance in tilapia (Wu et al., 2021). Dietary supplementation was of canola oil helpful to replace menhaden fish oil up to 100% in fishmeal-based diets and up to 75% in poultry meals without affecting the growth performance of *L. vannamei.* Canola oil supplements are not only developed for particular species, they are potentially important multi-species feed ingredients in the aquaculture sector (Gia Vo et al., 2021). Dietary supplementation of canola (*B. napus*) meal with GLS content of 2.18 μmoles/g significantly did not affect feed intake or growth performance of red seabream (Glencross et al., 2004 a, b). Dietary supplementation of glucosinolates and sinapic acid concentrations has no adverse effects on the growth and physiological function of turbot, and plant proteins are helpful to replace a fish meal or fish oil, and most significant supplement for fish nutrition (von Danwitz and Schulz, 2020).

Conclusion

Brassica species is the most important traditional, medicinal, and food-value of plants. *Brassica* species and their components have more positive effects in human and livestock such as anti-oxidant, antimicrobial, anticancer, anti-scurvy, anti-inflammatory, anti-hyperglycemic, anti-tumor, diabetes, stomach diseases, and cardioprotective, but so far very limited applications are available in aquaculture. This review provides some information about *Brassica* species, and their components that are utilized to enhance antimicrobial activity, antioxidant activity, immune system against infections, and growth performance in aquatic animals. This review is helpful to develop the aquaculture application in future research. In the future *Brassica* species and their components may be utilized to enhance aquatic animals' health, increase healthy aquatic production and aquatic feed quality in the feed industry, and also to understand clear metabolic pathway study.

Data availability

The data that support the findings of this study are available upon reasonable request to the corresponding authors.

Compliance with ethical standards

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Conflicts of interest

The authors declare no conflict of interest.

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