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Status and potential of herbal applications in aquaculture: A review

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Abstract

Disease are recognized as one of the major constraint to sustainable animal production which can cause significant economic loss especially in aquaculture. Various chemotherapeutic agents have been traditionally used in the treatment and prevention of diseases in farmed fish but they are not recommended since improper and continuous use of antibiotics may lead to potential development of antibiotic resistant bacteria, environmental pollution and accumulation of toxic residues in fish. Therefore, scientists have intensified efforts to exploit natural products such as herbs in developing alternative dietary supplements that enhance growth performance, and health and immune system of cultured fish, as these products are inexpensive, safer, effective, and can be easily prepared and are biodegradable. This review discusses the findings from different studies related to the *in-vitro* and *in-vivo* applications of herbs and plant extracts or their combinations, in relation to appetite stimulator, growth promoter, antimicrobial, antiparasitic, antioxidant and immunostimulation in fish.

Keywords: Aquaculture, Herbal extracts, Potential, Chemotherapeutics, Alternatives.

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Introduction

The aquaculture industry has grown considerably in recent years due to the market demand since the oceans' wild stocks of most commercially important fish have declined. In 2012, total production of global capture was 91.3 million tonnes, a decrease of 2.6% compared with the previous year. In contrast, aquaculture industry has continued to show strong growth, where an average annual production rate has increased by 6.1% from 36.8 million tonnes in 2002 to 66.6 million tonnes in 2012. The value of farmed food fish production is estimated at USD 137.7 billion for 2012 (FAO, 2014).This impressive industrial development has been accompanied by the expansion of semi-intensive culture to the intensive culture system. Unfortunately, the intensive culture of fish generates a stressful environment leading to the suppression of the immune system and increasing of the susceptibility of fish to infectious diseases (Harikrishnan *et al*., 2011). Approximately, a third to a half of farm food fish is lost due to diseases before they could reach marketable size. Thus, disease can cause significant economic loss either through mortality and morbidity, poor growth rate, low quality of flesh, or reduced trade, resulting in reduced profit margins (Smith *et al*., 2003).

Various chemotherapeutic agents such as antibiotics and disinfectants have been traditionally used in the treatment and prevention of numerous diseases in farmed fish. However, they cannot be recommended since improper and continuous use of antibiotics may lead to potential development of antibiotic resistant bacteria, environmental pollution and the accumulation of residues in fish (Ringo *et al*., 2010). Hence, the effectiveness of the antibiotics for treating fish diseases is no longer assured (Romero Ormazábal *et al*., 2012). Many countries have forbidden the use of certain chemotherapeutics, and also refuse to import aquaculture products treated with antibiotics and chemicals. Therefore, researchers have intensified efforts to exploit natural products such as herbs and plants in development of alternative dietary supplements that enhance growth performance, and health and immune system of cultured fish instead of chemotherapeutic agents.

Herbs and medicinal plants are promising to be an important source of therapeutics in fish culture since these products provide a cheaper source for treatment and greater accuracy without causing toxicity (Madhuri *et al*., 2012). In general, plants have a variety of functions due to the presence of various active compounds like alkaloids, flavanoids, pigments, phenolics, terpenoids, steroids and essential oils (Citarasu *et al*., 2010). This review focuses on the research currently being conducted on the use of different herbs and plant extracts or their combinations, as appetite stimulator, growth promoter, antimicrobial, antiparasitic, antioxidant and immunostimulating agents on *in-vitro* and *in-vivo* applications.

Herbs as appetite stimulatorsand growth promoters

Many reports have documented the effect of herbs as appetizers and growth promoters in aquatic species. According to

Lee and Gao (2012) herbs perform their initial activity in feeding as a flavour and thereby influence eating patterns, the secretion of digestive fluids and total feed intake. The stimulation of digestive secretions including saliva, digestive enzymes, bile and mucus is considered to be an important action of feed additives. In another way, olfactory feed ingredients enhance the growth through their ability to act as feeding enhancers for fish to eat more feed than normal (Adams, 2005).

For instance, promising results were achieved when Harada (1990) used garlic as stimulatory effect on olfaction instead of chemotherapeutics. He found that garlic had a strong food calling effect on Oriental weather loach (*Misgurnus anguillicaudatus*) and Japanese amberjack (*Seriolaquin queradiata*). This is similar with what was reported by Lee and Gao (2012) on most aquatic animals including *Pelodiscus sinensis*, *Ctenopharyngodon idellus*, *Cyprinus carpio*, *Carassius auratus* and *Oreochromis niloticus.* An active compound of garlic, allicincan induce fish to ingest and increase feed intake. Zeng (1996) also reported that adding 50 mg/kg synthesized allicin to tilapia feed helped to increase more than 2–3% of its weight gain and survival rates after 45 days of culture. The feed conversion ratio also increased by 11% and the biological appraisal was 12% higher than in the control group. The use of other culinary herbs, red clover (*Trifolium pratense*), caraway (*Carum carvi*) and basil (*Ocimum basilium*) as a growth promoting agent has also demonstrated positive results in many species of tilapia (Turan, 2006; El-Dakar *et al*., 2008; Metwally, 2009; Ahmad and Abdel-Tawwab, 2011). Hwang *et al*. (2013) tested the effect of green tea methanol extract (*Camellia sinensis*) in diets of black rockfish (*Sebastess chlegeli*). In their study, green tea was found to be a promising source in enhancing the growth, survival rate, feed utilization and protein content in fish body. In other study, Venkatramalingam *et al*. (2007) reported that post larvae of *Penaeus monodon* had significantly higher weight gain and specific growth rate when fed with herbal appetizer, *Zingiber officinalis* enriched *Artemia.* Babu (1999) also reported the positive results of fecundity, gonadal weight and reduced intermoult period in *P. monodon* when the shrimp were given a maturation diet containing *Withania somnifera, Mucuna pruita, Ferula asafoetida* and *Piper longum* extracts. According to Citarasu *et al*.(1999, 2003) the use of various herbs such as *Hygrophila spinosa, W. somnifera, Z. officinalis, Solanum trilobatum, Andrographis paniculata, Psoralea corylifolia, Eclipta erecta, O. sacnctum, Picrorhiza kurooa, Phyllanthus niruri, Tinospora cordifolia,* purified Silajit and cod liver oil have a good influence in the *Penaeus* larviculture due to the feed and growth stimulator, antistress, immunostimulation, and antibacterial characteristics.

Since the use of herbs promotes good effects, various commercial herbal additives have been introduced in aquaculture. A preliminary study by Rawling *et al*. (2009) demonstrated that low levels (25–100 mg/kg) of Sangrovit® (commercial product containing the isoquinoline alkaloid sanguinarine) had a positive effect on tilapia growth. The daily

feed intake was significantly higher in fish fed with Sangrovit® supplemented diets compared to a control, suggesting that improved growth was likely to be due to improved appetite of fish fed with diets containing Sangrovit®. Adekunle (2012) investigated the effect of dietary herbal powder (Superliv®) on growth and body composition of *O.niloticus*. After an eight weeks of feeding, the results showed that the Superliv® powder meal treatment enhanced nutrient utilization, which was reflected in improved weight gain, FCR, PER, PE and SGR of *O. niloticus* fingerlings. A report by Goda (2008) indicated that a dietary ginseng herb (Ginsana G115) in Nile tilapia fingerlings greatly enhanced growth performance, diet utilization efficiency and hematological indices. Herbal products, stressol-I and stressol-II enriched *Artemia* nauplii fed to *P. indicus* postlarvae (PL 10–20) successfully increased the growth and efficiencies and also reduced osmotic stress (Chitra, 1995). Beside the shifting away from synthetic drugs, the use of herbs as an alternative to antibiotic growth promoters (AGP) in fish is becoming popular and acceptable due to diverse positive effects (Adedeji *et al*., 2008).

Herbs as antimicrobial agents

Numerous investigations have pointed out the great antimicrobial potential of the herbs as an alternative biomedicine in aquaculture (Zheng *et al*., 2009). Either extracted to essential oil or crude through several processes by hot or cold water or any solvents, herbs still have excellent antimicrobial properties since they can inhibit various tested microorganisms. Syahidah *et al*. (2012, 2013) through her *in-vitro* study for antibacterial potential of aqueous and methanolic extracts of Malaysian local herbs, *Cosmos caudatus, P. betle, Justicia gendarussa, Curcuma mangga* and *Z. zerumet* against important aquatic bacteria, *Aeromonas hydrophilla, Pseudomonas sp.* and *Streptococcus agalactiae* found that the highest level of antibacterial activity among all five herbs tested was demonstrated by *P. betle* methanolic extract. A test by Zilberg *et al*. (2010) on rosemary (*Rosmarinus officinalis*) displayed positive results when dried leaf and leaf extract of this herb inhibited a common tilapia pathogen, *S. iniae*. The essential oil extracted from this herb also showed a wide spectrum of antibacterial properties (Mangena and Muyima, 1999; Viuda-Martos *et al*., 2008). Similarly, chamomile extract was used successfully as antibacterial agent against *S. agalactiae*, where the minimal inhibitory concentration (MIC) was 6.25mg/ml (Abdelhadi *et al*., 2012). Moreover, Alsaid *et al*. (2010) reported that several aquatic pathogens such as *Mycobacterium sp., Staphylococcus sp., Enterococcus sp., Pseudomonas sp.* and *Micrococcus sp.* could be effectively inhibited by cinnamon's (*Cinnamomum sp.*) extract, while essential oils from this herb also possess antibacterial, antifungal, antiviral, insecticidal and antioxidant properties due to eugenoll, cinnamic acid and cinnamaldehyde content. The potent antimicrobial activity of cinnamon could be attributed to phenolic compounds, and also ugenol limits growth of microorganisms by inhibiting production of certain enzymes needed for growth (Parasa, 2012).

Some herbs and plant extracts have been demonstrated to prevent and control infectious microbes in culture systems. Abdel-Tawwab *et al*.(2010) investigated the survival of Nile tilapia (*O.niloticus*) challenged by pathogenic *A. hydrophila* after 12 weeks of feeding diet supplemented with green tea (*C. sinensis*) at different levels (0.0, 0.125, 0.25, 0.50, 1.0, or 2.0 g/kg diet). The results illustrated that the survival of fish showed incremental growth increases with increasing green tea levels in fish diets up to an optimum level of 0.50 g/kg diet indicating that green tea supplements could improve fish performance, health and prevent tilapia Aeromoniosis. This result was in agreement with the administration of herbal supplemented diets showing a mortality reduction and resistance against *A. hydrophila* in tilapia fed with ethanolic extract of *Psidium guajava* (Pachanawan *et al*., 2008). Another research proved that *P.guajava* was also able to eliminate *Vibrio* infection in Black tiger shrimp (*P.monodon).* Impressively, it demonstrated higher efficacy than the antibiotic oxytetracycline (Direkbusarakom, 2004).

There are also some reports on the use of herbs in managing the fungal infection. Gormez and Diler (2012) successfully controlled the fungal pathogen (*Saprolegnia parasitica*) by the essential oils of the three Lamiaceae species i.e. black tyme (*Thymbra spicata* L.), oregano (*Origanu monites* L.) and savory (*Satureja tymbra* L.) through *in-vitro* study. Furthermore, *in-vivo* study by Ilondu *et al*. (2009) demonstrated that the inhibition of the growth of *Saproleginia* increased with incremental rise in concentration of Astraceous (*Vernonia amygdalina*) plant's extract, while the control without the extract showed fluffy tufts of fungus growing on the body of fish after 28 days. It was also elucidated that *V. amygdalina* has potential in suppressing fungal growth in *Clarias gariepinus*. Recently, administration of *Zataria multiflora* essence to possibly control fungus contamination in cultured shrimp, *Litopenaeus vannemei* has been studied (Sharif Rohani *et al*., 2013).The results indicated that. *Z. multiflora's* essential oil has a significant anti-fungal effect and eliminates *Candida albicans* and *Fusarium solani* in abiotic condition, suggesting the potential use for disinfecting equipment but there was a limitation in application if we had shrimp species in the environment.

Harikrishnan *et al*. (2010 a,b); and Micol *et al*. (2005) reported that extract derived from olive tree leaf (*Olea europaea*) and its major compound, oleuropein (Ole) was very successful in controlling *Salmonid rhabdovirus*, and Viral Haemorrhagic Septicaemia virus (VHSV). *Punica granatum* solvent extracts showed antiviral effectiveness against Lymphocystis Disease virus (LDV) in *Paralichthys olivaceus* (Harikrishnan *et al*., 2010a). Direkbusarakom (2004) found that supplementation of *Clinacanthus nutansethanol* extract with polyvinylpyrolidone to shrimp increased their resistance to the Yellow Head virus (YHV). Balasubramanian *et al*.(2007) reported that the use of petroleum ether, benzene, diethyl ether, chloroform, ethyl acetate, methanol and ethanol extracts of 20 species of Indian traditional medicinal

plants such as *Aegle marmelos, C. dactylon, Lantana camara, Momordica charantia* and *Phyllanthus amarus* have antiviral activity against White Spot Syndrome virus (WSSV).This finding was similar to the recent report byYogeeswaran *et al*.(2012) where methanolic extracts of herbal immunostimulants such as *Acalypha indica, Cynodon dactylon, Picrorrhiza kurrooa, W. somnifera* and *Z. officinalis* incorporated in formulated diets fed to shrimp for 60 days after vaccination, successfully protected them from WSSV. Generally, herbal active compounds bring about effects by inhibiting or blocking the transcription of the virus to reduce its replication in the host cells, hence enhancing the innate immunity of the host (Citarasu, 2010).

Herbs as anti-parasitic agents

There are also reports on the use of herbs and plant products in the treatment of some parasitic diseases like myxobolasis, trichodiniasis, gyrodactylosis, argulosis, and scuticociliates in farm fishes (Micol *et al*., 2005; Harikrishnan *et al*., 2010 a,b). Extract of garlic has been reported to be effective against some intestinal protozoan parasites such as *Opalina ranarum*, *O. dimidicita*, *Balantidium entozoon*, *Trypanosoma, Leishmania, Leptomonas*, *Crithidia* (Reuter *et al*., 1996), *Entaemoeba histolytica* and *Giardia lamblia* (Ankri and Mirelman, 1999). Madsen *et al*. (2000) demonstrated the raw and squeezed garlic at 200 ppm had potential to treat Trichodiniasis in eel fish. According to Chitmanat *et al*. (2003) crude extracts of either Indian almond (*Terminalia catappa*) or garlic at 800 ppm was able to eliminate all *Trichodina sp*. from tilapia after two days of treatment.This is similar to what was reported by Pandey (2013). Bartolome *et al*. (2010) also reported that garlic extract at 10–100% could effectively control or delay *Ichthyopthirius multifiliis* infection, the most pathogenic parasites affecting freshwater fishes.

In other study, Yao *et al*. (2010) found that bath treatment of sanguinarine with the leaves of *Macleaya cordata* in different concentrations (0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 mg/L) to *I. multifiliis*-infected grass carp, *Ctenopharyngodon idella* decreased the number of parasites on the fish gills. Additionally, crude extracts of green tea were reported to be useful in controlling the flagellate fish parasites, *Ichthyobodon ecator* in Chum salmon, *Oncorhynchus keta* and Masu salmon, *O. masou* (Suzuki *et al*., 2006). Abdelhadi (2007) has successfully used purified *Commiphora myrrha* extract to treat and control the monogenetic trematodes (gill flukes) infesting the gills of common carp fingerlings, when mixed with feed. However, he reported that the Commiphora extract had no effect when added to water and impaired the survival of the fish because the extract caused white clouds, which precipitated on the gills of carp fingerlings, blocking the process of oxygen exchange.

Herbs as antioxidant agents

Fish from the intensive culture systems are continuously exposed to several forms of stressors including chemical, biological and physical disturbances, which lead in significant changes on the physiological and biochemical conditions of fish. A

change in biological condition beyond the normal resting state that challenges homeostasis can be considered to be overall effect of stress, and consequently threats the fish health. A wide variety of chemical compounds found in plants possess antioxidative effects which help organisms deal with oxidative stress caused by free radical damage, hence, improve the general physiological condition of fish (Ali *et al*., 2008; Chakraborty and Hancz, 2011).

For example, Metwally (2009) found that fish fed with diets with different sources of garlic, *A. sativum* could reduce glucose concentration in blood serum significantly. It also increased the activity of antioxidant enzymes, including glutathione peroxidase, superoxide dismutase (SOD) and catalase (CAT) in *O. niloticus.* The result was in agreement with the finding by Li *et al*. (2008) where the activities of CAT and SOD increased significantly and malonaldehyde diethyl acetal decreased in the allicin supplemented group. A study conducted by Shahsavani *et al*. (2010) showed that dietary supplementation of organosulfide allicin at 10 mg/kg in common carp was effective in reducing lead accumulation in the liver, kidney, brain, bone and blood. The mechanism behind this effect might be due to metal-chelating ability of allicin which in turn leads to a reduction in the tissue lead burden (Chakraborty and Hancz, 2011).

Wu *et al*.(2007) observed the effects of *Astragalus membranaceus*, *Portulaca oleracea*, *Flavescent sophora* and *A. paniculata* on stress resistance and immunological parameters of *C.carpio*. The result showed that herbal extracts acted as an antistress and inducer to serum lysozyme activity, SOD, NOS, levels of total serum protein, globulin and albumin of fish. *C. carpio* var. Jian, fed with supplemented diets of 1.0–2.0% anthraquinone extract from rhubarb (*Rheum officinale*) for 10 weeks were able to mitigate the negative effects of crowding stress.The results showed lower blood cortisol, glucose and hepatic malondialdehydelevels but higher hepatic catalase and superoxide dismutase activities compared to the control group after exposure to crowding stress for 1 and 7 days (Xie *et al*., 2008). Herbs-derived antioxidants such as tannins, lignans, stilbenes, coumarins, quinones, xanthones, phenolic acids, flavonols, catechins, anthocyanins and proanthocyanins could delay or prevent the onset of degenerative diseases because of their redox properties, which allow them to act as hydrogen donors, reducing agents, hydroxyl radicals or superoxide radical scavengers (Marwah *et al*., 2007) and may lead to increase immune factors, thus indirectly raising fish resistance to various stresses (Chakraborty and Hancz, 2011).

Herbs as immunostimulants for fish

Herbs are rich sources of immune-enhancing substances and herbal immunostimulants in contrast to vaccines, can modulate the innate or non-specific immune response and are currently being used to control fish and shellfish diseases especially in cases where disease outbreaks are cyclic and can be predicted (Galeotti, M. *et al*., 1995; Sakai, 1999; Citarasu, 2010). Many herbs and herbal extracts have been proven effective in enhancing the immune function in traditional practices

and might also be recommended as immunostimulants in aquaculture. A study by Divyagnaneswari *et al*. (2007) on the effect of Indian herb (*S. trilobatum*) on the non-specific immune mechanisms of tilapia found that intraperitoneal injection with different doses (4, 40 or 400 mg/kg) of the water-soluble and hexane-soluble fractions significantly enhanced the production of reactive oxygen species (ROS) and serum lysozyme activity on different days after treatment (2, 4, 6 or 8 days) and decreased percentage of mortality following challenge with *A. hydrophila*. Wu *et al*. (2010) reported that tilapia (*O.mossambicus*) given an intraperitoneal injection with hot water extract of the Chinese herb (*Toona sinensis),* (4 or 8 µg/g) showed increased respiratory burst, lysozyme activity and the phagocytic cell activity. This was in agreement with the report by Yin *et al*. (2006) and Ardó *et al*. (2008) where administration of Chinese herb (*Astragalus* sp.) extract for one week enhanced the phagocytic activity in Nile tilapia. *A.* root has also been reported to increase the phagocytosis of blood cells in soft-shelled turtles (Zhou *et al*., 2003). Analysis of the *Astragalus* showed that some of the components, such as polysaccharides, organic acids, alkaloids, glucosides and volatile oil, enhance the immune function (Wang *et al*., 1997; Liu, 2002).

Sivaram *et al*. (2004) through their study on immunity of juvenile grouper, *Epinephelus tauvina* larviculture reported that immune parameters such as phagocytic activity, serum bactericidal activity, albumin–globulin (A/G) ratio and leucocrit has increased significantly against *V. harveyi* challenge when fed with methanolic extracts of the herbals *O. sanctum, W. somnifera* and *Myristica fragrans*. In other examples, Praseetha (2005) found that shrimp fed with butanolic extract of *W. somnifera* through *Artemia* enriched diet successfully controlled *V. parahaemolyticus* and *V. damsela* infection, while juvenile shrimp fed with seaweed extracts were protected from *V. parahaemolyticus* (Immanuel *et al*., 2004). Mixed extracts from various herbs such as *Viscum album, Urtica dioica* and *Z. officinale* (Dügenci *et al*., 2003), *Radix astragalin* and *R. angelicae* (Jian and Wu, 2003), *A. radix* and *Ganoderma lucidum* (Yin *et al*., 2009) and *A. radix* and *Scutellari radix*, (Yin *et al*., 2006, 2009) have also enhanced immunity in fishes to bacterial infection. Moreover, immunostimulants not only stimulate the acquired immune response by increasing the diseases resistance, but also enhance innate, humoral and cellular defense mechanisms (Galindo-Villegas and Hosokawa, 2004). In addition, immunostimulants have positive additional effects such as enhancing the growth and improving the survival rates of the fishes under stress.

Herbs as adjuvants in vaccine preparation

Recently, herbal extracts have been tested as adjuvants for aquatic vaccines to replace the chemical adjuvants such as formalin and aluminium hydroxide, which are commonly used as adjuvants for killed bacterin or inactivated bacterial vaccines. Thyme (*Origanum vulgare*) was found effective on three tested *Pseudomonas* species, where the minimal bactericidal concentration (MBC) was 40 mg/ml and the

minimal inhibitory concentration (MIC) was 25 mg/ml (Siti Fatimah *et al*., 2013a). Thus, it was used successfully as herbal adjuvant for *P.putida* inactivated vaccine when tested in red hybrid tilapia, *Oreochromis sp*. at the rate of 40 and 100 mg/ml, where the 100 mg/ml concentration gave the best level of protection (Relative Survival or RPS was 90%) when the fish were challenged with a virulent strain of *P. putida* (Siti Fatimah *et al*., 2013b). However, further studies are still needed using different herbs and different bacterial species to determine the proper concentration of the promising herbal adjuvant.

Advantages of herbs and plant extracts

Many herbs and plant extracts have been proven useful in various applications in fish culture and aquaculture practices as mentioned above. In comparison to chemotherapeutics, most herbs and plant extracts have the potential to act against a broad spectrum of pathogens, having synergistic effects without developing herbal-resistance towards pathogens. Besides, raw herbal materials are inexpensive, locally available, can be easily prepared and biodegradable with no adverse effects to the enviroment. Raw herbs or their extracts and their active constituents could be practically administered through dietary, intraperitoneal or intramuscular injection and immersion or bathing techniques. Administration via injection is the most effective method especially for large fish, and also enables the extract to be quickly absorbed and functional but the process is labour intensive and stressful to the fish. Thus, oral administration has been more preferable for mass administration regardless of fish sizes (Sakai, 1999; Galindo-Villegas and Hosokawa, 2004).

The herbs and medicinal plants contain a number of bioactive compounds e.g., glycyrrhizin (GL) and its aglyconglycyrrhetic acid (GA), liquiritin (LQ), liquiritinapioside (LA), isoliquiritin (IL) and glabridin (GLAB) as well as several active components such as polysaccharides, alkaloids and/or flavonoids that play different role in each mechanism of fish physiological functions. They are beneficial in enhancing different innate immune parameters such as lysozyme, complement, antiprotease, reactive oxygen species, reactive nitrogen species, phagocytosis and respiratory burst activity, and adaptive immune parameters such as antibody titre, bactericidal, haemagglutination against pathogens (bacteria, virus, fungus, protozoa and parasites). Beside these effects, the bioactive compounds promote better growth and survival in various fish species (Harikrishnan *et al*., 2011).

Disadvantages of herbs and plant extracts

Despite the wide safety margin of herbs and plant extracts, there are also scant reports on their negative impacts in fish culture. Plants such as garlic (*Allium sativum*) have been described in numerous research to have benefits where they were effective in controlling fish diseases, enhancing the cultured performance and immune response of farmed fishes. However, garlic has been shown to cause a harmful and even lethal effect on certainlarviculture farming. Abdelhadi *et al*. (2008) conducted a study

of garlic on newly hatched larvae of cyprinid fish, silver carps. They concluded that garlic at the rate of 4 g/L could kill all larvae, while 3 g/L killed 50% (LC_{50}) of the newly hatched larvae of silver carp. In addition, the use of medicinal plants takes longer time compared to antibiotics (seven days) to resolve infection as tested in laboratory trials (Rahman *et al*. 2009).

In addition, some plants such as black seed (*Nigella sativa*) and garlic bulbs showed contradictive effect on growth rate and immune response of tested tilapia, when used for prolonged durations or periods more than 2 months. This time-dose relationship was studied and reported by Diab *et al*. (2006a) on tilapia fed with diets mixed with garlic and black seed mixtures for 3 months. The exact dose and duration of herbs and plant extracts still has not yet been established in aquaculture, and animal production sectors, in general. The high cost and low availability of some herbs are also a constraint. For instance, *Echinacea purperea* (purple coneflower) has showed best results and the highest value for growth parameters and immune-response when mixed with feed for Nile tilapia (*O. niloticus*). However, this herb is expensive and uneconomic to be applied in aquaculture as the benefit-cost ratio will not be encouraging (Diab *et al*., 2006b).

Conclusions and Recommendations

In general, natural products were found to be less toxic and safer than chemical preparations. Currently, attention is being switched to the use of natural products such as herbs and plant extracts as effective alternatives for disease control and growth promotion in aquaculture since drugs of synthetic origin were noted to have many negative and continuous side effects. Drug and chemical residuals in fish products could be transmitted to human and terrestrial animal via aquaculture practices and become health hazards through accumulation in tissue residues. The treatment of various diseases with different herbs and plant extracts, instead, have revealed good safety and highly effective in fish culture. Their effects are sometimes dose-dependent and there is a potential for overdosing, however, these negative effects can be prevented through method improvements. Hence, dosage optimization in terms of ideal dose, duration and mode of administration is strongly recommended to be further studied. Also, extensive research on phytochemicals including isolation and characterization of the active compounds from cheaper sources are recommended, so that more potential herbs can be commercialized as a product. Due to their beneficiary attributes, we conclude that herbs can be used as potential and promising alternatives to chemotherapeutics agents in aquaculture. Thus, the use of herbs could be an efficient tool to achieve sustainable, economic, safer and eco-friendly fish production.

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