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Grishma Tewari
Department of Fisheries Resource Management, College of Fisheries, GADVASU, Ludhiana, Punjab, India

Rajinder Kaur
Krishi Vigyan Kendra, Handiaya (Barnala), GADVASU, Ludhiana, Punjab, India

Corresponding Author
Grishma Tewari
Department of Fisheries Resource Management, College of Fisheries, GADVASU, Ludhiana, Punjab, India

Fish feed supplementation using non-conventional plant resources: Way to sustainable aquaculture

Grishma Tewari and Rajinder Kaur

Abstract
The global demand for aqua feed have intensified owing to the spectacular growth in the aquaculture sector with the advancement of culture practices which further relies on the availability of cost-effective and quality feeds. Addressing the role of nutrition and feeding for the sustained development of aquaculture practices, the use of expensive animal protein sources and artificial feed additives is being discouraged along with exploration of alternative cost effective and ecofriendly options throughout the world. In view of that information on non-conventional plant resources as fish feed ingredient has been reviewed in this article. Various plants and their non-edible parts contribute towards desirable traits in aquaculture, like-growth promotion, reproductive promotion, immuno-stimulation, disease resistance, color enhancement etc for enhanced fish production and productivity. To avail these properties, the waste of fruits and vegetables, non- edible parts of plants, aquatic weeds, part of flowers etc. can be utilized in aquafeed to enhance the desirable attributes in fish produce in a sustainable way without putting extra pressure on ecosystem. The present review concludes that integration of feeding management practices with cost effective and pro-environmental approach is the key to sustainable aquaculture.

Keywords: Agro-waste, plant by-products, non-conventional resources, supplementary feed, sustainable aquaculture

1. Introduction

Aquaculture is a major food industry which is growing at a faster rate due to increasing demand of fish and fisheries products throughout the world. With the global fish production of 178.5 million tonnes (mt) in year 2018, aquaculture sector contributed a share of 45.99% (82.1 mt) (Handbook of Fisheries Statistics, 2020) [62]. With the total national fish production of 14.18 mmt in year 2019-20, there has been a significant shift in terms of increasing contribution from inland fisheries sector propelled by freshwater aquaculture. At national level aquaculture production has increased to 6.2 million metric tons in FY 2017-18 from 1.9 million metric tons in 2000-01and about 88% of the farmed fish comes from freshwater aquaculture (NFP, 2020)

Globally, aquaculture sector is also trying to fulfill the enormously increasing demand of fish to combat against malnutrition and enhance food and nutritional security (FAO, 2018) [50]. With an objective to increase the fish production, aquaculture practices have been shifted from extensive to semi-intensive and intensive culture systems where nutrition plays a critical role by influencing not only the production cost but fish growth, health and waste production, too (Gatlin, 2002) [56]. In semi-intensive and intensive fish farming systems, fish feed contributes about 60-70% of operational cost (FAO, 1999) [47]. In order to reduce the expenditure involved with fish feed and increase the net profit earned by the fish farmers, alternative cost-effective plant sources may be a viable alternative to be incorporated in the formulated feed. The use of these natural resources will further be instrumental for ensuring the sustainable aquaculture development in terms of environmental, social and economical returns (FAO, 2017) [46].

At present in aquaculture sector, the conventional plant resources are used in the form of oilcake (mustard, groundnut, soyabean etc) as a source of protein to enhance growth. Along with the basic nutrients (protein, carbohydrates, lipids), the fishes are also provided with micro-nutrients, immunostimulants, feed attractants, synthetic growth promoters, color enhancer (FAO, 1980) [51] to enhance disease resistance, flesh quality, pigmentation and other desirable traits. These artificial compounds may leave their residual effects in long term and affect the fish health and further its consumers through the process of bio-magnification.

2. Nutritional Requirement of Fish

Quality nutrition in animal production systems is essential to economical production of a healthy, high-quality product especially in aquaculture, where approximately 50-60 percent of the variable production cost is invested on feed (FAO, 2009) [48]. Nutrient requirements of fish are reported as minimum dietary levels needed to support maximum performance of fish under experimental conditions when fed diets typically made using semi-purified ingredients (Small *et al*., 2016) [123]. Nutritional requirement of fish varies with factors like species, developmental stages, feeding habit, physico-chemical and biological parameters of water including primary productivity along with availability of natural food. The recommended fish diet for semi-intensive culture practices consists of oilcake, fish meal, meat meal (protein source) and rice bran, wheat bran, maize (carbohydrate source) to fulfill the growth and energy requirements along with vitamin –mineral premix for supplementing the basic diet.

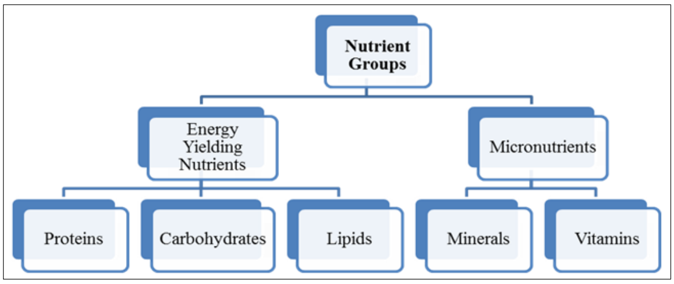

Fig 1: Flow chart showing different categories of major nutrient groups

3. Need of Alternative Feed Supplements

The rapid growth of aquaculture has been resulted in higher demand for supplementary feed which in turn has raised the cost of feed ingredients. Fish feed accounts for a substantial amount in the variable expenditure of fish farming enterprises (Falaye, 1993) [45], accounting for more than 60% of the total cost in a commercial aquaculture operation. Among the major ingredients of formulated feed, protein is the most expensive one and the major sources of protein in aqua feed are fish meal and de-oiled cakes. However, due to high cost, poor quality and limited availability, replacement of fish meal by plant protein sources is of great interest (Rumsey, 1993) [115]. Hence, the fish farmers from all over the world are in need to explore the usage of alternate cost effective and easily available plant-based feed ingredients (Bhosale *et al*., 2010) [24]. Moreover, introduction of animal protein may lead to problems of contamination in long run. Besides this, use of various anabolic products, hormones and their analogues, antibiotics, and synthetic growth promoters are also in practice to augment the aquaculture production. Since the last decade, several countries have restricted the use of antibiotics to combat the disease problem in aquaculture due to its serious consequences such as bacterial drug-resistance, breakage of the animal intestinal micro-ecological balance and the presence of antibiotic residues in resultant fish/shrimp products (Smith, 1962) [124] and efforts are being made to find some effective pro-environmental alternative. All these artificial feed additives ultimately affect the health of consumer and resulting in decreased consumer acceptance of fish and fishery products (Hua *et al*., 2019) [66]. In view of that, now-a –days, most of the fish farmers are preferably opting for herbal or plant-based products in place of artificial growth enhancer with an objective to make aquaculture activities more environment friendly and economically viable. In this direction, plant resources may serve as an ideal alternative to be used in fish feed for promoting various desirable traits in aquaculture, like- growth promotion, appetite stimulation, gonadal maturation, immuno-stimulation, along with anti-stress, antimicrobial and color enhancement properties as suggested by different studies (Kaur, 2017a; Kaur, 2017b) [74-75].

4. Non-conventional Plant Resources

Non-conventional plant resources (NCPR) generally refer to all those plants that have not been traditionally used for feeding animals including fish and are not commercially used in the production of animal or aquaculture feeds. The non-conventional plant resources are good source of protein and energy and may possibly be used to replace existing conventional sources in fish feed. NCPRs are credited for being non-competitive in terms of human consumption, very cheap to purchase by-products or waste products from agriculture, farm made feeds and food processing industries along with serving the purpose of waste management to keep the environment clean.

The non-conventional plant resources that can be used effectively to supplement the fish feed includes agro-waste in the form of fruit and vegetable waste, aquatic weeds, herbs and medicinal plants, flowers etc. These resources may aid in achieving desired production targets in aquaculture by promoting growth, disease resistance, reproductive performance, color enhancement etc with a cost-effective and pro-environmental approach.

4.1 Agro-waste as potential alternative

The amount of agro-waste generated in the form of fruit and vegetable waste is increasing day by day and imposing a tremendous pressure on the environment. In 2019, India is the second major producer of fruits and vegetables in the world after China and around 16% of the total production of fruits and vegetables being wasted every year (Sharma, 2019) [118]. The waste from fruits and vegetables processing plants consists of a great untapped source of energy and proteins which is being merely dumped in fields and causing pollution. The use of food wastes in fish feed may be an alternative of high interest in respect to cleaning the environment (eco-friendly) and also reducing the cost of production (economically viable). Applicability of these wastes in animal feed preparation has been reported by many researchers (Table 2). The plant resources are able to provide the required nutrients to produce high quality and safe fisheries products for human consumption, at the same time with minimal effect on environment. Fruit processing waste and vegetable processing wastes are the potential source of energy and has been established to stand good source of numerous polyphenols which help in digestion and growth promotion (Peschel *et al.*, 2006). Use of non-food parts from agricultural products as animal / fish feed will not only enhance food security but also contribute to alleviation of environmental problems associated with their disposal **(**Bakshi *et al*., 2016) [22].

4.1.1 *Bioactive compounds in agro-waste*

Agro-wastes (fruit and vegetable losses and waste [FVW]) are rich sources of phytochemicals including phenolic compounds, dietary fibers, and other bioactive compounds

(Galanakis, 2012) [55]. In most fruits and vegetables, only the flesh or pulp is consumed but significant amounts of phytochemicals and essential nutrients are also present in the non-edible and unconsumed parts like seeds, peels, and other components of fruits and vegetables as reported by various studies (Table 1). Earlier studies have revealed that peels of lemon, grapes, orange and the seeds of avocado, jackfruit, longan and mango contain more than 15% higher phenolic concentrations in comparison to their fruit pulp (Gorinstein *et al*., 2001; Soong and Barlow, 2004) [60, 125]. High amount of protein in the peels of kiwi, avocado and papaya (1.79%, 1.57%, and 1.55%, respectively) and citrus (2.5 to 9.0%) have been recorded (Dugo and Di Giacomo, 2002; Pfaltzgraff *et al*., 2013; Mamma and Christakopoulos, 2014) [41, 141, 91]. These nutrients and compounds present in the fruits and vegetables waste can be efficiently utilized to enhance the nutritional value of aquafeed (Kumar *et al*., 2017) [84].

Table 1: Bioactive substances derived from some fruit and plant waste and their action

Bioactive substance	Source	Action	Reference
Anthocyanidins	Roots of banana	Anti-parasitic	Anosa and Okoro, 2011 [13]
Caffeic acid	Coffee shells	Anti-oxidant; Anti-bacterial	Marinova *et al*., 2009 [93]
Cinnamaldehyde	Bark of cinnamon	Anti-bacterial; Anti-parasitic; Appetite stimulant	Yan and Kim, 2012 [144]
Limonene, linalool and flavonoids	Peels and pulp of lemon/orange	Anti-bacterial	Caccioni *et al*., 1998 [30]
Oleanenoic acid	Leaves of olive tree	Anti-inflammatory; Anti-oxidant	Abbas *et al*., 2012 [1]
Papain	Leaves and peels of papaya	Anti-parasitic	Bozkurt *et al*., 2013 [29]
Tannins	Seeds of grapes	Anti-oxidant	Abbas *et al*., 2012 [1]

4.2 *Medicinal plants*

The medicinal plants have been reported to possess various desirable properties such as anti-stress, growth promotion, appetite stimulation, immune-stimulation, aphrodisiac and anti-pathogen properties in fish and shrimp aquaculture due to presence of varied active principle compound, such as - alkaloids, terpenoids, tannins, saponins and flavonoids (Chakraborty and Hancz, 2011; Citarasu, 2010) [32, 37]. These plants can be administered in fish diet as a whole plant or parts (leaf, root, seed, fruit) in dried or fresh form or as prepared herbal extracts with different solvents (water, methanol, chloroform, ethyl acetate) (Van Hai, 2015). Various scientific studies have confirmed the use of medicinal plants in aquaculture (Bhuvansewari and Balasundaram, 2006; Harikrishnan *et al*., 2011) [25, 63]. Some of the plant species that are being intensively used with the great potential in aquaculture are ashwagandha, aloevera, garlic, tulsi, amla, lemon grass, ginger, turmeric etc.

4.3 Duckweeds

Duckweed species are small floating aquatic plants found worldwide and often seen growing in thick, blanket-like mats on still or slow moving, nutrient-rich waters (Leng *et al.*, 1995) [87]. These are small green plants belonging to family lemnaceae. Taxonomically they belong to monocotyledons and have four generas *Lemna*, *Spirodela*, *Wolffia and Wolffiella* (Ansal *et al.*, 2010) [14]. About 40 species of duckweeds are reported worldwide (Les *et al*., 2002). The biomass of duckweeds may get doubled in 23 days (Iqbal, 1999, Sillikorn *et al*., 1993) [68, 120] under ideal conditions of available nutrients, sunlight, pH (6.5-7.5) and temperature (20^0C-30^0C) and can be cultured without much cost, labor and expertise (Ansal *et al*., 2010) [14]. Duckweeds have a great potential to be as an alternative fish feed ingredient, due to its certain attributes like – easy availability, free of cost and nutritive qualities (low fiber and high protein, when grown under ideal conditions). It can be incorporated in fish feed in fresh form for herbivorous fishes, like-grass carp or in dried powdered form along with other feed ingredients for the fishes with different feeding habit.

Floating aquatic macrophytes, like – water hyacinth, *Eichhornia crassipes* also possess a great potential for its inclusion in fish feed. It is a monocotyledonous freshwater aquatic plant belonging to the family *Pontederiaceae*, and native to the Brazil and Ecuador region. Recently, considerable attention has been given to its harvesting for practical uses, as an alternative plant protein source in livestock feed including fish (Sotolu 2008; Aderolu & Akinremi 2009) [126, 8]. Some studies have been conducted in respect to utilization of water hyacinth as feed for different fish species including Indian major carps (Edwards *et al*., 1985; Hasan *et al*., 1990; Ray & Das 1994) [42, 64, 113].

4.4 Flowers

Ornamental fish culture is now a days a rapidly growing sector in view of its aesthetic value as well as their huge commercial value in the global export trade. The commercial value of ornamental fishes is dedicated to the beauty of colors they have, that is further depends upon the intensity and pattern of pigmentation. Carotenoids are the main pigments, representing a class of over 600 natural lipid soluble pigments present in plants, algae, photosynthetic, some non-photosynthetic bacteria and animals, which are required for healthy growth, metabolism, photosynthesis and reproduction, besides color development (Halten *et al*., 1997; Kaur, 2017b) [61, 74]. To fulfill the requirement of carotenoids, various synthetic as well as natural sources (animal and plant) are being developed for use in color enhancement of ornamental fishes. Synthetic processes result in production of only specific carotenoids like â-carotene or astaxanthin, whereas, natural sources are always a combination of several carotenoids like α-carotene, β-carotene, zeaxanthin, lutein, cryptoxanthin, etc. (Mezzomo and Ferreira, 2016) [96]. Plant based natural carotenoids are mainly derived from flowers, fruits, vegetables, algae, yeast etc. (Chapman, 2000) [33], which are not only inexpensive, but also a potential source of mixed carotenoids. Among natural flower pigment source, Rose (*Rosa indica*), Marigold (*Tagetes*), China rose (*Hibiscus rosasinensis*), Palash (*Butea monosperma*), Jungle geranium (*Ixora coccinea*), Firecracker flower (*Crossandra infundibuliformis*) etc have great potential to be used as natural carotenoid source in ornamental aquaculture. Specific studies related to utilization of flower resources in the diet of ornamental fishes have been reviewed in this paper.

5. Properties of plant resources

5.1 *Growth promotion:* The waste from vegetables and fruit processing operation constitutes a large untapped source of energy and proteins. Extracts/ meal prepared from herbs, barks, leaves, peels and seeds of fruit and plant waste are reported to improve animal performance by stimulating action on digestive secretions (Caipang *et al.*, 2019) [31]. The plant products are residue-free and are generally considered safe to be used as ingredients or additives in the food industry and as ideal growth promoters in animal diets (Hashemi *et al*., 2008) [65]. Applicability of Phytogenics as larval diet of African catfish, *Clarias gariepinus* was assessed by feeding them with combination of lettuce and neem seed meal (1:1) resulted in comparable growth with their counterparts fed with live Artemia, indicating the possibility of using these non-edible part as feed additives (Enyidi & Nduh-Nduh, 2016) [44]. The addition of sweet potato, *Ipomoea batatas* peels (@ 15%) in the diets of tilapia (*Oreochromis niloticus*) resulted in better growth, feed utilization and improved biochemical response of the fish (Omoregie *et al*., 2009) [107] along with economic benefits in the form of reduced production cost. Incorporation of papaya leaf meal in diet of *Penaeus monodon* post larvae resulted in better protein digestion, feed conversion ratio, specific growth rate and weight gain. (Penaflorida, 1995) [109]. The fingerlings of *Cyprinus carpio* (common carp) showed improved growth performance fed with papaya leaf (@2.5%) mixed diet (Tewari *et al.*, 2018) [138]. Tewari *et al*., (2019) [139] reported the better growth performance of fingerlings of Common Carp by dietary inclusion of dried empty pea pods in powdered form @ 20%. Kaur *et al*., (2016) [18] conducted a study to assess the efficacy of sun-dried duckweed (*Lemna minor*) in the diet of carps *viz.* Rohu, *Labeo rohita* and common carp under semi-intensive culture system and resulted with improved growth performance of fish @10% dietary inclusion. Mavani and Vyas (2020) [95] proposed to provide fish feed fortified with *Lemna minor* meal @ 15% to fry of *Catla catla* for obtaining better growth, survival rate and improved cost benefit ratio. Srirangam (2016) [128] investigated the effect of partial replacement of fish meal with duck weed (*L. minor*), and soybean meal on the growth performance of *Ctenopharyngodon Idella* (Grass carp) and recorded that Duckweed meal can replace fishmeal up to 50% without affecting growth and nutrient utilization significantly. Ansal and Dhawan (2007) [17] and Ansal *et al*. (2008) [16] reported significantly higher weight gain in carps like *L. rohita* (20.60%), *Cirrhinus mrigala* (26.80%) and *Cyprinus carpio* (70%) fed with diets containing 20% sundried Spirodela and saved up to 50% on feed cost by 100% replacement of animal protein supplement in the traditional diets. Azolla is another potential aquatic macrophytes to be included in fish diets. The dietary Azolla supplementation showed positive effect on growth performance of fish and reduce the feeding cost. The aquatic fern Azolla has been successfully used in tilapia culture as feed ingredients (Fiogbe *et al*., 2004; Abou *et al*., 2007a; Abou *et al*., 2007b; Abou *et al*., 2010; Abou *et al*., 2012) [54,5-6] in reference to improved growth performance and survivability by providing Azolla partially or fully as a component in the fish feed (Mandal *et al*., 2010) [92] and reported with the improvement on growth performance, feed utilization and survival rate on Nile tilapia fry at the increased dietary inclusion of Azolla up to a certain level. Several studies have been focused on growth and survival of herbivorous fishes including Rohu fingerlings by providing Azolla species partially or fully as a component in the fish feed (Datta, 2011; Mandal *et al*., 2010) [40, 92]. Kumari *et al*., 2017 [84] reported better growth performance of fingerlings of *L. rohita* when fed with 200g / kg feed Azolla supplemented diet. Mosha (2018) [99] suggested the inclusion of Azolla @ 10-45% level in the diet for Tilapia species, while in Cyprinids; the inclusion level should be 10-50%. Jafar *et al*. (2018) [69] studied the effect of molasses-fermented water hyacinth feed on growth and body composition of common carp and reported it as an abundant alternative natural un-utilized resource for less expensive fish feed and higher fish yield to enhance farmer's income. Although medicinal plants or herbs used for immunostimulation to enhance the disease resistance in fishes, it also contributes towards growth promotion and gonadal development of fishes. Several studies have been conducted to assess the impact of these herbs like-ashwagandha, aloevera, ginger, garlic, turmeric, tulsi etc on growth, survival and flesh quality of fishes. Some of the recent studies have been reviewed in this article. Datta *et al*. (2020) [39] reported that Asian striped catfish *P. hypophthalmus* can be reared with dietary supplementation of ginger powder @ 1% to obtain enhanced growth, survival, FCR and SGR by altering the hematological parameters in pond cage system. Kaur and Ansal (2020) [48] investigated that Aloevera powder (AVP) supplementation improved fish survival and enhanced fish growth (net weight gain, specific growth rate and feed conversion ratio) and flesh quality significantly ($P \leq 0.05$) at inclusion levels of 1-3%. Kaur and Ansal (2020) [48] assessed the efficacy of garlic powder as feed additive in the diet of an Indian Major Carp, *L. rohita* fingerlings and reported with improved growth, flesh quality and fish production @2% supplementation along with higher income thereof. Farwah *et al*., 2017 [53] also observed significant results using garlic supplemented feed on growth and survival of common carp. Srivastava *et al*. (2019) [130] investigated the efficacy of Amla (*Phyllanthus emblica*) supplemented feeds, on survival, growth and flesh quality of *L. rohita* (Ham.) fingerlings and recommended that 3% AFP inclusion level as best in terms of growth enhancement and flesh quality improvement. Srivastava *et al.* (2020) [131] reported that supplementation of ashwagandha root powder can serve as a potential feed additive @ 2% in the grow-out feed of *L. rohita* for enhanced growth performance and improved flesh quality.

5.2 *Immuno-stimulation*: Being the fastest growing sector**,** aquaculture is shifting towards intensive culture practices where disease outbreak is considered as a potential constraint leading to decreased fish production with massive financial loss. Modulation of the immune response of the host as a means to combat infectious diseases has generated a great deal of interest among immunologists. Immunomodulation either stimulates or suppresses the various indicators of cellular, humoral, and non-specific defense mechanisms of the host (Bakuridze *et al*., 1993) [23]. Natural plant products have a great role in aquaculture as an immuno-stimulating agent with anti-stress and antimicrobial properties due to presence of principal active components, such as- phenolics, flavonoids, alkaloids, pigments, steroids etc (Chakraborty and Hancz, 2011) [32]. Thanikachalam *et al*., (2010) [140] showed that the inclusion of garlic peels in feed enhanced the hematological parameters of African catfish, *Clarias gariepinus* fingerlings even at low dosage and enabled the fish to be more resistant to infection with *Aeromonas hydrophila*. Similarly, some humoral and cellular immune

responses in common carp, *C. carpio* were up regulated following the addition of stem and root extracts from Chinese herbs *Astragalus sp*. (Yuan *et al*., 2008) [148].
The herbal immunostimulants *E. officinalis* (Amla), *Cynodon dactylon* and *Adathoda vasica* improved the immune system and reduced microbial infection in the goldfish *Carassius auratus* **(**Minomol, 2005) [97]. Dietary intake of Basel (Tulsi) *O. sanctum* positively influenced the immunostimulatory effects in *Oreochromis mossambicus* against *A. hydrophila* infection by enhancing antibody response and disease resistance (Logambal *et al*., 2000) [89]. Kaur *et al*. (2020) [39] investigated higher phagocytic activity in *C. carpio* fed with Neem leaf powder as compare to control revealing the efficacy of neem towards improved non-specific immunity of fish. Talpura and Ikhwanuddin (2013) [134] also reported that neem extract showed maximum antibody titre and phagocytic activity in Asian seabass, *Lates calcarifer* challenged with *Vibrio harveyi*. Abdel-Tawwab and Abbass (2016) [3] reported the role of turmeric powder as a promising immunostimulant in improving the growth performance of Common carp and innate immunity against *Aeromonas* at a level of 2.0 g/kg diet.

5.3 *Anti-microbial:* Bioactive substances present in plants are capable to fight against microbes like bacteria, fungi, parasite etc. This property can be availed by using the medicinal plants and herbs in the fish diet. Citarasu *et al*., 2006 [36] showed effects from including a combination of methanolic plant extracts in the diet of black tiger shrimp (*Penaeus monodon*) on survival and viral load during White Spot Syndrome Virus (WSSV) infection. The dietary administration of a synergistic blend of botanical extracts with antibacterial and anti-parasitic activities resulted in reduced incidence of monogenean gill parasites and improved disease resistance against two important bacterial pathogens (*Edwardsiella ictaluri* and *A. hydrophila*) in an experimental infection trial (Coutteau *et al*., 2011) [38]. Successfully controlled the pathogens, *Aspergillus flavus* by the ethanol & methanol extracts from Tulsi through *in vitro* Indian almond leaves, *T. catatppa*, extract can reduce the fungal infection in tilapia eggs (Chitmanat *et al*., 2005) [34].

5.4 *Color enhancement in ornamental fishes:* The beautiful and flamboyant coloration exhibited by ornamental fishes is basically due to the presence of carotenoid pigments and nutrition in their diet. Therefore, there is a direct relationship between dietary carotenoids and pigmentation in fish (Halten *et al*., 1997) [61]. Carotenoids refer to any group of non-nitrogenous and bio-chromes yellow, orange or red pigments that are almost universally distributed in living organisms. They are most conspicuous in the petals, pollen and fruit (e.g., carrots, tomatoes, sweet potatoes and citrus fruits) of the flowering plants. Plant based natural carotenoids are mainly derived from flowers, fruits, vegetables, algae, yeast, etc. (Chapman, 2000; Matsuno and Tsushima, 2001) [33, 94], which are potential source of mixed carotenoids as well as cost effective. Jha *et al.*, 2012 [73] incorporated inexpensive and readily available natural carotenoid sources i.e., marigold flower and beetroot meals into diets of Snow trout (*Schizothorax richardsonii*) to enhance pigmentation and ornamental value. Palaparthi *et al*. (2017) recorded the positive effect of three natural plant pigment sources (African tulip tree flower, red paprika, pomegranate peel @ 5% dietary inclusion) in the colour enhancement of goldfish, *C. auratus* with increased pigment concentration. Plant sources like Spirulina have been used as a source of carotenoid pigments for trout and koi (Choubert, 1979; Boonyaratpalin and phromkunthong, 1986; Alagappan *et al*., 2004) [35, 28, 12] while marigold petal was used for ornamental fishes like sword tail and barb (Boonyaratpalin and Lovell, 1977) [27]. Jain and Kaur (2016) [18] concluded that Rose petal meal can be supplemented in koi carp diet up to 3 % level both as colour enhancer and growth promoter. In another investigation China rose, *Hibiscus rosasinensis* petals with a dietary inclusion of 5 mg/kg feed yielded highest pigmentation and color enhancement in Gold fish along with accelerated gonadal development (Sinha and Asimi., 2007) [122]. The mixture of dietary tomato (*Solanum lycopersicum*) and carrot (*Daccus carota*) @ 50 mg/kg had enhanced the colour and carotenoid content of flesh in case of Guppy fish, *Poecilia reticullata* (Mirzaee *et al*., 2012) [98]. Dietary inclusion of beet root powder @15% had highest carotenoid deposition in the flesh resulted in enhanced coloration in Red sword tail, *Xiphophorus helleri* (Singh and Kumar, 2016) [121]. Jain *et al*. (2019) [70] investigated the efficacy of dietary supplementation of carrot meal in koi carp diet up to 5 % level both as color enhancer as well as growth promoter. Yanar and Tekelioglu (1999) [145] also suggested utilization of carrot as potential carotenoid source for colour development in gold fish, *C. auratus*. Ramamoorthy *et al*. (2010) [111] too showed enhanced growth and coloration of marine ornamental fish, *Amphiprion ocellaris* fed on four pigment sources (carrot, marigold meal, China rose petal, and rose petal) as compared to non-pigmented diet.

6. Surplus benefits of plant resources in aquaculture

In this article, studies pertaining to use of different plant resources have been reviewed highlighting their diverse uses in aquaculture such as growth promotion, appetite stimulation, improved reproductive performance, immuno-stimulation along with antimicrobial properties, enhanced pigmentation etc. These plant resources also offer several other benefits indirectly to pave the way towards sustainable aquaculture with pro-environmental and economically viable options.

6.1 Additional farmers income by reducing input cost

As conferred above, fish feed supplementation with varied plant resources may lead to a way for better co-ordination of fish farming with horticulture and establishing a sustainable relationship between agriculture and aquaculture. Integration of fruit and vegetable farming on the fish pond embankment has been tested in India, along with several advantages:

1. Being a viable alternative for doubling farmer income, this integrating farming option may help the farmers to get additional income and reduce input cost by growing fruits, vegetables, herbs, flowers on the pond embankment.
2. Leading to way of waste management and clean environment, the residues / non-edible part of growing plants may be used for fish feed supplementation.
3. The nutrient-rich pond mud may serve as fertilizer and pond water for irrigation for plants on dyke, thereby eliminating the cost of fertilizers to fulfill their nutrient requirements.
4. The plants on the embankment strengthen the dikes of aquaculture ponds and reduce the maintenance cost.

6.2 Bioremdiation of aquaculture ponds

Many surface floating aquatic plants like water hyacinth (*Eichhornia*) and duckweeds (*Spirodela, Lemna, Wolffia*) are well known for their phytoremediation qualities (Zhu *et al*., 1999; Raskin and Ensley, 2000) [148, 112]. Due to their ability to propagate rapidly by consuming dissolved nutrients from water, duckweeds act as an excellent "Nutrient Sink" for harvesting nutrients over a short period of time, as a "Nutrient Pump" (Ansal *et al*., 2010) [14] in waste water treatment absorbing various nutrients like nitrates, phosphates, calcium, sodium, potassium, magnesium, carbon, and chloride from the waste water. The problem of excessive nutrients, like- algal bloom, water quality deterioration may be resolved by culture of duckweed at one side of pond with scientific recommendations, as they absorb excess nutrients for their growth and further being used as feed in dried / fresh form in different aquaculture systems.

6.3 Fertilization of aquaculture ponds

The compost prepared from aquatic weeds, like– Azolla, Eichhornia etc may be used for fish pond fertilization to reduce the cost of manures/ fertilizers needed for natural food (plankton) production. Water hyacinth compost forms an abundant alternative natural unutilized resource for less expensive manure to improve pond productivity (Kumari and Pandey, 2018) [85]. Tavares and Braga (2007) [135] studied the feeding activity of larvae of *Colossoma macropomum* (tambaqui) in fish ponds manured with water hyacinth and reported with higher plankton abundance during the entire production period. Sahu *et al*. (2002) [116] recorded the improved growth and survival of larvae of *L. rohita* reared in nursery ponds fertilized with water hyacinth compost @ 8000 kg/ha. Kumari and Pandey (2018) [85] signified the utilization of water hyacinth compost as manure for rearing of *L. rohita* fry without supplementary feeding. Efficacy of Azolla compost (AC), as bio-fertilizer in carp culture, was evaluated by Ansal *et al*. (2016) [18] and concluded that AC can be used as a potential biofertilizer, either alone or in combination with cowdung (CD+AC, 1: 3) for higher fish growth and productivity in carp culture.

7. Conclusion

With the expansions of aquaculture practices, there is an exigent need to find out alternative fish feed resources without driving up the operational cost. In reference to this, the use of non-conventional plant resources in the aqua feed will be of great significance. The agro waste like peels, leaves, rotten fruits and vegetables, aquatic macrophytes, duckweeds, herbs, flowers etc may be incorporated in fish diet as additional component or by partially replacing the traditional sources of protein / carbohydrate with remarkable acceptability and palatability. Various studies suggested that supplementation of these plant resources in aqua feed not only improves the nutrient content but also leads to waste utilization and reduced feed cost in advanced aquaculture systems along with enhanced fish growth, flesh quality and immune response. Besides, these plant resources propose several other advantages like- fertilization of fish pond, bioremediation etc along with improved farmer's income through integrated farming. Ultimately, the use of plant resources in fish farming is a viable alternative to achieve the target of augmented fish production with an eco-friendly, cost-effective and sustainable approach which is the absolute necessity of aquaculture industry.

Table 2: Different plants / parts of plants used in fish feed

Plant	Part to be used	Form	% Inclusion in feed	Importance	Reference
Protein Source					
Mulberry (*Morus alba*, Linn.)	Leaves	Meal	100 %	Enhanced feed efficiency and GSI	Bag *et al*., 2012 [20]
Duckweed	Plant	Powder	10-25 %	Growth enhancement	Aslam and Zuberi, 2017 [19]
Azolla	Plant	Powder	10-40 %	Enhanced growth, feed utilization and carcass composition	Mosha, 2018 [99]
Cowpea (*Vigna unguiculata*)	Seed	Powder	20-30 %	Enhanced growth performance and survival	Olvera-Novoa *et al*., 1997 [106]
Spirulina (*Spirulina platensis*)	Algae	Powder	40 %	Enhanced growth performance	Olvera-Novoa *et al*., 1998 [105]
Carbohydrate/ Energy Source					
Banana (*Musa paradisiaca*)	Peels	Powder	5 %	Enhanced growth and immunity	Sreeja *et al*., 2013; [127] Giri *et al*., 2016 [57]
Beet root (*Beta vulgaris*)	Fruit	Powder	10 %	Growth and color enhancement	Jha *et al*., 2012 [73]
Guava (*Psidium guajava*)	Leaves	Extract	2 %	Enhanced growth	Abdelhamid *et al*., 2012 [2]
Moringa (*Moringa oleifera*)	Leaves	Extract	2 %	Enhanced growth	Suleiman *et al*., 2018 [132]
Papaya (*Carica papaya*)	Leaves	Extract	20 %	Enhanced growth and nutrient utilization	Olaniyi and Salau, 2013; [104] Muralidhar *et al*., 2017 [100]
	Seed	Powder	6 g/Kg feed	Enhanced growth performance, survival and feed utilization	Towers, 2014 [141]
	Unripe fruit / leaves	Paste / powder		Enhanced growth and feed utilization	Tewari and Ram, 2012; [139] Tewari *et al*., 2018 [138]
Pointed gourd (*Trichosanthes dioica*)	Fruit	Paste	5, 10 & 15 %	Enhanced serum parameters	Kaur *et al*., 2016; [18] Kaur *et al*., 2017c [76]
Coriandrum sativum				Enhanced immunity and protection against *Aeromonas hydrophila*	Innocent *et al*., 2011
Garden Pea pod *Pisum sativum*	Empty pod	Powder	20 %	Improved growth performance	Tewari *et al*., 2019 [137]
Sweet Potato *Ipomea batatas*	Peel	Powder	15 %	Improved growth	Omoregie *et al*., 2009; [107] Faramarzi *et al*., 2012 [52]

Potato	Peel	Powder	10 %	Improved weight gain and FCR	El-Nadi *et al.*, 2017 [43]
Immunostimulant					
Garlic *Allium sativum*	Fruit	Powder	20 g/Kg fish feed	Enhanced growth, feed utilization and immunity	Nya and Austin, 2009 [103] Adineh *et al.*, 2020 [109]
Ashwagandha *Withania somnifera*	Roots	Powder	20 g/Kg fish feed	Enhanced growth and protection against bacteria	Sharma *et al.*, 2017 [117]
Giloy *Tinospora cordifolia*	Leaves	Powder	1%	Enhanced specific growth rate and feed conversion ratio	Upreti and Chauhan, 2018 [142]
Aloe vera	Leaves	Gel & Extract	1% & 2%	Improve growth, feed utilization, blood parameters and immunity	Khan *et al.*, 2018 [83]
Amla *Phyllanthus emblica*	Fruit	Powder	3%	Growth enhancement and flesh quality improvement	Srivastava *et al.*, 2019 [130]
Phyllanthus niruri	Leaves	Extract	20 mg/Kg	Activate the immune system	Muthlakshmi *et al.*, 2016
Guava *Psidium guajava*	Leaves	Extract	10 mg/g	Reduced mortality against *A. hydrophila*	Gobi *et al.*, 2016 [58]
Astragalus membranaceus	Root & Stem	Powder	0.5 and 1 %	Enhanced immunity	Yuan *et al.*, 2007 [146]
Neem *Azadirachta indica*	Leaf	Extract	1 g/Kg	Enhanced survival and immuno-stimulatory effects	Kaur *et al.*, 2019 [71] Kaur *et al.*, 2017d [82]
Turmeric *Curcuma longa*	Root	Powder	0.5 %	Enhanced growth and resistance against *Pseudomonas fluorescens*	Mahmoud *et al.*, 2014 [90]
Tulsi *Ocimum sanctum*	Leaf	Extract	0.2 %	Enhance immune response & disease resistance against *Aeromonas hydrophila*	Das *et al.*, 2015
			3 %	Increased storage life of Tuna chunks under chilling condition	Suyani *et al.*, 2020 [133]
		Powder	2 %	Improved growth & survival	Sikotariya and Yusufzai, 2019 [119]
Moringa oleifera	Leaf	Powder	15 %	Enhanced growth and improve skin mucus immunity	Bisht *et al.*, 2020 [26]
Color Enhancement					
Carrot *Daucus carota*	Waste	Powdered meal	5 %	Enhanced growth and pigmentation	Jain *et al.*, 2019b [71]
Spirulina platensis and *Haematococcus pluvialis*	Algae	Powder	1.5- 2 % and 1 % resp	Color enhancement	Ako *et al.*, 1997 [11]
Marigold *Tagestes erecta* and Ixora *Ixora coccinea*	Flower	Powder	5 %	Color enhancement	Golandaj *et al.*, 2015 [59]
Hibiscus rosa siensis	Flower	Powder	10 %	Promote pigmentation	Bagre *et al.*, 2011 [21]
Amaranth *Amanranthus spp*. and Mint *Mentha spp.*	Leaves	Powder	1 %	Enhanced growth and body coloration	Ahilan *et al.*, 2008 [10]

Carbohydrate/ Energy Source


Banana Peels


Guava Leaves


Pointed Gourd


Spirulina Powder


Mulberry Leaves


Cow Pea


Papaya Seed


Papaya Leaves


Empty Pea Pods

		
Sweet Potato Peels	Potato Peels	Vegetable- Fruit Waste
		
Lemna	Spirodela	Azolla

IMMUNOSTIMULANTS

		
Garlic	Ashwagandha Roots	Aloe Vera
		
Giloy	Amla	Neem
		
Turmeric	Tulsi	Onion

CAROTENOID SOURCE

		
Carrot Waste	Marigold Flower	Amaranth

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