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Research Article

Evaluating the influences of fishmeal replacement on growth, immune and nutritional performance in aquaculture

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Abstract

Aquaculture serves as an auspicious protein source for the human consumption. To cultivate aquatic organism proficiently, the prepared feed should have eminence protein constituents. Feed for aquatic animals contain raw fish as a main product e.g fish oil and fishmeal that gained from the whole fish and its remains. The fish silage is feasible for using in feed after their bioconversion or transformation. Feed for aquatic animals includes raw fish as a primary ingredient, such as fish oil and fishmeal obtained from whole fish and their by-products. Fish silage can be used in feed after undergoing bioconversion or processing. This impending ingredient is the main cost effective component of the whole feed of fish. In this review we discuss the alternative protein sources in the fish feed based on plant or animal, that can reduce the budget and improved the fish efficacy, effective for the sustainability of aquaculture for low to high scale farming. Production of aquaculture inflates worldwide to meet the demand of world for protein (fish, seafood etc.). Hence, investigation on low cost substitute protein sources of fishmeal was prolific, provide good information that could be helpful for the small fish farmers.

Keywords: Fishmeal, Morinaga, Nutritional Profile, Rapeseed, Palm Date.

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Introduction

Now aquaculture is well-recognized source of animal protein for the consumption of human. In 2013 production of aquaculture has exceed from the production of beef. [1], in 2018 provided fish for the consumption of human were more than 50% [2]. In the last decades, the evolution and formation of aquaculture cannot be dissociated with the improvements in fish nutrition [3]. Protein is the costly nutrient in the diet of fish, and insertion level approximately ranges from 30 to 50%. For years, the main protein source in fish diet is fishmeal, due to its balanced amino acid profile and high content of protein. For the consumption of human, aquaculture and fishery by-products are produced from the processing of fish from industrial scale. Protein is the most expensive nutrient in fish diets, with inclusion levels typically ranging from 30%

to 50%. For many years, fishmeal has been the main protein source in fish diets because of its balanced amino acid profile and high protein content [4]. Aquaculture and fishery by-products are generated during the industrial-scale processing of fish for human consumption. After dispensation, between 50-70% the remaining products are considered as indigestible and classically consist of appurtenances (i.e., heads, skin, viscera, blood, and bones). Presently, 20% universal production of fishmeal is produce from the by-products of fishery. Nearly 10% of the fishmeal production is brought for the use of by-products of aquaculture [5].

Nutritional composition

Contents of nutrients present in fishmeal depend on type of manufacturing process and raw material used in its production. As a whole, produce good quality of fish meal by using complete fish Contents of nutrients present in fishmeal depend on type of manufacturing process and raw material used in its production. As a whole, produce good quality of fish meal by using complete fish that have <12% ash, 66-74% protein and lipids 6-11% [6]. In contrast, byproduct produced from fishmeal contains approximately 7%–14% crude lipids, 12%–23% ash and 52%–67% crude protein e.g, white fishmeal formed from byproducts comprises 21%–23% ash, 60%–67% crude protein and 7%–11% lipids. In tuna FM produced from spinoffs covers nearly 57%–60% crude protein, 12%–21% ash and fat 8%–14% [7].

The production of fish oil and fishmeal on the industrial scale contain substantial investment cost [8] although protracted efficiency of economy contain a constant supply of large amount of raw material. Following factors are significantly challenge for byproducts and also it can be unjustifiable for economic condition, when only small amount of raw material production taken from remote areas fish-processing plants [9]. Acceptable, to completely comprehend the benefits of using byproducts, get along a strategy is vital to guarantee the occurrence of suitable capability substructures, the accomplishment of financial prudence of scale, and the obtainability of effectual transportation systems. To fully understand the benefits of using by-products, it is essential to develop a strategy as mentioned in (Table 1) that ensures the availability of appropriate infrastructure, achieves economic efficiency at scale, and provides effective transportation systems.

Table 1: Inclusion and substitute of fishmeal.

Fig	Protein ingredient	Inclusion level	Animal model	Trail duration	Ref
1	Soybean	±20%	Atlantic salmon Rainbow trout	50 days	[11, 12]
2	Bioprocessed soybean	30%	Rainbow trout	125 days	[13]
3	Chlorella + soybean	20%	Atlantic salmon	80-100 days	[14, 15]
4	Chlorella	50%	Crucian carp	34 days	[16]
5	Probiotics + Soybean	20%	Atlantic salmon	70 days	[12]
6	Moringa	10%	Rohu fingerlings	30 days	[17]
7	Water spinach	25%	Tilapia	53 days	[18]
8	Mulberry	30%	Tilapia	35 days	[19]
9	Peanut meal	15%	Shrimp	30 days	[20]
10	Lupin meal	51%	Tilapia	56 days	[21]
11	Cyanobacteria	20%	European seabass	93 days	[22]
12	Rapeseed meal, Fermented	23-34%	Red seabream	56 days	[23]
13	Azolla	20%	Tilapia	20 days	[24]
14	Poultry by byproduct	24%	Japanese seabass	62 days	[25]
15	Silkworm pupae	30%	Catla, Rohu	50 days	[26]

These three factors presently aid as restraints on the consumption of aquaculture byproducts in some regions [10].

Fish meal replacement with soybean

Approximately 70% of the overall effective expenditures can be attributed to the price of feed, chiefly due to the substantial cost linked with proteins, which serve as essential dietary component in intensive or semi-intensive operations for grow-out farming. In the chase of successful aquaculture, a crucial aim is to gain finest growth by lowering the investment costs. Approximately 70% of total operational expenses are attributed to feed costs, mainly due to the high price of protein, which is an essential dietary component in intensive or semi-intensive grow-out farming systems [27 - 28]. In successful aquaculture, a key objective is to achieve optimal growth while reducing investment costs.

Fish meal, which is comparatively expensive, is often regarded as a chief protein source in aqua-feed production because of its valuable micronutrients, consistent amino acid profile, and good digestible energy [29]. The raised up cost and unpredictable availability of fish meal have stimulated the examination of cost-effective and readily accessible plant-based feed ingredients like rapeseed meal, sorghum, soybean, guar, and moong beans etc. [15, 30]. Among the various plant protein sources, soybean meal (SBM) stands out for its exceptional attributes, including high protein content, a stable amino acid profile, dependable availability, and cost-effectiveness. Among various plant protein sources, soybean meal (SBM) stands out due to its high protein content, well-balanced amino acid profile, reliable availability, and cost-effectiveness [31 - 32].

Various studies have examined replacing fish meal (FM) with soybean meal (SBM) in the diets of different fish species, emphasizing that SBM is globally recognized as a highly protein-rich source [33 - 34]. However, the effects of fish meal (FM) protein substitution with soybean meal (SBM) on physiological status and fish growth vary by species and feeding mechanism [35]. As compared to carnivorous fish species, omnivorous and herbivorous fish utilize soybean meal (SBM) more efficiently. Furthermore, the full or half substitution of fish meal (FM) with soybean meal does not have ill effects on the physiology and growth of numerous omnivorous and herbivorous fish species [36]. Replacing fish meal by 75% with soybean meal (SBM) had no physiological effect on tilapia (*O. niloticus*) [32].

increasing the extent of substitution of FM (fish meal) protein with SBM (soybean meal) led to alower value of white blood cells (WBC), red blood cells (RBC) and hemoglobin (Hb) in beluga [37]. Improving the dietary value of protein from plant-based sources, such as by-products of soybeans, and decreasing the occurrence of ANFs (anti-nutritional factors) can be accomplished through the process of fermentation [38 - 41]. Some studies showed that for replacing fish meal in aquaculture [42 - 44] and in feed of other animal [45] fermented soybean meal were used. Soybean (SBM) a plant based protein ingredient with minimum level of anti-nutritional factors (ANFs) like trypsin inhibitor, while being rich in crucial nutritional constituents, including elevated concentrations of free amino acids, high protein content, and small peptide sizes [38].

Feed expenditure represents the significant part of the overall cost in bearable farming of fishes, including the carps and African catfish etc. The price of feed is of supreme importance because typically it constitutes 30-70% of the total working expenses and has a substantial effect on the investment

productivity in aquaculture [46 - 47]. Use of soybean extract, as mentioned in (Table 2) the extensive convenience and cost-effectiveness of plant-based proteins, making them the most useful substitute [48].

Replacement of fish meal with palm date

In the past few decades, development in nutritional research in the aquaculture field have considerably enhanced, which provide identification of alternative resources for aquaculture feeds. [58]. At present, production of aquatic feed mainly relies on fish oil and fishmeal take out from wild-caught fish silage. Though, greater the use of fish silage is unmanageable, because of given project needs a supplementary 37.4 million tons of aquatic feed by 2025 [59]. Accordingly, certain specialists of fish nutrition have tried to formulate feed which will be cost-effective for aquaculture and also stimulate the growth of farmed fish. Global, producers of feed have started efforts on research targeted at substituting fish oil and fishmeal from feed of aquaculture [60, 61, 48, 41]. *Phoenix dactylifera*, mentioned as date palm or date, a flowering plant species belonging to the *Arecaceae* family. It is primarily grown for its appetizing, sweet fruits and their associated seeds [62]. There are about 3000 different kinds of dates everywhere in the world, and among the cultivated fruit trees 'palm tree' is the first place in the world and it is considered one of the most classic fruits of the ancient world likewise; the figs and olives [63].

Cultivation of date

In the withered areas of Middle East, North Africa and Arabian Peninsula, palm date is one of the most important crops of fruit. Over the past 3 centuries, dates have been introduced to new production areas in India, South Africa, Australia, Pakistan, the United States, Mexico and South America [64]. Some of the researchers used new palm seed and kernels as energy and protein source in diet of fish to increase efficiency of feed utilization [65].

Table 2: Digestibility coefficients of various soybean products [6].

Digestibility Coefficients of Various Soybean Products for Selected Freshwater, Omnivorous Fish Species			
Feedstuff	**Fish specie**	**Digestibility Coefficient Protein**	**Reference**
Soybean meal, solvent-extracted, without hulls	Channel catfish Silver perch[5]	97[8], 93, 85[9] 95[5]	1. [49] 2. [50] 3. [51] 4. [52] 5. [53] 6. [54] 7. [55] 8. [56] 9. [57]
(SBM) Soybean meal, solvent-extracted, with hulls	Blue tilapia[2] Channel catfish[1] Nile tilapia[3] Common carp[4] Hybrid tilapia[4]	94[2] 77[1] 91[3] 92[5], 70[6], 95[7] 95[4]	
Soybean meal, dehulled, full-fat	Silver perch[5]	92[5]	

Nutritional composition

Some studies examined that pharmacological characteristics of dates might be characterized by their compositional component concentration including potassium, manganese, copper, magnesium, phosphorus, calcium and iron [66 - 68]. In (Figure 1), it is mentioned that palm date meal can be shaped from the byproduct of date fruit and seed of date can be collected from the harvesting, conditioning, storage and processing of date production [69]. Waste of date comes in different forms including seed, flesh and mixture of both [70 - 71]. Date fruits have decent foundation of sugar content around 70–80 % that also depend on the maturity stage of fruit specie, like glucose, sucrose and fructose which are absorbed easily by the body and provide efficient source of energy [9]. Typically the protein content ought to be logged 1.22–3.30%, ash 1.43–6.20%, carbohydrates 65.7–88.02%, and fat 0.11–7.33% [72 - 73].

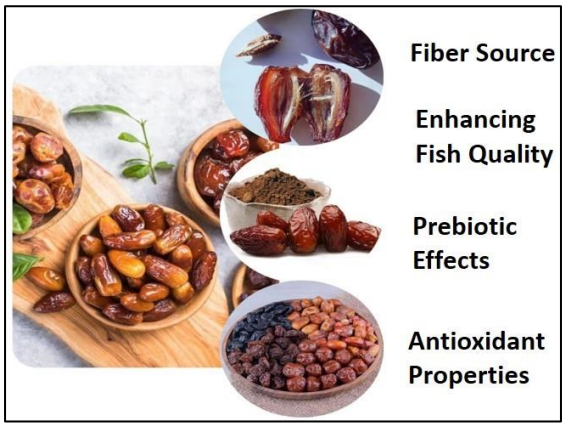


Figure 1: Nutrition profile and role of date in fish.

Another study reported that the content of protein decreases throughout the non-enzymatic tanning and browning stage of precipitation. Date fruit comprise non-essential and essential amino acids, mainly lysine, serine, glutamic acid, proline, alanine, glycine and aspartic acid. But the content of fatty acid is (0.2 - 0.5) and also the content of vitamin was low [74 - 75]. The amount of Vitamin B complex is high in palm date [76]. The content of dietary fiber in date fruit is recorded: soluble fiber 6-16% and insoluble fiber 84-94% [77]. A meal of palm date is considered a good source of phytochemicals, including sterols, carotenoids and phenols. Seed of date comprise good amount of dietary minerals such as cooper, magnesium, potassium, cadmium, calcium, zinc, iron, manganese, lead, phosphorous, cobalt, and nikal [78, 79, 75, 3].

Study reported that palm date meal were also utilized in fish feed as an alternative to carbohydrate. Formulated Diet having palm date meal given to juveniles of catfish and their results show enhance feed utilization and growth rate. Studies have reported that palm date meal can be used in fish feed as an alternative carbohydrate source. Formulated diets containing palm date meal given to catfish juveniles showed improved feed utilization and growth rate [65].

During fermentation process of palm date meal, increase of amino acid composition due to the breakdown of protein and converted into soluble form that can digest easily by fish [80]. application of fermented palm date meal using Aspergillus oryzae at 103.3 - 164.7 g/kg diet can enhance the digestive activity, immune response and growth rate of *Oreochromis niloticus* (tilapia) [81].

The effect of a palm diet meal on Pacific white shrimp as a substitute for carbohydrate. The study demonstrated that the diet showed a good effect on the performance of the species. For production of fish, growth rate is the main factor to be seen [82]. Different studies demonstrated the possibility of application of palm meal diet as a substitute to fish meal for aquatic animal diet including African catfish [65],white shrimp of pacific region and common carp [14, 82-86].Using formulated feed having 200g/kg PDM decreased the growth of *Oreochromis niloticus.* PDM

(palm date meal) have high ANF and fiber content that cause negative effect on growth and efficacy of feed [81]. High levels of DSM (date seed meal) in the diet can decrease weight by increasing energy expenditure and metabolic energy rate, which also decreases digestibility due to its ANF content, including catechin, tannin, caffeine and monomers. DSM (date seed meal) have been discovered to put their effect upon the blend edge, where they interact with digestive enzymes that leads to reduce weight gain and feed utilization. [65, 86]. where they interact with digestive enzymes, leading to reduced weight gain and feed utilization

In one study, fermented DSM (date seed meal) was suggested, and date seed meal was indicated to be a low-cost ingredient that should be used in the aquaculture industry. Another study indicated that using PDM in the diet of common carp can increase growth performance [83]. Fish feed formulated with palm date meal shows higher arginine levels (4.3-4.6%), which are important for increasing intestinal enzyme activity and changing the composition and activity of the fish gut microbiota [58].

Besides arginine, palm date meal produces a good quantity of glutamic acid; its offshoots, glutamate and glutamine, play an important role in moderating the structure of the intestine and also provide protection from oxidative harm [58, 87]. Application of palm date meal in fish diet can enhance the hematological parameters as compare to the control group treatment of *Oreochromis niloticus*[57, 86]. Fermented date seed meal enhanced the blood quality and immunity. He also described that the valuerys of earthrocytes increased (i.e. RBC, Hb, MCV, PCV, MCHC, and MCH) by using 0.5% palm date seed in fish feed. Fermented date seed meal improved blood quality and immunity. It was reported that using 0.5% palm date seed in fish feed increased erythrocyte values (RBC, Hb, MCV, PCV, MCHC, and MCH) . The mucosal immune markers like lysozyme, immunoglobulin, ALP and protease can enhance fry of common carp when fed with date palm fruit extract [84].

Replacement of fish meal with Moringa

Moringa oleifera is one of the most important emerging protein sources that can used in diets of aquaculture [88]. Chiefly it is an important plant that can be widely cultivated, and belongs to the genus Moringa, this genus of family *Moringaceae* comprising leaves which have high protein content Primarily, it is an important plant that can be widely cultivated and belongs to the genus Moringa of the family *Moringaceae*, with leaves that are high in protein content (251 g/kg DM) but low anti nutritional compound and tannins content [89].

In Table 3, the nutritional profile of leaves of Moringa shows that they are a rich source of protein; their amount varies from 25% to 35% [90]. Because of a high level of soluble nitrogen (82-91%), a high level of protein is available for good digestion, due to a higher level of soluble nitrogen, pepsin and a low amount of insoluble protein acid detergent (1-2%) [91].

Table 3: Nutritional profile of *Moringal olefera*.

Nutrients	Dry leaf powder	Dry leaves	Fresh leaves	Ref
Protein (g)	27.1	29.4	6.7	92
Fiber (g)	19.2	12.5	0.9	
Fats (g)	2.3	5.2	1.7	
Carbohydrates (g)	38.2	41.2	12.5	

The protein contain good amount of sulphur containing AA (amino acid) that associate

well with soybean, which can be considered as a good quality plant based protein [93]. Moringa leaves are important source of minerals, iron, ascorbic acid and carotenoids. Past studies on moringa oleifera concluded that it is a vital source of protein in the diet of fish [94]. Moringa leaves are the rich source of nutrient components including crude fat, gross energy and crude protein [95]. Moringa is a significant source of soluble protein and high pepsin consider as an alternative source of fish meal used in aquaculture [96].

Moringa olefera leaf meal

Leaves of moringa were attained and soaked all night in the tank for removing anti-nutritional factors and saponins. Moringa leaves were collected and soaked overnight in a tank to remove anti-nutritional factors and saponins. Then the dried leaves were grinded to form powder and then stored in plastic zipper bags in the room temperature [97]. Moringa leaves are widely studied as a substitute for fish meal in the diet of fish, and it seems to be an important ingredient of protein sources. Moringa leaf could be partially replaced as a predictable source of feed that don't cause any decline in the growth rate of tilapia Moringa leaves have been widely studied as a substitute for fishmeal in fish diets and appear to be an important protein source. They can partially replace fishmeal as a reliable feed ingredient without causing any decline in the growth rate of tilapia (*O. niloticus*) [98 - 99]. Moringa olifera leaf meal (MOLM) can be replaced at 0, 10, 20, 30%. They concluded that fish digestibility is high at 10% replacement of fish meal for fingerlings of *Labeo rohita* [17].

Fish meal with chlorella

A new single-celled plant-based protein microalgae has now received substantial attention in the aquafeed industry because of its high protein, polyunsaturated fatty acids (PUFAs), polysaccharides, microelements and vitamins [100 - 101]. Chlorella is a widely distributed single-celled microalga that can be easily cultured outside the pond and is an important source of protein [7]. Due use of chlorella as a dietary source of protein and have rich nutritional value, it is considered as helpful ingredient for improving carcass quality and weight of marine and fresh water fish [40, 102].

In one study, 50% of fish meal was replaced with chlorella meal; this supplementation improved feed utilization and growth rate in crucian carp [16]. Other studies report that heavy use of plant-based substitutes for fish meal can reduce crucian carp growth [103]. Replacing 100% fish meal with chlorella meal can enhance growth rate and feed utilization in crucian carp. Crucian carp have no stomach. In the intestine, digestion takes place, in which different enzymes of the intestine are involved, including pepsin, trypsin, lipase and amylase [51]. The use of chlorella meal as a substitution for fish meal can increase the activity of amylase but did not see any enhancement in the activity of lipase and trypsin in crucian carp's intestine. Fishmeal in fish diets appears to be an important protein source. They can partially replace fishmeal as a reliable feed ingredient without causing any decline in the g rowth rate of tilapia [102].

Replacement of fishmeal with Azolla

Industry of aquafeed is predominantly relies on fish meal because of its good protein, high nutrient digestibility and efficient amino acid profile in the formulation of feed [24]. Currently, the supply of fishmeal decrease in the market because of the decreasing of natural resources of fishery. So it is an important need to used alternate source of non-predictable aquatic plant sources of protein that can decrease the cost of feed. Therefore, it is important to use alternative, reliable aquatic plant protein sources that

can reduce feed costs.

In this context Azolla microphylla meal can be used as an efficient substitute due to its greater nutritive value and productivity, which can include 13-30% (dry weight basis) of crude protein, vitamins, minerals and essential amino acids profile. These nutrients can improve growth performance, metabolic rate, immune function and digestive system. [104 - 107].

Addition of nearly 20% Azolla enhances the growth of Tilapia (*Oreochromis niloticus)* [24]. Increasing the inclusion of Azolla in the fish diet can decrease the growth performance[103]. Poor performance was attributed to higher azolla concentrations, which can reduce protein digestibility in *Oreochromis niloticus* [109]. Replacing fish meal with 25% alternative source Azolla meal in the diet of Tilapia can be cost effective [19]. use 20% Azolla meal in the *Orechromis niloticus* diet showed rate effective [110].

Importance of Azolla

Azolla efficiently contain protein, growth-supporting mediators and minerals like magnesium, copper, phosphorus, potassium, calcium and ferrous, etc vitamins (vitamin A, vitamin B12, beta-carotene) and essential amino acids. Azolla contain 7-10% a mixture of amino acid, bio-polymers and bio-active substances, 10-15% minerals and 25-35% protein [111].

The free-floating aquatic fern, Azolla cristata, is considered a super plant due to its high efficiency, which may be the reason for its large attention for use as a dietary source of nitrogen for herbivorous fish when used as a nitrogen fertilizer [112]. The protein content of Azolla is consider nearly 20-30% and it is found as optimum for good growth of fish [112, 24).

In addition with good source of protein, it is also rich in minerals, several probiotics, vitamins and biopolymers [113]. It is reported that Azolla is used in feed of carps that can convert the raw plant into eatable form of animal protein [114 - 115]. It is reported that processed Azolla and dried feeding enhance the feed utilization and growth rate in common carps, mrigal, Nile tilapia, rohu and Mozambique tilapia [104].

Sheeno and Sahu [116] determined that utilization of protein of rohu fry was reduced after feeding a diet having good enclosure level of Azolla. Furthermore, it is reported by some workers that azolla meal should be consider as qualitively substitute of fishmeal in the feed of fish that are cultured significantly such as 45% in *Cirrhinus mrigala* fry [117], 10%–20% fishmeal can be substituted in the feed of Genetically improved form of tilapia (GIFT) [24] and 20% in *O. niloticus* [118].

Azolla named as aquatic fern booming at a good rates in the bodies of freshwater, uncertainly protein amount is 19-31% relay on the growing media, strain and source [119]. Our research results explore in-sufficiency by replacing the FM (fish meal) 100% with Azolla (water fern) in the diet of *C. carpio var. communis* fingerlings. Our findings are consistent with the results that increase the level of aquatic plants ingredients can decrease the growth rate of fish [19, 120]

It is concluded that using higher level of azolla increase the level of energy expenditure and metabolic rate which can decrease the weight gain, and also digestibility due to its ANF content [83, 24, 86]. Water fern (azolla) can be used as an alternate source of fishmeal in herbivorous fish species due to its paired profile of digestive enzymes and the existence of ω-6 fatty acids from feed of Azolla. Fish feed containing Azolla as a supplemented diet can increased the utilization of glycogenic amino acids, protein conversion and mobilization. More or additional

supplementation of Azolla can decreased the protein digestibility due high fiber content, reduce conversion efficiency and growth of fish [121].

O. mozambicuss and *O. niloticus* showed better growth rate when using 20-42% of dietary Azolla [108]. Report suggested as mentioned in (Table 4), the level of Azolla inclusion in the diet of species belonging to Caprinidae family can enhanced utilization of feed and growth performance in feed of rohu 10%–50% Azolla meal. [114, 107, 61] while Orange fin labeo [104], Catla [122], silver carp and mrigal [61] and grass carp [123] reported 10-25% enclosure level in their diet [124].

Table: 4 %age of Azola use in different feed of various fish species.

Fig	Azolla %	Species	Ref
1	20%	*O. niloticus*	[24]
2	25%	*O. niloticus*	[125]
3	20%	*O. niloticus*	[110]
4	45%	*Cirrhinus mrigal*	[69]
5	10-20%	GIFT Tilapia	[24]
6	20%	*O. niloticus*	[36]
7	20-42%	*O. mozumibiques*	[108]
8	10-50%	*Labeo rohita*	[107]
9	10-25%	*Catla catla*	[122]
10	10-25%	Silver	[61]
11	10-25%	Grass carp	[123]

Replacement of fish meal with rapeseed

In 2016, aquaculture sector approximately consumed 69% of worldwide production of fishmeal [2]. Different articles emphasized that, replace fish meal with their substitute source of protein to confirm its cost effectiveness and sustainability in the sector of aquaculture production [126, 59, 128 - 129].

These chosen qualities remain unaffected till today various plant based source of protein have been examined as replacement of fishmeal in various species of fish due their universal availability and less in cost over past decades. The substitute that are used as a plant based protein source is pea, [130], wheat [131], corn, [132] rapeseed, [10, 133], lupine, [134, 132] soy, [135] sunflower, [136] and others.

By-product of oil-industry, rapeseed a plant based source of protein is considered as capable protein for feed formed in aquaculture [137, 138]. Rapeseed meal is the repercussion in the industry of oil that is one of the imported exported protein after soybean meal [139]. Factor of anti-nutritive content in rapeseed cake meal and insufficiency of some amino acids e.g lysine which can reduced the growth and health of fish when add in aqua feed [140]. Over the last decades various techniques of processing were applied, devoted to decrease in the content of anti-nutritive factors in rapeseed protein product and to raise the protein content [141]. Anti-nutrient and nutrient configuration of rapeseed seeds vary, strain and origin dependent. 17-18% weight of seed is consider as hull [142] and nitrogen present nearly 90% as napin and cruciferin two important storage protein in rapeseed [143].

Yellow-seeded rapeseed lines are linked with lower tannin and fibre content, along with level of protein increased. Variety in the composition of seed and different method of processing lead to enormous alteration in protein of rapeseed. [144]. Figure 2 clearly shows that the availability of nutrients increases from the fermentation of rapeseed meal [23, 47, 145], besides enhancing the crude protein and amino acid content, whereas it decreases the content of tannin and phytate in rapeseed meal [145 - 146].

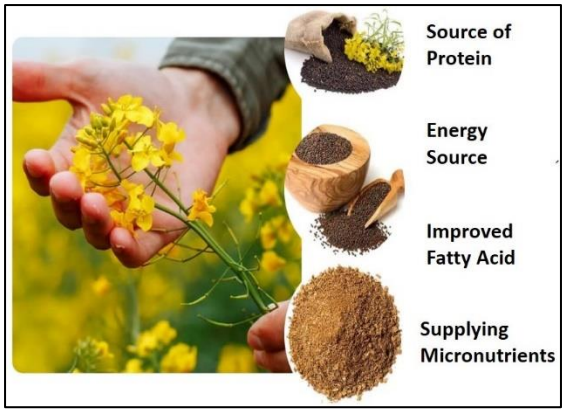


Figure 2: Nutritional effects of rapeseed in fish.

Products of processed rapeseed protein as shown in (Table 5) give immense difference in the digestibility with the same fish species. On the other hand the digestibility difference is due to using of various method and direct evaluations between studies had been evaded in the subsequent section. Variation in the energy digestibility and in protein had been linked with occurrence of anti-nutritive factors e.g proteinase inhibitors, phenolic compounds and phytic acid, along with indigestible carbohydrates [10, 140, 147 - 151].

Table 5: Rapeseed inclusion in different forms [144].

Rapeseed						
Processing of cake and meal						
Protein extraction [3, 4, 6]		**Filtration** [2, 3, 4]			**Precipitation** [1, 5]	
Advantages						
Amplified amount of protein Removed soluble sugars oligosaccharides glucosinolates, and phenolics		Highly raised content of protein, In extraction solution reduced salt content, reduced anti-nutritive factor			Highest increase of protein content	
Protein content						
Rapeseed seed		**Rapeseed cake**	**Rapeseed meal**	**Rapeseed concentrate**	**Rapeseed isolate**	**Ref**
17.5-24.6		29.4-38.4	30.0-60.6	48.3-80.6	81.2-98.7	
Amino Acid Composition %						1. [10] 2. [18] 3. [133] 4. [141] 5. [152] 6. [4]
Histidine	2.6-3.5	2.5	1.6-5.4	2.0-3.9	2.4-2.9	
Arginine	5.6-7.3	5.6	3.1-8.4	3.4-7.6	6.7-7.7	
Isoleucine	3.9-5.6	3.6	2.6-4.5	3.4-4.4	3.7-5	
Leucine	6.3-9.5	6.4	3.8-9.2	6.7-8	6.4-8.9	
Tryptophan	1.3	1.4	0.6-1.6	1.4	1.5-1.6	
Cysteine	2.3-2.8	2.2	1.2-2.9	4.2-5.2	1.2-4.1	
Methionine	1.8-2.1	1.9	0.6-2.4	1.9-2.1	1.7-2	
Lysine	5.8-6.8	5	3.4-6.9	4.8-7.9	3.3-5.4	
Valine	4.9-7	4.7	2.3-6.1	3.7-5.4	4.5-5.9	

Replacement of fish meal with peanut meal (PNM)

Compared to soybean meal PNM (peanut meal) contain small amount of methionine ad lysine and have low quality of protein, yet it is used in aquaculture feed due to presence of high crude protein. In the world it is the 4th largest crop of oilseed and it is cultured approximately in 60 different countries. Nearly 35 million tonnes, production it gives annually [20].

Pulp of peanut that obtained after the withdrawal can be utilized in the feed of animals as a source of protein for pigs [153], fish [154] and poultry [155] mentioned in (Figure 3). It is expected that the low level of methionine and lysine in the peanut meal could show poor growth rate, but recent study showed that the use of PNM (peanut meal) nearly 20% in the diet of fish as a substitute of fishmeal donot show any opposing effect on the performance of growth [156].

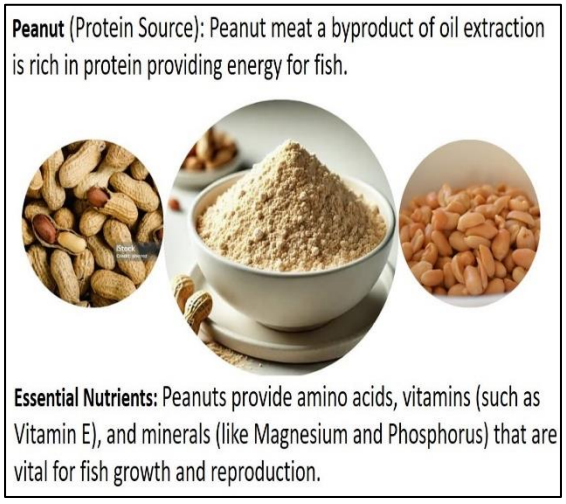


Figure 3: Profile of peanut.

Replacement of fish meal with water spinach

Water spinach comprises significant amounts of organic acids, polyphenols, amino acids and non-essential amino acids [157]. In recent report it is observed that, good growth performance was seen in fish because diet containing 5% water spinach [158].

Water spinach (*Ipomoea aquatic)* have good nutritive composition, give information in (Figure 4) with significant numbers of fatty acids, organic acids and polyphenols, macro and micro salts crude fibers; essential amino acids, nonessential amino acids, [157], the leaves of *Ipomoea aquatic* are quite composed with vital vitamins [159]. The most plentiful constituents of essential amino acids were Tyrosine + phenylalanine (1124 mg/100 g), threonine (606 mg/100 g), leucine (1365 mg/100 g) and lysine (682 mg/100 g) [160].

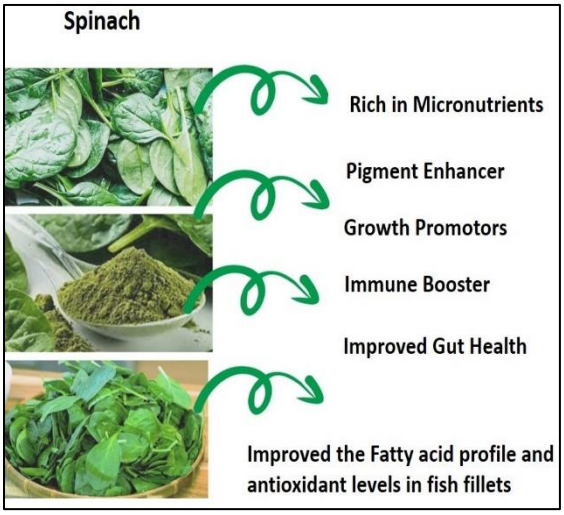


Figure 4: Nutritional details of spinach

Leaves of water spinach is full with vital vitamins e.g pyridoxine, phylloquinone, thiamine, a- tocopherol, niacin, riboflavin, cyanocobalamin, and ascorbic acid [161, 159]. Tilapia (*Oreochromis niloticus*) were fed with diet which contain 25% water spinach as an alternate of fishmeal and their results show significant on growth performance [162].

Replacement of fish meal with Garlic

Allium sativum (garlic) is from the family Liliaceae [163]. It has been used for long time as a herbal medicine and might be applicable in the feed of aquaculturedue to its properties of immunostimulant [164].

Allicin (diallyl thiosulfate) a compound present in garlic that is responsible for its medicinal properties and pungent smell [163] and further bioactive complexes, including flavonoids (phenolic acids), minerals (phosphorus, potassium, magnesium, calcium, iron, sodium, germanium and selenium), vitamins (riboflavin, thiamine and ascorbic acid) [165], and amino acids [166]. It is reported that the powder of garlic can enhance the growth of (*Oncorhynchus mykiss)* rainbow trout [167] and japanses seabass (*Lateolabrax japonicus*) [168] also known to use for the improvement in the body composition of *Salmo caspius* (brown trout) [169].

Dietary garlic powder has revealed a promising effect on phagocytic activity, blood total protein and albumin, in rainbow trout [170], the plant of garlic can amplified the capacity of fish resistance to the stress of ammonia [171]. From garlic powder it is seen that it improved the immunoglobulins in European seabass (*Dicentrarchus labrax*) [172].

Replacement of fishmeal with meat meal

By-product from slaughterhouses of meat cause meat meal (MM) of animals. It is reasonable in price and rich in protein and can use extensively in production of fish (173, 174, 175]. (Sato, T and Kikuchi 1977) shows that 60% of white fishmeal should be certainly relieved with pet-grade MM (80% crude protein and 12% crude lipid) for the supply of the important amino acids of lysine, methionine, and tryptophan.

Replacement of fish meal with zooplankton

Protein is the most lavish constituent required for the diets of aquatic species. one of the most basic and essential issues in aquaculture industries over the world, specifically in Egypt and other developing countries, cost, the availability, mismanaged treatment of protein and adulteration during the manufacturing of diet (GAFRD, 2012). As compare to the formulated diet of fish live feed is more stable and a good option for growth and survival [176]. For larvae, planktons appear to be a good source of exogenous enzymes and immune. The nutritional value of planktons vary and it play a good role in making great quality of larvae of fish, fry and juveniles [177]. Reviewing the community of zooplanktons within the farm system of fish is an effective method for measuring the effectiveness of ecosystem of aquaculture [178 - 179].

Copepods and rotifers organized the community of zooplanktons and together they form 95.9%. [180 - 181]. The diet were formulated and contain 42% crude protein. Zooplankton, soybean meal and fishmeal used as protein source. Fish oil (3%), yellow corn (15%) and wheat (10%) used as source of energy. 2% vitamin and mineral premixes were used in the experimental diet. In earthen pond community of zooplankton were grown, that can be used as nutritional unit of crude protein (73-79%), which can facilitate in the rearing and nursing of fish larvae and juveniles. Food conversion ratio, growth rate and good weight gain were seen in *Dicentrarchus labrax* from the 100% replacement of fishmeal with zooplanktons [182].

Replacement of fishmeal with Mulberry

Morus Alba (Mulberry) plant is a significant alternative source of fishmeal, its leaves contain good amount of protein (21.1%) and it is cultured in the sericulture industry. Usually mulberry is cultivated in sericulture industry for gaining leaves that can be used as feed of silkworm (*Bombyx mori*). From sericulture farm good amount of leaves can be taken in low price for fish feed preparation. Sting fish is a hardy fish which can breathe air was selected for the experiment, good fish which is high in

market demand for food [72].

For biomass production and light harvesting mulberry is more efficient than grass, for underground nutrients as mentioned in (Figure 5), and water retention their roots play vital role in it [183]. Mulberry have worthy composition regarding nutritionally and chemically, and have crude protein level considerably above from 20% [184].

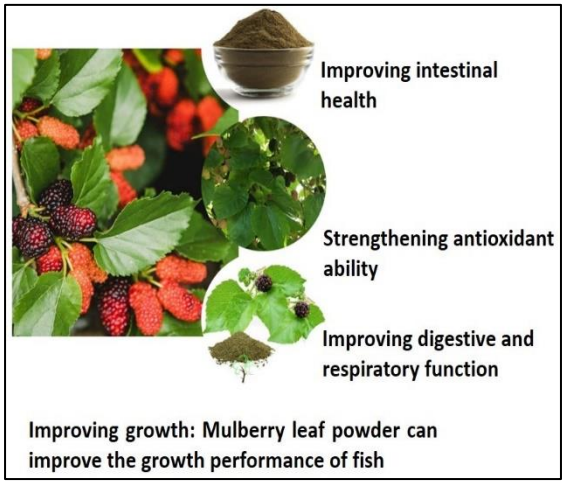


Figure 5: Mulberry.

(MLM) Mulberry leaf meal can be used as an alternative source of fish meal in *Heteropneustes* fossilis sting fish feed [185] for gaining good performance and fingerlings survival [68] it is also reported that nearly 30% substitute diet of mulberry were given to tilapia [19].

Digestible protein value of mulberry leaf meal was higher than *manicoba* [186 - 187] and *leucena* [186]. Compared with conventional sources of protein, MLM contain half of the digestible protein present in poultry offal and soybean [188] compared to fishmeal, depending on the source [88], which can reach values ranging from half to a little less than half the value it delivers to *Oreochromis niloticus* (Nile tilapia).

Replacement of fishmeal with silkworm

Plant-based protein source diets for aquaculture species were considered a good alternative, but some of the problems that couldn't be neglected include anti-nutritional factors [93] and an incomplete amino acid profile. The sources of crude protein from animals are similar nutritionally to fish meal and are considered considerably more suitable as a dietary alternative[124]. Originaton of sericulture occurred in 27th century BC in china after it, it will spread throughout the world. In 2011 silkworm cocoons world production was nearly 485, 000 tonnes [189].

(*B. mori*) domesticated silkworm is grown on leaves of mulberry and used for producing silk yarn by heat-killed pupae. Fibroine, peculiar elongated molecule thread of silk is produced nearly 800m from one cocoon [190]. The remaining pupae after the whirling of silk fibre, becomes industries's waste product which can play a role of feedstuff [191]. The spent SWP are vastly degradable so more often they are thrown away in the open environment or used as fertilizers, the consumption of the SWP waste for feed or for the generation of biological beneficial substances such as protein, chitin, oil and fatty acids can be ecological method to diminish the environmental impact of silk production [192].

Nutritional aspects

The nutritional value of dried silkworm pupae is compared with fishmeal, and it is cheap to buy. Range of crude protein is 52% to 72% while for deoiled meal it ranges from 65% to 80% essential amino acids are extensively found in SWP protein such as methionine, valine and phenylalanine. The components of important amino acids in SWP are balanced according to the suggested nutritional needs of fish; in indo-pacific region silkworm pupae is an important feed ingredient [193].

Increased incorporation of raw pupae for a long time leads to the production of bad

odour [194] and an unpleasant taste [195]. In fish feed dead moth and silkworm pupae is used [196]. The silkworm pupae have a higher amount of protein content than the non-deoiled SWP meal and are considered a good protein source for fish diet. In silkworm pupae the presence of good protein quality, appetite stimulants [195] and some attractants can be responsible for good fish growth[197].

Dried, non-deoiled silkworm pupae are a high-protein, low-cost source, making them a good substitute for fish meal in the feed of several fishes [198 - 199]. A diet with 30% non-deoiled silkworm pupae for catla and rohu showed good results on the growth of catla, but compared with rohu, it showed a different rate of growth that was considerably not good [26]. The growth of catla and rohu was significantly influenced by using the faecal matter and silkworm pupae in the diet of fish, and it is considered a potential feed ingredient when used in the diet of carp [200]. Fermented silage of silkworm pupae used in the feed, the results give good SGR, FCR and body weight gain and proved a good alternative source of fishmeal when used in the diet of carp species [201].

The effect of silkworm pupae replacement with fishmeal, and stated that by using 40% SWP meal in the diet of (*Cyprinus carpio, var specularis*) minor carp can show good growth rate and increase in the levels of protein and lipid [199]. The replacement of 50% fish meal with silkworm pupae (SWP) in the feed of fingerlings (*Cyprinus carpio, var. specularis*) enhanced the deposition of protein in the whole body [203]. Using 50% de-oiled SWP (silkworm pupae) in the diet of mahseer can significantly increase their growth rate [204]. Feed formed for the fingerings of *Tor putitora* (mahseer) containing SWP showed good growth performance, and then it was concluded that SWP was a cheaper alternate source of fishmeal that can enhance the economic returns of farmers for growing fingerlings of mahseer [205].

The silkworm pupae meal could be a good alternate of fishmeal nearly 75% showing good FCR, PER, growth performance, and net utilization of protein in the diet of fingerlings of (*Heteropneustes* fossils) catfish [206]. Silkworm pupae is a cheap substitute of source of protein by using in the feed of Asian catfish fingerlings (*Clarias batrachus*). Diet having 100% silkworm pupae meal generated efficient growth, protein utilization and feed conversion in fingerlings of *Clarias gariepinus* (African catfish) [207 - 208] and in *Clarias batrachuz* [209].

Conclusion

In conclusion, this review delivers treasured intuitions. It highlights aqua-feed formulations. Touching the advance points, review focus on thoughtful the long-term penalties of fishmeal protein alternative resources usage and emerge the approaches to alleviate potential opposing effects. In the feed of fish, protein is the ingredient that makes the diet nutritive and enhances its quality. It is valuable and main expensive part of feed. Fishmeal is the ingredient mainly used for protein requirement in fish feed. The replacement techniques of fishmeal to other plant based protein are moving high in this century. Plant protein sources use in feed as supplements in aquaculture for the development and extensions is the point to study in this review. The study concluded the effects of alternative protein sources of fishmeal including cost effectiveness; reduce ancient trends and sustainability criteria. Different researches also focused the point that how to minimize the difference of amino acid profile of plant protein from fishmeal. This could be lessening the cost effectiveness problems faced from supplementary feed, to ensure the development in aquaculture and provide good enhancement for the welfare of aquatic life. Soybean is a good alternate to fishmeal composition protein.

Enhance the growth and give good outcomes when used in fish feed. Silkworm, rapeseed, mulberry are the products used in the review to discuss their effect on fish health and these items provide productive results.

References

1. Larsen J, Marshall M. Farmed Fish Production Overtakes Beef. Earth Policy Institute: New Brunswick, NJ, USA; 2013. [accessed 2022 Jan 15].
2. FAO. The State of the World Fisheries and Aquaculture 2020. Sustainability in Action. Food and Agriculture Organization of the United Nations: Rome, Italy; 2020.
3. Ogungbenle H. Chemical and fatty acid compositions of date palm fruit (*Phoenix dactylifera* L.) flour. Bangladesh J Sci Ind Res. 2011;46(2):255–258.
4. Glencross BD, Baily J, Berntssen MHG, Hardy R, MacKenzie S, Tocher DR. Risk assessment of the use of alternative animal and plant raw material resources in aquaculture feeds. Rev Aquac. 2020;12:703–758.
5. FAO. The State of World Fisheries and Aquaculture 2018—Meeting the Sustainable Development Goals. Food and Agriculture Organization of the United Nations; 2018.
6. Gatlin DM. Use of soybean meal in the diets of omnivorous freshwater fish. Department of Wildlife and Fisheries Sciences, Faculty of Nutrition, Texas A&M University System; 2002.
7. Huo S, Wang Z, Zhu S, Zhou W, Dong R, Yuan Z. Cultivation of *Chlorella zofingiensis* in bench-scale outdoor ponds by regulation of pH using dairy wastewater in winter, South China. Bioresour Technol. 2012;121:76–82.
8. Naylor RL, Hardy RW, Bureau DP, Chiu A, Elliott M, Farrell AP, et al. Feeding aquaculture in an era of finite resources. Proc Natl Acad Sci U S A. 2009;106(36):15103–15110.
9. Zhang CR, Aldosari SA, Vidyasagar P, Shukla P, Nair MG. Determination of the variability of sugars in date fruit varieties. J Plant Crops. 2015;43(1):53–61.
10. Kaiser F, Harloff HJ, Tressel RP, Graßl AL, Parsche F, Schulz C. Fat encapsulation and supplementation with free amino acids cannot compensate for negative effects from dietary rapeseed protein isolate on growth performance of rainbow trout (*Oncorhynchus mykiss*). Aquac Rep. 2021;20:100702.
11. Krogdahl Å, Kortner TM, Jaramillo-Torres A, Gamil AAA, Chikwati E, Li Y, et al. Removal of three proteinaceous antinutrients from soybean does not mitigate soybean-induced enteritis in Atlantic salmon (*Salmo salar*, L.). Aquaculture. 2020;514:734495.
12. Nimalan N, Sørensen SL, Feˇckaninová A, Košˇcová J, Mudroˇnová D, Gancarˇcíková S, et al. Mucosal barrier status in Atlantic salmon fed marine or plant-based diets supplemented with probiotics. Aquaculture. 2022;547:737516.
13. Voorhees JM, Barnes ME, Chipps SR, Brown ML. Bioprocessed soybean meal replacement of fish meal in rainbow trout (*Oncorhynchus mykiss*) diets. Cogent Food Agric. 2019;5:1579482.
14. Grammes F, Reveco FE, Romarheim OH, Landsverk T, Mydland LT, Øverland M. *Candida utilis* and *Chlorella vulgaris* counteract intestinal inflammation in Atlantic salmon (*Salmo salar* L.). PLoS ONE. 2013;8(12):e83213.
15. Robinson EH, Li MH. Catfish Protein Nutrition: Revised. Vol. 1159. Office of Agricultural Communications, Division of Agriculture, Forestry, and Veterinary Medicine, Mississippi State University; 2007.
16. Shi X, Luo Z, Chen F, Huang C, Zhu XM, Liu X. Effects of dietary cellulase addition on growth performance,

nutrient digestibility and digestive enzyme activities of juvenile crucian carp *Carassius auratus*. Aquac Nutr. 2016;22(6):1277–1284..
17. Mehdi H, Khan N, Iqbal JK, Rasool F, Chaudhry MS, Khan KJ. Effect of *Moringa oleifera* meal on the growth, body composition and nutrient digestibility of *L. rohita*. Int J Biosci. 2016;8(4):11–17.
18. Ramzy AY, Obied JA, Ahmed MA, Mohammed IA, Fawzi AM. Effect of replacing fishmeal with water spinach (*Ipomoea aquatica*) on growth, feed conversion and carcass composition for Nile tilapia fry (*Oreochromis niloticus*). J Aquatic Science Marine Biology. 2019;2:13–20.
19. Astuti D, Becker K, Richter N. Energy and protein balance of Nile tilapia fed with moringa and mulberry leaves. JPHPI. 2012;15(1):71–79.
20. Liu X, Ye J, Wang K, Kong K, Yang W, Zhou L. Partial replacement of fish meal with peanut meal in practical diets for the Pacific white shrimp, *Litopenaeus vannamei*. Aquac Res. 2012;43(5):745–755.
21. Siddik MAB, Pham HD, Francis DS, Vo BV, Shahjahan M. Dietary supplementation of fish protein hydrolysate in high plant protein diets modulates growth, liver and kidney health, and immunity of barramundi (*Lates calcarifer*). Aquac Nutr. 2021;27(1):86–98.
22. Pérez-Pascual D, Estellé J, Dutto G, Rodde C, Bernardet JF, Marchand Y, et al. Growth performance and adaptability of European sea bass (*Dicentrarchus labrax*) gut microbiota to alternative diets free of fish products. Microorganisms. 2020;8(9):1346.
23. Dossou S, Koshio S, Ishikawa M, Yokoyama S, Dawood MAO, el Basuini MF, et al. Growth performance, blood health, antioxidant status and immune response in red sea bream (*Pagrus major*) fed *Aspergillus oryzae* fermented rapeseed meal (RM-Koji). Fish Shellfish Immunol. 2018;75:253–262.
24. Magouz FI, Dawood MAO, Salem MFI, Mohamed AAI. The effects of fish feed supplemented with Azolla meal on the growth performance, digestive enzyme activity, and health condition of genetically-improved farmed tilapia (*Oreochromis niloticus*). Ann Anim Sci. 2020;20(4):1393–1410.
25. Hu L, Yun B, Xue M, Wang J, Wu X, Zheng Y, et al. Effects of fish meal quality and fish meal substitution by animal protein blend on growth performance, flesh quality and liver histology of Japanese seabass (*Lateolabrax japonicus*). Aquaculture. 2013;372–375:52–61.
26. Jayaram MG, Shetty HPC. Studies on the shelf-life of two types of pelletted feeds. Curr Res. 1980;9:46–47.
27. Hossain MM, Ali ML, Khan S, Haque MM, Shahjahan M. Use of Asian watergrass as feed of grass carp. Aquac Rep. 2020;18:100434.
28. Hossain MM, Rahman MH, Ali ML, Khan S, Haque MM, Shahjahan M. Development of a low-cost polyculture system utilizing *Hygroryza aristata* floating grass in the coastal wetlands of Bangladesh. Aquaculture. 2020;527:735430.
29. Tacon AG, Hasan MR, Metian M. Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects. FAO Fisheries and Aquaculture Technical Paper No. 564. Rome: FAO; 2011.
30. Uddin MN, Rahman M, Shahjahan M. Effects of duckweed (*Lemna minor*) as supplementary feed on monoculture of GIFT strain of tilapia (*Oreochromis niloticus*). Progress Agric. 2007;18(2): 183–188.
31. Meng F, Li B, Xie Y, Li M, Wang RX. Substituting fishmeal with extruded soybean meal in diets did not affect the growth performance, hepatic enzyme activities, but hypoxia tolerance of Dolly Varden (*Salvelinus malma*)

juveniles. Aquac Res. 2020;51(1):379–388.
32. Pervin MA, Jahan H, Akter R, Omri A, Hossain Z. Appraisal of different levels of soybean meal in diets on growth, digestive enzyme activity, antioxidation, and gut histology of tilapia (*Oreochromis niloticus*). Fish Physiol Biochem. 2020;46(4):1397–1407.
33. Nyirenda J, Mwabumba M, Kaunda E, Sales J. Effect of substituting animal protein sources with soybean meal in diets of *Oncorhynchus karongae* (Trewavas 1941). Naga, The ICLARM Quarterly. 2000;23(4):14–16.
34. Kalla A, Garg SK, Kaushik CP, Arasu ART, Dinodia GS. Effect of replacement of fishmeal with processed soybean on growth, digestibility and nutrient retention in *Mugil cephalus* (Linn.) fry. Indian J Fish. 2003;50(4):509–518.
35. Zhou Z, Ringø E, Olsen RE, Song SK. Dietary effects of soybean products on gut microbiota and immunity of aquatic animals: a review. Aquac Nutr. 2018;24(2):644–665.
36. Liu T, Han T, Wang J, Liu T, Bian P, Wang Y, et al. Effects of replacing fish meal with soybean meal on growth performance, feed utilization and physiological status of juvenile redlip mullet *Liza haematocheila*. Aquac Rep. 2021;20:100756.
37. Hosseini SA, Khajepour F. Effect of partial replacement of dietary fish meal with soybean meal on some hematological and serum biochemical parameters of juvenile beluga, *Huso huso*. Iran J Fish Sci. 2013;12(2):348–356.
38. Shiu YL, Wong SL, Guei WC, Shin YC, Liu CH. Increase in the plant protein ratio in the diet of white shrimp, *Litopenaeus vannamei* (Boone), using *Bacillus subtilis* E20-fermented soybean meal as a replacement. Aquac Res. 2013;46(2):382–394.
39. Azarm HM, Lee SM. Effects of partial substitution of dietary fish meal by fermented soybean meal on growth performance, amino acid and biochemical parameters of juvenile black sea bream, *Acanthopagrus schlegeli*. Aquac Res. 2014;45(6):994–1003.
40. Jiang Y, Zhao PF, Lin SM, Tang RJ, Chen YJ, Luo L. Partial substitution of soybean meal with fermented soybean residue in diets for juvenile largemouth bass, *Micropterus salmoides*. Aquac Nutr. 2018;24(4):1213–1222.
41. Zulhisyam AK, Kabir MA, Munir MB, Wei LS. Using of fermented soy pulp as an edible coating material on fish feed pellet in African catfish (*Clarias gariepinus*) production. AACL Bioflux. 2020;13(1):296–308.
42. Azarm HM, Lee SM. Effects of partial substitution of dietary fish meal by fermented soybean meal on growth performance, amino acid and biochemical parameters of juvenile black sea bream, *Acanthopagrus schlegeli*. Aquac Res. 2014;45(6):994–1003.
43. Goda AMAS, Saad A, Wafa M, Sharawy Z. Complete substitution of dietary wheatbran with Duckweed *Lemna* species supplemented with exogenous digestive enzymes for freshwater prawn, *Macrobrachium rosenbergii* (De Man 1879) postlarvae. In: Aquaculture Europe; 2014 Oct.
44. Mzengereza K, Ishikawa M, Koshio S, Yokoyama S, Yukun Z, Shadrack RS, et al. Effect of substituting fish oil with Camelina oil on growth performance, fatty acid profile, digestibility, liver histology, and antioxidative status of red seabream (*Pagrus major*). Animals. 2021;11(7):1990.
45. Rahman MM, Nakawaga T, Abdullah RB, Emong WKW, Akashi R. Feed intake and growth performance of goats supplemented with soy waste. Pesq Agropec Bras. 2014;49(7):554–558.
46. Danial N. A review on replacing fish meal in aqua feeds using plant protein

sources. Int J Fish Aquat Stud. 2018;6(4):164–179.
47. Dossou S, Dawood MA, Zaineldin AI, Abouelsaad IA, Mzengereza K, Shadrack RS, et al. Dynamical hybrid system for optimizing and controlling efficacy of plant-based protein in aquafeeds. Complexity. 2021;2021: 5536481.
48. Zulhisyam AK, Muhammad Anamul K, Mohammad Khairul Azhar AR, Mohammad Bodrul M, Po Teen L, Lee Seong W. A replacement of plant protein sources as an alternative of fish meal ingredient for African catfish, *Clarias gariepinus*: a review. J Trop Res Sustain Sci. 2020;8(1):47–59.
49. Cruz ME. Determination of nutrient digestibility in various feedstuffs for channel catfish [dissertation]. Auburn University; 1975.
50. Popma TJ. Digestibility of selected feedstuffs and naturally occurring algae for tilapia [dissertation]. Auburn University; 1982.
51. Hanley F. The digestibility of foodstuffs and the effects of feeding selectivity on digestibility determinations in tilapia, *Oreochromis niloticus* (L). Aquaculture. 1987;66(2): 163–179.
52. Degani G, Viola S, Yehuda Y. Apparent digestibility of protein and carbohydrate in feed ingredients for adult tilapia (*Oreochromis aureus* x *O. niloticus*). Bamidgeh. 1997;49(3):115–123.
53. Allan GL, Parkinson S, Booth MA, Stone DAJ, Rowland SJ, Frances J, et al. Replacement of fish meal in diets for Australian silver perch, *Bidyanus bidyanus*: I. Digestibility of alternative ingredients. Aquaculture. 2000;186(3–4):293–310.
54. Degani G, Viola S, Yehuda Y. Apparent digestibility coefficient of protein sources for carp, *Cyprinus carpio* L. Aquac Res. 1997;28(1):23–28.
55. Takeuchi T, Satoh S, Kiron V. Common carp. In: Webster CD, Lim C, editors. Nutrient Requirements and Feeding of Finfish for Aquaculture. CABI Publishing; 2002. p. 245–261.
56. Wilson RP, Poe WE. Apparent digestible protein and energy coefficients of common feed ingredients for channel catfish. Prog Fish-Cult. 1985;47(3):154–158.
57. Brown PB, Strange RJ, Robbins KR. Protein digestibility coefficients for yearling channel catfish fed high protein feedstuffs. Prog Fish-Cult. 1985;47(2):94–97.
58. Andersen SM, Waagbø R, Espe M. Functional amino acids in fish health and welfare. Front Biosci. 2016;8(1):143–169.
59. Hua K, Cobcroft JM, Cole A, Condon K, Jerry DR, Mangott A, et al. The future of aquatic protein: implications for protein sources in aquaculture diets. One Earth. 2019;1(3):316–329.
60. Kari ZA, Kabir MA, Mat K, Rusli ND, Razab MKAA, Ariff NSNA, et al. The possibility of replacing fish meal with fermented soy pulp on the growth performance, blood biochemistry, liver, and intestinal morphology of African catfish (*Clarias gariepinus*). Aquac Rep. 2021;21:100815.
61. Turchini GM, Trushenski JT, Glencross BD. Thoughts for the future of aquaculture nutrition: realigning perspectives to reflect contemporary issues related to judicious use of marine resources in aquafeeds. North Am J Aquac. 2019;81(1):13–39.
62. Qadir A, Shakeel F, Ali A, Faiyazuddin M. Phytotherapeutic potential and pharmaceutical impact of *Phoenix dactylifera* (date palm): current research and future prospects. J Food Sci Technol. 2020;57(4):1191–1204.
63. Zohary D, Hopf M. Domestication of Plants in the Old World: the Origin and Spread of Cultivated Plants in West Asia, Europe and the Nile Valley. Oxford University Press; 2020.
64. Chao CT, Krueger RR. The date palm

(*Phoenix dactylifera* L.): overview of biology, uses, and cultivation. HortScience. 2007;42(5):1077–1082.
65. Sotolu AO, Kigbu AA, Oshinowo AJ. Supplementation of date palm (*Phoenix dactylifera*) seed as feed additive in the diets of juvenile African catfish (Burchell, 1822). J Fish Aquat Sci. 2014;9(5):359.
66. Al-Farsi MA, Lee CY. Nutritional and functional properties of dates: a review. Crit Rev Food Sci Nutr. 2008;48(10):877–887.
67. Ali-Mohamed AY, Khamis AS. Mineral ion content of the seeds of six cultivars of Bahraini date palm (*Phoenix dactylifera*). J Agric Food Chem. 2004;52(21):6522–6525.
68. Bag MP, Ghorai M, Mahapatra SC, Rao PS, Pal H. Evaluation of Mulberry (*Morus alba*, Linn.) leaf meal as a complete diet for sting fish (*Heteropneustes fossilis*, Bloch.). Int J Pharm Life Sci. 2012;3(9):1980–1984.
69. Debache K. Growth performance of novel food based on mixture of boiled-dried granulated *Tenebrio molitor* larvae and date-fruit waste in broiler chicken farming. Asian J Agric. 2021;5(1):22–28.
70. Ghnimi S, Umer S, Karim A, Kamal-Eldin A. Date fruit (*Phoenix dactylifera* L.): an underutilized food seeking industrial valorization. NFS J. 2017;6:1–10.
71. Sakr MM, Abu-Zeid IM, Hassan AE, Baz AGIO, Hassan WM. Identification of some Date palm (*Phoenix dactylifera*) cultivars by fruit characters. Indian J Sci Technol. 2010;3(3):338–343.
72. Benmeziane-Ferradji F. Nutritional value, phytochemical composition, and biological activities of Middle Eastern and North African date fruit: an overview. Eur Mediterr J Environ Integr. 2019;4(1):24.
73. Chai M, Isa M. The oleic acid composition effect on the carboxymethyl cellulose based biopolymer electrolyte. J Cryst Process Technol. 2013;3(1):1–4.
74. Alharbi KL, Raman J, Shin HJ. Date fruit and seed in nutricosmetics. Cosmetics. 2021;8(3):59.
75. Golshan Tafti A, Solaimani Dahdivan N, Yasini Ardakani S. Physicochemical properties and applications of date seed and its oil. Int Food Res J. 2017;24(4):1395–1403.
76. Siddiq M, Greiby I. Overview of date fruit production, postharvest handling, processing, and nutrition. In: Siddiq M, Aleid SM, Kader AA, editors. Dates: Postharvest Science, Processing Technology and Health Benefits. John Wiley and Sons; 2014: 1–28.
77. Alghamdi AA, Awadelkarem AM, Hossain A, Ibrahim NA, Fawzi M, Ashraf SA. Nutritional assessment of different date fruits (*Phoenix dactylifera* L.) varieties cultivated in Hail province, Saudi Arabia. Biosci Biotechnol Res Commun. 2018;11(2):263–269.
78. Assirey EAR. Nutritional composition of fruit of 10 date palm (*Phoenix dactylifera* L.) cultivars grown in Saudi Arabia. J Taibah Univ Sci. 2015;9(1):75–79.
79. Besbes S, Blecker C, Deroanne C, Drira NE, Attia H. Date seeds: chemical composition and characteristic profiles of the lipid fraction. Food Chem. 2004;84(4):577–584.
80. Azaza M, Mensi F, Kammoun W, Abdelouaheb A, Brini B, Kraiem m. Nutritional evaluation of waste date fruit as partial substitute for soybean meal in practical diets of juvenile Nile tilapia, *Oreochromis niloticus* L. Aquac Nutr. 2009;15(3):262–272.
81. Dawood MAO, Eweedah NM, Khalafalla MM, Khalid A. Evaluation of fermented date palm seed meal with *Aspergillus oryzae* on the growth, digestion capacity and immune response of Nile tilapia (*Oreochromis niloticus*). Aquac Nutr. 2020; 26(3):828–841.

82. Akbarzadeh A, Niroomand M, Abkenar KB, Nimvari ME, Karimi K, Ghazvini A, et al. Effect of dietary date seed meal as an alternative carbohydrate source on immune-related gene expression of Pacific white shrimp *Penaeus vannamei*. Fish Shellfish Immunol. 2019;86:994–998.
83. Ahmed VM, Abdulrahman NM, HamaAmeen SA, Hassan BR, Abbas AK, Hussen BA, et al. Impacts of date palm seeds (*Phoenix dactyliferous* L.) on growth indices and nutrient utilization of common carp *Cyprinus carpio* L. J Agric Sci Technol B. 2017;7:280–284. doi:10.17265/2161-6264/2017.04.005.
84. Hoseinifar SH, Dadar M, Khalili M, Cerezuela R, Esteban MÁ. Effect of dietary supplementation of palm fruit extracts on the transcriptomes of growth, antioxidant enzyme and immune-related genes in common carp (*Cyprinus carpio*) fingerlings. Aquac Res. 2017;48(7):3684–3692.
85. Kamali-Sanzighi M, Akrami R, Ghelichi A, Shamloofar M. Partial replacement of plant sources by waste date (*Phoenix dactylifera*) in the diet of fingerling common carp (*Cyprinus carpio*) on growth performance, feed utilization, hematological parameters and resistance to stress. Turk J Fish Aquat Sci. 2019;19(9):775–784.
86. Mohammadi M, Soltani M, Siahpoosh A, Hosseini Shekarabi SP, Shamsaie Mehrgan M, Lymbery A. Effect of date palm (*Phoenix dactylifera*) seed extract as a dietary supplementation on growth performance immunological haematological biochemical parameters of common carp. Aquac Res. 2018;49(9):2903–2912.
87. Bouaziz MA, Besbes S, Blecker C, Wathelet B, Deroanne C, Attia H. Protein and amino acid profiles of Tunisian Deglet Nour and Allig date palm fruit seeds. Fruits. 2008;63(1):37–43.
88. Chiseva S. The growth rates and feed conversion ratios of fry fed conventional fry diets and *Moringa oleifera* supplemented diets [dissertation]. Bindura University of Science Education; 2006.
89. Nouala FS, Akinbamijo OO, Adewumi A, Hoffman S, Muetzel S, Becker K. The influence of *Moringa oleifera* leaves as substitute to conventional concentrate on the in vitro gas production and digestibility of groundnut hay. LRRD. 2006;18(9):121.
90. Soliva CR, Kreuzer M, Foidl N, Foidl G, Machmuller A, Hess HD. Feeding value of whole and extracted *Moringa oleifera* leaves for ruminants and their effects on ruminal fermentation in vitro. Anim Feed Sci Technol. 2005;118(1–2):47–62. doi:10.1016/j.anifeedsci.2004.10.005.
91. Makkar HPS, Becker K. Nutritional value and antinutritional components of whole and ethanol extracted *Moringa oleifera* leaves. Anim Feed Sci Technol. 1996;63(1–4):211–228.
92. Islam Z, Islam SR, Hossen F, Mahtab-ul-Islam K, Hasan MR, Karim R. *Moringa oleifera* is a prominent source of nutrients with potential health benefits. Int J Food Sci. 2021;2021:6627265.
93. Francis G, Makkar HP, Becker K. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. Aquaculture. 2001;199(3–4):197–227.
94. Ayotunde EO, Offem BO, Bekeh AF. Toxicity of *Carica papaya* Linn: Haematological and piscicidal effect on adult catfish (*Clarias gariepinus*). J Fish Aquat Sci. 2011;6(3):291–307.
95. Bosch CH. *Moringa oleifera* Lam. In: Grubben GJH, Denton OA, editors. Plant Resources of Tropical Africa. PROTA; 2004.
96. Tagwireyi T, Mupangwa JF, Jepsen J, Mwera P. The effect of feeding heat treated *Moringa oleifera* (Lam) leaf meal on the growth performance of *Oreochromis niloticus* (Lam) fry.

UNISWA J Agric. 2014;17:14–20.
97. Hussain M, Hussain SM, Iqbal R, Javid A, Shahzad MM, Arsalan MZUH. Hematological indices, nutrient digestibility and growth performance of *Catla catla* fingerlings fed citric acid supplemented *Moringa oleifera* leaf meal based diet. Pak J Zool. 2018;50(6):2307–2315.
98. Afuang W, Siddhuraju P, Becker K. Comparative nutritional evaluation of raw, methanol extracted residues and methanol extracts of moringa (*Moringa oleifera* Lam.) leaves on growth performance and feed utilization in Nile tilapia (*Oreochromis niloticus* L.). Aquac Res. 2003;34(13):1147–1159. doi:10.1046/j.1365-2109.2003.00920.x.
99. Richter N, Siddhuraju P, Becker K. Evaluation of nutritional quality of moringa (*Moringa oleifera* Lam.) leaves as an alternative protein source for Nile tilapia (*Oreochromis niloticus* L.). Aquaculture. 2003;217(1–4):599–611.
100. Spolaore P, Joannis-Cassan C, Duran E, Isambert A. Commercial applications of microalgae. J Biosci Bioeng. 2006;101(2):87–96.
101. Hemaiswarya S, Raja R, Ravi Kumar R, Ganesan V, Anbazhagan C. Microalgae: a sustainable feed source for aquaculture. World J Microbiol Biotechnol. 2011;27(8):1737–1746.
102. Xu W, Gao Z, Qi ZT, Qiu M, Peng JQ, Shao R. Effect of dietary chlorella on the growth performance and physiological parameters of gibel carp, *Carassius auratus gibelio*. Turk J Fish Aquat Sci. 2014;14(1):53–57.
103. Wilson RP, Poe WE. Apparent digestible protein and energy coefficients of common feed ingredients for channel catfish. Prog Fish-Cult. 1985;47(3):154–158.
104. Gangadhar B, Umalatha H, Hegde G, Sridhar N. Digestibility of Dry Matter and Nutrients from *Azolla pinnata* by *Labeo calbasu* (Hamilton, 1822) with a Note on Digestive Enzyme Activity. Fish Technol. 2017;54(2):94–99.
105. Dawood MAO, Koshio S. Application of fermentation strategy in aquafeed for sustainable aquaculture. Rev Aquac. 2020;12(2):987–1002.
106. Volkmann H, Imianovsky U, Oliveira JLB, Sant-Anna ES. Cultivation of *Arthrospira platensis* in desalinator wastewater and salinated synthetic medium: protein content and amino acid profile. Braz J Microbiol. 2008;39(1):98–101.
107. Panigrahi S, Choudhary D, Sahoo JK, Das SS, Rath RK. Effect of dietary supplementation of Azolla on growth and survivibility of *Labeo rohita* fingerlings. Asian J Anim Sci. 2014;9(1):33–37.
108. Ebrahim MSM, Zeinhom MM, Abou-Seif RA. Response of Nile tilapia (*Oreochromis niloticus*) fingerlings to diets containing Azolla meal as a source of protein. J Arab Aquac Soc. 2007;2(2):54–69.
109. Leonard V, Breyne C, Micha JC, Larondelle Y. Digestibility and transit time of *Azolla filiculoides* Lamarck in *Oreochromis aureus* (Steindachner). Aquac Res. 1998;29(3):159–165.
110. Fiogbe ED, Micha JC, Van Hove C. Use of a natural aquatic fern, *Azolla microphylla*, as a main component in food for the omnivorous–phytoplanktonophagous tilapia, *Oreochromis niloticus* L. J Appl Ichthyol. 2004;20(6):517–520.
111. Kamalasanana Pillai P, Premalatha S, Rajamony S. Natural Resources Development Project. Vivekananda Kendra; 2005.
112. Das M, Rahim FI, Hossain MA. Evaluation of fresh *Azolla pinnata* as a low-cost supplemental feed for Thai silver barb *Barbonymus gonionotus*. Fishes. 2018;3(1):15.
113. Pillai PK, Premalatha S, Rajamony S. Azolla—A sustainable feed substitute for livestock. LEISA India.

2002;4(1):15–17.
114. Datta SN. Culture of Azolla and its efficacy in diet of *Labeo rohita*. Aquaculture. 2011;310(3–4):376–379.
115. Maity J, Patra BC. Effect of replacement of fishmeal by Azolla leaf meal on growth, food utilization, pancreatic protease activity and RNA/DNA ratio in the fingerlings of *Labeo rohita* (Ham.). Can J Pure Appl Sci. 2008;2(2):323–333.
116. Sheeno TP, Sahu NP. Use of freshwater aquatic plants as a substitute of fishmeal in the diet of *Labeo rohita* fry. J Fish Aquat Sci. 2006;1(2):126–135.
117. Gangadhar B, Sridhar N, Saurabh S, Raghavendra CH, Hemaprasanth KP, Raghunath MR, et al. Growth response of *Cirrhinus mrigala* fry to Azolla (*Azolla pinnata*) – incorporated diets. Fish Technol. 2014;51(3):156–161.
118. Abou Y, Fiogbe ED, Micha JC. A preliminary assessment of growth and production of Nile tilapia, *Oreochromis niloticus* L., fed Azolla-based-diets in earthen ponds. J Appl Aquac. 2007;19(4):55–69.
119. Fasakin EA, Balogun AM, Fagbenro OA. Evaluation of sun-dried water fern, *Azolla africana* and duckweed, *Spirodela polyrrhiza* in practical diets for Nile tilapia, *Oreochromis niloticus* fingerlings. J Appl Aquac. 2001;11(4):83–92.
120. Almazan GJ, Pullin RSV, Angeles AF, Manalo TA, Agbayani RA, Trono MTV. *Azolla pinnata* as a dietary component for Nile tilapia, *Oreochromis niloticus*. In: Proceedings of the Second Asian Fisheries Forum; 1986. p. 523–528.
121. Mosha SS. A review on significance of Azolla meal as a protein plant source in finfish culture. J Aquac Res Dev. 2018;9(6):544.
122. Umalatha H, Gangadhar B, Hegde G, Sridhar N. Digestibility of three feed ingredients by *Catla catla* (Hamilton, 1822). Oceanogr Fish Open Access J. 2018;5(5):555672.
123. Majhi SK, Das A, Mandal BK. Growth performance and production of organically cultured grass carp *Ctenopharyngodon idella* (Val.) under mid-hill conditions of Meghalaya; north eastern India. Turk J Fish Aquat Sci. 2006;6(2):105–108.
124. Kumari R, Ojha ML, Saini VP, Sharma SK. Effect of Azolla supplementation on growth of rohu (*Labeo rohita*) fingerlings. J Entomol Zool Stud. 2017;5(4):1116–1119.
125. Carré P, Citeau M, Robin G, Estorges M. Hull content and chemical composition of whole seeds, hulls and germs in cultivars of rapeseed (*Brassica napus*). OCL. 2016;23(3):A302.
126. Chakraborty P, Mallik A, Sarang N, Lingam SS. A review on alternative plant protein sources available for future sustainable aqua feed production. Int J Chem Stud. 2019;7(4):1399–1404.
127. Hua K, Cobcroft JM, Cole A, Condon K, Jerry DR, Mangott A, et al. The future of aquatic protein: implications for protein sources in aquaculture diets. One Earth. 2019;1(3):316–329.
128. Sarker PK, Kapuscinski AR, Vandenberg GW, Proulx E, Sitek AJ, Thomsen L. Towards sustainable and ocean-friendly aquafeeds: evaluating a fish-free feed for rainbow trout (*Oncorhynchus mykiss*) using three marine microalgae species. Elementa. 2020;8:5.
129. Alfred O, Shaahu A, Jibung GG, et al. Fish nutrition: plant source as an alternative. Int J Res Sci Innov. 2020;7(12):2321–2705.
130. Øverland M, Sørensen M, Storebakken T, Penn M, Krogdahl Å, Skrede A. Pea protein concentrate substituting fish meal or soybean meal in diets for Atlantic salmon (*Salmo salar*)—effect on growth performance, nutrient digestibility, carcass composition, gut health, and physical feed quality. Aquaculture. 2009;288

(3–4):305–311.
131. Reis B, Marques A, Campos I, Dias E, Valente LM. Wheat germ as an alternative ingredient to a fair average quality fishmeal in diets for European seabass. Aquac Nutr. 2019;25(4):932–945.
132. Pereira TG, Oliva-Teles A. Evaluation of micronized lupin seed meal as an alternative protein source in diets for gilthead sea bream *Sparus aurata* L. juveniles. Aquac Res. 2004;35(9):828–835.
133. Slawski H. Rapeseed protein products as fish meal replacement in fish nutrition [dissertation]. Institute for Animal Breeding and Husbandry; 2012.
134. De la Higuera M, Garcia-Gallego M, Sanz A, Cardenete G, Suarez MD, Moyano FJ. Evaluation of lupin seed meal as an alternative protein source in feeding of rainbow trout (*Salmo gairdneri*). Aquaculture. 1988;71(1–2):37–50.
135. Alam MS, Watanabe WO, Myers AR, Rezek TC, Carroll PM. Replacement of menhaden fish meal protein by solvent extracted soybean meal and soy protein concentrate supplemented with L-methionine and L-lysine in the diet of juvenile red porgy *Pagrus pagrus*. Austin J Aquac Mar Biol. 2014;1(1):10.
136. Ogello EO, Kembenya EM, Githukia CM, Aera CN, Munguti JM, Nyamweya CS. Substitution of fish meal with sunflower seed meal in diets for Nile tilapia (*Oreochromis niloticus* L.) reared in earthen ponds. J Appl Aquac. 2017;29(1):81–99.
137. Higgs DA, McBride JR, Markert JR, Dosanjh BS, Plotnikoff MD, Clarke WC. Evaluation of tower and candle rapeseed (canola) meal and Bronowski rapeseed protein concentrate as protein supplements in practical dry diets for juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture. 1982;29(1–2):1–31.
138. Suárez JA, Gaxiola G, Mendoza R, et al. Substitution of fish meal with plant protein sources and energy budget for white shrimp *Litopenaeus vannamei* (Boone, 1931). Aquaculture. 2009;289(1–2):118–123.
139. Sallam EA, Matter AF, Mohammed LS, Azam AE, Shehab A, Soliman MM. Replacing fish meal with rapeseed meal: potential impact on the growth performance, profitability measures, serum biomarkers, antioxidant status, intestinal morphometric analysis, and water quality of *Oreochromis niloticus* and *Sarotherodon galilaeus* fingerlings. Vet Res Commun. 2021;45(3):223–241.
140. Burel C, Boujard T, Escaffre AM, et al. Dietary low-glucosinolate rapeseed meal affects thyroid status and nutrient utilization in rainbow trout (*Oncorhynchus mykiss*). Br J Nutr. 2000;83(6):653–664.
141. Adem HN. Herstellung von Rapsproteinprodukten für die Fischernährung [doctoral dissertation]. Magdeburg: Otto-von-Guericke-Universität Magdeburg; 2014.
142. Büyükdeveci ME, Balcázar JL, Demirkale I, Dikel S. Effects of garlic-supplemented diet on growth performance and intestinal microbiota of rainbow trout (*Oncorhynchus mykiss*). Aquaculture. 2018;486:170–174.
143. Eklund A, Ågren G, Langter T. Rapeseed protein fractions: I. Preparation of a detoxified lipid-protein concentrate from rapeseed (*Brassica napus* L.) by a water-ethanol extraction method. J Sci Food Agric. 1971;22(12):650–652.
144. Kaiser F, Harbach H, Schulz C. Rapeseed proteins as fishmeal alternatives: a review. Rev Aquac. 2022;14(4):1887–1911.
145. Plaipetch P, Yakupitiyage A. Nutrient digestibility of conventionally processed canola meal in Nile Tilapia. In: ASEAN Fisheries and Aquaculture

Conference and Exposition 2016: ASEAN Seafood for the World, and 11th Asian Fisheries and Aquaculture Forum; 2016 Aug 3–7; Bangkok, Thailand; 2016.
146. Zhang C. Effect of yeast-fermentation of canola meal on digestibility, growth performance and hindgut inflammation of Nile tilapia *Oreochromis niloticus* and rainbow trout *Oncorhynchus mykiss* [doctoral dissertation]. University of Saskatchewan; 2017.
147. Cheng Z, Ai Q, Mai K, et al. Effects of dietary canola meal on growth performance, digestion and metabolism of Japanese seabass, *Lateolabrax japonicus*. Aquaculture. 2010;305(1–4):102–108.
148. Francis G, Makkar HP, Becker K. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. Aquaculture. 2001;199(3–4):197–227.
149. Greiling AM, Reiter R, Rodehutscord M. Utilization of unprocessed and fibre-reduced oilseed cakes of rapeseed and sunflower seed in rainbow trout (*Oncorhynchus mykiss* W.) nutrition—evaluation of apparent digestibility and growth performance. Aquac Nutr. 2018;24(3):1133–1143.
150. Bu XY, Wang YY, Chen FY, et al. An evaluation of replacing fishmeal with rapeseed meal in the diet of *Pseudobagrus ussuriensis*: growth, feed utilization, nonspecific immunity, and growth-related gene expression. J World Aquac Soc. 2018;49(6):1068–1080.
151. Von Danwitz A, Schulz C. Effects of dietary rapeseed glucosinolates, sinapic acid and phytic acid on feed intake, growth performance and fish health in turbot (*Psetta maxima* L.). Aquaculture. 2020;516:734624.
152. Nagel F, von Danwitz A, Tusche K, et al. Nutritional evaluation of rapeseed protein isolate as fish meal substitute for juvenile turbot (*Psetta maxima* L.)—impact on growth performance, body composition, nutrient digestibility and blood physiology. Aquaculture. 2012;356–357:357–364.
153. Adeola O. Bioavailability of threonine and tryptophan in peanut meal for starter pigs using slope-ratio assay. Animal. 2009;3(5):677–684.
154. Yildirim Ö, Acar Ü, Türker A, Sunar MC, Yilmaz S. The effects of partial or total replacement of fish oil by unrefined peanut oil on growth performance and body chemical composition of Common Carp (*Cyprinus carpio*). Isr J Aquacult-Bamidgeh. 2013;65:919.
155. Costa EF, Miller BR, Pesti GM, Bakalli RI, Ewing HP. Studies on feeding peanut meal as a protein source for broiler chickens. Poult Sci. 2001;80(3):306–313.
156. Yıldırım Ö, Acar Ü, Türker A, Sunar MC, Kesbic OS. Effects of replacing fish meal with peanut meal (*Arachis hypogaea*) on growth, feed utilization and body composition of Mozambique tilapia fries (*Oreochromis mossambicus*). Pak J Zool. 2014;46(2):499–505.
157. Doka GI, Tigni SE, Yagi S. Nutritional composition and antioxidant properties of *Ipomoea aquatica* (Forsk) leaves. J For Prod. 2014;3(2):204–210.
158. Chepkirui M, Orina PS, Opiyo M, Muendo P, Mbogo K, et al. Growth performance of Nile Tilapia (*Oreochromis niloticus*) fingerlings fed with water spinach (*Ipomoea aquatica*) diets. Ann Mar Sci. 2022;6(1):001–006.
159. Misra S, Misra MK. Nutritional evaluation of some leafy vegetable used by the tribal and rural people of south Odisha, India. J Nat Prod Plant Resour. 2014;4(1):23–28.
160. Koumi AR, Atse BC, Kouame LP. Utilization of soya protein as an alternative protein source in *Oreochromis niloticus* diet: growth performance, feed utilization,

proximate composition and organoleptic characteristics. Afr J Biotechnol. 2009;8(1):091–097.
161. Igwenyi IO, Offor CE, Ajah DA, Nwankwo OC, Ukaomah JI, Aja PM. Chemical compositions of *Ipomoea aquatica* (green kangkong). Int J Pharma Biosci. 2011;2(4):B593–B598.
162. Fabusoro AA, Odulate DO, Idowu AA, Odebiyi CO. Growth performance of juvenile *Clarias gariepinus* (Burchell, 1822) fed *Ipomoea aquatica* based diets. J Fish Aquat Sci. 2014;9(6):468–472.
163. Santhosha S, Jamuna P, Prabhavathi SN. Bioactive components of garlic and their physiological role in health maintenance: a review. Food Biosci. 2013;3:59–74.
164. Firmino JP, Galindo-Villegas J, Reyes-López FE, Gisbert E. Phytogenic bioactive compounds shape fish mucosal immunity. Front Immunol. 2021;12:695973.
165. Lawson LD. Garlic: a review of its medicinal effects and indicated active compounds. In: Lawson LS, Bauer R, editors. Phytomedicines of Europe: Chemistry and Biological Activity. Washington, DC: American Chemical Society; 1998. p. 176–209.
166. Sasaki J, Lu C, Machiya E, Tanahashi M, Hamada K. Processed black garlic (*Allium sativum*) extracts enhance anti-tumor potency against mouse tumors. Med Aromat Plant Sci Biotechnol. 2007;2(2):278–281.
167. Büyükdeveci ME, Balcázar JL, Demirkale I, Dikel S. Effects of garlic-supplemented diet on growth performance and intestinal microbiota of rainbow trout (*Oncorhynchus mykiss*). Aquaculture. 2018;486:170–174.
168. Xu A, Shang-Guan J, Li Z, Gao Z, Huang Y, Chen Q. Effects of garlic powder on feeding attraction activity, growth and digestive enzyme activities of Japanese seabass, *Lateolabrax japonicus*. Aquac Nutr. 2020;26(2):390–399.
169. Zaefarian A, Yeganeh S, Adhami B. Dietary effects of garlic powder (*Allium sativum*) on growth, blood indices, carcass composition, and lysozyme activity in brown trout (*Salmo caspius*) and resistance against *Yersinia ruckeri* infection. Aquac Int. 2017;25(5):1987–1996.
170. Nya EJ, Austin B. Development of immunity in rainbow trout (*Oncorhynchus mykiss*, Walbaum) to *Aeromonas hydrophila* after the dietary application of garlic. Fish Shellfish Immunol. 2011;30(3):845–850.
171. Esmaeili M, Abedian Kenari A, Rombenso A. Immunohematological status under acute ammonia stress of juvenile rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) fed garlic (*Allium sativum*) powder-supplemented meat and bone meal-based feeds. Comp Clin Path. 2017;26(4):853–866.
172. Abdel-Tawwab M, Khalil RH, Diab AM, Khallaf MA, Abdel-Razek N, Abdel-Latif HM, Khalifa E. Dietary garlic and chitosan enhance the antioxidant capacity, immunity, and modulate the transcription of HSP70 and Cytokine genes in Zearalenone-intoxicated European seabass. Fish Shellfish Immunol. 2021;113:35–41.
173. Choi W, Hamidoghli A, Rivero CJ, Bae J, Lee S, Lee BJ, Hur S, Han H, Choi YH, Bai SC. Animal and plant proteins as alternative ingredients in diets for sub-adult olive flounder *Paralichthys olivaceus* at farm conditions. Aquac Res. 2022;53(7): 2739–2749.
174. Cho SH, Lee SM, Park BH, Park IS, Choi CY, Lee SM, Min BH, Hur SB, Lim YS. Effect of partial dietary substitution of meat meal for fish meal on the growth and body composition of the juvenile olive flounder *Paralichthys olivaceus*. J Fish Sci Technol. 2005;8(3):138–141.

175. Yang Y, Xie S, Cui Y, Lei W, Zhu X, Yang Y, Yu Y. Effect of replacement of dietary fish meal by meat and bone meal and poultry by-product meal on growth and feed utilization of gibel carp, *Carassius auratus gibelio*. Aquac Nutr. 2004;10(5):289–294.
176. Verreth J, Storch V, Segner H. A comparative study on the nutritional quality of decapsulated *Artemia* cysts, micro-encapsulated egg diets and enriched dry feeds for *Clarias gariepinus* (Burchell) larvae. Aquaculture. 1987;63(1–4):269–282.
177. Van der Meeren T, Olsen RE, Hamre K, Fyhn HJ. Biochemical composition of copepods for evaluation of feed quality in production of juvenile marine fish. Aquaculture. 2008;274(2–4):375–397.
178. Tavares LHS, Millan RN, Santeiro RM. Characterization of a plankton community in a fish farm. Acta Limnol Bras. 2010;22(1):60–69.
179. Ssanyu GA, Rasowo J, Auma E, Ndunguru M. Evaluation of plankton community structure in fish refugia acting as *Oreochromis niloticus* propagation and nursery units for rice/fish trials, Uganda. J Aquac Res Dev. 2011;2(4):100–116.
180. Case M, Enide EL, Sigrid N, Eneida ES, Ralf S, Antonio TMJ. Plankton community as an indicator of water quality in tropical shrimp culture ponds. Mar Pollut Bull. 2008;56(7):1343–1352.
181. Ashour M, Abo-Taleb H, Abou-Mahmoud M, El-Feky MMM. Effect of the integration between plankton natural productivity and environmental assessment of irrigation water, El-Mahmoudia Canal, on aquaculture potential of *Oreochromis niloticus*. Turk J Fish Aquat Sci. 2018; 18(10):1163–1175.
182. El-Hassan S, Azab MA, Abo-Taleb H, El-Feky M. Effect of replacing fish meal in the fish diet by zooplankton meal on growth performance of *Dicentrarchus labrax* (Linnaeus, 1758). Egypt J Aquat Biol Fish. 2020;24(6):267–280.
183. Martín GJ, Pentón G, Noda Y, Milera M, Olivera Y, Valenciaga N, Lezcano JC. Management of *Morus alba* L. (mulberry). In: Valdes LLS, Borroto OG, Perez GF, editors. Mulberry, Moringa and Tithonia in Animal Feed, and Other Uses. Results in Latin America and the Caribbean. Rome: FAO; 2017: 1–28.
184. Martín GJ, Montejo JI, Milera MC, Garcia DE. Chemical composition and nutritive value of mulberry (*Morus alba*) in animal feeding. In: Valdes LLS, Borroto OG, Perez GF, editors. Mulberry, Moringa and Tithonia in Animal Feed, and Other Uses. Results in Latin America and the Caribbean. Rome: FAO; 2017: 29–42.
185. Mondal K, Kaviraj A, Mukhopadhyay PK. Introducing mulberry leaf meal along with fish offal meal in the diet of freshwater catfish, *Heteropneustes fossilis*. Electron J Biol. 2011;7(3):54–59.
186. Araújo JR, Santos LD, Silva LCR, Santos O, Meurer F. Digestibilidade aparente de ingredientes do Semi-Árido Nordestino para tilápia do Nilo. Cienc Rural. 2012;42(5):900–903.
187. Santos LD, Sousa SMN, Silva LCR, Bombardelli RA, Meurer F. Pelleting and extrusion effects on the digestibility of alternative ingredients in Northeast Semi-arid for Nile tilápia. Semina Cienc Agrar. 2014;35(6):3367–3376.
188. Boscolo WR, Hayashi C, Meurer F. Apparent digestibility of the energy and nutrients of conventional and alternative foods for Nile tilapia (*Oreochromis niloticus*, L.). Rev Bras Zootec. 2002;31(2):539–545.
189. FAO. FAOSTAT. Rome: Food and Agriculture Organization of the United Nations; 2012.
190. New MB. Feed and Feeding of Fish and Shrimp: A Manual on the Preparation and Presentation of

Compound Feeds for Shrimp and Fish in Aquaculture. Rome: FAO; 1987.
191. Nisha SN, Jothi BA, Geetha B. Growth performance and haematological parameters of the ornamental fish (*Maylandia estherae*), fed varying inclusion of silkworm pupae meal. Adv Biol Res. 2014;8(6):268–273.
192. Miles RD, Chapman FA. The benefits of fish meal in aquaculture diets. Gainesville: Department of Fisheries and Aquatic Sciences, University of Florida; 2006. Circular 122.
193. Hasan MR. Studies on the use of poultry offal and silk worm pupae as dietary protein sources for Indian major carp, *Catla catla* (Hamilton). Bangladesh J Agric Sci. 1991;18(1):51–56.
194. Hora SL, Pillay TV. Handbook of Fish Culture in the Indo-Pacific Region. FAO Fish Biol Tech Pap. 1962; (14):904.
195. Sawhney S. Effect of partial substitution of expensive ingredient i.e. fish meal on the growth of *Tor putitora* fed practical diets. J Int Acad Res Multidiscip. 2014;2(7):150–158.
196. Srikanth GK. Growth response of *Tor khudree* (Sykes) to pelleted feeds containing different sources of protein. Punjab Fish Bull. 1986;10(2):45–54.
197. Nandeesha MC, Srikanth GK, Keshavanath P, Varghese TJ, Basavaraja N, Das SK. Effects of non-defatted silkworm-pupae in diets on the growth of common carp *Cyprinus carpio*. Biol Wastes. 1990;33(1):17–23.
198. Rana KJ, Siriwardena S, Hasan MR. Impact of rising feed ingredient prices on aquafeeds and aquaculture production. Rome: Food and Agriculture Organization of the United Nations; 2009. FAO Fisheries and Aquaculture Technical Paper No. 541.
199. Nandeesha MC, Srikanth GK, Varghese TG, Keshavanath P, Shetty HP. Influence of silkworm pupae based diets on growth organoleptic quality and biochemical composition of catla-rohu hybrid. In: Aquaculture Research in Asia: Management Techniques and Nutrition. Proceedings of the Asian Seminar on Aquaculture; Malang, Indonesia; 1988: 211–220.
200. Karthick Raja P, Aanand S, Stephen Sampathkumar J, Padmavathy P. Silkworm pupae meal as an alternative protein source in aquafeed: a review. J Entomol Zool Stud. 2019;7(3):885–890.
201. Rana KJ, Siriwardena S, Hasan MR. Impact of rising feed ingredient prices on aquafeeds and aquaculture production. Rome: Food and Agriculture Organization of the United Nations; 2009. FAO Fisheries and Aquaculture Technical Paper No. 541.
202. Ji H, Zhang JL, Huang JQ, Cheng XF, Liu C. Effect of replacement of dietary fish meal with silkworm pupae meal on growth performance, body composition, intestinal protease activity and health status in juvenile Jian carp (*Cyprinus carpio* var. Jian). Aquac Res. 2015;46(5):1209–1221.
203. Shyama S, Keshavanath P. Growth response of *Tor khudree* to silkworm pupa incorporated diets. Colloq INRA. 1993;61:201–206.
204. Shakoori M, Gholipour H, Naseri S. Effect of replacing dietary fish meal with silkworm (*Bombyx mori*) pupae on hematological parameters of rainbow trout *Oncorhynchus mykiss*. Comp Clin Pathol. 2015;24(1):139–143.
205. Hossain MA, Nahar N, Kamal M, Islam MN. Nutrient digestibility coefficients of some plant and animal proteins for tilapia (*Oreochromis mossambicus*). J Aquac Trop. 1992;7(2):257–266.
206. Oso JA, Iwalaye OA. Growth performance and nutrient utilization efficiency of *Clarias gariepinus* juveniles fed *Bombyx mori* (Mulberry silkworm) meal as a partial replacement for fishmeal. Br J Appl Sci Technol.

2014;4(26):3805–3812.
207. Panda B. Silkworm pupae meal. Indian Poult Gaz. 1968;53(2):29–30.
208. Habib MA, Hasan MR, Akand AM, Siddiqua A. Evaluation of silkworm pupae meal as a dietary protein source for *Clarias batrachus* fingerlings. Aquaculture. 1994;124(1–4):62.