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A review of fish meal replacement with fermented biodegradable organic wastes in aquaculture

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Abstract
Fishmeal (FM), serves as the prime source of dietary protein in the formulated feed of carps and catfish. However, FM is a costly ingredient in the formulated feed and is being gradually scarce due to continuous growth in aquaculture with subsequent requirement of FM in the formulation of feed and demand of FM in other animal husbandry resources. Therefore, in recent years intensive researches have been conducted to search less expensive alternative protein sources among plant and animal wastes in order to reduce aquaculture production cost. However, there are inherent problems of using these wastes as feed stuff including poor digestibility and cross contamination by hazardous microorganisms. Fermentation has been found to be a convenient, environment friendly and cost effective technique to remove these difficulties and render the wastes as suitable supplement to replace FM in fish feed formulation The main objectives of this review was to explore possibilities of utilizing abundantly available organic wastes as feed stuff to replace FM in the formulation of feed for fish after processing through microbial fermentation, to find out a cost effective pathway for aquaculture industry.

Keywords: Fish meal, organic wastes, fermentation, aquaculture

1. Introduction
At present, more than 30% of human population across the globe is suffering from malnutrition [1]. The problem is most acute in developing and under developed countries where people cannot afford to buy costly nutrient rich food products to overcome the problem of malnutrition. Aquaculture presents a potential means to provide a cheap source of protein in the form of fish to overcome the problem of malnutrition in developing and under developed countries. As a result FAO has given importance on aquaculture which is growing @ 8.2% year^{-1} as a food production sector [1, 2]. But human demand for food fish is estimated to increase approximately to 150 million metric tons by the year of 2030 [3], especially in developing countries where fish is the primary source of dietary protein [4]. This has made several aqua culturists to engage in researches to develop aquaculture practice that curtail cost of production of fish and present it as a chief source of protein.
Fishmeal (FM) is considered as one of the most ideal source of protein for fish feed. FM enhances growth of fish through better feed palatability, nutrient uptake, digestion and absorption. FM has high biological value as a feedstuff, because it contains high level of digestible essential amino acids (EAA) such as lysine, methionine and leucine, low content of fiber and adequate quantity of vitamins (B1, B2, B6 and B12) and minerals (calcium, phosphorous, magnesium, potassium and trace elements including zinc, iodine, iron, copper, manganese, cobalt, selenium, and fluorine) [5, 6]. Thus FM is able to supply required amount of EAA to fish [7, 8].
Despite its static global production, seasonal or geographical variability in quality and composition [9], FM continues to serve as the most dependable source of protein in the formulated feed for fish [7, 8]. Aquaculture feeds typically have a higher percentage of FM than feeds for other animal species. As a result, 46% of the total annual FM produced is used to generate aquaculture feeds. Due to sharp increase in the aquaculture practice, currently the aquaculture production has accounted for 68% of the global FM consumption, causing an increase in the price of FM, which rose from about US$600 per metric ton in 2005 to about US$1500 per metric ton in the first quarter of 2013 [10; 11]. However, level of FM inclusion in the formulation of feed varies with species of fish and is based on the feeding habit and nutrient utilization capabilities of the species concerned [12].

In India aquaculture is a growing industry. But freshwater aquaculture production in the country is constrained by inadequate production of formulated feed [13]. While there is an adequate domestic feed ingredient resource base in the country, the huge gap between requirement and production of formulated fish feed is mainly due to poor production of quality fishmeal [14], necessitating import of fishmeal from abroad or relying on non-conventional sources of animal and plant protein resources. As a result, in recent years there have been intensive researches to find economically viable, environmental friendly and sustainable alternative protein source to reduce or eliminate the use of FM in the commercial aquaculture operation system in India [15, 16] and abroad [17, 18, 19, 20].

2. Necessity of alternative protein source in aquaculture industry

Exponential growth of aquaculture industries in India since last one decade has necessitated an increase in the production of formulated feeds in order to maintain a high production and steady supply of fish to the markets. This in turn has increased the cost of production of fish, because formulated feed alone accounts for up to 70% of the total cost in a commercial aquaculture operation [3, 21]. The rapid growth of aquaculture has also resulted in higher demand for fishmeal (FM), which serves as the prime dietary protein source in the formulated feed for aquaculture [7, 8]. In modern aquaculture practice several kinds of freshwater carps and catfish are used as farmed fish [1] and FM has been found as the best dietary protein source for these species because of its palatability, availability of essential amino acids and fatty acids and high digestible energy content [22]. But FM is the single most costly ingredient in the formulated feed and its price is expected to be further increased by continuous growth in aquaculture and subsequent requirement of FM in the formulation of feed [23]. There is also acute scarcity in the supply of FM because of equally high demand of this protein source from other animal husbandry practices and uncertainty in the supply of wild trash fish, the major source of FM [24].

Although, economically sound entrepreneurs holding large units of aquaculture can afford to buy high cost formulated feed and maintain aquaculture production, it is difficult for marginal rural farmers to buy the costly aquaculture feed supplemented by FM, leaving a big question of sustainability of aquaculture in the country. Therefore, in order to make aquaculture sustainable it is an urgent need to minimize the use of FM in fish feed formulation and to render the formulated feed as less expensive [12]. In recent years intensive researches have been conducted on replacement of FM by various less expensive alternative protein sources from plant and animal origin.

2.1 Plant by-products as alternative protein source

The efficiency of various plant by-products treated as partial and total replacer of FM in aquaculture feed has been investigated by a number of workers because of their easy accessibility, availability and protein quality. Mulberry leaves, water hyacinth, duck weeds, legumes, cassava leaves, barnyard grass are some common by-products used as a protein sources in fish feed [25, 26, 27, 18]. Among these plant by-products, utilization of nutrient rich mulberry leaves as aquaculture feed ingredient is gaining importance in recent years because of its huge disposal form sericulture industries [16]. Cauliflower leaves, a nutrient rich by-products generated from retail markets along the Indian sub-continent are also treated as wastes and disposed without any scope of recycling [28]. Incorporation of cauliflower leaves in the diet of terrestrial animals has been suggested previously [29]. However, this plant resource has not so far been experimented in fish diet to a great extent. Intense research effort during the last two decades, clearly documented that replacement of FM protein by plant protein (PP) was feasible in fish feed formulation and could potentially improve the sustainability, predictability and access with cost effectiveness of the feed [30, 18, 26]. During feed formulation replacement of 20–75% of marine protein sources / FM by various plant protein ingredients have been tested in *Cynoglossus macrolepidotus* [31], *Scophthalmus maximus* [32] *Sparus aurata* [33] *Lates calcarifer* [34], *Salmo salar* [35] and *Labeo bata* [27]. And limited to moderate successes have been reported. However, in comparison to wastes from animal industry there are some disadvantages of using plant ingredients as feed stuff. This has been discussed in detail below.

2.2 Animal by-products as alternative protein source

By-products generated from animal product processing industries contain better quality protein with higher amount of EAA as compared to plant protein sources [36, 37]. Some of the nutrient rich by-products generated from livestock, treated as wastes and are frequently used in fish feed formulation. India ranks as world's top most livestock holding country and produces huge amount of wastes during slaughtering [38]. Amount of wastes generated from slaughter houses is estimated to be more than 21 lakh tones/year in India, wastes generated from slaughter houses include blood, condemned offal and carcasses [39, 15]. After processing these are used as blood meal, meat and bone meal etc. in fish feed formulation [40, 41] Blood meal is most popular as feed stuff because of its high protein content and good lysine value [42]. However the rate at which blood meal is used to replace FM varies with the species of fish. Nengas *et al*., (1999) [43]. Observed that FM replacement at 75–100% level was possible with a high quality blood meal in the diet of *Sparus aurata*. Successful data on total replacement of FM with blood meal containing diet was found in catfish, *Clarias gariepinus* [44]. However, higher level of blood meal inclusion in the diets of Siberian sturgeon inhibited protein metabolism [8]. El-Sayed (2003) [45]. Found that in *Oreochromis niloticus* a blood meal with meat and bone meal mixture resulted in lower growth performances as compared to FM based diet. Lee *et al*. (2001), found that meat and bone meal alone could replace up to 30% of FM protein in diets for juvenile rainbow trout without any adverse effect on growth.

Wastes generated during slaughtering in poultry processing plants are also promising feedstuff in fish feed formulation. Poultry by-products show similarities with FM on the basis of nutritional composition [22]. Positive results on the utilization of feed that contains poultry by-product meal as FM replacer have been reported in *Nibea miichthioides* [47], *Morone* sp. and in many other fish, exhibiting successful growth performances [48, 49, 50]. Williams (2008) reported poultry by-product meal as protein stuff in the diet of *Trachinotus carolinus*. Hydrolyzed feather meal used as protein supplement was able to replace FM successfully @ 50% in tilapia [52], but only 20% in *Labeo rohita* [53]. Subhadra *et al*., (2006) successfully used blood meal of poultry as FM replacer while visceral portion of poultry has also been used as FM replacer by many workers in fish feed formulation [55, 56, 37].

By-products generated from fish processing industries serve as good source of protein, lipid and minerals. Heads, bones, scales, skin, viscera, fat and sometimes whole fish are generated as wastes from these industries, and are converted to valuable aquaculture feed ingredients [57]. World landings of finfish and shellfish are approaching 100 million metric tons / year [1]. Processed fish silage is some of the ingredients of fish processing industries used as FM replacer in fish feed formulation in recent years [58]. Mondal (2010) successfully used fish offal wastes, generated from wholesale fish markets around Kolkata (India), to partially replace FM in the diet of *Labeo rohita, Labeo bata* and *Heteropneustus fossilis*. Squid by-product meals containing excellent sources of high quality marine protein were used as feeding stimulant in the diets of *Carassius gibelio, Lutjanus campechanus* and *Pagrus major* [60, 61, 62]. Most promising result was however presented by Cavalheiro *et al*., (2007) who observed that 100% replacement of FM was possible with shrimp head silage in the diet of tilapia without compromising growth performance, though nutritive value of fish flesh was better in lower level of shrimp head wastes application.

3. Constraints of biodegradable organic wastes as feed stuff

Some of the biodegradable organic by-products are treated as wastes in Indian sub-continent. Such unconventional protein sources have been used in fish feeds for decades to make economical solution for the aquaculture industry. However, their direct and sole inclusion into diet has been greatly limited or even avoided for various reasons, such as poor digestibility and cross contamination by hazardous microorganisms [64, 65, 59]. Some of the common animal wastes generated from poultry processing industry and slaughter houses exhibited potentiality to replace dietary FM in many fish showed low digestibility [66, 67]. These constraints need to be addressed before inclusion of these ingredients as a feedstuff for fish [18]. Problem associated with the application of raw organic wastes (animal and plant wastes) is the presence of undesirable microorganisms in these wastes which may result in food borne illnesses in animals. Some of these microorganisms including coliform, *Salmonella* and clostridia are also responsible for food borne illness and some others like *Staphylococcus, Listeria*, bacilli, yeasts, and molds are responsible for aerobic spoilage. Among these the most common food poisoning agents are *Staphylococcus aureus, Salmonella* sp., *Clostridium perfringens, Listeria monocytogenes, Bacillus cereus,* and *Escherichia coli* [68].

4. Fermentation-a tool to convert animal wastes as fish feed ingredient

Fermentation is an environment friendly, cost effective technique, which can efficiently decrease or eliminate anti-nutritional constituents [69], reduce microbial load [70] and improve overall nutritional quality and digestibility [71] of ingredients before these are used in the formulation of feed for fish [72]. Fermented animal wastes have been widely used by several workers to replace FM in aquaculture feed to a satisfactory level. Rao *et al*., (1996) applied fermented fish offal to replace FM in the formulation of feed for *Cyprinus carpio*. Mondal *et al*., (2007) observed that fermented fish offal could replace 30% FM in the feed of *Labeo rohita* and *Heteropneustes fossilis*. Similar replacement in the feed of *Labeo bata* rendered 134% commercial benefit in yield [26]. Yano *et al*. (2008) also recommended use of fermented fishery wastes as potential FM replacer. Fagbenro *et al*. (1994) found lactic acid fermented fish silage could partially replace FM in the diet of *Clarias gariepinus* and *Oreochromis niloticus*. Kader *et al*. (2012) was able to replace 36% of FM protein in the diet of *Paralichthys olivaceus* with a fermented blend of soya bean and squid by-product meal. Besides fish wastes plenty of other animal wastes have been fermented in order to use as FM replacer. Bertsch and Coello (2005) used a strain of keratinolytic bacteria to obtain fermented poultry feather meal containing 71% of crude protein value with improved bioavailability of amino acids to include it into the diet of fish. Hasan *et al*. (1997) was able to replace 50% FM protein with fermented poultry feather meal in the diet of *Labeo rohita*. Biswas *et al*. (2003) found promising growth performance of *Heteropneustes fossilis* fed a diet with replacement of FM by fermented slaughter house wastes.

Lactic acid bacteria (LAB) play important roles in the fermentation of organic wastes. Besides carrying out fermentation, LAB inhibit growth of myriad kinds of putrefactive and food poisoning microorganisms present in the organic wastes [77]. During fermentation LAB produce two principal metabolites, lactic acid (LA) and acetic acid (AA), which are primarily responsible for reduction in of the pH level of the medium [78] and check the growth of hazardous microorganisms. Quick drop of pH to a desirable end point (4.0–4.2) was found necessary for maintaining microbial hygiene along with retaining quality of the product as an aquaculture feed stuff [79]. Milk and fermented dairy products are rich source of LAB, having good property to preserve food beverages [80]. Whey is generated as a by-product in yogurt production in the dairy industry. After yogurt is produced whey is disposed as a liquid effluent thereby creating threats of pollution of terrestrial and aquatic environments. However, whey is a potential source of LAB and may serve as a viable inoculum for fermentation of organic wastes. A few authors have attempted to develop biotechnological methods to recycle whey for its utilization in other industries and minimize environmental pollution arising out of disposal of whey [81, 82]. In the present study attempts have been made to use whey as source of LAB and as a potential inoculum to ferment and convert organic wastes as feed stuff in the formulation of feed for fish.

5. Fishmeal replacement with fermented organic wastes

Fermentation is a strong tool to reduce unwanted microbial load form biodegradable organic wastes and is discussed precisely in the upcoming parts of the review. Besides which, during fermentation substrate's protein get hydrolyzed and low molecular weight (less than 10 KD) proteins (peptides and amino acids) are produced, some of which have immunomodulatory effects and render increased palatability and digestibility in animals. Therefore, fermentation of protein resources probably enhances health parameters of fish [76]. Fermented biodegradable organic wastes have been successfully used by several workers to replace FM in aquaculture feed formulation. Fermentation of organic wastes generated from fish industries and their recycling through aquaculture is gaining importance. Fermented fish offal containing diet was able to replace 30% of FM in the diet of *Labeo rohita, Heteropneustes fossilis* [72, 84].

6. Concluding remarks

Interest in the use of nutritional strategies in aquaculture to reduce waste output and minimize the environmental impact

through recycling organic wastes has grown tremendously over the past two decades. The review of the published data showed that fermentation is a potential way to convert potential biodegradable organic wastes into feed stuff for fish in an ecofriendly and cost effective manner of microbial fermentation. These have resulted in a significant reduction in waste outputs with reduction of feed cost in aquaculture. The number of research publications is ever expanding and covers an increasing number of cultivable fish species. Conversely, it is interesting to note that only minor improvements have been achieved in practice for so-called omnivorous fish species mainly by utilizing organic wastes as feed stuff after processing through fermentation.

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