Backyard farming of tilapia using a biofloc-based culture system

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ABSTRACT

The pressures brought about by the increase in human population resulted in the rapid expansion of the food production industries including aquaculture to provide the nutritional requirements of the growing population. As aquaculture operations intensify, there is also an urgent need to preserve the environment; hence, all activities must be carried out in a sustainable way. The use of the biofloc technology (BFT) in aquaculture addresses these issues on restrictions on the usage of water and land as well as matters concerning sustainability of the production. BFT is a technique that maintains optimum water quality in the aquaculture system by manipulating the carbon and nitrogen ratios in the system. This optimum ratio favors the growth of heterotrophic bacteria that contribute in maintaining good water quality and at the same time provide sources of natural food for the cultured fish or crustaceans. In this review, the mechanisms of the biofloc technology particularly in the production of tilapia in freshwater systems are discussed. Moreover, some of the intrinsic advantages of this technology are highlighted in the context of developing and supporting backyard aquaculture of freshwater tilapias as a means of providing the food demands of the population in rural communities and as source of income for the marginalized small-scale fish farmers.

Keywords: BFT, fish farming, small-scale aquaculture, sustainable technology

INTRODUCTION

Global population is expected to reach 9.6 billion people by 2050 and it is important that the food demands of the growing population are met while safeguarding the world's natural resources for future generations (FAO 2014). In this regard, aquaculture has a crucial role in the elimination of hunger, promotion of good health, reduction of poverty and in the provision of jobs and economic opportunities. According to FAO (2014), fish production from

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aquaculture is expanding at an annual rate of at least 6%. This sector provides jobs and supports livelihood of the population and proof of that is the fact that fish continues to be one of the most traded food commodities worldwide. In some cases, there are developing countries where fish and aquatic products would constitute half the total value of their traded commodities (Emerenciano et al. 2013).

Due to the rapid expansion of aquaculture, several technologies have been developed to ensure increased and sustainable production of fish and crustaceans. An example of such technology is biofloc technology or commonly known as BFT. This technology is an aquaculture practice that is based on natural processes that are widely occurring in the aquatic ecosystem. According to Emerenciano et al. (2013), BFT is considered as the new "blue revolution" because nutrients are continuously recycled and reused during the culture phase and at the same time there is minimum or zero-water exchange. The sustainable approach of this system is based on the high production of fish or shrimp in small areas but with minimal or zero discharge of wastewater back to the source, thereby reducing the ecological footprint. In addition, the bioflocs which are the products of this aquaculture technology are rich in proteins and lipids that could serve as natural sources of food for the cultured stock. These food resources are available in the culture system all day long as a result of the complex interaction between organic matter, the physical substrate and wide array of microorganisms (Emerenciano et al. 2013). The natural productivity in a biofloc-based aquaculture system enables the recycling of nutrients and maintaining the water quality in the pond or tank. The consumption of biofloc by shrimp or fish has resulted in a wide range of benefits including improvement of growth, decrease in feed conversion ratio (FCR) and associated costs in feed (Avnimelech 2015; Choo and Caipang 2015). In this type of aquaculture system, the growth of heterotrophic bacteria that assimilate the toxic ammonia-N from the water, and the corresponding increase in bacterial biomass is facilitated through supplementation of external organic carbon sources (Azim and Little 2008). This microbial biomass may further form aggregates with other micro- and macro-organisms including phytoplankton and zooplankton; hence the term "bioflocs" (Hari et al. 2004). Bioflocs are a rich source of growth promoters and bioactive composites, which enhance both the digestive enzymes and the health status of the aquatic organism (Hari et al. 2004; Choo and Caipang 2015).

This review discusses the mechanisms of the biofloc technology particularly in the production of tilapia in freshwater systems. Moreover, some of the intrinsic advantages of this technology are elucidated in the context of developing and supporting backyard aquaculture of freshwater tilapias as a means of answering the food demands of the population in rural

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communities as well as a source of livelihood for the marginalized small-scale fish farmers.

THE BIOFLOC-BASED CULTURE SYSTEM

The biofloc technology as a type of an aquaculture system was believed to have started in the early 70s in France by IFREMER-COP (French Research Institute for Exploitation of the Sea - Oceanic Centre of Pacific) using shrimp as the main species for culture, with the concept being likened to an external rumen (Cuzon et al. 2004; Emerenciano et al. 2012b). In 1980, the Ecotron Science Program was started by IFREMER to better understand how such systems work through intensive research (Emerenciano et al. 2013). Later, research initiatives on BFT began in the USA and Israel in the late 80s and early 90s, respectively. The main focus of those activities was to develop an aquaculture technology using tilapia as a model culture species with the driving force of limiting water and land usage, as well as to finding ways of reducing the negative environmental impacts of the prevailing aquaculture practices (Emerenciano et al. 2013; Hargreaves 2013). The first commercial application of the biofloc concept took place at the Sopomer farm in Tahiti and at the Belize Aquaculture farms in 1988, where shrimp were reared in biofloc systems (Emerenciano et al. 2013). Today, BFT systems are being commercialized on a global scale, with tilapia and shrimp as the major species being used (Avnimelech 2015).

There are a few types of biofloc systems that are being used in both commercial aquaculture and in research. The two basic types of biofloc systems are those that are exposed to natural light and those that are not (Hargreaves 2013). Biofloc culture systems that are exposed to natural light include outdoor, lined ponds or tanks that are used for the culture of shrimp or tilapia. In this system, a complex mixture of algal and bacterial processes helps to control the water quality; hence, these are also known as the "greenwater" biofloc due to the greenish coloration of the water as a result of the dominance of the algal community. However, there are some biofloc systems that are not exposed to natural light, but are situated indoors with no exposure to natural light. This type of system operates as a "brown-water" biofloc, where only bacterial processes predominantly control the water quality (Pérez-Rostro et al. 2014; Hargreaves 2013)

The biofloc-based culture system is based on the principle of assimilating the dissolved ammonia-nitrogen (TAN) that is excreted by fish as metabolic waste and also through the breakdown of organic nitrogen such as uneaten fish feeds by heterotrophic bacteria and converting them into microbial protein (Avnimelech 1999; Hargreaves 2006; Crab et al. 2012). Figure 1 shows the general mechanisms of a biofloc-based culture system that is commonly used in the farming of fish and crustaceans. The excretion of

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nitrogenous metabolic wastes and their subsequent assimilation by heterotrophic bacteria create a balance through the manipulation of the carbon-to-nitrogen ratio (C:N ratio) by adding various organic carbon sources to the water. The production of the heterotrophic bacterial biomass further results in the formation of macro-aggregates known as bioflocs. These bioflocs are composed of not only the bacteria but also other microorganisms including microalgae, zooplankton and trapped organic and inorganic particles (Hargreaves 2013). This concept is based on the production of predominantly heterotrophic bacteria, which can be attained by increasing the carbon to nitrogen ratio (C:N) within the water of the culture environment through the addition of organic carbon sources (Avnimelech 2015). In a biofloc-based culture system, the water is well-aerated and vigorously mixed

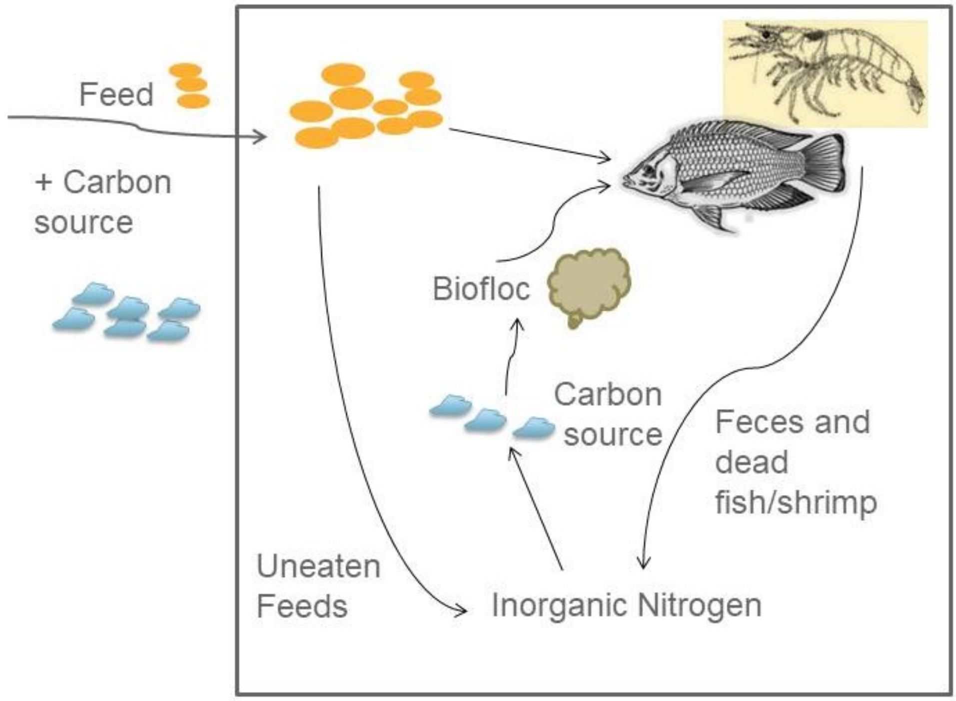

Figure 1. Mechanisms of the production and maintenance of bioflocs in ponds and tanks. Adapted from Crab et al. (2012)

to ensure that the heterotrophic bacteria remain in suspension and proliferate, and will have continuous supply of the nitrogenous compounds from fish wastes and excess feeds. The amount of nitrogen is the limiting factor to the growth of the heterotrophic bacterial community (Hargreaves 2013; Avnimelech 2015); hence, sufficient aeration and mixing are required to keep the flocs in suspension within the water column, thereby keeping the water quality controlled (Hargreaves 2013). The mixing has a critical role in keeping

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the bioflocs in suspension, which also prevents anoxic conditions from developing at the bottom of the ponds or tanks (Avnimelech 2015). Table 1 shows some of the critical parameters that must be met and how these parameters are manipulated to ensure successful production of bioflocs in the rearing environment. By successfully implementing a BFT system in the farming of fish and crustaceans, the benefits can be attained in the following ways: firstly, toxic nitrogen species (especially the un-ionized ammonia) are eliminated from the water *in situ*, thus avoiding the need for expensive filtration systems, and at the same time allowing for higher stocking densities than that being practiced in extensive systems (Hargreaves 2013). Secondly, nutrients are recycled from the waste and converted into microbial protein by the bioflocs, which are then utilized by some filter-feeding aquatic organisms including tilapia and shrimp; hence, it significantly reduces the need for the provision of formulated feeds without adversely affecting the growth rate of the cultured stock (Avnimelech 2015). It should be noted that the optimum stocking densities for semi- or intensive systems that are being used for the culture of either tilapia or shrimp will likely be similar to those systems that will employ biofloc technology. The added benefits of using BFT in the culture system are discussed in the succeeding section of this review.

Table 1. Water parameters in a biofloc-based culture system and strategies in optimizing their effects on the production and maintenance of biofloc.

Water Quality Parameter	**Floc Parameter/s Being Affected**	**Manipulation Strategies**	**Impact on other Water Quality Parameter**
Water mixing/aeration	Floc structure and size	Choice of power input and type of aeration device	Dissolved oxygen
Organic carbon source	Chemical floc composition	Type of organic carbon source	Organic loading rate; Dissolved oxygen
Loading rate of organic matter	Microbial floc composition; chemical floc composition	Feeding strategy	Dissolved oxygen
Dissolved oxygen (DO)	Microbial floc composition; floc structure and volume	Choice of power input; Aeration device	Mixing intensity; Source of organic carbon
Temperature	Floc structure and activity	Addition of heat	Dissolved oxygen
pH	Floc stability	Addition of acid/base	Alkalinity; Conductivity

The data provided were adapted from Rathore et al. (2016).

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The microbial community which is composed predominantly of heterotrophic bacteria in the water acts as a biofilter. Their presence results in a faster rate of increase in nitrogen uptake and reduced ammonia levels in comparison with the natural nitrification process (Avnimelech 1999; Crab et al. 2012). Biofloc systems have very low water exchange, and thus have a significantly lower impact on the surrounding environment through lesser water requirements and minimal or zero discharges of effluents (Avnimelech 2007 2012; Hargreaves 2013). Degradation of the environment is further reduced by the lower amount of pelleted feeds that are given to the cultured stock and the higher efficiency in recycling nutrients from the fish waste and uneaten feeds (Hargreaves 2013). With all these benefits, it is not surprising that large scale BFT systems have been set up in various parts of the world, with the smaller scale greenhouse biofloc systems having a wider application (Emerenciano et al. 2013).

The carbon to nitrogen ratio (C:N) has an integral part in the BFT system (Hargreaves 2013). It is through this ratio that effectively regulates the proliferation of heterotrophic bacteria, which are generally limited by the availability of organic carbon (Avnimelech 1999; Michaud et al. 2006; Emerenciano et al. 2013; Hargreaves 2013; Luo et al. 2014). By increasing the C:N ratio, the growth and production of heterotrophic bacteria is enhanced, and ammonia is taken up from the water and converted into microbial biomass that is rich in protein (Hargreaves 2013). The critical point of this ratio where heterotrophic bacteria will dominate nitrifying bacteria is variable depending on the type and quality of the organic carbon sources that are being used in the production of bioflocs (Michaud et al. 2006). For example, Luo et al. (2014) recommended that in a BFT system the C:N ratio should be maintained at greater than 10:1, while Hargreaves (2013) suggested that it should be closer to 12-15:1 to support the heterotrophic pathway. On the other hand, Emerenciano et al. (2013) pointed out that the optimal ratio of C:N is at the range of 15-20:1. From these studies, it is evident that there is no fixed C:N ratio, but all biofloc researchers are in agreement that the C:N ratio must be sufficiently elevated and this can be achieved through the provision of an additional organic carbon source to the water of the rearing environment.

In practice, the choice of an organic carbon source is largely dependent on the availability of a cheap carbon source that is near to where the BFT system is located (Emerenciano et al. 2013). A range of organic carbon sources such as wheat bran (Emerenciano et al. 2011; Emerenciano et al. 2012a), molasses (Burford et al. 2004;), glucose (Crab et al. 2010), cellulose (Avnimelech et al. 1989), cassava meal (Avnimelech and Mokady 1988; Chen et al. 2015), sorghum meal (Avnimelech et al. 1989; López-Elías et al. 2015), sweet potato flour (Caipang et al. 2015), wheat flour (Azim and Little 2008; Xu et al. 2012) and corn/maize meal (Milstein et al. 2001; Asaduzzaman et al. 2010; Xu et al. 2012) has been tested and proven to be

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effective in producing and maintaining biofloc volume and density in the culture system. Table 2 shows some of the carbon sources that were tested for the maintenance of biofloc in selected aquaculture species. Wheat flour, starch, corn starch and cellulose were commonly used in tilapia culture, while wheat bran, molasses and glycerol were the common carbon sources in shrimp biofloc systems. The organic carbon source is linked to the feeding rate and is usually added to the water once, or twice a day and usually after feeding has taken place (Avnimelech 1999; Azim and Little 2008; Xu et al. 2012). The practical application and the specific routine when to add the organic carbon source is dependent on the nature of the BFT system that is being implemented (Avnimelech 1999). Before stocking of fish or crustaceans, biofloc-based culture units are thoroughly prepared for a number of weeks, where the water is seeded with biofloc water from an existing BFT pond or tank followed by fertilization with the organic carbon source and allowing the bioflocs to be produced and stabilized in the water column (Avnimelech 2012; Hargreaves 2013). Ekasari et al. (2014) recommended a three-week period of preparation until the total suspended solids (TSS) will exceed a concentration of 500 mg/L. Once this concentration is reached, stocking of fish or shrimp juveniles will commence. This recommended time frame is also in agreement with the suggestion of Avnimelech (2012). It should be noted that the water quality parameters fluctuate throughout this period of biofloc establishment and the various water quality parameters must be strictly monitored to ensure that these levels are within the optimum range for the rearing of either fish or crustaceans.

Table 2. Sources of organic carbon that are used for the production and maintenance of bioflocs in tilapia and shrimp culture.

Source of organic carbon	Cultured species
Acetate	*Macrobrachium rosenbergii*
Cassava meal	*Penaeus monodon*
Cassava flour	*M. rosenbergii*; *Litopenaeus vannamei*; *Oreochromis* sp.
Cellulose	*Oreochromis* sp.
Corn flour	*Orecochromis* sp.
Dextrose	*L. vannamei*
Glucose	*M. rosenbergii*
Glycerol	*M. rosenbergii*
Molasses	*L. vannamei*; *P. monodon*
Sorghum meal	*Oreochromis* sp.
Starch	*Oreochromis* sp. and their hybrids
Wheat flour	*Oreochromis niloticus*
Wheat bran and molasses	*Farfantepenaeus brasiensis*; *Farfantepenaeus paulensis*

The data were modified from Caipang et al. (2015) and Rathore et al. (2016).

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Most BFT systems are often situated in areas where there is scarcity of water supply. Limitations in the availability of water together with biosecurity issues in the aquaculture site have driven fish farmers to use the minimal to zero water exchange approach (Hargreaves 2013). The stability of zero or minimal water exchange depends on the dynamic interaction among communities of bacteria and other biotic communities that occur within the biofloc system. These aggregates of the microorganism help in the maintenance of the water quality and in the recycling of wastes to produce nutritious food for the cultured stock (Emerenciano et al. 2013). BFT is therefore perceived to be an environment-friendly aquaculture technique, with sustainability as the major issue it addresses (Widanarni et al. 2012).

ADVANTAGES OF BIOFLOC SYSTEM IN BACKYARD PRODUCTION OF TILAPIA

There are several factors that promote the implementation of the biofloc technique in aquaculture (Crab et al. 2012). Firstly, water has become scarce or expensive that it has become a limiting factor in aquaculture development. Secondly, the release of waste waters from the aquaculture sites into the environment is prohibited in some countries. Thirdly, severe outbreaks of infectious diseases resulted in the development of stringent biosecurity measures including the reduction of water exchange rates (Avnimelech 2015). Rathore et al. (2016) cited the many advantages of a biofloc-based system in the rearing of fish and crustaceans. These include its applications in the breeding, nursery and grow-out production of both shrimp and some species of fish as well as it can be integrated into the aquaponics system of fish and vegetable production. Because bioflocs harbor a number of microorganisms, it can also act as natural probiotics in the system (Avnimelech 1999).

The species that are chosen to be cultured in a BFT system must be able to tolerate sub-optimal water quality with high suspended solids, and must have the ability to obtain nutrition from the bioflocs through filter feeding (Crab et al. 2012; Hargreaves 2013). Furthermore, it is suggested by Crab et al. (2012) that the focus on the choice of the aquaculture species should be on the lower trophic species, which exhibit an herbivorous diet. Hargreaves (2013) indicated that shrimp, carp and tilapia meet these requirements and as a result they are being used as the species of choice in almost all BFT systems worldwide. To a certain extent, some studies have also shown the potential of using sturgeon and some species of catfish (Serfling 2006; Green et al. 2014).

Tilapia has been deemed as the fish of the 21st century (El-Sayed 2013), with a continued rise in its share of global fish production. Currently it

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is the most widely produced species around the world, with production being recorded in 135 countries (FAO 2014). The production systems for tilapia culture are usually simple extensive or modified semi-intensive systems, with only the basic techniques required for successful cultivation. This species of fish favors warmer water and because it can be easily cultured (El-Sayed 2013), tilapia shows great aquaculture potential in many developing countries that are located in warmer regions. The hardy nature of the species is evident in the wide range of environmental parameters that can be tolerated by tilapia (Boyd 2004; Jamandre et al. 2011). This trait is beneficial during the culture phase, where there may be a lack in the availability of effective mechanisms for water quality control and monitoring due to the nature of the prevailing systems. Even though tilapias are being positioned at a low-trophic level with its omnivorous feeding habits (Njiru et al. 2004; Fitzsimmons et al. 2011), they are able to effectively utilize a plant-based diet and the corresponding product at harvest is well accepted by the consumers (Andretto et al. 2015). The role of freshwater fish farming, identified as the major mechanism towards attaining food and protein security (FAO 2014), cements the place of tilapia in the future as a key aquaculture species in most developing countries. With large portions of the population in developing countries living below the poverty line, the potential for tilapia culture employing the basic culture methods is recommended.

Tilapia farming in biofloc systems is very promising because it uses minimal or zero water exchange, can be stocked at high densities, can reach high yields due to the availability of natural food by manipulating the C:N ratio in the water and better water quality because of the presence of microorganisms that remove and recycle nutrients (De Schryver et al. 2008; Crab et al. 2012; Emerenciano et al. 2013; Avnimelech 2012). Also, the physiological functions such as immune and antioxidant systems, which are essential for tilapias in maintaining their health and growth performance (Shourbela et al. 2017) are also enhanced in biofloc-based culture systems. The presence of bioflocs is also shown to enhance immune functions of the fish (Azim and Little 2008). An improved immunity in fish and better antioxidant defense mechanism would likely result in higher resistance against pathogens that will prevent disease outbreaks (Bachère 2000).

In addition to maintaining optimum water quality in tilapia ponds and tanks via the uptake of nitrogenous compounds to generate microbial proteins on-site, biofloc-based culture system also increases fish production by reducing feed conversion ratio through higher protein utilization and lower inputs of commercial feed, thereby decreasing feed cost (Choo and Caipang 2015). The cost of feeds represents at least 50% of the total aquaculture production cost, which is predominantly due to the high cost of the protein component in commercial diets (De Schryver et al. 2008). Tilapia ingest a wide variety of natural food organisms including plankters, aquatic

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macrophytes, planktonic and benthic aquatic invertebrates, detritus and decomposing organic matter. With heavy supplemental feeding, natural food organisms typically account for 30 - 50% of tilapia growth (Emerenciano et al. 2013). The gills of tilapia secrete mucus that traps planktonic organisms. The plankton-rich mucus is then swallowed and is a rich source of nutrients for the fish. In general, tilapia uses natural food efficiently and their production can be sustained in well-fertilized ponds even without the addition of supplemental feeds (Popma and Lovshin 1996). As such, in a biofloc-based culture system, tilapias are able to efficiently utilize single-cell microbial proteins that are produced by the heterotrophic bacteria through assimilation of inorganic nitrogen (TAN) from the water. These characteristics of tilapia favor them to be suitable fish species that can be cultured using bioflocs.

So how will a biofloc-based culture system of tilapia contribute towards the successful implementation of backyard aquaculture? It is widely known that marginalized fish farmers would greatly benefit from using this simple aquaculture technology. The small-scale or marginalized fish farmers in developing countries are often poorer than the rest of the population and they have less access to proper nutrition in order to lead healthy lives (Matte 2019). As such, alleviating poverty and hunger means confronting the problems that farmers face in their daily struggle for survival. Through backyard farming of tilapia using low inputs, which are the beneficial features of a biofloc-based culture system, it contributes immensely to the food needs as well economic empowerment of many families especially in rural communities. The fish farmers are able to be productive all-year round; thus, fully maximizing fish production (Mathias 1998), as tilapias are tolerant to wide fluctuations in environmental conditions. In addition, the requirements for the establishment of a biofloc system for backyard aquaculture of freshwater tilapia are cheap and readily available as materials. The rearing units can be sourced from scrap such as used canvass tanks and the food to be given to the fish could include food and vegetable wastes. The carbon sources for the production and maintenance of biofloc are all by-products of the food production process, which may include molasses and fermented vegetables. All the inputs in a biofloc-based culture system can be easily procured by small-scale fish farmers to start their aquaculture activity regardless of their location. The main problem that these small-scale fish farmers would likely encounter is how to maintain constant aeration in the biofloc tanks to ensure that the biofloc particles are kept in suspension. This can be addressed by stocking the fish at low densities so that there will be no problems with oxygen depletion. To provide aeration to the tank, the fish farmers can fabricate aeration systems from scrap materials and these will only be run at short durations during the day so as to save on electricity or fuel costs. These advantages of a biofloc-based culture system for freshwater tilapia would definitely be attractive to small-scale fish farmers to start

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farming of fish in their backyards as their source of food and at the same time as potential source of livelihood.

FUTURE PERSPECTIVES AND CONCLUSION

Biofloc-based culture system for tilapia has an immense potential in addressing issues on income instability, food insecurity, unemployment and poverty of small-scale farmers in most rural communities. As biofloc technology can only be applied predominantly in land-based aquaculture, fish farmers should rethink of a paradigm shift towards setting up more land-based rural aquaculture using biofloc technology as a substitute for intensive fish cage farming where fish kills are becoming more frequent. A variety of beneficial features can be attributed to biofloc technology. These advantages range from water quality control to source of feed and even in the inhibition of certain pathogens. Biofloc technology will enable aquaculture to shift towards an environment-friendly approach and biosecure culture operations. The consumption of microorganisms by the cultured stock in a biofloc-based culture system will significantly reduce feed conversion ratio (FCR) and consequently the costs in feed. Also, microbial community is able to rapidly convert toxic nitrogenous wastes that are derived from the feces of fish or shrimp and uneaten feeds and subsequently convert them into microbial protein. The conversion of toxic nitrogenous wastes to the less toxic forms is crucial in maintaining optimum water quality in biofloc-based culture systems. It would be an interesting topic for future research to determine the composition of bacterial population in a biofloc system so as identify and isolate beneficial heterotrophic bacterial species that are responsible for the added benefits of bioflocs in aquaculture.

The physical, chemical, and biological interactions that occur within the biofloc systems are complex; hence, further studies are needed to elucidate specific phenomena and their possible applications to other fields, and such interactions that take place in freshwater tilapia culture system should not be overlooked as well. Given the numerous benefits of bioflocs to tilapia aquaculture, BFT also provides a sustainable way to simultaneously address the environmental, social and economic issues that are related to the growth of this particular aquaculture sector. As an ecologically-friendly culture system that is characterized by reduced wastes, the ecological importance of the biofloc-based culture system must be taken seriously into consideration as this will impact its sustainability. In this regard, clear linkages between aquaculture and the environment must be defined and made known to all stakeholders. In addition, it is a challenge to the tilapia researchers and farmers to collaborate in order to further develop and refine BFT as the requirements could be site-specific. The basic principles of the

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BFT are already available, but further development of this technology needs fine-tuning and its implementation needs further research to enable this technique become a major feature of sustainable aquaculture in the future.

ACKNOWLEDGEMENTS

The preparation of this review paper was partly supported by the WPU Extension Program, “Western Philippines University Learning Environment-friendly Advocacy Farm and Family-based Education Towards Fisheries Resource Management and Popularization of Aquaculture and Alternative Agriculture in Western Philippines” funded by CHED-NAFES Extension Project. CMA Caipang is supported by the Balik Scientist Program of the Department of Science and Technology, Philippines through the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD). Logistics provided by the College of Fisheries and Aquatic Sciences, Western Philippines University, Puerto Princesa is also gratefully acknowledged. The comments and suggestions made by the two anonymous reviewers for the improvement of the manuscripts are greatly appreciated.

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ARTICLE INFO

Received: 07 February 2019
Revised: 26 June 2019
Accepted: 28 June 2019
Available online: 08 July 2019

Role of authors CMAC - conceptualized, wrote and revised the review paper; AL A - co-wrote, conducted literature search and proof-read the manuscript

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