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Biofloc technology (BFT) and its application towards improved production in freshwater tilapia culture

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Abstract. Biofloc technology (BFT) has beneficial effects in aquaculture management, including water quality, feeding and disease control. Application of BFT in aquaculture offers a solution to avoid the environmental impact of high nutrient discharges and to reduce the use of artificial feed. In BFT, excess of nutrients in aquaculture systems are converted into microbial biomass, which can be consumed by the cultured animals as a food source. This technology, to a certain extent, has also the capacity to control pathogens in aquaculture. A review of the previous studies demonstrated that the benefits of BFT are also evident in the freshwater tilapia culture to include improved production through lower feed conversion rate, better nutrition, optimum water quality and health. The basic principles and mechanisms of the BFT are already established, however, this technology needs fine-tuning and its implementation needs further intensive research in order to make this technology a major feature of future sustainable freshwater tilapia aquaculture.
Key Words: aquaculture, alternative culture system, fish culture, heterotrophic bacteria, sustainability.

Introduction. In Singapore, fish consumption every year amounts up to 100,000 tonnes and about 5% is accounted for by the local food fish aquaculture (www.ava.gov.sg). Through the use of intensive aquaculture, production of both freshwater and marine foodfish has been increased significantly. However, the aquaculture industry has come under scrutiny for contribution to environmental pollution and degradation. As a result, the requirement for more sustainable and environmentally friendly management and culture practices remains fully necessary. One such environmentally friendly aquaculture system is called Biofloc Technology (BFT).

BFT has been widely studied and applied in aquaculture. This system applies the principle of assimilation of dissolved ammonia-nitrogen (TAN) that is excreted by fish as metabolic waste and also through the breakdown of organic nitrogen source such as uneaten fish feeds as microbial protein by heterotrophic bacteria in the water (Figure 1) (Crab et al 2012). The excretion of nitrogenous metabolic wastes and their assimilation by heterotrophic bacteria maintain a balance by manipulating the carbon-to-nitrogen ration (C:N ratio) by the addition of carbon sources in the water. The production of the heterotrophic bacterial biomass further results in the formation of macroaggregates known as biofloc comprising of not only the bacteria, but also other microorganisms, including microalgae, zooplankton, as well as trapped organic and inorganic particles or solids (Hargreaves 2013).

Types of biofloc system. There are few types of biofloc systems used in both commercial aquaculture or evaluated in research. Among these systems, two basic types of biofloc systems are those that are exposed to natural light and those that are not. Biofloc 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 help to control the water quality and hence these systems are also known as the "green-water" biofloc systems due to the green discoloration of the water by the algae community. However, some biofloc systems are not exposed to natural light but instead are installed indoor with no exposure to natural light. This system operate as "brown-water" biofloc system where only bacterial processes control the water quality in the system (Hargreaves 2013; Pérez-Rostro et al 2014).

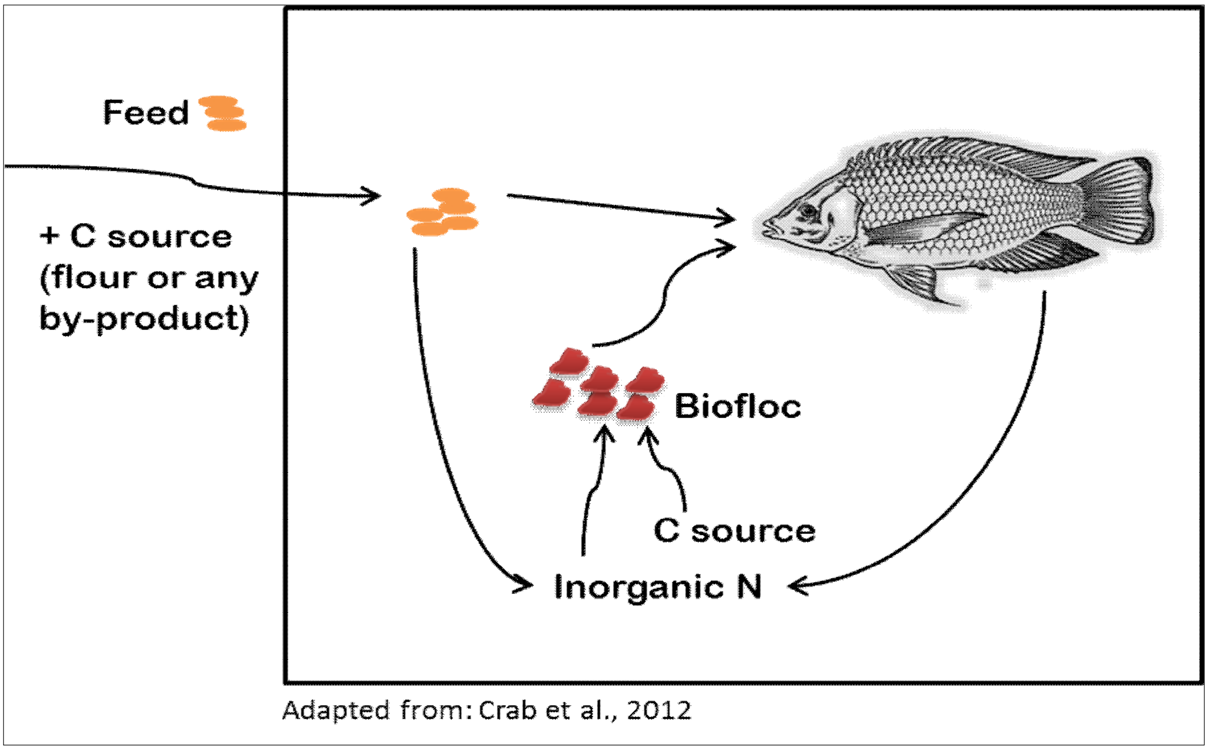

Figure 1. Production of biofloc in a tilapia pond/tank culture system.

How biofloc technology works. Bioflocs are macroaggregates (flocs) of bacteria, algae, protozoa (also known as zooplankton) and particulate organic matter such as uneaten food and feces. The flocs are held together by a loose matrix of mucus secreted by the bacteria, bound by filamentous microorganisms or held together by electrostatic attraction (Hargreaves 2013). Phytoplankton in the biofloc system could either be introduced into the system through the water that is used during the system start-up or inoculated into the system from a phytoplankton stock. In a green-water biofloc system, phytoplankton can help to control the water quality by uptake of toxic substances like ammonia-nitrogen. Being autotrophic, phytoplankton can also perform photosynthesis in the presence of sunlight, thereby enriching the system with oxygen produced (Hargreaves 2013).

In a biofloc system, locally available cheap carbon sources such as wheat flour are added into the system to manipulate the C/N ratio in order to stimulate heterotrophic bacteria growth as well as control inorganic nitrogen concentration in the system through assimilating of ammonia into bacteria as single-cell microbial protein. The microbial protein (biofloc) will then be eaten by the fish, thereby recycling protein that are excreted from the fish as only 20-25% of fed protein is retained in the fishes raised in intensive system, with the remainder being excreted into the system as ammonia and organic nitrogen in feces and feed residues (Avnimelech 1999).

Constant intensive turbulent mixing is also essential in a BFT system in order to keep the solids suspended in the water column at all times. Without mixing, bioflocs can settle out of suspension and form dense piles that rapidly consume nearby dissolved oxygen, creating an anaerobic zone. These zones can lead to the release of chemical compounds such as hydrogen sulfide, methane and ammonia that are toxic to shrimps and fish. In some practice, sludge banks are resuspended periodically by moving and repositioning aerators, creating a turbulent condition (Hargreaves 2013).

In comparison to aquaculture ponds or most recirculating systems, water in biofloc system has an increased respiration rate due to high concentration of suspended solids. In indoor brownwater biofloc system, respiration rate is normally 6 mg O^2 L^{-1} $hour^{-1}$, excluding the respiration by fish or shrimp crops which could contribute 5-8 mg O^2 L^{-1} $hour^{-1}$ to the overall respiration. In view of this, high amount of aeration is absolutely essential to provide sufficient oxygenation to meet the high oxygen demand in the biofloc system and to maintain oxygen concentration in safe levels. In the event where oxygen demand exceeds what the aeration can provide, oxygen concentration could fall to dangerous level, which could lead to depressed metabolism, growth rate and disease resistance and even possibly mortality of cultured crops (Hargreaves 2013).

Dynamics of ammonia production in biofloc systems. In aquaculture, one major goal of water quality management is the management of ammonia concentration below toxic levels. In BFT treatment, ammonia concentration is controlled via three main pathways: algal uptake, bacterial assimilation and nitrification. The relative importance of the three processes depends on several factors such as ammonia concentration, biofloc volume, daily feeding rate, light intensity and the input carbon/nitrogen ratio.

In BFT tanks that are exposed to natural light (green-water system), a dense algal bloom will develop in response to nutrient load from the feeding. Nutrients released from decomposing organic matter such as uneaten feed, fecal matter and dead algae will be rapidly taken up and stored in the algal cells. The rate of algal uptake of ammonia in a biofloc treatment is dependent on the under-water light intensity. In these systems, during prolonged periods when natural light is not strong (cloudy days), there could be spikes in ammonia concentration due to shading of algae by dense biofloc solids, thereby limiting algal uptake of ammonia. Dissolved oxygen and pH will also tend to fluctuate in these tanks even in the presence of aeration.

In contrast, ammonia concentrations in tanks that are kept indoor and not exposed to natural sunlight (brown-water system) are not controlled by the algal community but instead are mainly controlled by heterotrophic bacteria found in the system. In this system, C/N ratio is increased through supplementation of an organic carbon source or reduced protein levels in feed. By this manipulation, the heterotrophic bacteria create a demand for nitrogen in the form of ammonia in the water. As organic carbon and inorganic nitrogen are generally taken up in a fixed ratio by the bacteria, therefore, ammonia concentration can be controlled through the addition of a carbon source.

Ammonia concentration can also be controlled by a third pathway, which is through the use of the nitrification process. This process is a two-step oxidation of toxic ammonia to nitrate, a form of inorganic nitrogen that is only toxic at high concentration. Nitrification process can be found in intensive aquaculture system and is responsible for the long term ammonia control because ultimately, 25-50% of the nitrogen from feed added to the intensive system are controlled through this pathway. In this system, instead of rapid cycling between dissolved ammonia and algal or bacterial cell, ammonia is oxidized by ammonia-oxidizing bacteria to another toxic form of inorganic nitrogen known as nitrite. Nitrite is then converted to nitrate by nitrite-oxidizing bacteria. Nitrate can then be removed from the system either through the process of denitrification to ammonia gas or when solids are removed from the system during water exchange.

In a biofloc system with low water exchange, nitrogenous waste is repeatedly recycled between dissolved ammonia and cells of bacteria or algae. Should these cells be removed along with the solids during water exchange, a large fraction of nitrogen will be removed from the system. If the solids are not removed through water exchange, a large proportion of nitrogen in the system (ammonia) will eventually be oxidized into nitrate and hence resulting in accumulation of nitrate concentration, which is only toxic at high concentration (Hargreaves 2013).

Application of biofloc technology to freshwater tilapia aquaculture. The sustainable approach of BFT is based on the growth of microorganisms in the culture medium, benefited from the minimum to zero water exchange required. Lesser usage of water helps reduce the cost of water exchange in aquaculture that could become a limiting factor in intensive aquaculture operations. The biofloc (microorganisms) has two major roles: (i) maintains water quality by the uptake of nitrogenous compounds to generate microbial proteins on-site; and (ii) increases culture feasibility by reducing feed conversion ratio through higher protein utilization and lower inputs of commercial feed, hence decreasing feed cost. 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 (Bender et al 2004; De Schryver et al 2008).

Tilapia ingest a wide variety of natural food organisms, including planktons, some aquatic macrophytes, planktonic and benthic aquatic invertebrates, larval fish detritus and decomposing organic matter. With heavy supplemental feeding, natural food organisms typically account for 30-50% of tilapia growth. The gills of tilapia secrete mucus that traps planktonic organisms. The plankton-rich mucus is then swallowed and digestion occurs along the length of the intestine. In general, tilapia uses natural food efficiently that crops of more than 2,700 pounds of fish per acre (3000 kg ha^{-1}) can be sustained in a well fertilized pond without supplemental feed (Popma & Masser 1999). As such, in a BFT treatment, tilapia are able to efficiently utilize single-cell microbial protein produced through TAN in the heterotrophic bacterial community. These characteristics of tilapia favor them to be suitable fish species that can be be cultured using BFT.

Using tilapia stocked in indoor tanks, Azim et al (2008) also found that the concentrations of biochemical oxygen demand (BOD) level and total suspended solids (TSS) in BFT tanks are higher than the control tanks because the readings for BOD level corresponded to the TSS level, where TSS levels of control tanks (16 mg L^{-1}) were 36 times lower than BFT tanks (597 mg L^{-1}).

In terms of growth and production, Azim & Little (2008) observed that individual fish weight at harvest was higher in the BFT treatment compared to the control using a recirculating system. BFT treatments in the experiment also contributed 44-46% greater individual weight gain and net fish production than those in controls. Food conversion ratio (FCR) value was also significantly higher in the control compared to the BFT treatment tanks (Azim & Little 2008). In the study of Avnimelech (1999) evaluating feed uptake and response to additional carbohydrates with tilapia hybrids (*O. niloticus* x *O. aureus*), fish growth in BFT ponds enriched with carbohydrate fed with 20% protein feed yielded superior fish growth compared to conventional non-BFT ponds fed with 30% protein. Daily gain and final weight of tilapia were higher in the BFT ponds compared to the conventional ponds and FCR and mortality rate (%) was lower in the BFT ponds. Lower FCR could suggest a higher rate of protein utilization in the BFT ponds, and the constant recirculation of proteins in the ponds are credited for the increased in protein utilization.

In summary, the use of BFT systems to freshwater tilapia aquaculture benefits both the cultured stock and the rearing water of the fish. Table 1 summarizes the positive effects of biofloc when applied to the culture of freshwater tilapia. The beneficial effects on the fish include improvement in production, low feed conversion, better nutrition and health. On the other hand, BFT systems also result in optimum levels of the water quality of the rearing environment.

Table 1

Benefits of biofloc to tilapia and their rearing environment

Benefits	*References*
Improved fish production	Azim & Little (2008); Avnimelech (1999)
Better nutrition	Ekasari et al (2014)
Low FCR	Luo et al (2014)
Water quality within optimum levels	Avnimelech (2007)
Fish health uncompromised	Azim & Little (2008)

Conclusions. A number of studies showed the numerous benefits of BFT to freshwater tilapia aquaculture. This technology provides a sustainable tool to simultaneously address the environmental, social and economic issues that are related to the growth of this particular aquaculture sector. It is a challenge to researchers and tilapia farmers to further develop and refine this technique as well as to implement this technology in future aquaculture systems.

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References

Avnimelech Y., 1999 Carbon/nitrogen ratio as a control element in aquaculture systems. Aquaculture 176:227-235.
Avnimelech Y., 2007 Feeding with microbial flocs by tilapia in minimal discharge bioflocs technology ponds. Aquaculture 264:140–147.
Azim M. E., Little D. C., 2008 The biofloc technology (BFT) in indoor tanks: water quality, biofloc composition, and growth and welfare of Nile tilapia (*Oreochromis niloticus*). Aquaculture 283:29-35.
Azim M. E., Little D. C., Bron J. E., 2008 Microbial protein production in activated suspension tanks manipulating C:N ratio in feed and the implications for fish culture. Bioresource Technology 99:3590-3599.
Bender J., Lee R., Sheppard M., Brinkley K., Phillips P., Yeboah Y., Wah R. C., 2004 A waste effluent treatment system based on microbial mats for black sea bass *Centropristis striata* recycled water mariculture. Aquaculture Engineering 31:73-82.
Crab R., Defoirdt T., Bossier P., Verstraete W., 2012 Biofloc technology in aquaculture: beneficial effects and future challenges. Aquaculture 356-357:351-356.
De Schryver P., Crab R., Defoirdt T., Boon N., Verstraete W., 2008 The basics of bio-flocs technology: the added value for aquaculture. Aquaculture 277:125-137.
Ekasari J., Angela D., Waluyo S. H., Bachtiar T., Surawidjaja E. H., Bosier P., De Schryver P., 2014 The size of biofloc determines the nutritional composition and the nitrogen recovery by aquaculture animals. Aquaculture 426-427:105-111.
Hargreaves J. A., 2013 Biofloc production systems for aquaculture. SRAC Publication number 4503, 12 pp.
Luo G., Gao Q., Wang C., Liu W., Sun D., Li L., Tan H., 2014 Growth, digestive activity, welfare, and partial cost-effectiveness of genetically improved farmed tilapia (*Oreochromis niloticus*) cultured in a recirculating aquaculture system and an indoor biofloc system. Aquaculture 422-423:1-7.
Popma T., Masser M., 1999. Tilapia life history and biology. SRAC Publication number 283, 4 pp.
Pérez-Rostro C. I., Pérez-Fuentes J. A., Hernández-Vergara M. P., 2014 Biofloc, a technical alternative for culturing Malaysian prawn *Macrobrachium rosenbergii*. In: Sustainable aquaculture techniques. Hernandez-Vergara M., Perez-Rostro C. I. (eds), ISBN: 978-953-51-1224-2, doi: 10.5772/57501.
*** www.ava.gov.sg.

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