Biofloc technology in aquaculture: Beneficial effects and future challenges

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Review

Biofloc technology in aquaculture: Beneficial effects and future challenges

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ABSTRACT

As the human population continues to grow, food production industries such as aquaculture will need to expand as well. In order to preserve the environment and the natural resources, this expansion will need to take place in a sustainable way. Biofloc technology is a technique of enhancing water quality in aquaculture through balancing carbon and nitrogen in the system. The technology has recently gained attention as a sustainable method to control water quality, with the added value of producing proteinaceous feed *in situ*. In this review, we will discuss the beneficial effects of the technology and identify some challenges for future research.

Contents

1. Introduction

With almost seven billion people on earth, the demand for aquatic food carries on to increase and hence, expansion and intensification of aquaculture production are highly required. The prime goal of aquaculture expansion must be to produce more aquaculture products without significantly increasing the usage of the basic natural resources of water and land (Avnimelech, 2009). The second goal is to develop sustainable aquaculture systems that will not damage the environment (Naylor et al., 2000). The third goal is to build up systems providing an equitable cost/benefit ratio to support economic and social sustainability (Avnimelech, 2009). All these three prerequisites for sustainable aquaculture development can be met by biofloc technology.

2. Biofloc technology

If carbon and nitrogen are well balanced in the solution, ammonium in addition to organic nitrogenous waste will be converted into bacterial biomass (Schneider et al., 2005). By adding carbohydrates to the pond, heterotrophic bacterial growth is stimulated and nitrogen uptake through the production of microbial proteins takes place (Avnimelech, 1999). Biofloc technology is a technique of enhancing water quality through the addition of extra carbon to the aquaculture system, through an external carbon source or elevated carbon content of the feed (Fig. 1). This promoted nitrogen uptake by bacterial growth decreases the ammonium concentration more rapidly than nitrification (Hargreaves, 2006). Immobilization of ammonium by

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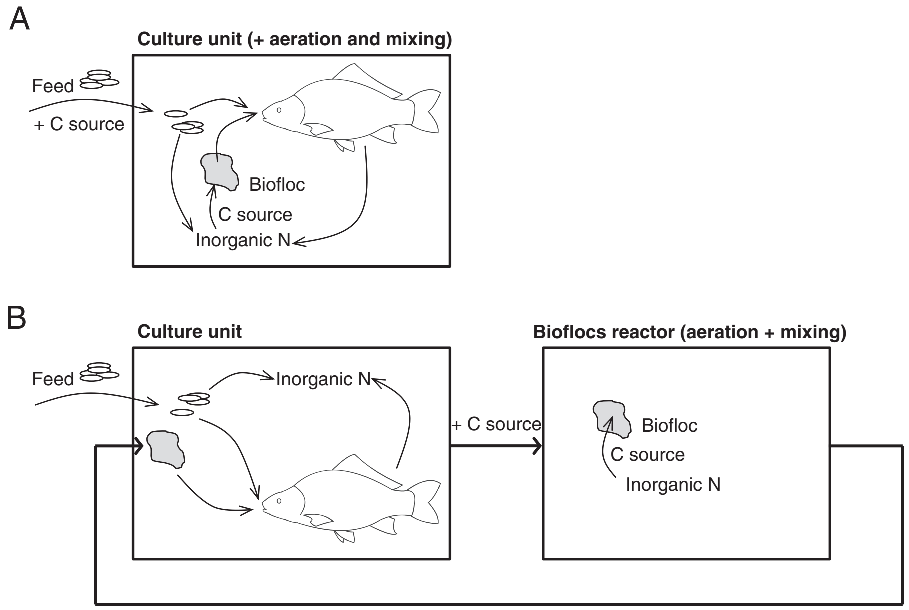

Fig. 1. Schematic representation of how bioflocs can be implemented in aquaculture systems. (A) Integration of bioflocs within the culture unit by using feed with a relatively low N content and/or the addition of a carbon source. The bioflocs consume inorganic N waste together with the carbon source, thereby producing microbial biomass that can be used as a feed by the animals. (B) Use of a separate bioflocs reactor. The waste water from the culture tank is brought into the biofloc reactor, where a carbon source is added in order to stimulate biofloc growth. The water of the biofloc reactor can be recirculated into the culture tank and/or bioflocs can be harvested and used as a supplementary feed.

heterotrophic bacteria occurs much more rapidly because the growth rate and microbial biomass yield per unit substrate of heterotrophs are a factor 10 higher than that of nitrifying bacteria (Hargreaves, 2006). The microbial biomass yield per unit substrate of heterotrophic bacteria is about 0.5 g biomass C/g substrate C used (Eding et al., 2006). A schematic calculation of the amount of carbon needed for biofloc growth is presented in Fig. 2.

Suspended growth in ponds consists of phytoplankton, bacteria, aggregates of living and dead particulate organic matter, and grazers of the bacteria (Hargreaves, 2006). Typical flocs are irregular by shape, have a broad distribution of particle size, are fine, easily compressible, highly porous (up to more than 99% porosity) and are permeable to fluids (Chu and Lee, 2004). Avnimelech (2009) recently published the handbook 'Biofloc Technology — A practical guide book' that is directed to aquaculturists, farmers, students and scientists and is a first tremendous step forward in providing general information on this technology. We refer readers to this book and to our previous paper on the basics of biofloc technology (De Schryver et al., 2008) for detailed information on the use of biofloc technology in aquaculture. The current review aims to highlight the strengths of the technology and identify challenges for further research (Box 1).

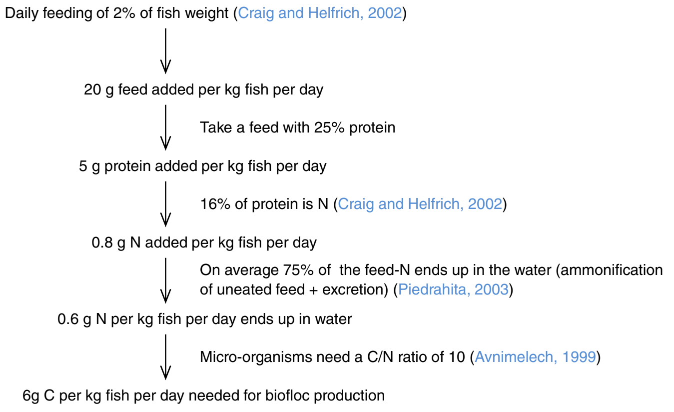

Fig. 2. Schematic calculation of the daily amount of carbon needed to remove the nitrogen wasted from uneaten feed and excretion from the animals by bioflocs. The amount of carbon source added will then depend on the carbon content of the carbon source. In case of acetate or glycerol (both containing 0.4 g C per g), 15 g of carbon source would be needed per kg fish per day. The assumption that 75% of the feed-N ends up in the water is based on Piedrahita (2003).

3. The strengths of biofloc technology

Box 1
Challenges for further research.

- Selection and positioning of aerators.
- Integration in existing systems (*e.g.* raceways, polyculture systems).
- Identification of micro-organisms yielding bioflocs with beneficial characteristics (nutritional quality, biocontrol effects) to be used as inoculum for biofloc systems.
- Development of monitoring techniques for floc characteristics and floc composition.
- Optimalization of the nutritional quality (amino acid composition, fatty acid composition, vitamin content).
- Determination of the impact of the carbon source type on biofloc characteristics.

Biofloc technology makes it possible to minimize water exchange and water usage in aquaculture systems through maintaining adequate water quality within the culture unit, while producing low cost bioflocs rich in protein, which in turn can serve as a feed for aquatic organisms (Crab, 2010; Crab et al., 2007, 2009, 2010a). Compared to conventional water treatment technologies used in aquaculture, biofloc technology provides a more economical alternative (decrease of water treatment expenses in the order of 30%), and additionally, a potential gain on feed expenses (the efficiency of protein utilization is twice as high in biofloc technology systems when compared to conventional ponds), making it a low-cost sustainable constituent to future aquaculture development (Avnimelech, 2009; De Schryver et al., 2008). Conventional technologies to manage and remove nitrogen compounds are based on either earthen treatment systems, or a combination of solids removal and nitrification reactors (Crab et al., 2007). These methods have the disadvantage of requiring frequent maintenance and in most instances the units can achieve only partial water purification. They generate secondary pollution and are often costly (Lezama-Cervantes and Paniagua-Michel, 2010). Biofloc technology, on the other hand, is robust, economical technique and easy in operation. One important aspect of the technology to consider is the high concentration of total suspended solids present in the pond water. Suitable aeration and mixing needs to be sustained in order to keep particles in suspension and intervention through either water exchange or drainage of sludge might be needed when suspended solids concentrations become too high (Avnimelech, 2009). Although it is a critical aspect of biofloc technology, detailed knowledge about selection and placement of aerators is still lacking. Future research should address this issue and could also investigate new concepts, such as the integration of biofloc technology in raceways, which might prevent solids build up through its proper system configuration (Avnimelech, 2009). Construction aspects for biofloc technology ponds merely deal with aeration. So improving and fine-tuning of the design of these ponds in terms of water mixing and sludge control is needed (Avnimelech, 2009).

Unlike the conventional techniques such as biofilters, biofloc technology supports nitrogen removal even when organic matter and biological oxygen demand of the system water is high (Avnimelech, 2009). When establishing biofloc technology in aquaculture ponds, a certain start-up period is needed to obtain a well-functioning system with respect to controlling water quality and this will depend on the nitrogen and organic load of the culture water and thus the intensity of the system. Likewise, in order to establish the required microbial community in a biofilter one needs approximately 4 weeks, depending on nutrients, water flow rate and temperature (Avnimelech, 2009). However, because heterotrophs grow at a rate that is 10 times higher than that of nitrifying bacteria in biofilters (Crab et al., 2007), bioflocs can usually be established much faster than conventional biofilters. To even further shorten the start-up period of biofloc technology, it might be interesting to investigate the effect of adding nucleation sites, such as clay, to the water at start-up, which will stimulate floc formation. Also the inoculation with water from existing good-performing biofloc ponds or with specific inocula might allow an accelerated start-up.

The strength of the biofloc technology lies in its 'cradle to cradle'-concept as described by McDonough and Braungart (2002), in which the term waste in fact does not exist. Translated in biofloc terms, 'waste'-nitrogen generated by uneaten feed and excreta from the cultured organisms is converted into proteinaceous feed available for those same organisms. Instead of 'downcycling', a phenomenon often found in an attempt to recycle, the technique actually 'upcycles' through closing the nutrient loop. Hence, the water exchange can be decreased without deterioration of water quality and, consequently, the total amount of nutrients discharged into adjacent water bodies may be decreased (Lezama-Cervantes and Paniagua-Michel, 2010). In this context, biofloc technology can also be used in the specific case of maintaining appropriate water temperature, good water quality and high fish survival in low/no water exchange, greenhouse ponds to overcome periods of lower temperature during winter. Indeed, fish survival levels in overwintering tilapia cultured in greenhouse ponds with biofloc technology were excellent, being 97 ± 6% for 100 g fish and 80 ± 4 for 50 g fish (Crab et al., 2009). Moreover, at harvest, the condition of the fish was good in all ponds, with a fish condition factor of 2.1–2.3. Besides winter periods, we need to be aware of the fact that future impacts of climate change on fisheries and aquaculture are still poorly understood and colder periods might be more often an issue to deal with in the future. The key to minimizing possible negative impacts of climate change on aquaculture and maximizing opportunities will be through understanding and promoting a wide range of inventive adaptive new technologies, such as the biofloc technology combined with greenhouse ponds.

4. Implementation of biofloc technology in aquaculture

No technique is without drawbacks and also biofloc technique is prone to obstacles. A major obstacle is to convince farmers to implement the technique, since the concept of biofloc technology goes in against common wisdom that water in the pond has to be clear (Avnimelech, 2009). On the other hand, several factors promote the implementation of the technique. Firstly, water has become scarce or expensive to an extent of limiting aquaculture development. Secondly, the release of polluted effluents into the environment is prohibited in most countries. Thirdly, severe outbreaks of infectious diseases led to more stringent biosecurity measures, such as reducing water exchange rates (Avnimelech, 2009). Experience regarding biofloc technology and technical knowledge about the technique needs to be transferred to the farmers in a clear, practical and straightforward way, not forgetting to emphasize the economic benefits of this technique. A very important aspect in the implementation of biofloc technology in aquaculture is monitoring of the ponds. Biofloc technology is not yet fully predictable and can therefore be risky to implement at farm level. Possible monitoring tools are the concentration of total suspended solids or bioflocs, and the settleability of the biofloc, which can both be measured quickly and easily (De Schryver et al., 2008). Molecular monitoring can also provide information on the condition of the bioflocs, but time and cost limitations might prevent the utility of this approach in real biofloc systems.

As soon as future research has fine-tuned the art of biofloc technology and farmers can be convinced to implement the technique, consumers still will need to be convinced to buy aquaculture products originating from biofloc ponds. The simplified idea of recycling excreta of aquatic organisms into feed might frighten the consumers and prohibit them from buying these products. Despite this hitch, it is clear that with the growing human population, technological progress in aquaculture is needed to protect wild fish stocks and control fish prices (Jiang, 2010). Population growth pushes up fish prices as a result of a seafood shortage and increases pressure on wild fish stocks (Péron et al., 2010). In contrast, technological improvement tends to decrease fish prices and increases wild fish stocks by making the alternative fish product, farmed fish, relatively easier to produce. Therefore, biofloc technology could alleviate the depletion of wild fish stocks and poverty, while improving social welfare through lowering the fish production prices, all beneficial for both farmer and consumer. Moreover, consumers now call for guarantees that their food has been produced, dealt with and commercialized in a way that is not hazardous to their health, respects the environment and addresses diverse other ethical and social considerations (FAO, 2009).

In addition to biofloc technology on its own, several researchers are looking at combinations of this technology with other innovative techniques to control water quality in aquaculture and its effluents. Researchers are now investigating the combination of periphyton with carbon to nitrogen ratio control (Asaduzzaman et al., 2008, 2010). Lezama-Cervantes and Paniagua-Michel (2010) investigated microbial mats that are able to adapt to large fluctuations in dissolved oxygen and pH and were able to remove and stabilize different organic and inorganic substrates partly due to the mixed autotrophic and heterotrophic communities that co-exist in the substrate matrix. Kumar and Lin (2010) investigated the use of short-cut nitrification–denitrification and anaerobic ammonium oxidation (anammox) for nitrogen removal. Their research indicated that these techniques could be useful and cost-effective especially for recirculating aquaculture systems with lower energy demand. The use of biofloc technology ponds integrated in a polyculture set-up is also an inventive and promising approach. Kuhn et al. (2009) included dried and processed bioflocs from tilapia ponds into shrimp feed and obtained about 1.6 times higher average weight gain per week than that obtained with commercial diets. Although this is an indirect form of polyculture, the more direct form – where the culture of fish or shrimp is integrated with vegetables, microalgae, shellfish and/or seaweed – can be very promising (Neori et al., 2004). This integrated intensive aquaculture strategy finds its origin in traditional extensive polycultures. Most of today's world aquaculture production is reared in semi-intensive and extensive systems. Nowadays, the interest in high technology intensive aquaculture systems increases with the increasing demand for aquaculture products. Biofloc technology could be combined with polyculture ponds, further enhancing the water quality, natural food availability, dietary preference, growth and production in an intensive set-up (Rahman et al., 2008). At the University of the Virgin Islands, researchers are currently looking at tilapia and shrimp polyculture in intensive, bacterial-based, aerated tanks. The multitrophic approach of combining species with different specific feeding niches brings about a more complete use of resources than in the monoculture approach (Rahman et al., 2008).

5. The use of bioflocs as a feed for aquaculture species

In addition to the growing demand for seafood for human consumption, the demand for aquatic products used by the industrial sector for conversion into fishmeal and fish oil products also increases (Péron et al., 2010). Fishmeal and fish oil are used as feed for other human food supply systems, such as poultry, pigs and aquaculture. Hitherto, part of the aquaculture production relies on wild fish harvests, as fishmeal and fish oil are essential elements of the diet of many aquaculture species, both carnivorous and herbivorous fish and shrimp. About 5–6 million tonnes of low-value/trash fish are used as direct feed in aquaculture worldwide either provided without processing or as part of farm-made feeds (FAO, 2009). FAO (2009) reported that the total amount of fishmeal and fish oil used in aquafeeds is estimated to have grown more than threefold between 1992 and 2006, from 0.96 million tonnes to 3.06 million tonnes and from 0.23 million tonnes to 0.78 million tonnes, respectively. For the 10 types of fish most regularly farmed, a mean of 1.9 kg of wild fish is required for every kilogram of fish produced (Naylor et al., 2000). In terms of fishmeal, many intensive and semi-intensive aquaculture systems use 2 to 5 times more fish protein to feed the farmed species than is supplied by the farmed product (Naylor et al., 2000). Therefore, research in recent times has focused on the development of feed substitution strategies with a minimal supply of fishmeal and fish oil, which are then replaced by alternative and cheaper sources of protein such as plant proteins. In contrast to intensive and semi-intensive systems, extensive and traditional systems already use little or no fishmeal, and farmers often supply nutrient-rich materials to the water to enhance growth of algae and other indigenous organisms on which the fish can feed (Naylor et al., 2000). This inspired researchers to develop the biofloc technology, which is also applicable to intensive and semi-intensive systems. With biofloc technology, where nitrogenous waste generated by the cultivated organisms is converted into bacterial biomass (containing protein), *in situ* feed production is stimulated through the addition of an external carbon source (Schneider et al., 2005).

Although bioflocs show an adequate protein, lipid, carbohydrate and ash content for use as an aquaculture feed (Crab et al., 2010a), more research is needed on their amino acid and fatty acid composition. Now, fishmeal and fish oil supply essential amino acids (such as lysine and methionine) that are deficient in plant proteins and fatty acids (eicosapentanoic acid and docosahexanoic acid) not found in vegetable oils (Naylor et al., 2000). Herbivorous, omnivorous and carnivorous finfish all necessitate about the same amount of dietary protein per unit weight, but herbivorous and omnivorous species utilize plant-based proteins and oils better and they require minimal quantities of fishmeal to supply essential amino acids (Naylor et al., 2000). However, compound feeds for omnivorous fish often exceed required levels (Naylor et al., 2000). On the other hand, lowering the input of wild fish required for production of farmed carnivorous fish seems not feasible at this time. As already discussed above, it is very important to inform the farmers clearly and thoroughly, at this juncture about feeding strategies and management. New initiatives by governments and funding organizations are needed that can act as incentives for aquaculture to augment farming of low trophic level with herbivorous diets in stead of high-value, carnivorous fish that increases the need for fishmeal and fish oil, which in turn could place even more stress on pelagic fisheries, resulting in high feed prices and damage to marine ecosystems (Naylor et al., 2000). Concomitantly, more research is needed regarding feed replacement strategies such as using vegetable oils, meat byproducts and also biofloc technology. With biofloc technology, one also needs to consider that the choice of cultivated species should take into account their capability of dealing with high suspended solid concentrations, since this negatively affects certain fish species.

Another important factor that is essential for the growth and survival of aquaculture species are vitamins. We measured before vitamin C concentrations in bioflocs ranging from 0 to 54 μg/g dry matter (Crab, 2010). These values are below the required concentration for fish and shrimp. Besides vitamin C, other vitamins such as thiamine, riboflavin, pyridoxine, pantothenic acid, nicotinic acid, biotin, folic acid, vitamin B12, inositol, choline, vitamin A, vitamin D3, vitamin E and vitamin K, are usually not sufficiently synthesized by the cultured organism either and need to be supplied through the feed. Hence, it needs to be established to what extent bioflocs can contribute to the supply of these essential nutrients.

Several studies were performed on the use of bioflocs as an *in situ* produced feed and they indicate that bioflocs can be taken up by aquaculture species and uptake depends on the species and feeding traits, animal size, floc size and floc density (Avnimelech, 2009; Crab, 2010; Crab et al., 2009, 2010a). Our previous work revealed that giant freshwater prawn (*Macrobrachium rosenbergii*), whiteleg shrimp (*Litopenaeus vannamei*) and tilapia (*Oreochromis niloticus* × *Oreochromis aureus*) were all able to take up bioflocs and profit from this additional protein source. This indicates that biofloc technology is applicable to both freshwater and seawater systems, both to control water quality and to produce as an additional feed source *in situ*. The potential feed gain of the application of biofloc technology is estimated to be in the order of 10–20% (De Schryver et al., 2008). With this, production costs will decline considerably since food represents 40–50% of the total production costs (Craig and Helfrich, 2002).

Although bioflocs meet nutritional standards to serve as a aquaculture feed in general, research has shown that the capacity of the technique to control the water quality in the culture system and the nutritional properties of the flocs are influenced by the type of carbon source used to produce the flocs (Crab, 2010; Crab et al., 2010a). Different organic carbon sources each stimulated specific bacteria, protozoa and algae, and hence influenced the microbial composition and community organization of the bioflocs and thereby also their nutritional properties (Crab, 2010). Feeding experiments revealed that besides these characteristics, the type of carbon source also influenced the availability, palatability and digestibility for the cultured organisms (Crab, 2010; Crab et al., 2010a). Overall, bioflocs produced on glycerol gave the best results in our previous work (Crab, 2010). However, further research should focus on the use of low-cost non-conventional agro-industrial residues as carbon source and hence upgrade waste to nutritious feed. Different carbon sources will stimulate the growth of the indigenous microbiota in another way and thus exert a distinctive effect on water quality, *in situ* feed production and utilization of the flocs by the cultured organisms. Downstream carbonaceous byproducts of local industry can provide a low cost external carbon source for application in biofloc technology in nearby ponds, but will need preceding research before implementation. The problem might be that nowadays all carbon sources have a certain value and possible application, which raises the question whether it is acceptable to take a carbon source with a certain value to upgrade nitrogen from feces to microbial protein in aquaculture ponds. These questions can be answered through field studies and case-by-case economical analysis. Balancing the carbon content of the feed fed to the culture organism could be an alternative to elevating the organic carbon to nitrogen ratio through addition of an external organic carbon source (Crab et al., 2009). The application of these lower protein pellets has the advantage of convenience and saving labor, as compared to separate application of feed pellets and an organic carbon source (Avnimelech, 2009). Another consideration to make in this decision process is the possible added features that are related to a specific carbon source. For example, bioflocs grown on glycerol tend to have a higher $n-6$ fatty acids content when compared to bioflocs grown on acetate or glucose (Crab et al., 2010a).

In addition, not only the carbon source, but also the indigenous microbiota present in the pond water will put forth a characteristic effect that needs to be considered. An important factor here is to determine the role of algae and their interaction with the bacteria in the bioflocs. Crab (2010) showed that with *L. vannamei*, bioflocs grown on glucose lacked accessibility and palatability for good survival and growth. The latter opens an interesting field of research, where one can look at carbon sources that would increase attractiveness of the bioflocs toward fish and shrimp. A worthy carbon source to look at in this regard is molasses obtained during sugar processing of sugar beet (*Beta vulgaris* L. v. *altissima*), which contains glycine betaine, a known attractants used in aquaculture (Felix and Sudharsan, 2004; Mäkelä et al., 1998). An interesting topic for further research could be the identification of micro-organisms (bacteria and micro-algae) that are able to produce bioflocs with the desired nutritional properties and a good ability to control the water quality. Such micro-organisms could be used as an inoculum for the start-up of aquaculture systems with biofloc technology. All these findings and possible modus operandi emphasize the need for further study of biofloc composition in order to achieve a desired nutritional outcome, since different research groups have obtained different results in respect to biofloc nutritional composition (Avnimelech, 2009).

6. The use of bioflocs as a biocontrol measure

In addition to the advantages of biofloc technology discussed above, Crab et al. (2010b) have recently shown that biofloc technology constitutes a possible alternative measure to fight pathogenic bacteria in aquaculture. Intensive aquaculture of crustaceans is one of the fastest-growing sectors in aquaculture production (Wang et al., 2008). Despite its huge success, shrimp culture is facing severe outbreaks of infectious diseases, which have caused significant economic losses. Due to the haphazard mishandling of antibiotics in aquaculture, pathogenic bacteria are now becoming resistant to numerous antibiotics and as a result, antibiotics are no longer effective in treating bacterial disease (Defoirdt et al., 2011). The disruption of quorum sensing, bacterial cell-to-cell communication with small signal molecules (Defoirdt et al., 2008), has been proposed as a new strategy to control bacterial infections in aquaculture as this cell-to-cell communication mechanism regulates the expression of virulence factors (Defoirdt et al., 2004). Interestingly, we recently found that bioflocs grown on glycerol were able to protect gnotobiotic brine shrimp (*Artemia franciscana*) against pathogenic *Vibrio harveyi*, and that the beneficial effect was likely due to interference with the pathogen's quorum sensing system (Crab et al., 2010b). Indeed, survival of challenged nauplii increased 3-fold after the addition of live bioflocs. This complies with former research that revealed that primary production and promotion of *in situ* microbial populations, as is the case in biofloc technology, were found to be beneficial for shrimp (Lezama-Cervantes and Paniagua-Michel, 2010). The exact mechanism of the protective action of bioflocs and its selective action, however, needs further in-depth investigation.

Another interesting feature of bioflocs to further investigate with respect to biocontrol effects is the capability to accumulate the bacterial storage compound poly-β-hydroxybutyrate (PHB). PHB and PHB-accumulating bacteria have been shown before to protect different aquaculture animals from bacterial infections (De Schryver et al., 2010; Defoirdt et al., 2007; Dinh et al., 2010; Halet et al., 2007). PHB-accumulating bacteria are present in bioflocs as we have measured PHB levels in bioflocs of between 0.5 and 18% of the dry matter (Crab, 2010; De Schryver and Verstraete, 2009). The latter bioflocs contain a sufficient PHB level to protect cultured animals from infection by pathogenic bacteria (Halet et al., 2007).

Numerous researches have noted that shrimp are healthiest and grow best in aquaculture systems that have high levels of algae, bacteria and other natural biota (Kuhn et al., 2009). Probiotics are viable microbial cells that have a beneficial effect on the health of a host by improving its intestinal equilibrium through improved feed value, enzymatic contribution to digestion, inhibition of pathogenic microorganisms, antimutagenic and anticarcinogenic actions, growth-promoting factors, and an increased immune response (Verschuere et al., 2000). Since several research articles have been published on the benefits of using *Bacillus* to improve shrimp growth performance, survival, immunity, and disease resistance in aquaculture (Decamp et al., 2008; Tseng et al., 2009; Verschuere et al., 2000) we inoculated biofloc reactors with a probiotic *Bacillus* mixture in an attempt to produce probiotic bioflocs.

Our preliminary results showed that the water of shrimp tanks fed bioflocs inoculated with *Bacillus* had an on average 5 times lower *Vibrio* load when compared to the shrimp tanks fed an artificial feed (Crab, 2010). These results indicate that inoculating biofloc reactors with probiotic bacteria might have biocontrol effect toward *Vibrio* spp., but the inoculation of biofloc systems with specific desired microorganisms needs further investigation in order to confirm these beneficial effects. Other interesting fields of research regarding this subject are possible immunostimulatory features of the bioflocs. Enhancement of the innate immunity of cultured organisms may provide broad-spectrum resistance to infections. Existing immunostimulants include bacteria and bacterial products, complex carbohydrates, nutritional factors, animal extracts, cytokines, lectins, plant extracts and synthetic drugs such as levamisole (Wang et al., 2008). Bioflocs might also contain immunostimulatory compounds since biofloc technology deals with bacteria and bacterial products.

7. Conclusions

A variety of beneficial features can be ascribed to biofloc technology, from water quality control to *in situ* feed production and some possible extra features. Biofloc technology offers aquaculture a sustainable tool to simultaneously address its environmental, social and economical issues concurrent with its growth. Researchers are challenged to further develop this technique and farmers to implement it in their future aquaculture systems. The basics of the technology is there, but its further development, fine-tuning and implementation will need further research and development from the present and future generation of researchers, farmers and consumers to make this technique a keystone of future sustainable aquaculture.

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