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Biofloc technology in aquaculture and its potentiality: A review

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Abstract
The ever increasing population of Bangladesh demands for more intensive production from aquaculture without sacrificing the quality. However, managing the wastes from aquaculture has become an emerging issue for environmental safe guard. So the expansion and intensification of aquaculture will need to take place in a sustainable way. Biofloc technology (BFT), the new "blue revolution" in aquaculture, could be promising in attaining this sustainability. It is mainly based on the principle of waste nutrients recycling, in particular nitrogen, into microbial biomass that can be used *in situ* by the cultured animals or be harvested and processed into feed ingredients. Such technique is based on in situ microorganism production which plays three major roles: (i) maintenance of water quality, by the uptake of nitrogen compounds generating *in situ* microbial protein; (ii) nutrition, increasing culture feasibility by reducing feed conversion ratio (FCR) and a decrease of feed costs; and (iii) competition with pathogens. The potentiality of biofloc in aquaculture will be discussed in this review.

Keywords: Biofloc, aquaculture, potentiality, future challenges, Bangladesh

1. Introduction
With almost seven billion people on earth, the demand for aquatic food is increasing accordingly and hence, expansion and intensification of aquaculture production are highly required. Aquaculture as a food-producing sector offers ample opportunities to alleviate poverty, hunger and malnutrition, generates economic growth and ensures better use of natural resources (FAO, 2017) [28]. Aquaculture production is projected to rise from 40 million tonnes by 2008 to 82 million tonnes in 2050 (FAO, 2010) [27]. The necessity to increase aquaculture production has been activated by the increasing demand of global population. 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) [7]. The second goal is to develop sustainable aquaculture systems that will not damage the environment (Naylor *et al*., 2000) [38]. The third goal is to build up systems providing an equitable cost/benefit ratio to support economic and social sustainability (Avnimelech, 2009) [7]. All these three are prerequisites for sustainable aquaculture development can be met by biofloc technology. However, the development of a sustainable aquaculture industry is particularly challenged by the limited availability of natural resources as well as the impact of the industry on the environment (Costa-Pierce *et al*., 2012; Verdegem, 2013) [14, 48]. With these limitations in mind, the development of sustainable aquaculture industry should focus on the conceptualization of systems that despite their high productivity and profitability, utilize fewer resources including water, space, energy and eventually capital, and at the same time has lower impact on the environment (Asche *et al*., 2008; FAO, 2017) [4, 28]. Along with (SDG#14) targets, sustainable aquaculture development could contribute to multiple objectives including ending poverty (SDG#1), ending hunger, achieving food security and improved nutrition (SDG#2) and promoting sustained, inclusive and sustainable economic growth (SDG#8) (FAO, 2017) [28]. Biofloc technology is mainly based on the principle of waste nutrients recycling, in particular nitrogen, into microbial biomass that can be used *in situ* by the cultured animals or be harvested and processed into feed ingredients (Avnimelech, 2009; Kuhn *et al*., 2010) [7, 32]. Heterotrophic microbiota is stimulated to grow by steering the C/N ratio in the water through the modification of the carbohydrate content in the feed or by the addition of an external carbon source in the water (Avnimelech, 1999) [6], so that the bacteria can assimilate the waste ammonium for new biomass production.

Hence, ammonium/ammonia can be maintained at a low and non-toxic concentration so that water replacement is no longer required. Biofloc technology enhances the production and productivity by its contribution to the supply of good quality fish juveniles, the latter being one of the most important inputs in the production. In addition, it contributes to the improvement of the fish production. In relation to the former, biofloc technology could support the supply of good quality seeds by improving the reproductive performance of aquaculture animals and by enhancing the larval immunity and robustness (Ekasari *et al*., 2015; Ekasari *et al*., 2016 and Emerenciano *et al*., 2013) [22, 23, 25]. In relation to the latter, the application of biofloc technology in grow out systems of some aquaculture species could improve net productivity by 8–43%, relative to the non-biofloc control (traditional with water exchange, clear water system or recirculating aquaculture system) (Ekasari, 2014) [21].
Biofloc technology (BFT) application offers benefits in improving aquaculture production that could contribute to the achievement of sustainable development goals. This technology could result in higher productivity with less impact to the environment. Furthermore, biofloc systems may be developed and performed in integration with other food production, thus promoting productive integrated systems, aiming at producing more food and feed from the same area of land with fewer input. The biofloc technology is still in its infant stage. A lot more research is needed to optimize the system (in relation to operational parameters) e.g. in relation to nutrient recycling. In addition, research findings will need to be communicated to farmers as the implementation of biofloc technology will require upgrading their skills.

2. Materials and Methods

The study was carried out based on the information through review of related thesis, journals, reports and books. Some practical knowledge was gained through observing research presentation related with biofloc and aquaculture. The necessary data were collected from internet, different annual statistical yearbooks of Bangladesh, National Fish week compendiums, newspapers, watching with different on-going researches in YouTube and consulting associated consultants and researchers.

3. Results and discussion

3.1. Principle and Concept

The main principle of this technique is the practice of nutrient recycling (Ray *et al*., 2011) [42]. It is originated depends on the maintenance of carbon/nitrogen supplementation to pond water (Avnimelech *et al*.1994) [8]. Initially researchers acquired the knowledge of carbon/nitrogen for the production of heterotrophic bacteria, which in reverse they feed for the fish and shrimp (Avnimelech, 2009) [7]. A ratio of the carbon/ nitrogen (C/N) is managed to stimulate the growth of heterotrophic bacteria to produce microbial biomass (Avnimelech, 1999) [6]. Supplemented carbon will help to hold the excreted ammonia from the animals (Avnimelech *et al*., 1994) [8]; and by the proper inclusion of carbon and nitrogen to the system ammonia in the water will be altered into bacterial biomass (Schneider *et al*., 2006) [43].

3.2. Reasons to maintain C/N ratio

The maintenance of C/N ratio is quite prerequisite for controlling of accumulating organic nitrogen and for the production of microbial communities in the water (Asaduzzaman *et al*., 2008 and Emerenciano, 2012) [5, 24]. The inorganic nitrogen is converted into organic nitrogen when C:N ratio is sufficient to produce bacterial cells; preferably (Aly *et al*., 2008) [1]. As carbohydrate is involved in the part of respiration process, during aerobic situations the condition of C: N ratio must be more than bacterial body compositions (Emerenciano, 2013) [26]. It was found that around 10 mg NH^{4+}-N/L can be completely absorbed when glucose was added as a substrate and when the maintenance of C/N ratio was 10:110. To minimize the artificial feed requirement, the practice of increasing C: N of higher than 10:1 by utilizing different low-cost carbon sources which are locally obtainable is common in biofloc waters (Crab, 2010) [12]. Apart from reducing the feed cost, utilization of biofloc components will also decrease the amount of protein in the feed (Avnimelech, 1999; Hargreaves, 2006) [6, 30]. It was established that the accumulation of toxic inorganic components including, NH4+ and NO2- will be stopped in the water when the maintenance of C/N ratio is high in the biofloc system as the ammonium consumption by the microbial community.

3.3. The strengths of biofloc technology

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.
- Optimization of the nutritional quality (amino acid composition, fatty acid composition, vitamin content)
- Determination of the impact of the carbon source type on biofloc characteristics

3.4. Component of Biofloc

In general, biofloc is the macro-aggregation of bacteria, algae, detritus and other decomposed components (Avnimelech *et al*., 1994) [8]. It is the combination of bacteria, diatoms, zooplankton, protozoa, macro-algae, feces, uneaten feed (Fig: 1), and exoskeleton from dead organisms (Decamp *et al*., 2008) [16]. Tt is a group of biotic and abiotic particulate components suspended in the water which includes bacteria, planktons, and other organic materials (Hargreaves, 2006) [30]

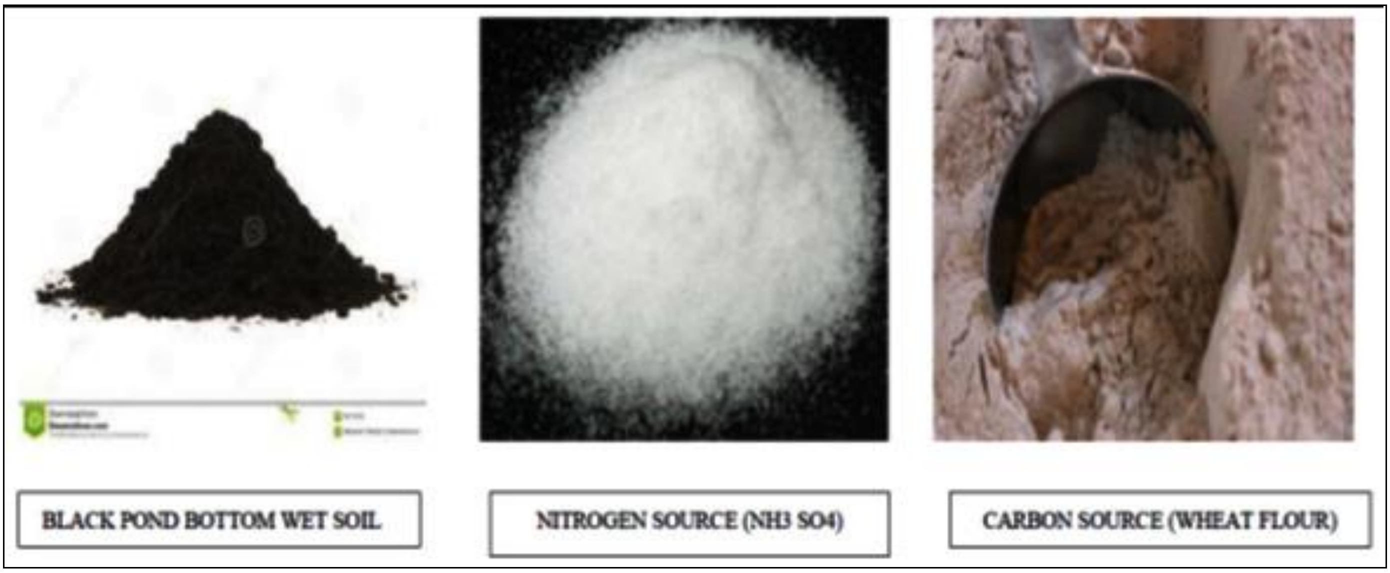

Fig 1: Components needed for biofloc preparation (Source: Daniel N and P. Nageswari 2017) [17].

3.5. Biofloc preparation

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) [43]. By adding carbohydrates to the pond, heterotrophic bacterial growth is stimulated and nitrogen uptake through the production of microbial proteins takes place (Avnimelech, 1999) [6] (Fig: 2). 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) [19]. Suspended growth in ponds consists of phytoplankton, bacteria, aggregates of living and dead particulate organic matter, and grazers of the bacteria (Hargreaves, 2006) [30]. A biofloc technology preparation has been shown in Fig: 3 & 4.

Fig 2: Observation of biofloc volume in imhoff cone

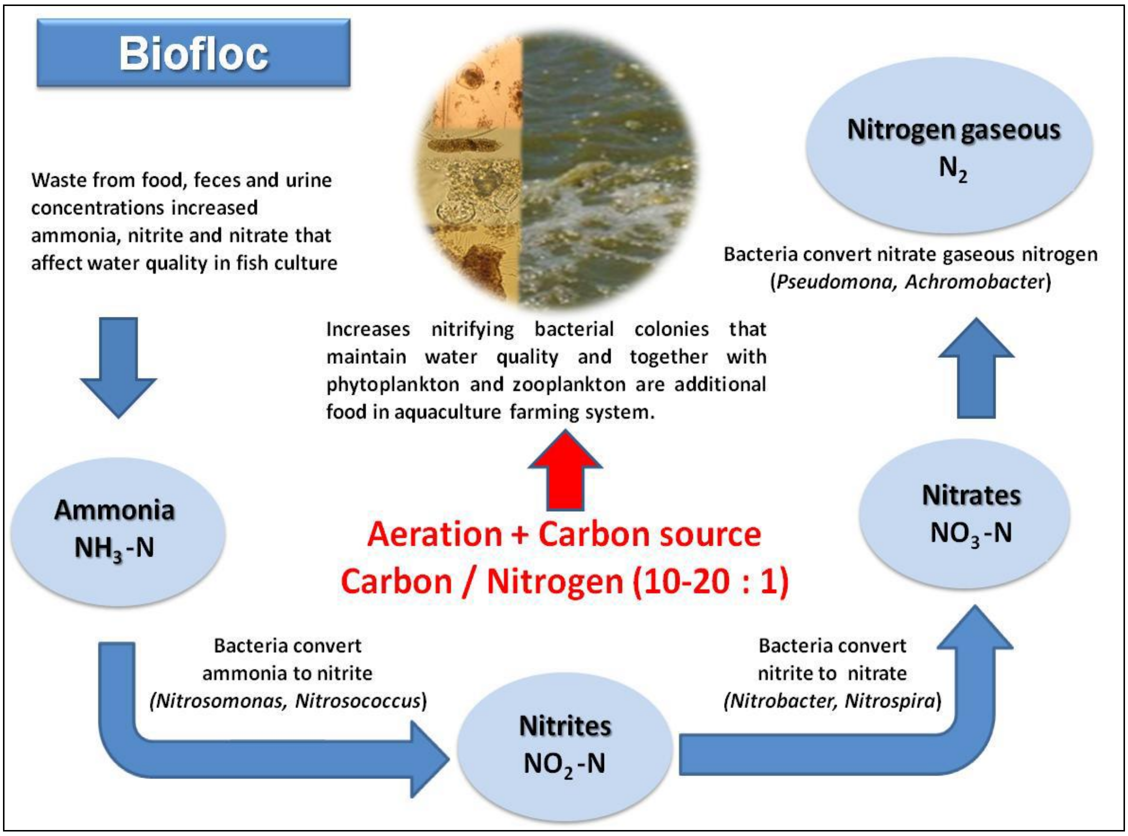

Fig 3: Preparation of biofloc (Source: Goggle)

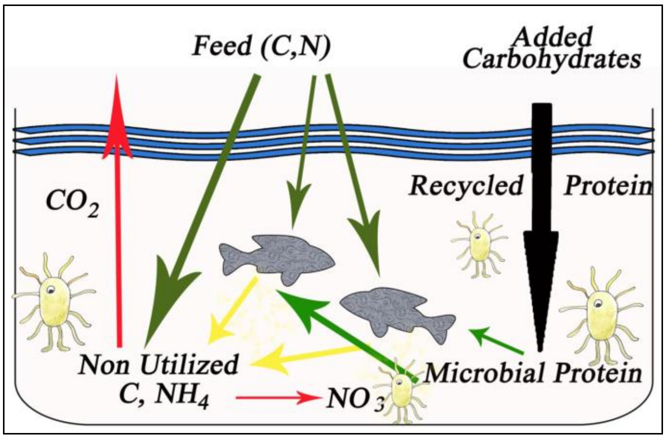

Fig 4: Scheme of biofloc technology in pond (Source: Goggle)

3.6. Water quality management

Biofloc technology offers an ample advantage ensuring zero water exchange through minimal consumption of water and less water pollution (Emerenciano *et al*., 2013) [25]. Biofloc technology is applied for decreasing the effluent discharge, preventing risks from the disease outbreak, protecting the water from pathogen entry; thus, ultimately improve the biosecurity at the farm level (Burford *et al*., 2003) [10]. Regarding the presence of microorganisms, biofloc play a major role in the management of water quality (Moriarty, 1997 and MacIntosh, 2000) [35, 36]. In order to attain more growth usually fish are fed with lots of feed. As aqua feeds are rich in protein that contain 65% of nitrogen content, it is considered that most of the uneaten feeds that present in the water damage the pond water and threaten the animals to disease susceptibility (Francis-Floyd *et al*., 2009) [29]. It was demonstrated in the earlier findings that adopting biofloc technology would solve the problems concerned with ammonia toxicity, with the increasing consumption of nitrogen by heterotrophic bacteria the nitrification process advances, which ensures the reduction in the concentration of ammonium in the culture systems (Hargreaves, 2006) [30]. The study also demonstrated that the production rate for heterotrophic bacteria for the utilization of ammonium is 10 times greater by heterotrophic bacteria as compared to that of nitrifying bacteria (Hargreaves, 2006) [30].

3.7. Feeding, Growth and metabolism

It is known that aquaculture cannot be sustainable without supplementary feed as it relies on 50 to 60% of artificial feed which is about 60% of the total operating cost. In order to reduce the feed costs, methods including the addition of live feeds are followed as an alternate to supplementary feeds (Lim *et al*., 2013) [34]. Biofloc water reduces the FCR and feed costs (Craig and Helfrich, 2002 and Emerenciano, 2013) [11, 25]. The results from the earlier studies also indicated that the supplementary feeding was replaced up to 29% with biofloc method opts for the culture of *L. vannamei*can (Burford *et al*., 2004) [10]. In addition to these, the available reports also show that there was 20% improvement in feed utilization with tilapia reared in Biofloc (Avnimelech *et al*., 1994) [8]. Earlier study reported that the bacterial biomass yield per gram of carbon used as a substrate is 0.5 g (Crab *et al*., 2012) [13]. It was reported in the early study that production of bioflocs takes place when the microbial concentration reaches at 107 CFU/ml (Burford *et al*., 2004) [10].

3.8. Immune response and disease resistance

Biofloc contains the abundant amounts of beneficial bacteria which help in the improvement of immunity to the animals (Defoirdt *et al*., 2010; De Schryver *et al*., 2010; Halet *et al*., 2007; Nhan *et al*., 2010) [15, 18, 31, 39] . Further evidences support that there were significant improvement in the non-specific immunity of the animals cultured in the biofloc water (Decamp *et al*., 2008; Tseng *et al*., 2009; Verschuere *et al*., 2000) [16, 46, 47]. Biofloc bacteria have poly hydroxyl butyrate (PHB), which terminate the pathogenic bacterial attack on the farming animals (Defoirdt *et al*., 2010; Halet *et al*., 2007) [15, 31]. It is speculated that the presence of heterotrophic microbial biomass in the biofloc tends to mitigate the invasion of pathogenic bacteria (Emerenciano *et al*., 2013) [25]. The mortality rate can be seen when the biofloc treated animals were injected with the potentially harmful bacteria (Emerenciano *et al*., 2012) [24].

Table 1: Some of the study conducted in fish with reference to biofloc based culture Systems

SL. No.	Species studied	Results acquired in the study with biofloc
01	*Labeo rohita*	Reduced the artificial feed reliance and improved the utilisation of bioflocs as feed to 50% (Sharma *et al*., 2015) [45].
02	*Oreochromis niloticus*	Fish survival was 100% and results in the utilization of biofloc as food (Azim and Little, 2008) [9].
03	*Oreochromis sps.*	Improvement in the water quality, fish survival and minimization in the external feed requirement (Sharma *et al*., 2015) [45].
04	*Litopenaeus vannamei*	Promoted the animal growth, health, digestion and feed utilization performances (Xu *et al*., 2012) [50].
05	*Penaeus monodon*	Gave the beneficial effects on growth performances and digestive enzyme activities (Anand *et al*., 2013) [3].
06	*Litopenaeus vannamei*	Increase in 30% growth and survival of shrimp in Biofloc treatment (Piedrahita, 2003) [41].

3.9. Potentiality of Biofloc

This technology is basically of zero water exchange oriented i.e. water exchange is not required in the culture ponds; therefore it required less water input which is not only economical to the farmers, but these will also minimize the pathogenic entry of animals through water and certify for more biosecurity in the fish culture. It also promises the less environmental impacts and footprints (Wasielesky *et al*., 2006) [49].This technology allows the animals to rear under the higher stocking density with effective feed management (Crab *et al*., 2010; Crab *et al*., 2012) [12, 13]. The requirement for the feed is considerably less as biofloc itself will be a feed for the cultivable animals, which results in the lower FCR (Aiyushirota, 2009; Krummenauer *et al*., 2011; Pérez-Fuentes *et al*., 2013) [2, 33, 40]. Therefore, application of the technology will reduce the feed cost to the farmers. Biofloc increases the survival of fish since the beneficial microorganisms dominate in the biofloc acts as an antagonism to the pathogenic bacteria which prevent the disease outbreak and expand the percentage of survival during the harvest. This way (beneficial) bacteria present in the biofloc prevent the colonization of any harmful bacteria that ensure the highest survival rate of the fish in the farms (Megahed, 2010; Samocha, 2007; Pérez-Fuentes *et al*., 2013) [37, 44, 40]. Biofloc bacteria produce the poly hydroxyl butyrate (PHB) which are beneficial in the digestion and metabolism of fatty acid and growth increment to the fish (De Schryver *et al*., 2012) [18]. Biofloc waters rich in the heterotrophic bacteria which utilize the toxic nitrogenous matters as a substrate for their growth that helps maintaining the water quality through reducing the organic loads as well as biochemical oxygen demand of the system (Avnimelech, 1994; Burford *et al*., 2004; Wasielesky *et al*., 2006) [8, 10, 49]. Bioflocs comprise a wide assemblage of bacteria, algae, protozoa and other zooplankton organisms, perhaps as many as 1000-2000 different species. As yet we do not know enough about the composition of the bioflocs, nor our ability to affect it and the different effects it may have on fish production and on the eco-stability of the system.

It has been shown that the immune systems of shrimp are enhanced in the presence of bioflocs and there is a lower incidence of diseases among shrimp grown in biofloc systems. It has demonstrated the probiotic effects of bioflocs against *Streptococcus* infection in tilapia. Research on the effects of bioflocs on diseases is actively ongoing, and we can expect getting more on how to use this system to control diseases. Interesting new results demonstrate the effects of bioflocs on the fecundity of both shrimp and tilapia: in both cases the number of eggs per female were about doubled. We do not know exactly the mechanism of this effect. It is possibly caused by the high quality of the biofloc feed components, better water quality, or the presence of hormones (or of components having hormonal effects). Biofloc technology has become a common way of running hatcheries and nurseries. Moreover, biofloc systems are environmentally friendly due to the fact that there is almost no release of nutrient rich drainage water to the environment.

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5. Conclusion

Biofloc technology offers benefits in improving aquaculture production that could contribute to the achievement of sustainable development goals. This technology could result in higher productivity with less impact to the environment. Furthermore, biofloc systems may be developed and performed in integration with other food production, thus promoting productive integrated systems, aiming at producing more food and feed from the same area of land with fewer input. The biofloc technology is still in its infant stage. A lot more research is needed to optimize the system (in relation to operational parameters) e.g. in relation to nutrient recycling, MAMP production and immunological effects. In addition, research findings will need to be communicated to farmers as the implementation of biofloc technology will require upgrading their skills.

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