

The application of ceramsite ecological floating bed in aquaculture: its effects on water quality, phytoplankton, bacteria and fish production

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ABSTRACT

In recent years, biological floating bed technology has been applied increasingly in aquaculture ponds. In this study we developed a novel floating bed made from ceramsite and studied its effect on water quality, phytoplankton, bacteria and fish growth. Water quality was effectively regulated and controlled in ceramsite floating bed (CFB) ponds with an average transparency of 23.18 cm, ammonia nitrogen ($\text{NH}_4^+\text{-N}$) of 2.30 mg L^{-1} , total nitrogen (TN) of 5.09 mg L^{-1} and total phosphate (TP) of 1.32 mg L^{-1} which are lower than in control ponds without CFB. Increased phytoplankton species diversity, bacterial number, metabolic activity and microbial diversity was observed with CFB. At the end of growth stage, feed conversion ratio (FCR) was reduced with a total fish yield of $14,838 \text{ kg ha}^{-1}$ at a survival rate of 77.2% in CFB ponds, which is significantly higher than control ($P < 0.05$). These results emphasize the potential of ecological floating bed to improve water quality, microalgal diversity, reduce the risk of harmful algal blooms and increase the number, activity and diversity of microorganisms as well as fish yield.

Key words | aquaculture, ceramsite floating bed, fish pond, microorganisms, phytoplankton, water quality

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INTRODUCTION

Intensive aquaculture has become prevalent in recent years. However, the heavy input of artificial feed has resulted in large amounts of un-utilized feed that will deposit at the bottom, which can lead to deterioration of the pond bottom and overall water quality (Hossain *et al.* 2016). This additional organic matter is likely to cause harmful blue green algal blooms after mineralization by microorganisms, which produce harmful algal toxins and may be detrimental to farmed organisms and a threat to humans via the food chain (Brett 2003). The deterioration of water quality also affects the growth of cultured animals therein and increases the incidence of diseases (Paulraj *et al.* 2016).

According to the principles of water treatment, aquaculture water treatment technology is divided into three categories: (1) physical treatment methods, such as adsorption, filtration and aeration, (2) chemical treatment methods, such as flocculation and complexation, and (3) biological treatment methods such as artificial wetlands, floating beds, and microbial bioremediation. Ecological

floating bed (EFB) technology has attracted much attention due to its advantages of low costs and high efficiency (Li *et al.* 2010). Several researchers have investigated the effects of floating beds in aquaculture ponds (Pfeiffer & Wills 2011). However, there are two restrictions regarding the purification effects of the floating bed at present: (1) the hybrid EFB technology still relies on hydrophytes for bioremediation, which are strongly influenced by low temperature conditions (Luo *et al.* 2010); (2) although hybrid EFBs can be used to purify eutrophic water, these technologies are not efficient for removing nitrogenous compounds in fishing ponds, a great deal of which originate from the excess feed. This leads to low removal efficiency of nitrogenous compounds (Zhi & Ji 2014). At present, the floating bed adopts polyethylene as a frame, but this material does not withstand wind and wave impacts very well.

Ceramsite is a type of material that uses natural mineral or industrial waste as the main raw material through direct crushing or processing into particles, which are then burned into an

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Table 1 | Chemical composition of ceramsite

Composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO + CaO	K ₂ O + Na ₂ O	Others
Percentage	59.65	15.46	4.13	3.68	4.12	12.96

artificial light aggregate. There are many tiny holes on the surface and interior that can easily harbor microorganisms. Furthermore, it has a high biological and chemical stability (Bao et al. 2016). Thus it can be applied in the study of wastewater treatment technology. In this study, we developed a ceramsite based ecological floating bed (CFB) using ceramsites as a substrate for macrophytes. Compared with conventional EFBs, the CFB has advantages like creating a coupling function between bio-carriers and hydrophytes, which is helpful for enhancing the plant biomass. The objective of this study was to explore the effect of the ceramsite EFB on aquaculture water improvement and to further study how it facilitates improvement of beneficial bacteria and phytoplankton so as to provide a basis for further research and applications of the CFB technology.

MATERIAL AND METHODS

Ceramsite composition and fabrication

The primary material of the ceramic floating plate was constituted of light shale aggregate purchased from Yichang Guangda Ceramic Products Co., Ltd (Yichang, Hubei). The main chemical composition is listed in Table 1. The production process of the ceramsite plate was as follows: (1) lightweight ceramsite with large porosity and strong buoyancy, and a particle size of 10–20 mm, were selected as the raw material; (2) perlite was added in order to increase the

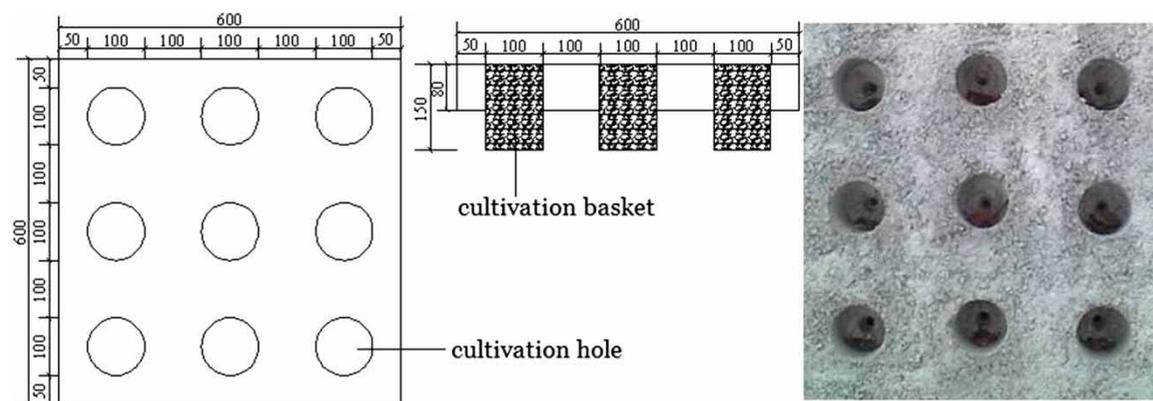
buoyancy of the floating plate; (3) a small amount of fly ash was added to increase the structural strength of the floating plate, and to reduce the pH; (4) PII52.5 Portland cement was used as the binder; (5) the mixed materials were poured into a floating bed mold measuring 60 cm × 60 cm × 8 cm (the mold possessed holes with 10 cm diameter, for plant propagation); (6) the ceramic floating plates could be put into use after natural air drying.

Ceramsite EFB design

The frame of the CFB was constructed from a ceramsite plate which measured 0.6 m in length, 0.6 m in width and 0.15 m in height (Figure 1). The frame can provide buoyancy. The CFB comprises three zones: the ceramsite plate zone, the bulk material zone, and the plant zone. In order to prevent the grass carp eating the roots of plants during breeding, the bottom of the CFB was protected by a net cage with 2 cm × 2 cm mesh holes.

Floating bed plants

In this study, we chose to use *Arundo donax* as a floating bed plant due to its large biomass and good purification effect on water quality (Tuttolomondo et al. 2015). The plants were transplanted in to the cultivation basket after being grown on ground until they reach 15 cm height. Two plants were placed into each cultivation basket and fixed with ceramic aggregate, and were then moved into the hole in the floating plate. Individual floating beds were connected by wire as a single block in the pond. No harvesting of plants was done during the breeding period because they were not fully grown. The floating bed area covered 5% of the total pond area (Figure 2).

**Figure 1** | Schematic diagram showing design and dimensions of CFB (a) and molded ceramsite plate with cultivation hole (b).

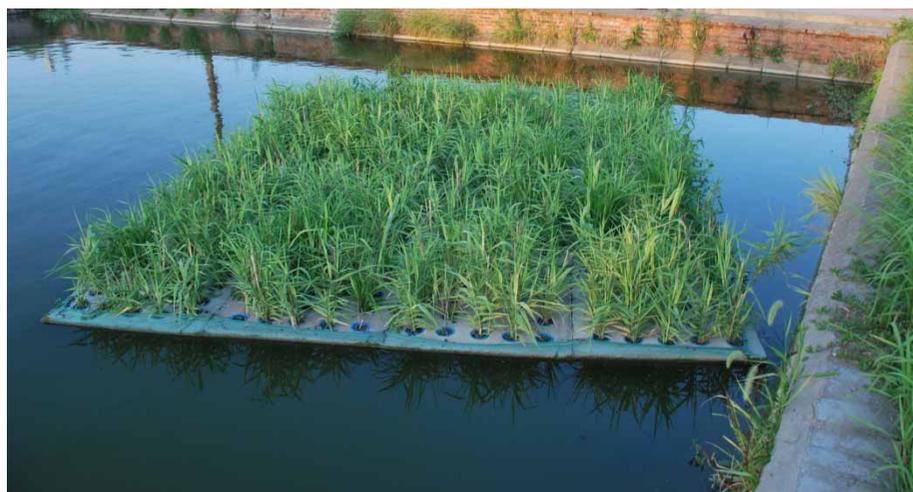


Figure 2 | Ceramsite floating bed in fish pond.

Cultivation ponds

The study site was located at the experimental base of the research center for pond ecological engineering, Chinese academy of fishery sciences, Jingzhou, Hubei Province, China. All ponds were artificial and did not communicate with rivers and lakes. In total, six culture ponds were selected. Ceramsite EFBs were applied to three of the ponds, while three ponds were used as the control without floating beds. Each of the culture ponds had an area of 400 m². Prior to stocking with fish, all the ponds were drained, desilted and the pond bottoms were disinfected with lime. Water pumped from a nearby reservoir was then used to fill the culture ponds to a depth of approximately 1.5 m. The supplementation for the water lost due to evaporation was mainly achieved using groundwater or by rainfall.

Fish culture

In this study, a polyculture fish stocking strategy was adopted. Grass carp (*Ctenopharyngodon idella*), was the main culture species, at an initial weight of 65 g and with a breeding density of 17,991 tail ha⁻¹, which were mixed with a minor quantity of silver carp (*Hypophthalmichthys molitrix*) with an initial weight of 200 g at a breeding density of 2,249 tail ha⁻¹. The fish stocking began on April 20th and fish were harvested on November 8th, corresponding to a rearing period of 172 days. The ponds were harvested by complete drainage at the end of the rearing period. During the study, the fish were fed to satiation twice daily with a commercial diet, and the amount of feed administered was measured to determine the feeding efficiency. The feed

was purchased from Tongwei Feedstuff Co., Ltd (Dongxihu Development Zone, Wuhan, China). A commercial grass carp floating feed (~34% protein, 5% fat, 7% cellulose, 14% ash, 1.6% lysine and 1.2% available phosphorus) was used.

The feed conversion ratio (FCR) was calculated according to the following formula:

$$FCR = \frac{FI}{W}$$

where FI is the feed intake (kg) and W is the live weight gain (kg).

Water sampling and analysis

Water samples were collected to monitor water quality parameters of each pond every 15 d between 8:00–9:00 a.m. 500 ml samples were collected from the four corners and the center of each pond using a siphon pipe and a composite sample was obtained by mixing all five samples. Transparency was measured using a Secchi disk at the same point where the water sample was drawn. Once a composite sample was collected, water temperature, dissolved oxygen (DO) and pH were measured immediately using a YSI 650MDS Multi Probe System (YSI Inc., Ohio, USA). The chemical oxygen demand was measured using the titrimetric method; ammonia nitrogen (NH₄⁺-N), nitrite (NO₂⁻-N), total nitrogen (TN), total phosphorus (TP) and phosphate (PO₄³⁻-P) was measured using the colorimetric method according to standard methods described by the State Environmental Protection Administration (SEPA) of China (SEPA 2002).

Phytoplankton analysis

A 1-liter phytoplankton sample was preserved with Lugol's iodine solution from each sampling station. The supernatant was removed after 48 h sedimentation and the remaining sediment was collected for phytoplankton analysis. *Microcystis* colonies were split up into cells by sonication for three minutes. Phytoplankton cell volume was obtained by measuring the average cell dimensions for each species. Phytoplankton biovolume (wet weight) was evaluated according to Zhang & Huang (1991). Phytoplankton species identification was performed according to Hu *et al.* (1980).

Microbial analysis

The total bacteria was measured with a fluorescence microscope according to Weinbauer *et al.* (1998). The bottom layer of mud was removed and 80 μL diluents were collected in a centrifuge tube. To this, 10 μL (10 \times) SYBR Green I fluorochrome was added and allowed to stain in the dark for 1 min, 10 μL of anti-fading agent was added to the samples. Finally, the enumeration was done under a fluorescence microscope.

Metabolic activity of the bacterial community was estimated using average well color development (AWCD) assay according to Garland & Mills (1991). Briefly, water samples were added to a Biolog Eco microplate using an eight channel sample injector at 150 μL per well in triplicates. Subsequently, samples were cultured at 28 $^{\circ}\text{C}$ in an incubator under dark condition for 0, 24, 48, 72, 96, 120, 144 and 168 h and the sample absorbance was measured at 590 nm (color + turbidity) and 750 nm (turbidity) using a Biolog microplate reader (Biolog Inc., USA), and AWCD was calculated.

Data analysis

Shannon, Simpson and McIntosh indices were calculated following Zak *et al.* (1994). Data were processed and mapped with Microsoft Excel 2003 and Origin V. 7.0. The diversity of microflora carbon source utilization was analyzed using principal component analysis. Statistical analyses were performed using SPSS Base V. 13.0 statistical software (SPSS Inc., Chicago, IL, USA).

RESULTS

Physicochemical analysis

The physicochemical parameters of pond water were measured during the entire experimental period. Seasonal variation of major parameters like transparency, DO, pH and temperature of the pond water were measured (Table 2). The initial values before treatment indicate that the water met the requirements for aquaculture. The water temperature, pH and DO did not show any significant difference ($P > 0.05$) between two treatments but transparency of ponds with CFB was significantly higher than that of control ($P < 0.05$).

During the initial culture period, inorganic nutrient concentration of NH_4 , NO_2 , PO_4 , TN and TP were at low levels in all experimental ponds. After the supply of artificial feed, the physicochemical indexes of the pond water gradually increased. During the late stage of culture, the nutrient levels in ponds with CFB were significantly lower than control ($P < 0.05$), with NO_2^- -N of 0.33 mg L^{-1} and PO_4^{3-} -P of 0.17 mg L^{-1} except for NH_4^+ -N (Figure 3(a)). The TN and TP content reached their highest values of 7.28 mg L^{-1} and

Table 2 | Monthly variation in water quality parameters of test ponds

Parameters	Treatment	Month						Mean value
		May	June	July	August	September	October	
Temperature ($^{\circ}\text{C}$)	With CFB	22.3 \pm 1.2	25.2 \pm 2.4	27.1 \pm 1.7	31.0 \pm 1.4	30.0 \pm 2.7	28.4 \pm 1.4	28.57 \pm 1.99 ^a
	Control	22.3 \pm 1.1	25.3 \pm 1.7	27.2 \pm 2.7	31.2 \pm 2.4	30.1 \pm 1.4	28.3 \pm 2.4	28.71 \pm 2.07 ^a
pH	With CFB	7.9 \pm 0.2	7.9 \pm 0.4	7.8 \pm 0.1	8.1 \pm 0.3	7.7 \pm 0.4	7.5 \pm 0.3	7.93 \pm 0.13 ^a
	Control	7.9 \pm 0.3	7.9 \pm 0.1	7.8 \pm 0.2	8.0 \pm 0.3	8.0 \pm 0.3	7.8 \pm 0.2	7.98 \pm 0.11 ^a
DO mg L^{-1}	With CFB	12.5 \pm 3.1	10.3 \pm 2.7	11.4 \pm 1.5	9.3 \pm 4.4	7.6 \pm 2.4	11.8 \pm 2.0	4.13 \pm 1.83 ^a
	Control	12.3 \pm 2.5	12.0 \pm 3.5	9.4 \pm 2.6	10.4 \pm 2.5	8.5 \pm 1.5	12.7 \pm 3.8	4.01 \pm 2.06 ^a
Transparency (cm)	With CFB	40.0 \pm 3.2	35.5 \pm 2.4	33.0 \pm 2.9	30.0 \pm 1.4	28.0 \pm 1.4	30.5 \pm 3.7	23.18 \pm 4.01 ^a
	Control	39.5 \pm 2.4	30.0 \pm 2.7	25.0 \pm 2.4	16.0 \pm 3.4	17.5 \pm 1.9	20.0 \pm 1.7	18.04 \pm 5.44 ^b

Values mentioned are averages of three ponds \pm SD with CFB and control.

^{a,b}Letter superscripts indicate significant difference between CFB and control ($P < 0.05$).

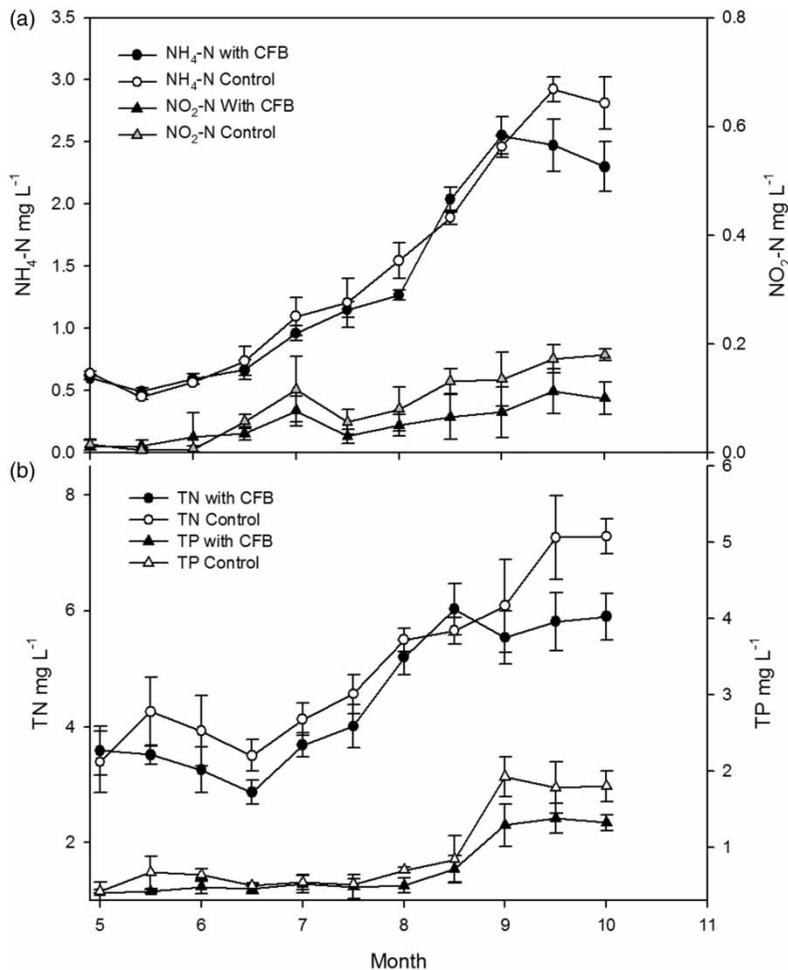


Figure 3 | Seasonal variation of inorganic nutrients during the culture phase in ponds with CFB and control. Error bars represent \pm SD.

1.80 mg L⁻¹ respectively in ponds without CFB, whereas they remained at 5.81 mg L⁻¹ and 1.30 mg L⁻¹ respectively in ponds with CFB (Figure 3(b)). The overall fluctuations in physicochemical parameters studied were considerably lower in ponds with CFB.

Phytoplankton analysis

During the experimental period, a total of 179 phytoplankton species belonging to eight phyla and 111 genera were observed in the samples collected from different sampling sites (Table 3). During the early stage, the species composition of phytoplankton was similar between test and control ponds. With an increase in water temperature, the number of phytoplankton species began to increase in all ponds, with the appearance of Cryptophyta and Chrysophyta. Phytoplankton species in ponds with CFB were significantly higher during the middle stage of fish growth

(July–August) but in the late stage (September–October) this difference gradually decreased when compared with control ponds. The number of cyanobacteria species was lower and the number of Bacillariophyta species higher in ponds with CFB.

The dominant species of phytoplankton during the early stage of culture were *Scenedesmus* (47.9% with CFB; 39.1% control) and *Merismopedia* sp. (22.8% control). During the mid phase, *Scenedesmus* sp. continued to dominate in the CFB ponds, while the quantities of *Microcystis* sp. and *Merismopedia* sp. changed. With the increase in water temperature and change in nutrients, *Merismopedia* became the dominant algae, constituting 91.2% in control ponds (particularly in July). In the late breeding stage, the decrease in water temperature resulted in increased density of *Chlorococcum* sp. and *Scenedesmus* sp. In ponds with CFB, *Chlorophyta* was dominant during the early phase followed by a gradual succession of *Euglenophyta* and *Bacillariophyta*.

Table 3 | Phytoplankton diversity and their percentage observed during the growth stage in ponds with CFB and control

Phyla	Number of species												Percentage (%)	
	May		June		July		August		September		October			
	With CFB	Control	With CFB	Control	With CFB	Control	With CFB	Control	With CFB	Control	With CFB	Control		
Chlorophyta	30	32	38	40	40	41	38	29	29	27	33	34	48/93	52.0
Cyanophyta	4	5	7	5	10	10	8	8	6	9	8	8	18/25	14.0
Bacillariophyta	7	6	6	4	5	5	9	7	9	4	6	7	19/23	12.9
Euglenophyta	2	2	3	6	3	3	4	3	2	3	4	4	8/17	9.5
Pyrrophyta	2	1	2	1	2	1	2	1	2	1	2	2	5/5	2.8
Cryptophyta	-	-	2	2	3	2	5	4	3	3	2	2	3/5	2.8
Chrysophyta	-	-	1	1	2	-	2	3	-	1	-	1	4/5	2.8
Xanthophyta	-	-	-	-	4	-	2	1	-	-	-	-	6/6	3.4
Total	45	46	59	59	69	62	70	56	51	48	55	58	111/179	100
Total biomass g L ⁻¹	0.116	0.090	0.155	0.117	0.212	0.255	0.277	0.189	0.502	0.349	0.831	0.402		

In control ponds, *Chlorophyta* was the dominant group throughout the culture period but a sudden bloom of cyanobacteria was observed during September.

The seasonal variation in total phytoplankton biomass was measured using wet biomass, which reached 0.402 g L⁻¹ and 0.831 g L⁻¹ respectively in control and with CFB at late growth stage. The total phytoplankton biomass in ponds with CFB was significantly higher than control ($P < 0.05$) in the middle and later growth periods.

The diversity index and species richness of phytoplankton decreased gradually during the entire breeding period in the culture ponds. There was no significant difference in the phytoplankton diversity between the two treatments. However, the species evenness index was higher with CFB during the late stage (July to October). The Shannon diversity index $H'(\log_e)$ and Simpson diversity index $1-\text{Lambda}$ both showed a trend of an initial decrease followed by gradual increase (Table 4).

Microbial analysis

The bacterial number (BN) in the pond water during the entire growth phase was estimated using fluorescence microscopy (Figure 4). The fluctuation range of BN during May to October was 0.56×10^6 – 6.45×10^6 ind. m L⁻¹ in ponds with CFB and 0.58×10^6 – 4.00×10^6 ind. m L⁻¹ in control. The BN without CFB was lower than with CFB during the same period ($P < 0.05$).

The AWCD values in Eco Biolog microplate analysis were used to judge the carbon source utilization ability and metabolic activity of the microbial community. The AWCD of the pond water changed during the three breeding stages, including early (June), middle (August) and late (October) stage, as shown in Figure 5. The value of AWCD was highest during the middle stage in both groups, and was higher in the floating bed group than in the control group during the same period. Analysis of variance revealed that the AWCD in the floating bed group was significantly higher than in the control group ($P < 0.05$). This difference was consistent with the microbial biomass in the unit volume of the water body.

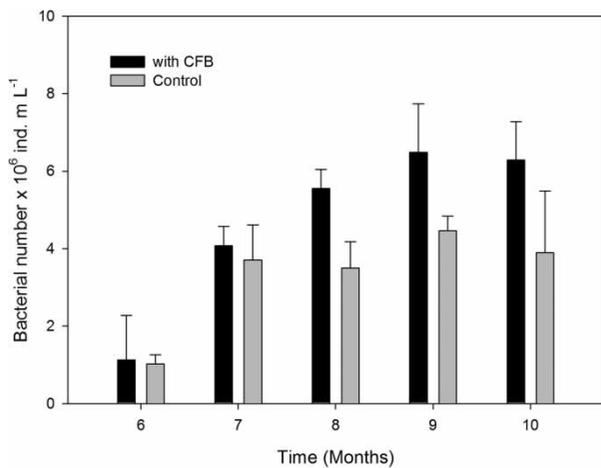
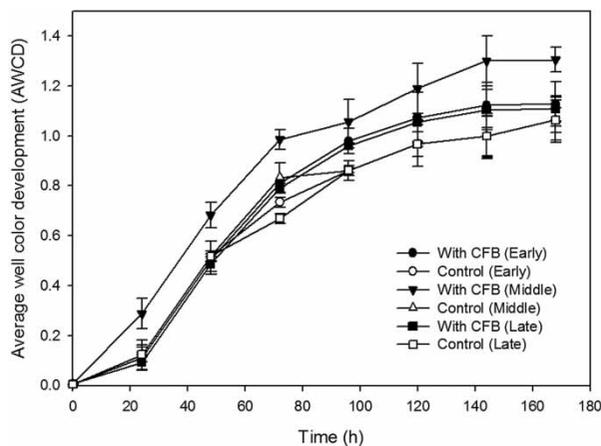
Fish growth

After completion of the growth stage, growth parameters like weight, survival rate and FCR were calculated and compared between two treatments (Table 5). FCR in ponds with CFB was significantly lower. The average carp weight reached 1,125 g per fish, with a total yield of 14838.1 kg ha⁻¹ with CFB whereas in control ponds a total yield of

Table 4 | Phytoplankton community under different treatments analyzed by different diversity indexes

Sampling time	Species richness (d)		Pielou' evenness (J')		Shannon index (H')		Simpson index (1-Lambda')	
	With CFB	Control	With CFB	Control	With CFB	Control	With CFB	Control
May	5.59 ± 0.80	4.23 ± 0.75	0.72 ± 0.02	0.75 ± 0.04	2.46 ± 0.25	2.46 ± 0.33	0.83 ± 0.10	0.87 ± 0.09
June	4.47 ± 1.29	3.16 ± 0.10	0.69 ± 0.01	0.48 ± 0.10	2.34 ± 0.21	1.50 ± 0.32	0.85 ± 0.01	0.61 ± 0.20
July	4.00 ± 0.04	4.22 ± 1.94	0.49 ± 0.10	0.46 ± 0.09	1.51 ± 0.45	1.61 ± 1.53	0.58 ± 0.21	0.54 ± 0.52
August	4.77 ± 1.00	4.45 ± 1.82	0.75 ± 0.14	0.65 ± 0.11	1.94 ± 0.61	2.15 ± 0.63	0.70 ± 0.19	0.78 ± 0.14
September	3.56 ± 0.93	3.69 ± 0.37	0.71 ± 0.13	0.68 ± 0.04	2.17 ± 0.06	2.15 ± 0.06	0.87 ± 0.01	0.83 ± 0.03
October	3.82 ± 0.31	3.76 ± 1.36	0.67 ± 0.04	0.65 ± 0.08	1.84 ± 0.52	2.04 ± 0.45	0.75 ± 0.14	0.80 ± 0.07

The values are represented as ±SD.

**Figure 4** | Seasonal changes in total bacterial number during the culture phase with and without treatment. Error bars represent ±SD.**Figure 5** | Changes in metabolic activity of the microbial community under different treatments during early, middle and late stages of fish growth. Error bars represent ±SD.

10899.5 kg ha⁻¹ was obtained, which was significantly lower than with CFB ($P < 0.05$). Furthermore, the survival rate in CFB containing ponds was 77.2%, which was also significantly higher than in control ponds ($P < 0.05$).

DISCUSSION

Studies suggest that the floating bed coverage area is an important factor influencing the removal of water pollutants. *Chao et al. (2011)* found that nutrient removal efficiency of a traditional floating bed depends on its coverage area and planting time. However, a higher coverage area of floating bed prevents atmospheric gaseous exchange with water, resulting in reduced DO levels, and it also prevents shading resulting in reduced phytoplankton photosynthesis and oxygen production (*Li & Li 2009*). Furthermore, the respiration of plant roots increased the oxygen consumption (*Bing & Chen 2000*). Therefore, use of efficient techniques to reduce the coverage area without compromising the nutrient removal efficiency is needed. In this study, the CFB coverage accounted for 5% of the total water surface area but still we were able to maintain an average DO level of 4.13 mg L⁻¹ during the entire breeding process. This indicated that the floating bed coverage rate of 5% could effectively maintain a high DO level. As a result of the adsorption of suspended solids in the water to the plant roots and planktonic algae inhibition (*Gagnon et al. 2007*), the average values of water transparency and organic matter content were 23.8 cm and 19.48 mg L⁻¹, respectively, with CFB, which was significantly lower than control. This might be due to an aerobic and anaerobic zone formed around the root of the floating bed and organic compounds secreted by the roots, which might have provided an

Table 5 | Differences in growth, survival and feed conversion ratio of fish grown with CFB and in control ponds

Treatment	Initial weight (g)	Final weight (g)	Weight gain rate (%)	Survival rate (%)	Total output (kg/ha)	Feed conversion ratio (FCR)
With CFB	65.0 ± 0.1	1125 ± 25 ^a	1630.8 ± 54.4 ^a	73.2 ± 5.2 ^a	14838.1 ± 101.4 ^a	1.86 ± 0.23 ^a
Control	65.2 ± 0.1	925 ± 75 ^b	1323.1 ± 16.3 ^b	65.6 ± 2.2 ^b	10899.5 ± 59.0 ^b	2.53 ± 0.16 ^b

Values shown are ±SD.

^{a,b}Letter superscripts indicate significant difference between columns ($P < 0.05$).

alternative habitat and food source for nitrogen reducing bacteria (Susarla et al. 2002; Stottmeister et al. 2003).

The different effects of biological floating beds on phytoplankton like the shading effect, nutrient competition, interception by plant roots and attached microbial degradation were studied by Mulderij et al. (2007). Coverage area of the floating bed is crucial in maintaining oxygen diffusion and water quality, with higher coverage of >50% leading to anoxic conditions whereas lower cover can lead to insufficient treatment (Borne et al. 2014). A coverage area of 20% was found to be ideal for optimum aeration and removal efficiency using traditional floating beds (Yueya et al. 2017). In the present study, we found that reduced CFB coverage area using highly porous ceramsite beds might have provided ideal conditions in terms of light availability and solid substrate for attached growth of benthic algae, resulting in enhanced phytoplankton density and diversity. Accumulation of excess nutrient in pond water is a major concern, leading to harmful algal blooms (Thomas Kiran et al. 2016). *Microcystis* sp., which produces microcystin, was of particular concern to fish and shrimp ponds, in the present work the use of CFB reduced *Microcystis* sp. blooms; this might be due to the balanced N:P ratio, which is not ideal for cyanobacterial blooms, and subsequent enhancement of benthic algae especially diatoms instead of planktonic species. A balanced N:P ratio of 15:1 results in enhancement of water quality with a higher concentration of beneficial diatom algae in fish pond water (Li et al. 2017).

Symbiosis between bacteria and algae plays an integral role in the efficiency of waste water bioremediation (Su et al. 2011). The average BN value of ponds with CFB was significantly higher than in control ponds. This may be due to the availability of solid substrates like the ceramsite platforms and plant roots. Organic carbon from root exudates and other organic matter accumulated on roots could have provided essential nutrients for enhanced microbial growth. CFB may have facilitated the symbiotic relation between plants and microorganisms. CFB contain micropores and mesopores on the surface and the interior of the ceramsite, which facilitated the easy attachment of microorganisms and benthic algae, which might have resulted

in their enhanced growth. Guo et al. (2006) isolated algicidal bacteria with a strong algae cell wall lysis potential, although in this present study we did not screen for this bacteria, but it might have played a role in reduction of harmful planktonic algae, especially cyanobacteria, as significantly lower amounts were detected with CFB than without CFB ($P < 0.05$). Furthermore, CFB ponds did not experience a large-scale outbreak of *Microcystis* sp. during the summer month of June.

CONCLUSIONS

Novel ceramsite EFB resulted in higher water transparency and lower concentrations of major nutritive salts with the least fluctuations in physicochemical indexes during the culture period. By removing excess nutrients, water quality was effectively regulated and controlled by CFB. There was a remarkable difference in the planktonic algae community, with higher species diversity and density with CFB. This shows the ability of CFB to increase beneficial phytoplankton and reduce the risk of harmful algal blooms. Increased total bacterial number and microbial activity with CFB might influence excess nutrient removal and facilitate benthic algal growth. Total fish yield and survival rate was higher in ponds with CFB. This work emphasizes the enormous potential of novel ceramsite EFB in improving water quality, beneficial phytoplankton growth, in reducing the risks of harmful algal blooms, increased beneficial bacterial number, activity and diversity and in enhancing fish yield.

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