Periphyton Growth on Three Bio-substrates and Its Influence on the Performance of Jaraqui (Semaprochilodus insignis)

Keshavanath P.¹, Leao da Fonseca F.A.², Affonso E.G.¹, Nobre A.D.¹, Jeffson N.P.¹

¹ Aquaculture Division, National Institute of Research in the Amazon, Post Box no. 478, CEP 69060-001, Manaus-AM, Brazil
² Instituto Federal do Amazonas-Campus Manaus Zona Leste, Avenida Cosme Ferreira, 8045–São José Operário, CEP: 69083–000, Manaus–AM, Brazil

Corresponding author Email: perarkeshavanath@yahoo.co.in

International Journal of Aquaculture, 2017, Vol. 7, No.13  doi: 10.5376/ija.2017.07.0013

Received: 17 Jul., 2017
Accepted: 08 Aug., 2017
Published: 18 Aug., 2017

Copyright © 2017 Keshavanath et al., This is an open access article published under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Preferred citation for this article:
Keshavanath P., Leao da Fonseca F.A., Affonso E.G., Nobre A.D., and Jeffson, N.P., 2017, Periphyton growth on three bio-substrates and its influence on the performance of Jaraqui (Semaprochilodus insignis), International Journal of Aquaculture, 7(13): 86–93 (doi: 10.5376/ija.2017.07.0013)

Abstract Two experiments were conducted using plant substrates viz. bamboo (Bambusa vulgaris), ambay (Cecropia pachystachya) and leucaena (Leucaena leucocephala) without and with fish to evaluate their suitability for periphyton development, and influence on water quality and growth performance of jaraqui (Semaprochilodus insignis). In the first experiment of 45 days, carried out with only the substrates, periphyton growth and water quality were assessed, while in the second experiment of 120 days fish growth was monitored, in addition to periphyton development and water quality. The best growth of periphyton was observed on bamboo, followed by ambay and leucaena. Bamboo grown periphyton had the highest chlorophyll-a (39.59 µg/cm²) and protein (24.42%) content. All the water quality parameters monitored were within the limits suitable for aquaculture. Fish of av. length 6.5±0.15 cm and av. wt. 5.83±0.23 g stocked at a density of 1 per m² attained the best final av. length of 11.23±0.69 cm and av. wt. of 34.34±2.05 g in bamboo installed tanks, indicating its superiority as a substrate. Jaraqui growth was higher by 76.65, 53.55 and 25.41% in bamboo, ambay and leucaena treatments over the control with no substrate.

Keywords Aquaculture; Substrate; Jaraqui; Growth; Water quality

1 Introduction
Natural food is a valuable source of proteins, free amino acids and oligopeptides, fat and fatty acids and vitamins that are essential substances for growth and development of fish (Kibria et al., 1997). Its enhancement in fish/prawn culture ponds is effected through fertilization, substrate introduction or biofloc technology. Biofilm/periphyton-based fish culture offers a new direction, especially since periphyton is effectively utilized by many fish species which thrive low in the food chain (Van Dam et al., 2002). In recent years, periphyton-based fish culture is developing as an alternative to systems with low input supplemental feeding, due to the high cost of artificial diets. It results in increased fish/prawn production (Mridula et al., 2005; Jana et al., 2006; Garg et al., 2007; Asaduzzaman et al., 2010, Keshavanath et al., 2015; Bharti et al., 2016; Shilta et al., 2016; Tortolero et al., 2016; Kumar et al., 2017), simultaneously addressing environmental concerns through effective recycling of nutrients from the aquatic system. Higher fish yield from such systems is enabled by the nutritional contribution of periphyton growing on the substrates and also better survival since substrates act as shelters for fish. Actively photosynthesizing population of periphyton increases pH and oxygen in water, enhancing water quality. Furthermore, periphyton also traps particulate material from the water column (Dodds, 2003). Results reported on organic tilapia production by Milstein et al. (2008, 2013) point towards periphyton-based aquaculture as an appropriate technology for reduction in production cost.

In studies aimed at determining the efficiency of substrate type on the production of periphyton for aquaculture, both biodegradable substrates and non-biodegradable substrates have been tested, employing several fish/prawn species. Biodegradable substrates are considered to be better suited for periphyton growth because of the high C:N ratio. Herbivorous species such as rohu (Labeo rohita), fimbriatus (Labeo fimbriatus), mahseer (Tor khudree) and tilapia (Sarotherodon niloticus) are more suitable for exploiting periphyton (Azim et al., 2001; Keshavanath et al., 2002; Uddin et al., 2009) due to their feeding habit. Even the African catfish, Clarias garepinus has been shown...
to effectively utilize periphyton from bamboo substrate (Amisah et al., 2008). However, such studies using native fish species in Brazil are very limited. Jaraqui (Semaprochilodus insignis), an iliophagous scavenger, has great potential for substrate-based aquaculture since it consumes periphyton (Santos et al., 2006). Further, this genus plays an important social role by catering to the needs of low-income population in the Amazon, accounting for approximately 50% of fish landings in the port of Manaus (Gandra, 2010).

This study was conducted to evaluate the suitability of three locally available plant substrates (bamboo, ambay and leucaena) in supporting periphyton growth and in turn the performance of jaraqui (Semaprochilodus insignis).

2 Material and Methods
2.1 Area of study and preparation of the experimental tanks
The two experiments of 45 and 120-day duration respectively were carried out in 9 and 12 mud-bottomed outdoor tanks of 100 m² size each at the Coordination of Research in Aquaculture (CPAQ) fish farm of the National Institute of Research in the Amazon (INPA), Manaus, Brazil. The experimental tanks were drained, disinfected and dried. Lime (CaO) was applied at 30 g/m² to the tank bottom. The ponds were initially fertilized with chicken manure at 10 kg and subsequently at 5 kg every 15 days. They were filled with water up to a depth of 0.8 m. Three locally available substrates viz. bamboo (Bambusa vulgaris), ambay (Cecropia pachystachya) and leucaena (Leucaena leucocephala) tree branches were collected from nearby areas of INPA and transported to CPAQ. Uniform sized (1.5 m length and 20 cm circumference) substrates were installed vertically in tanks, except those of the control in experiment 2, at a distance of 1 m each, keeping a margin of 50 cm on all sides. A total of 76 substrates went into each tank.

2.2 Water quality monitoring
Water quality in the culture tanks was monitored by sampling at 30 cm depth in the water column for recording values of dissolved oxygen (DO), electrical conductivity (EC), temperature, pH, alkalinity, free carbon dioxide (CO₂), hardness, nitrite nitrogen (NO₂), nitrate nitrogen (NO₃) ammonia (NH₃) and orthophosphate (PO₄). DO, temperature, pH and EC were measured on weekly basis, while the rest of the parameters were analysed at 15-day intervals. A combined digital YSI 85 meter was used to monitor DO and EC, whereas temperature and pH were measured with a digital YSI 60 meter. All the other parameters were determined by APHA (1992) methods.

2.3 Periphyton biomass estimation
Periphyton samples from the substrates were collected by scraping with the help of a scalpel from an area of 5x5 cm² in triplicate from each tank at 15-day intervals. Each sample was mixed in 50 ml of distilled water. Subsequently, the periphyton solutions were transferred individually to previously weighed falcon tubes and centrifuged for 15 minutes. The supernatant was discarded and the tubes were kept at 60°C for a period of 12 hours. Thereafter, each tube was reweighed to determine the periphyton biomass (dry).

2.4 Taxonomic and biochemical composition of periphyton
The periphyton sampling for determining the taxonomic composition was made only during experiment 2, at 30-day intervals, following the methodology described by Bicudo and Bicudo (1970). After extraction, the samples were preserved in Transeau solution (6:3:1 water: alcohol: formaldehyde) in polyethylene bottles. Taxonomic identification was performed using keys as per Bicudo and Menezes (2006).

The periphyton sample collection from substrates to determine the biochemical composition was done at 30-day intervals during experiment 2 as described earlier, except that the area sampled was 6 times larger. The samples were analyzed in triplicate to determine the percentage of moisture, protein and ash as per AOAC (1995). Total lipid was analysed by the method of Bligh and Dyer (1959). NFE fraction was calculated by subtracting the sum of the percentages of moisture, protein, lipid and ash from 100 (Hastings, 1976). Energy content was calculated by multiplying protein, fat and carbohydrate values by factors of 5 (Smith, 1975), 9 and 4 (Hastings, 1975) respectively. Further, chlorophyll-a content was also estimated (Stirling, 1985).
2.5 Fish stocking and biometry

In experiment 2, fish of av. length 6.5±0.15 cm and av. wt. 5.83±0.23 g were stocked at a density of 1 per m², employing the three selected substrates viz. bamboo, amby and leucaena in triplicate. A set of 3 tanks without substrate served as the control.

Biometry was performed at the beginning of the experiment and every thirty days until termination. Twenty fish from each replicate was weighed on an electronic balance (accuracy 0.1 g) and standard length was measured. In addition to weight and length, specific growth rate, survival, gross production and weight gain were determined at the end of the 120-day experiment as follows.

Specific growth rate (SGR) = [(ln Final weight - ln Initial weight/ Experimental duration in days)] × 100
Survival (%) = Number of live fish harvested / Number of fish stocked x 100
Gross production (g) = Av. body weight at harvest (g) x Total number of fish harvested
Percentage weight gain = Final weight - Initial weight / Initial weight x 100

2.6 Statistical analyses

One-way ANOVA (P<0.05) as described by Chambers et al. (1992) was used to check the effect of treatments on water quality variables, periphyton biomass and biochemical composition and fish growth parameters.

3 Results

All the water quality parameters monitored over the duration of the 2 experiments were within the limits suitable for aquaculture. They ranged as follows: dissolved oxygen 6.71-7.32/6.91-7.17 mg/L, pH 8.22-8.68/8.16-8.52, EC 58.56-63.15/62.33-65.35 µS/cm², temperature 28.36-29.85/27.86-29.28°C, total alkalinity (CaCO₃) 23.15-26.52/31.15-36.19 mg/L, nitrite N (NO₂) 0.01-0.03/0.04-0.05 mg/L, nitrate N (NO₃) 0.95-1.35/1.39-1.78 mg/L, ammonia (NH₃) 0.24-0.38/0.23-0.83 mg/L, and phosphate (PO₄) 1.82-2.69/1.13-1.29 mg/L (Table 1; Table 2).

Table 1 Physico-chemical parameters (mean ± SD) of water monitored in Experiment 1

| Parameter       | Control | Bamboo | Amby    | Leucaena |
|-----------------|---------|--------|---------|----------|
| DO (mg/L)       | 6.7±0.16a | 7.32±0.13b | 7.09±0.12ab | 7.11±0.15ab |
| pH              | 8.68±0.17a | 8.25±0.05a | 8.36±0.14a | 8.22±0.16a |
| EC (µS/cm²)     | 58.56±3.22a | 63.15±2.32a | 61.73±4.25a | 62.67±1.85a |
| Temperature (°C)| 29.85±0.38b | 28.62±0.12a | 28.45±0.38a | 28.36±0.24a |
| Alkalinity (mg/L) | 23.15±1.33a | 26.52±1.45a | 25.19±1.85a | 24.19±1.38a |
| NO₂ (mg/L)     | 0.01±0.00a | 0.02±0.00a | 0.03±0.01a | 0.02±0.00a |
| NO₃ (mg/L)      | 1.29±0.22a | 1.35±0.31a | 0.95±0.20a | 1.16±0.28a |
| NH₃ (mg/L)      | 0.38±0.18a | 0.24±0.12a | 0.33±0.16a | 0.30±0.15a |
| PO₄ (mg/L)      | 1.82±0.31a | 2.32±0.25a | 2.19±0.20a | 2.69±0.24a |

Note: Experimental duration 45 days. Values with the same superscript in each row are not statistically different (P>0.05)

Table 2 Physico-chemical parameters (mean ± SD) of water monitored in Experiment 2

| Parameter       | Control | Bamboo | Amby    | Leucaena |
|-----------------|---------|--------|---------|----------|
| DO (mg/L)       | 7.17±0.21a | 6.98±0.11a | 7.01±0.12a | 6.91±0.16a |
| pH              | 8.16±0.27a | 8.52±0.15a | 8.27±0.18a | 8.42±0.12a |
| EC (µS/cm²)     | 63.56±2.24a | 65.35±2.12a | 62.33±2.25a | 62.87±2.28a |
| Temperature (°C)| 29.28±0.38a | 28.12±0.12a | 28.27±0.08a | 27.86±0.14a |
| Alkalinity (mg/L) | 31.15±1.62a | 34.52±1.24a | 36.19±1.58a | 34.19±1.83a |
| NO₂ (mg/L)     | 0.05±0.01a | 0.04±0.01a | 0.04±0.01a | 0.04±0.01a |
| NO₃ (mg/L)      | 1.78±0.16a | 1.56±0.22a | 1.39±0.14a | 1.42±0.32a |
| NH₃ (mg/L)      | 0.83±0.12a | 0.27±0.09a | 0.23±0.06a | 0.34±0.08a |
| PO₄ (mg/L)      | 1.28±0.11a | 1.13±0.15a | 1.29±0.12a | 1.26±0.14a |

Note: Experimental duration 120 days. Values with the same superscript in each row are not statistically different (P>0.05)
The best growth of periphyton was observed on bamboo, followed by ambay and leucaena. In Experiment 1, periphyton biomass on bamboo substrate was 1.12±0.16 as against 0.95±0.13 and 0.87±0.11 mg/cm² of ambay and leucaena. In Experiment 2, the values were 1.43±0.22, 1.22±0.14 and 0.98±0.16 mg/cm² respectively (Table 3). Periphyton protein and fat contents of bamboo, ambay and leucaena periphyton were 24.42% and 22.18%, 21.63% and 2.35%, 1.87% and 1.93% respectively on dry weight basis (Table 4). Bamboo periphyton had 39.59 µg/cm² chlorophyll-a, while its value was 35.15 µg/cm² and 32.76 µg/cm² in ambay and leucaena periphyton. Zooplankton in bamboo periphyton consisted of chironomids, ostracods, nematomorphs, rotifers and calanoids, chironomids being predominant. Hydra, Ephemeroptera and Trichoptera were also encountered. Ambay periphyton lacked calanoids, Ephemeroptera and Trichoptera, whereas leucaena periphyton did not show Hydra. Zooplankton population in bamboo periphyton was 2 and 3 times higher than that of ambay and leucaena respectively. Phytoplankton population of periphyton belonged mainly to the families Chlorophyceae, Cyanophyceae, Bacillariophyceae and Chrysophyceae.

Jaraqui attained final av. length of 11.23±0.69 cm and av. wt. of 34.34±2.05 g under bamboo substrate, whereas the respective values were lower in ambay (10.14±0.52 cm and 29.85±1.71 g) and leucaena (9.21±0.25 cm and 24.38±1.65 g) treatments. In contrast, control fish reached av. length of 9.02±0.17 cm and av. wt. of 19.44±1.12 g (Table 5).

| Parameter       | Bamboo       | Ambay       | Leucaena    |
|-----------------|--------------|-------------|-------------|
| Moisture (%)    | 8.17±0.67a   | 9.23±0.36a  | 8.58±0.72a  |
| Protein (%)     | 24.42±0.83b  | 22.18±1.02a | 21.63±0.92a |
| Lipid (%)       | 2.35±0.32a   | 1.87±0.21a  | 1.93±0.28a  |
| Ash (%)         | 11.78±0.76a  | 12.85±0.98a | 13.42±1.27a |
| NFE (%)         | 53.28        | 53.87       | 54.44       |
| Gross Energy (kcal/100g) | 356.37       | 342.86      | 343.28      |

Note: Values with the same superscript in each row are not statistically different (P>0.05)
Table 5 Growth performance of jaraqui (mean±SD) over the culture period under different treatments

| Parameter                  | Control       | Bamboo        | Ambay         | Leucana        |
|----------------------------|---------------|---------------|---------------|----------------|
| Final av. weight (g)       | 19.44±1.12\(^a\) | 34.34±2.05\(^d\) | 29.85±1.71\(^c\) | 24.38±1.65\(^b\) |
| Final av. length (cm)      | 9.02±0.17\(^a\)  | 11.23±0.69\(^b\)  | 10.14±0.52\(^b\)  | 9.21±0.25\(^a\)  |
| Survival (%)               | 95.00±2.31\(^b\) | 100.00±0.00\(^c\) | 90.00±2.62\(^b\) | 85.00±3.33\(^a\) |
| Gross production (g/100m²) | 1846.80±33.26\(^a\) | 3440.00±45.49\(^d\) | 2686.50±26.93\(^c\) | 2072.30±38.15\(^b\) |
| Net weight gain (g)        | 13.61±1.31\(^a\) | 28.51±1.53\(^d\) | 24.02±1.21\(^c\) | 19.00±0.57\(^b\) |
| SGR (%/day)                | 1.00±0.02\(^a\) | 1.48±0.01\(^d\) | 1.36±0.02\(^c\)  | 1.19±0.01\(^b\)  |
| Weight gain over control (%) | --            | 76.65         | 53.55         | 25.41          |

Note: Initial av. length of fish was 6.5±0.15 cm and initial av. wt. 5.83±0.23 g. Values with the same superscript in each row are not statistically different (P<0.05)

4 Discussion

The physico-chemical parameters of aquatic ecosystems serve as water quality indicators. Water quality of fish ponds is influenced by various factors that include the feeding habit of the cultivated species, stocking density, and the quality and quantity of nutrient input through fertilizer and feed. Decomposition and accumulation of organic matter also affects water quality (Asaduzzaman et al., 2009). Inadequate conditions of water quality affect growth, reproduction, health, survival and quality of fish life, jeopardizing the success of aquaculture (Lourenco et al., 1999). The water quality parameters monitored in the present study were within the acceptable range for fish culture, as reported by Boyd (1981) and Tavares (1994). According Proença and Bittencourt (1994), the optimal level of oxygen for tropical fish species is in the range of 4 to 6 mg/L. In the current experiments, dissolved oxygen remained above 6 mg/L throughout. pH of pond water was in the alkaline range, the value remaining higher than 8 over the duration of the two experiments. Gangadhar and Keshavanath (2012) obtained good growth of rohu (*Labeo rohita*) in ponds with alkaline pH (8.39 to 9.82). Araujo-Lima and Goulding (1997) observed that in nature, jaraqui tolerates large ionic plasticity and survives well even in acidic waters, such as the Solimões river black water (pH 4.5) as well as white water (pH 6.5 to 7). EC was low in both the experiments (Table 1; Table 2). Tavares (1994), who recorded EC of 23-71 µS/cm² in fish ponds, opined that the values can be used as a reference to assess the availability of nutrients and regulate the concentration of ions in the water column. The average water temperature was between 27°C and 29°C during the present study, being within the desired range. Proença and Bittencourt (1994) stated that temperature in the range 20°C to 30°C is acceptable in fish cultivation, but the ideal range is from 25°C to 28°C. Jaraqui is found in nature in both lotic and lentic ecosystems, where the minimum temperature is 24°C and maximum 40°C, indicating high temperature tolerance (Araujo-Lima and Goulding, 1997). Temperature remained significantly lower in the substrate tanks. This can be attributed to the shading of these tanks by the substrates as reported earlier by Keshavanath et al. (2002). Alkalinity acts as a pH regulating buffering system of pond water (Tavares, 1994). When alkalinity (CaCO₃) is low (less than 20 mg/L), it can cause high fluctuations in pH index, hindering the performance and production of fish, due to the constant adaptation needs of the animal by osmotic exchange with the medium (Boyd, 1981). The values of nitrogen compounds NO₂, NO₃ and NH₃ were low (Table 1; Table 2). For fish, these are toxic in water when the concentration crosses 0.5 mg/L (Ostrenskey and Boeger, 1998), 5 mg/L and 2 mg/L respectively (Tavares, 1994). Ammonia values in experiment 2 showed a decline in substrate treatments which is attributable to its uptake by periphyton and plankton (Azim and Little, 2006).

Periphyton biomass on different substrates can be quite varied and is influenced by environmental (temperature, photoperiod) and operational (grazing pressure, fertilization, fish stocking density, density and type of substrate, etc.) processes (Azim et al., 2005). The average periphyton biomass recorded on bamboo, ambay and leucaena substrates was 1.12±0.16, 0.95±0.13 and 0.87±0.11 mg/cm² in experiment 1 and 1.43±0.22, 1.22±0.14 and 0.98±0.16 mg/cm² in experiment 2. The higher values recorded in experiment 2 could be related to the longer duration of the study and grazing by the fish stocked. Grazing is known to improve periphyton growth (Jacoby, 1987; Swamikannu and Hoagland, 1989). These values compare with those observed on glass (0.91 mg/cm²),
bamboo (0.90 mg/cm²), PVC (0.97 mg/cm²) (Gangadhar and Keshavanath, 2008), palm leaf (1.17 mg/cm²), coconut leaf (1.58 mg/cm²), bamboo (1.09 mg/cm²) and bagasse (1.06 mg/cm²) (Keshavanath et al., 2012). Azim et al. (2002) reported maximum periphyton productivities of 1.01, 1.38 and 1.03 g C m⁻²d for bamboo, hizol and kanchi substrates respectively. Nutritional quality of periphyton can be quite variable, depending on the taxonomic composition, type of substrate, ecosystem, fertilization and predation pressure (Azim et al., 2003; Keshavanath et al., 2012). Protein and lipid content of periphyton grown on bamboo, ambay and leucaena was 24.42% and 2.35%, 22.18% and 1.87%, 21.63% and 1.93% respectively. Azim et al. (2002) estimated 27.19% crude protein in periphyton developed on bamboo, 14.63% on hizol branches and 18.74% on kanchi (bamboo shoot), while the lipid content was 5.43% in hizol periphyton and 0.35% to 2.75% in periphyton from bamboo and kanchi. Periphyton protein and fat could be considered a good source for fish which can satisfy part of their requirement. Ash content was marginally lower at 11.78% in periphyton from bamboo as against 12.85% and 13.42% of ambay and leucaena. Azim et al. (2002) recorded higher periphyton ash content on hizol (41%) than on bamboo and kanchi (29%). In the present study, NFE accounted for 53.28-54.44% (Table 4). Ledger and Hildrew (1998) reported 29-33% carbohydrate in periphyton developed on stones. Nielsen et al. (1997) observed that the extra-cellular polymeric substances in biofilms are responsible for 50-80% of total organic matter and therefore, large amounts of carbohydrate, which explains the high proportion of carbohydrates in periphyton. The gross energy values were 356.37, 342.86 and 343.28 kcal/100g for periphyton from bamboo, ambay and leucaena substrates. These values are lower than those recorded in periphyton associated with hizol and kanchi (454 kcal/100g) by Azim et al. (2002). Bamboo periphyton had higher chlorophyll-a (39.59 μg/cm²) than that of ambay (35.15 μg/cm²) and leucaena (32.76 μg/cm²). The difference in values could be attributed to both the number and species of algae present. Phytoplankton population of periphyton from the three substrates belonged mainly to the families Chlorophyceae, Cyanophyceae, Bacillariophyceae and Chrysophyceae as reported in earlier studies (Gangadhar and Keshavanath, 2008; Tortolero et al., 2016). There was significant difference in the abundance of periphyton zooplankton, the numbers being 2 and 3 times higher in bamboo periphyton than that of ambay and leucaena. This could have influenced fish growth.

Fish showed the best growth in bamboo treatment, being significantly superior to not only the control, but also the other 2 substrate treatments (Table 5). Jaraqui growth under the 3 substrates (bamboo, ambay and leucaena) was higher by 76.65, 53.55 and 25.41% respectively over the control. Azim et al. (2002a) obtained 66-71% greater carp production with substrates, whereas Gangadhar and Keshavanath (2012) recorded 37.74-43.56% higher production. Keshavanath et al. (2012) reported 35-87% higher production of common carp using 4 bio-substrates. Bamboo provides a better surface structure for periphyton species to attach to, or might leach nutrients beneficial to periphyton growth (Keshavanath et al., 2001). This might be the reason for the superior growth of fish under bamboo treatment. Earlier studies have also shown the superiority of bamboo as a substrate in fish culture (Hem and Avit, 1994; Azim et al., 2002). Keshavanath et al. (2002) who obtained 41-75% increase in fish growth in non-fed substrate based tanks opined that substrates reduce the need for artificial feed and therefore, can be considered as an alternative to feeding in the culture of herbivorous fish.

The results of the present study show that 25 to 76% higher growth of jaraqui can be obtained in non-fed substrate-based tank culture, compared to the control without substrate. Further, the superiority of bamboo as a substrate is discernible. The findings have economic significance.

Acknowledgements
The financial grant received from Fundação de Amparo à Pesquisa do Estado do Amazonas-FAPEAM, Manaus, Brazil is gratefully acknowledged. We thank CPAQ and INPA for providing laboratory and field facilities to conduct this study.

References
Amisah S., Adjei-Boateng D., and Afianu D.D., 2008, Effects of bamboo substrate and supplementary feed on growth and production of the African catfish, Clarias gariepinus, Journal of Applied Sciences and Environmental Management, 12: 25-28
AOAC, 1995, Official Methods of Analysis, 16th ed., Association of Official Analytical Chemists, Washington DC, 1141 p
APHA, 1992, Standard Methods for Examination of the Water and Waste Water, 18th ed., American Public Health Association, Washington DC, 1268 p
Araujo-Lima C., and Goulding M., 1997, So Fruitful a Fish, Ecology, Conservation and Aquaculture of the Amazon's Tambaqui, Columbia University Press, New York, 191 p

Asaduzzaman M., Wahab M.A., Verdeghem M.C.J., Benerjee S., Akta T., Hasan M.M., and Azim M.E., 2009, Effects of addition of tilapia Oreochromis niloticus and substrates for periphyton developments on pond ecology and production in C/N-controlled freshwater prawn Macrobrachium rosenbergii farming systems, Aquaculture, 287: 371-380
https://doi.org/10.1016/j.aquaculture.2008.11.011

Asaduzzaman M., Wahab M.A., Verdeghem M.C.J., Adhikary R.K., Rahman S.M.S., Azim M.E., and Verreeth J.A.J., 2010, Effects of carbohydrate source for maintaining a high C:N ratio and fish driven re-suspension on pond ecology and production in periphyton-based freshwater prawn culture systems, Aquaculture, 301: 37-46
https://doi.org/10.1016/j.aquaculture.2010.01.025

Azim M.E., and Little D.E., 2006, Intensifying aquaculture production through new approaches to manipulating natural food, CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 1: 1-23
https://doi.org/10.1079/PARS00061062

Azim M.E., Verdeghem M.C.J., Mantingh I., van Dam A.A., and Beveridge M.C.M., 2003, Ingestion and utilization of periphyton grown on artificial substrates by Nile tilapia, Oreochromis niloticus I., Aquaculture Research, 34: 85-92
https://doi.org/10.1046/j.1365-2109.2003.00802.x

Azim M.E., Verdeghem M.C.J., Rahman M.M., Wahab M.A., van Dam A.A., and Beveridge M.C.M., 2002a, Evaluation of polyculture of Indian major carps in periphyton-based ponds, Aquaculture, 213: 131-149
https://doi.org/10.1016/S0044-8486(02)00029-7

Azim E., Verdeghem M., van Dam A., and Beveridge M., (Eds.), 2005, Periphyton: ecology, exploitation and management, CABI Publishing, UK, 319 p

Azim M.E., Wahab M.A., Verdeghem M.C.J., van Dam A.A., van Rooij J.M., and Beveridge M.C.M., 2002, The effects of artificial substrates on freshwater pond productivity and water quality and the implications for periphyton-based aquaculture, Aquatic Living Resources, 15: 231-241
https://doi.org/10.1016/S0934-7751(02)00179-8

Bharti V., Pandey P.K., Vemilia A., Rajkumar M., and Ajima M.N.O., 2016, Water quality, survival and growth performance of Cirrhinus mrigala (Hamilton 1822) in substrate based tanks, Asian Fisheries Science, 29: 137-150

Bicudo C.E.M., and Bicudo R.M.T., 1970, Algas de águas continentais brasileiras: chave ilustrada para identificação de gêneros. Editora da Universidade Federal, São Paulo, 228 p

Bicudo C.E.M., and Menezes M., 2006, Gêneros de algas de águas continentais do Brasil. Chave para identificação e descrições, 2nd Ed., Rima Editora, São Carlos, SP, 502 p
PMCID:PMC3242149

Bligh E. and Dyer W.J., 1959, A rapid method of total lipid extraction and purification, Canadian Journal of Biochemistry and Physiology, 37: 911-917
https://doi.org/10.1139/e59-099
PMid:13671378

Boyd C.E., 1981, Water quality in warm water fish culture, Auburn University, Alabama, 359 p

Chambers J.M., Freeny A., and Heiberger R.M., 1992, Analysis of variance; designed experiments. Statistical Models, In: J.M. Chambers and T.J. Hastie (Eds.), Wadsworth & Brooks/Cole, Pacific Grove, California, USA

Dodds W.K., 2003, The role of periphyton in phosphorus retention in shallow freshwater aquatic systems. Journal of Phycology, 39: 840-849
https://doi.org/10.1111/j.1529-8817.2003.02081.x

Gandra A.L.O., 2010, Mercado do pescado da região metropolitana de Manaus, CFC/FAO/INFOFISCA, 84 p
PMCID:PMC2863974

Gangadhar B., and Keshavanath P., 2008, Planktonic and biochemical composition of periphyton grown on some biodegradable and non-biodegradable substrates, Journal of Applied Aquaculture, 20: 203-232
https://doi.org/10.1080/10454430802329762

Gangadhar B., and Keshavanath P., 2012, Growth performance of rohu, Labeo rohita (Ham.) in tanks provided with different levels of sugarcane bagasse as periphyton substrate. Indian Journal of Fisheries, 59 (3): 77-82

Garg S.K., Kumar A., Arasu A.R.T., Bhatnagar A., Jana S.N., and Barman U.K., 2007, Effect of periphyton and supplementary feeding on growth performance and some aspects of nutritive physiology of Nile Tilapia, Oreochromis niloticus and Pearlspot, Etroplus suratensis under polyculture, Journal of Applied Aquaculture, 19 (3): 19-45
https://doi.org/10.1300/J028v19n03_02

Hastings W.H., 1975, Report on brackishwater shrimp and milkfish culture research, Jepra, Indonesia, FAO/UNDP

Hastings W.H., 1976, Fish nutrition and feed manufacture, Paper presented at FAO Technical Conference on Aquaculture, Kyoto, Japan, FJR: Aq/conf/76/R.23. 13 p

Hem S., and Avijit J.L.B., 1994, First results on 'acajja-enclos' as an extensive aquaculture system (West Africa), Bulletin of Marine Science, 55: 1038-1049

Jacob J.M., 1987, Alterations in periphyton characteristics due to grazing in a cascade foothill stream, Freshwater Biology, 18: 495-508
https://doi.org/10.1111/j.1365-2427.1987.tb01334.x

92
