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Jacob O. Abwao
Kenya Marine & Fisheries Research Institute (KMFRI), Sangoro Aquaculture Research Station, P.O.Box 136, Pap Onditi, Kenya

Priscilla N. Boera
Kenya Marine & Fisheries Research Institute (KMFRI), Sangoro Aquaculture Research Station, P.O.Box 136, Pap Onditi, Kenya

Jonathan M. Munguti
Kenya Marine & Fisheries Research Institute (KMFRI), National Aquaculture Research Development & Training Center (NARDTC), P.O. Box 451-10230, Sagana, Kenya

Paul S. Orina
Kenya Marine & Fisheries Research Institute (KMFRI), Sangoro Aquaculture Research Station, P.O.Box 136, Pap Onditi, Kenya

Erick O. Ogello
Kenya Marine & Fisheries Research Institute (KMFRI), Kegati Aquaculture Research Station, P.O. Box 3259, Kisii, Kenya.

Correspondence:
Jacob O. Abwao
Kenya Marine & Fisheries Research Institute (KMFRI), Sangoro Aquaculture Research Station, P.O.Box 136, Pap Onditi, Kenya

The potential of periphyton based aquaculture for nile tilapia (*Oreochromis niloticus* L.) production. a review

Jacob O. Abwao, Priscilla N. Boera, Jonathan M. Munguti, Paul S. Orina and Erick O. Ogello

Abstract
The rapid growth in aquaculture has triggered new technological advancement such as periphyton based aquaculture. Periphyton is comprised of groups of algae, filamentous bacteria etc. This technology works on the basis of introduction of substrates into the water to support the growth of periphyton, which becomes food for fish. Periphyton also purifies water in the culture system through uptake of nutrients from the water. Studies have reported higher Nile tilapia (*Oreochromis niloticus*) production in periphyton based systems. Proximate analysis has shown that periphyton contains 27.19% crude protein, 18% lipid and 52% carbohydrates indicating that periphyton are nutritionally better than most commercial grow out feeds used for *O. niloticus* grow outs. Upto 5.61% Specific growth rate for Nile tilapia can be achieved using the periphyton technology. This technology is cheap and is appropriate for fish farmers especially in the developing countries.

Keywords: Periphyton, Substrates, Nile tilapia, Aquaculture

1. Introduction
Periphyton is comprised of groups of micro-organisms living on submerged substrates. The group includes algae, filamentous bacteria, protozoans and free-swimming microorganisms such as rotifers and cladocerans. Azim ME *et al*. [1] described periphyton as an assemblage of organisms growing upon the free surfaces of submerged objects in water and covering them with a slimy coating. Periphyton comprises a major proportion of benthic algal production in shallow aquatic ecosystem [1]. Though, there is a common assumption that the phytoplankton community is the most important in terms of energy fixation and fueling the food web, research has shown that macrophytes and periphyton are significant and often the dominant contributor to primary production in aquatic ecosystems [2].

1.1 Global aquaculture and tilapia production
The rapid growth of global aquaculture industry cannot be over emphasized. Within the last 50 years, aquaculture global food production has grown from being almost negligible to fully comparable with capture fisheries [3, 4] a development resulting from new technological advancements in fish production. These technologies include hybridization, genetical engineering, formulated diets, biofloc technology (BFT) and periphyton based technology (PBA) practiced in ponds, cages, tanks and recirculation systems [3]. According to [5], top aquaculture producers are China, India, Vietnam, Indonesia and Thailand. China, with one-fifth of the world's population accounts for two-thirds of the worlds reported aquaculture production [3] China's 2005 reported harvest was 32.4 million tonnes, more than 10 times that of the second ranked nation, India, which reported 2.8 million tonnes [5]. Since 2002, China has been the world largest exporter of fish and fish products. At 2005, exports, including aquatic plants, were valued at US$7.7 billion, with Japan, the United States and the Republic of Korea as the main markets. In 2005, the total number of fish farmers world-wide was about 12 million with China reported 4.5 million people employed full time in aquaculture. The figure below shows the world trend in tilapia production in 2012 according to estimates by Fitzsimmons K [6]. This is a 6% growth from 2011 productions.

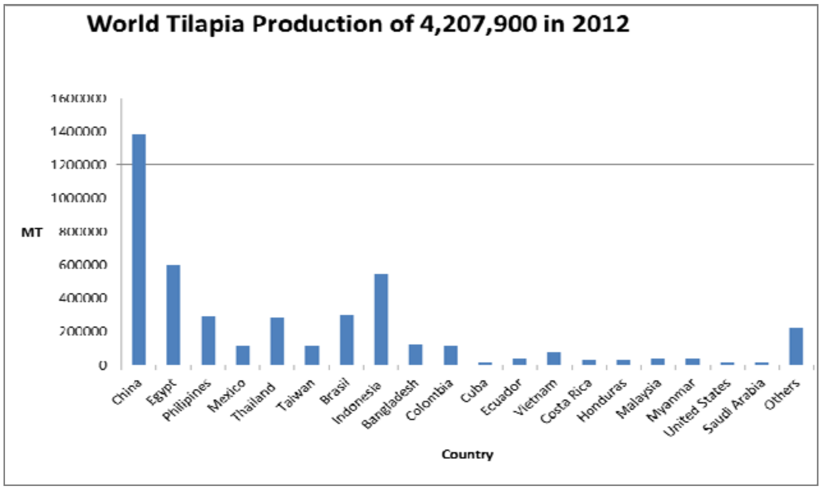

Fig 1: Trends in world tilapia productions worldwide. Modified from [6].

The global progress in aquaculture growth has been due to the ever declining capture fishery, thus shifting the heavy responsibility of increasing fish supply to aquaculture sector [7]. There is need for a fivefold increase in aquaculture production within the next five decades to maintain current aquatic food consumption level [8]. In view of this eminent dilemma, new sustainable technologies such as biofloc and periphyton become relevant. The technologies are cost effective, environmentally sustainable and support sustainable aquaculture [9, 8]. Today, *O. niloticus* has become very popular for farmers who have embraced it as a good source of dietary (a good source of protein) and for its economic success. Also referred to as the ‘aquatic chicken,’ it is the shining star of aquaculture with many farms beginning; others expand as consumption rate increases across the globe [3, 4, 10], leading to a significant increase in the annual global production of cultured tilapia in recent years [11].

One of the most important inputs in aquaculture is the fish feed and it accounts for over 50 % of the total cost of fish production [12]. Therefore sustainability and success of aquaculture depend on type of feed used and feed management. The ever diminishing capture fisheries are the major source of fishmeal which is a key ingredient in fish feed formulations therefore, the sustainability of the aquaculture sector is questioned [9]. Most formulated fish feeds have a feed conversion ratio (FCR) of 3, this means to produce 1 kg live weight fish, about 2.5-3 kg dry weight feed is needed [9]. To ensure sustainability of the aquaculture industry there is need for a progressive reduction of wild fish inputs into fish feed formulation [9, 13, 14]. Research on fish nutrition has for a long time concentrated on the replacement of animal protein by plant proteins [15, 16, 17], however, the palatability of many plant materials is hindered by presence of anti-nutritional factors and low bioavailability [18, 19, 20]. Initiatives geared towards developing nutrition strategies such as bioflocs and periphyton that maximize the contribution of natural and supplemental feeds in ponds would help to expand and maximize tilapia production. In this regard, this paper reviews the concept of periphyton based aquaculture (PBA) and its capacity in optimization of tilapia production especially in the developing countries, where access to complete fish feed is still a challenge, as seen in figure 1 on tilapia production trends it can be seen that countries especially in sub Saharan Africa have low production, therefore this technology should be implemented in these countries to compete with the rest of the world in tilapia and aquaculture production. This in effect will contribute to food security and accelerated economic development.

1.2 The concepts and application of Periphyton Based Aquaculture Technology (PBAT)

Introduction of substrates into the water column to aid the growth of biofilms and periphyton is used to increase the natural productivity in a water body and create food for cultured aquatic organisms [21]. Periphyton based systems have traditionally been used in Africa [22] and Asia, [23] as a way to enhance fisheries in coastal lagoons. This technology was adapted for aquaculture in small lakes [24] and ponds in the African rain forest where agricultural by-products to enhance the heterotrophic pathway are scarce or unavailable [25, 26]. Its application was recently expanded in Bangladesh and India, mainly in the polyculture of Indian carps, where introduction of the substrates had a positive effect on consequent periphyton development, production of the target species, and water quality [27].

A trial to improve natural food production for tilapia and reduce added feed costs was carried out using discarded irrigation pipes as submerged hard substrates for periphyton growth [28]. After four months, tilapia feeding on natural periphyton and on supplying with commercial formulated pellets showed the same harvesting weight, yield, survival and growth rate (Table 1). This provides evidence that periphyton-based aquaculture is an appropriate technology, which can reduce costs and allow an economically viable organic O. niloticus production.

Table 1: Tilapia harvesting data per half pond (250 m^2), courtesy of [28]

	Periphyton side	Feed side
Tilapia number	248	236
Biomass (kg)	110.5	107.4
Mean weight (g)	44	55
Survival (%)	96	91
Growth rate (g/day)	1.61	1.68
Yield (kg in 122 days)	48.5	48.4
Wild spawning (kg)	13	10
Feed (kg)		800
Manure (kg)	90	

A lab scale model study of periphyton using small plastic bottles as substrates Cavalcante DH *et al*. [29] were placed in some aquaria for periphyton development. Two feeding regimes were employed: "full-fed" (standard feeding rates were fully adopted) and "half- fed" 50% of standard feeding rates). The result of this experiment showed that (Table 2), the final body weight of fish in half fed aquaria with periphyton bottles (6.22 g) was significantly higher than in aquaria without bottles (4.65 g). Although the growth rate of fish was lower in the half-fed aquaria (4.27-4.72 vs. 5.29-5.61% BW day^{-1}), survival was significantly higher when compared to the full fed aquaria (93.3-100.0 vs 80.0-83.4%).

Table 2: Growth performance of Nile tilapia O. niloticus, juveniles (initial body weight = 0.77±0.09 g and initial body length = 2.8±0.20 cm reared for 6 weeks in 25L polyethylene outdoor aquaria provided with or without 180 cm² plastic bottles for periphyton development and submitted to two different feeding regimes. courtesy of: [29]

Variable	Feeding rate	No periphyton	periphyton
Final body wt (g)	full	7.22	7.58
	half	4.65	6.22
Survival (%)	full	80	83.4
	half	93.3	100.0
SGR (%BW day^{-1})	full	5.61	5.29
	half	4.27	4.72
Yield(gm)	full	88.5	79.5
	half	54.2	72.2
FCR	full	1.84	1.96
	half	1.41	1.13

Trials with periphyton-based aquaculture in freshwater ponds in Benin, West Africa gave significantly higher annual fish yields, as compared with production from other rural ponds managed for aquaculture [30]. Periphyton based aquaculture (PBA) is a new innovative pond management strategy and was proposed as a suitable technique to increase fish production in rural ponds in south Asia, in particular in Bangladesh and India. Studies have demonstrated significantly higher fish production over controls with the addition of various substrates [21, 31]. Trials in freshwater ponds stocked with 6000 *Labeo rohita*, 4000, *Catla catla* and 1500 *Labeo calbasu* per hectare, and containing substrate with a surface area roughly equal to the pond area, resulted in an annual production of 7000 kg ha $^{-1}$, a threefold increase in average pond production in Bangladesh [21] In addition to enhanced production, farmers trialing periphyton based aquaculture noted other benefits. They reported seeing fish rub against the branches in their pond to dislodge parasites and human predation which is a serious concern for many, was also believed to have decreased significantly.

Studies of [2] on the effects of periphyton grown on bamboo substrate, on growth and production of *O. niloticus* (Genetically Improved Farmed Tilapia strain) in monoculture and polyculture with the freshwater prawn (*Macrobrachium rosenbergii*) showed impressive results. The result showed that Survival of tilapia and prawn were higher in ponds with bamboo substrate (60% and 35%, respectively) than in the control ponds without substrates (55% and 20% respectively). Addition of substrate significantly increased growth and production of both species. In monoculture, substrate contributed 40% to tilapia production, whereas in polyculture, it contributed 46%. Prawn production increased by 127%. Highest total yield (2445 kg ha^{-1} tilapia and 141 kg ha^{-1}, the second prawn) over a 145 day culture period was recorded in substrate-based polyculture ponds. However, there was conclusive evidence that addition of periphyton substrates resulted in higher fish production and hence, polyculture of tilapia and prawn in periphyton ponds is a promising option for low-input ecological aquaculture.

Addition of substrates enhanced survival and production of both tilapia and freshwater prawn in mono and polyculture system and improved FCR for tilapia (Table 4) [2] This is mainly because of additional shelter and natural food in the form of periphyton colonized on bamboo substrates along with improvements of environmental conditions through a range of ecological and biological processes [32, 33]

Table 4: Comparing yield parameters of tilapia between substrate addition (with or without) and prawn addition (with and without). Source: [2]

Parameter	Substrate (S)		Prawn (P)	
	without	with	without	with
Survival (%)	55	60	55	60
Individual wt gain(g)	155	202	183	173
Total yield (kg ha^{-1})	1702	2445	2044	2107
Net yield Kgha^{-1}	1666	2410	2007	2010
FCR	1.88	1.42	1.53	1.77

1.3 Nutrient composition of Periphyton

The nutrient quality and availability on periphyton varies with several factors like grazing pressure, algal and bacterial taxonomic composition, nutrient level of environment, environmental purity, and most significantly to substrate type [31] Proximate analysis studies have shown that periphytons contain important inclusions and nutrients required in the diet of tilapia. Montgomery WL *et al.* [34] reported proximate composition of 16 periphytic algae grown on granite boulders suspended in the Gulf of California. Protein, lipid, carbohydrate and ash contents of these epilithic algae were 8-10, 2-5, 52 - 60, and 25 - 38% respectively. An average protein content of 15% was estimated in periphyton collected from coral reef [35, 36] reported 28-55% protein and 5-18% lipid in some algal species of periphytic nature. Azim ME *et al.* [31] estimated 27.19% crude protein from periphyton grown on bamboo substrate. They also recorded 14.63% protein in Hizol (*Barringtonia* sp.) branches, 18.74% on Kanchi (bamboo side shoot), and 12.69% protein on jute stick. Keshavanath P *et al*. [37] also recorded protein level of 19.27- 35.56% in periphyton grown on bamboo substrates. [38] recorded as low as 2-3% protein, 0.04- 0.29% lipid, and 29–33% carbohydrate in periphyton grown on stones. [39], in study, reported protein, lipid and fat content of some algae as 35-63%, 10-57% and 2-22% respectively. Azim ME [21] reported periphytic fat content of 5.43%, 0.35%, and 2.75%, respectively on substrates made of Hizol, Kanchi, and Jute stick. The ash content also shows variation with a range from 17.45–41%. Azim ME *et al*. [40] found ash content from periphyton on bamboo (29%), Hizol (41%), Kanchi (29%), and jute stick (31.12%). Ash content of periphyton is known to increase as the community grows older [41]

Thus, all sorts of nutrient components make their representation on the periphytic microhabitat. As periphytic microhabitat is constituted of heterogeneous prokaryotic as well as eukaryotic epiphytic microbial communities [31]. The interactions of periphytic microhabitat might be more intraspecific than interspecific. Such interactions could enable addition of variable food qualities to the periphytic communities as a whole. Probably, this anthropogenic nature of periphyton stimulates survival and growth rates of several cultivated organisms on consumption. Azim ME *et al.* [31] reported that periphyton alone can support fish production of 5000 kg/ha-1year-1 in pond culture systems

1.4 Effect of Periphyton on water quality

Drenner RW *et al.* [42] attempted to use fish and periphyton for removing nutrients from the water column. Suspended solids were trapped in the periphyton mat, which also took up ammonia and nitrate, produced oxygen, broke down organic matter and increased nitrification [21]. In traditional aquaculture ponds, nitrification occurs mostly at the sediment surface and is limited not only by surface area but also by oxygen availability. In addition, fast growing heterotrophic bacteria might limit the space needed by the slow growing chemo-autotrophic nitrifying bacteria. If insufficient nitrification takes place, ammonia toxicity can develop which is still one of the major constraints to intensifying pond aquaculture [43] In substrate-based ponds, nitrifying bacteria develop on the substrates which are located in the water column where more oxygen is available than at the water-sediment interface [44]. Therefore, periphytic biofilms enhance nitrification keeping ammonia levels low. Periphyton can also act as an antibiotic against a variety of fouling bacteria or as a probiotic/vaccine [45].

As a first step in assessing the viability of periphyton-based fish production in South Asian pond aquaculture systems, the effects of artificial substrates on development of periphyton and on water quality were evaluated by Azim ME *et al*. [31] In their findings, Means of daily monitored water quality data by substrate and control ponds are given in table 5. The presence of substrates significantly affected mean bottom DO values (control = 3.0 mg l^{-1}; substrate 2.2–2.5 mg l^{-1}. The pH fluctuated between 7.5 and 9 during the first half of the experiment, dropping to between 7 and 7.5 during the second half. During the final week of the trial, pH increased to around 9 in all treatments. Substrate type did not affect, but there was an effect of sampling date on all weekly monitored water quality parameters (Table 6). Alkalinity decreased slightly over the experimental period from around 140 to 110 mg l^{-1}, except in the kanchi treatment where it rose to 140 in the last 2 weeks. Nitrate fluctuated between 1 and 4 mgl^{-1}) with higher values during the last 2 weeks of the experiment for all substrates as well as in the control ponds. Total ammonia values were around 0.2 mg l^{-1} during the first 4 weeks and then rose to between 0.6 and 1.2 depending on the substrate type. Phosphate fluctuated in all substrate treatments with the highest concentration in the kanchi treatment in week 4 (1.6 mg l^{-1}). Pond water chlorophyll a values showed a cyclic pattern in all three substrates with values between 100 and 400 µgl^{-1}, except for the control ponds where 600 µg $^{-1}$ was the highest concentration in week 3; thereafter it decreased below 100 µgl^{-1} till the last day of the experiment.

1.5 Mean values of daily water quality parameters.

These results showed that the presence of substrates did not alter the water quality. The parameters were within the optimal range for the tilapia culture. Water temperature, DO concentrations were generally suitable for fish culture Bottom DO concentrations were significantly higher in the control ponds than in the other treatments, differences being approximately 0.5–1mgl $^{-1}$ (Table 7).

Table 5: Mean values of daily water quality parameters. [31]

Parameters	Substrate types			
	Bamboo	Hizol	Kanchi	Control
Surface temperature (°C)	30.4 (28.1–33.7)	30.5 (28.1–33.7)	30.4(28.0–33.5)	30.7 (28.2–33.7)
Bottom temperature (°C)	29.8 (27.6–31.9)	29.9(27.6–32.0)	29.9(27.7-31.9)	30.1 (27.6–32.4)
Secchi depth (cm)	43 (16–120)	38 (19–88)	36 (10–111)	46 (19–95)
Surface DO (mg l–1)	5.8 (0.8–14.7)	5.8 (0.4–14.2)	5.3 (0.4–13.5)	5.9 (0.4–14.8)
Bottom DO (mg l–1)	2.4 (0.2–10.5)	2.5 (0.1–7.2)	2.2 (0.1–7.2)	3.0 (0.3–9.1)
pH range	6.5–9.8	6.7–9.3	6.5–9.4	6.7–9.9

Table 6: Mean values of weekly water quality parameters. Figures are means of three replicates and seven sampling dates (n = 21). The range of observed values is given in parentheses (adapted from [31]

	Substrates			
Parameters	Bamboo	Hizol	Kanchi	Control
Total alkalinity(mgl–1)	126 (90–184)	120(84-162)	132(95-166)	121(91-156)
Nitrate nitrogen (mgl–1)	2.34 (1.0–3.8)	2.30(0.7-3.8)	2.78(1.0-5.7)	2.27(0.7-4.1)
Total ammonia (mgl–1)	0.43 (0–1.48)	0.28(0-2.13)	0.46 (0–1.38)	0.31(0-095)
Phosphate phosphorous (mg l–1)	0.60(0.07–1.74)	0.44(0-2.39)	0.81(0.03-2.7)	0.43(0.05-1.13)
Chlorophyll *a* (µg l–1)	139 (1–589)	165 (7–646)	153 (1–518)	107 (4–468)

1.6 The Economics of PBA

Periphyton based aquaculture has an advantage of being economically sustainable hence can easily be adopted by poorer fish farmers in the third world countries. Severally studies have shown how this technology is comparatively low in terms of cost of production while the returns are much higher than systems that do not use PBA. In a study by Huda FA *et al*. [46] evaluating the relative profitability of periphyton-based aquaculture both on-station and on-farm situation. The findings of the study showed relatively lower production cost compared to that of existing fish production practice (supplementary feeding).The net return was estimated 311USD ha-1 on-farm and 430 USD ha-^{1} on-station from periphyton-based aquaculture for three months while it was 126.5 USD ha-^{1} on farm and 216.22 USD ha-1 on-station without this technology. As shown in Table 7,the study thus confirms that it is an economically viable technology of fish production and the adopters could get better yield and net return from adopting such technology if positive steps undertaken for extension.

Table 7: Comparative net return of ponds with periphyton and those without periphyton both at the station and at the farm**.** Source**:** [46]

	ON -STATION			ON-FARM		
Items of comparison	**with**	**without**	**differences**	**with**	**without**	**differences**
Yield of fish (Kgs ha^{-1})	1108	629	479	988	638	350
Gross returns(USD ha^{-1})	715.39	406.12	309.27	637.91	411.93	225.98
Gross cost (USD ha^{-1})	285.3	189.9	95.4	326.89	285.43	41.45
Net return (USD ha^{-1})	430.09	216.22	213.87	311.03	126.5	184.53
Benefit cost Ratio	2.5	2.1	0.4	1.95	1.44	0.51

NB: The difference in per hectare yield of fish and net return were found statistically significant at 1.0% level of significance.

2. Conclusion and Recommendation

Aquaculture production in ponds consumes nutrient applied as inorganic or organic fertilizers, and/or feed. The majority of the fish farmers in the world especially Africa and Asia is poor and unable to buy expensive inputs like formulated on farm made and commercial feeds. The use of periphyton substrates in tilapia production has been found potentially promising and thus it has created awareness among the scientific communities and the farmers to explore further how to make the technology more robust and sustainable. Periphyton based aquaculture should be practiced in the sub Saharan Africa where the cost of inputs especially feeds has brought a lot of challenges in aquaculture development in the region. In considering this practice the choice of substrate should hinge strongly on availability of the material, its cost, durability and ease of use.

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