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Comparison of rice straw and bamboo stick substrates in periphyton-based carp polyculture systems

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Abstract

An experiment was conducted to compare rice straw mat and kanchi (bamboo sticks) as substrates in periphyton-based polyculture systems. The experiment had three treatments: (a) no substrate (control), (b) rice straw as a substrate (3×2.7 kg pond^{-1}) and (c) kanchi as a substrate (390 kanchi pond^{-1}). Fingerlings ($n = 40$) of rohu, *Labeo rohita* (24.5 ± 0.5 g); mrigal, *Cirrhinus mrigala* (25.1 ± 0.6 g); catla, *Catla catla* (25.8 ± 0.5 g); common carp, *Cyprinus carpio* (27.6 ± 0.6 g), and silver carp, *Hypophthalmichthys molitrix* (30.4 ± 0.9 g) were stocked at a 3:2:2:2:1 ratio and cultured for 90 days. There were no differences in the number of plankton, periphyton and macro-zoobenthos among the treatments. The total plate count of bacteria was higher in the rice straw treatment (41 320 million cfu m^{-2}) than that in the kanchi treatment (11 780 million cfu m^{-2}). Growth and the final mean weight of rohu, catla and common carp were higher in the substrate treatments than those in the control. Rice straw and kanchi treatment, respectively, resulted in 38% and 47% higher combined total weight gain over control. Gross margin analysis showed that rice straw treatment resulted in more profit than the control and kanchi treatment. Therefore, rice straw has the potential to be used to increase production in the low-input rural aquaculture.

Keywords: rice straw, kanchi, substrate, periphyton-based polyculture system

Introduction

A variety of biodegradable and non-biodegradable substrates have been used in the past to enhance fish production in periphyton-based aquaculture systems. Among these substrates, bamboo has performed the best (Azim, Verdegem, Rahman, Wahab, Van Dam & Beveridge 2002b; Van Dam, Beveridge, Azim & Verdegem 2002) but it is expensive and prohibitive for small-scale rural farmers. There is a need to explore an inexpensive and locally available substrate that enhances fish growth.

Rice straw is relatively low cost and is widely available in farms. It has been used to mitigate turbidity in fish ponds (Yi, Lin & Diana 2003) and to develop bacterial biofilm and periphyton (Ramesh, Shankar, Mohan & Varghese 1999). Rice straw used as bundles in tanks increased the growth of rohu (*Labeo rohita* Hamilton, 1822) and common carp, *Cyprinus carpio* Linnaeus, 1758 (Ramesh *et al.* 1999; Mridula, Manissary, Keshavnath, Shankar, Nandesha, & Rajesh 2005), and fringed lipped carp, *Labeo fimbriatus* Bloch, 1795 (Mridula, Manissary, Keshavnath, Shankar, Nandesha & Rajesh 2003) significantly. However, the potential use of rice straw in the carp polyculture pond is yet to be explored.

Commonly available kanchi (bamboo sticks) was reported to increase net fish yield by 78% in monoculture of Kalbaush, *Labeo calbasu* Hamilton, 1822 (Wahab, Azim, Ali, Beveridge & Khan 1999) and by 66% in polyculture of rohu, catla (*Catla catla* Hamilton, 1822) and Kalbaush (Azim, Verdegem, Khatun, Wahab, Van Dam & Beveridge 2002a) compared with that in the plankton-based system. These studies indicated that rice straw and kanchi could be alternatives to bamboo. The present experiment was carried out to compare the water quality, abundance of plankton, periphyton, benthos and bacteria, growth of carps and economic returns among a plankton-based carp polyculture system, and two periphyton-based carp polyculture systems using rice straw mats and kanchi, respectively, as substrates.

Materials and methods

The experiment was conducted in nine 40 m^2 (8 × 5 m) ponds of 1.5 m deep at Field Laboratory of Bangladesh Agricultural University (BAU) at Mymensingh for 90 days from February to May 2006. The experiment had three treatments in replications of three: (a) a plankton-based system without a substrate (control) (b) rice straw mat and (c) kanchi. The treatments were allocated randomly to the experimental ponds.

Before placing the substrates, all ponds were drained, dried and limed with CaO at a rate of 250 kg ha^{-1}. The ponds were filled to 0.30 m depth 3 days later. Afterwards, 390 kanchi (1.5 cm in diameter and 1.8 m in length) and three rice straw mats (2 × 1 m) were fixed vertically to the bottom. Kanchi added an extra surface area of 20 m^2 in each pond (Wahab *et al*. 1999). The number of rice straw mats per pond was derived from a preliminary study carried out at BAU, which revealed that three rice straw mats (2 × 1 m) were optimum for 40 m^2 ponds. Rice straw mats were prepared by pressing straw bundles between bamboo splits at a loading rate of 625 kg ha^{-1} (dry weight, 12% moisture). All ponds were filled to 1.10 m depth and fertilized with urea, triple superphosphate (TSP) and cow dung using BAU fertilization rates of 31, 16 and 1250 kg ha^{-1} respectively (Wahab *et al*. 1999). Dissolved oxygen (DO) concentrations in the rice straw treatment ponds were monitored for 2 weeks until DO recovered to 2.1 mg L^{-1}. Then, 40 fingerlings of rohu (24.5 ± 0.5 g), mrigal (25.1 ± 0.6 g), catla (25.8 ± 0.5 g), silver carp (30.4 ± 0.9 g) and common carp (27.6 ± 0.6 g) were stocked at a 3:2:2:2:1 ratio.

Dissolved oxygen, temperature and pH were measured weekly at 06:00, 18:00 and 06:00 hours the next day. Dissolved oxygen concentrations were measured at three depths: 10, 50 and 70 cm below the water surface. The Secchi disc visibility was monitored weekly at 09:00 h. Composite column water samples were collected monthly at 09:00–10:00 h from three locations of each pond for the analyses of total alkalinity, total ammonia nitrogen (TAN), nitrite–nitrogen, soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll *a*, total suspended solids (TSS) and total volatile solids (TVS) (APHA 1980). Total nitrogen (TN) was analysed following Raveh and Avnimelech (1979). Plankton number was estimated following Azim, Wahab, Van Dam, Beveridge and Verdegem (2001a).

Rice straws were cut from three different depths (surface, middle and bottom) of each mat, pooled and wrapped in an aluminium foil for monthly periphyton analyses. Each rice straw sample was transferred to an Erlenmeyer flask containing 50 mL distilled water and shaken in a mechanical shaker for 3 h to detach periphytons from the straw surface. After removing periphytons, the straw was dried overnight in an oven at 80 °C to obtain the dry weight. For sample preservation and taxonomic identification, the above method for planktons was followed. The number of periphyton was estimated using the following formula:

$$N = (P \times C \times 100)/W$$

where, N is the number of periphyton units; P is the number of periphyton units counted in 10 random fields of S-R cell; C is the volume of the final concentrated sample (mL); and W is the weight of rice straw (g).

Periphyton taxa were identified to the genus level using keys from Ward and Whipple (1959), Wetzel (1983) and Bellinger (1992). Dry matter of periphytons was estimated by filtering samples through preweighed and oven-dried Whatman GF/C filter papers and drying for 24 h in an oven at 105 °C. The oven-dried samples were combusted in a Muffle furnace at 550 °C for 30 min to obtain the ash content (%). Chlorophyll *a* concentration was determined following the standard methods (APHA 1980). Sampling, taxonomic identification, enumeration and estimation of biomass of periphytons in the kanchi were performed as described by Azim, Wahab, Van Dam, Beveridge, Huisman and Verdegem (2001b). Total plate counting of bacteria was performed following APHA (1980). Periphyton number, biomass and bacteria total plate count were estimated based on the pond area for comparisons between treatments.

An Ekman dredge (15 × 15 cm) was used to collect macro-zoobenthic organisms from the bottom of each pond monthly. Benthos were identified using a dissecting microscope (CH40RF200 Model, Olympus, Japan) following the keys from Ward and

Whipple (1959) and Needham and Needham (1962). The number of benthos was estimated following Rahman, Verdegem, Nagelkerke, Wahab, Milstein and Verreth (2006):

$$N = (Y \times 10\,000)/3A$$

where, N is the number of benthic organisms (individuals m^{-2}); Y is the total number of benthic organisms counted in three samples; and A is the area of Ekman dredge (cm^2).

At the end, substrates were removed from the ponds, and fish were harvested, counted and weighed individually to estimate weight gains and survival rates. Gross margin analysis was carried out to determine economic returns for the three treatments. The local market prices of all inputs and outputs in Mymensingh of Bangladesh were used in the economic analysis. The analysis excluded labour cost as rural farmers use family labours to get farm work done. Expectant life of bamboo and kanchi was assumed to be 3 and 1.5 years, respectively.

Water quality, plankton, fish growth and economic parameters were compared by one-way analysis of variance (ANOVA) using SPSS (version 12.0) statistical software (SPSS, Chicago, IL, USA). A Tukey's test was performed if significant differences were found by ANOVA. Periphyton and bacteria were compared by Student's *t*-test. Differences were considered significant at an α level of 0.05 ($P<0.05$). All means were given with $\pm$ 1 SD.

Results

All water quality parameters, except DO, did not differ among all treatments (Table 1). Dissolved oxygen concentrations at 06:00 and 18:00 hours were higher in the control and the kanchi treatment than those in the rice straw treatment at all three depths.

There were no differences in the densities of phytoplankton and zooplankton among the treatments (Tables 2 and 3). The abundance of macrozoobenthos in pond sediment was 361 $\pm$ 101, 320 $\pm$ 104 and 275 $\pm$ 90 individual m^{-2} in the control, rice straw and kanchi treatments, respectively.

There were no significant differences in the densities of periphyton between the rice straw and kanchi treatments (Table 4). Dry matter, ash and chlorophyll *a* content of periphyton also did not differ between the rice straw and kanchi treatments. However,

Table 1 Overall mean values ($\pm$ SD) of water quality parameters measured throughout the experiment

Water-quality parameters	Treatments		
	Control	Rice straw	Kanchi
Temperature at 06:00 hours (°C)	25.8 ± 0.6	25.9 ± 0.5	26.1 ± 0.1
Temperature at 18:00 hours (°C)	29.3 ± 0.1	29.4 ± 0.1	29.3 ± 0.1
DO at 06:00 hours (mg L^{-1})			
10 cm	5.3 ± 0.1^a	3.7 ± 0.1^b	4.9 ± 0.1^a
50 cm	4.6 ± 0.3^a	3.2 ± 0.1^b	4.2 ± 0.2^a
70 cm	4.0 ± 0.3^a	2.7 ± 0.1^b	3.5 ± 0.2^a
DO at 18:00 hours (mg L^{-1})			
10 cm	9.3 ± 0.5^a	7.5 ± 0.3^b	9.2 ± 0.3^a
50 cm	7.4 ± 0.5^a	5.8 ± 0.3^b	7.8 ± 0.8^a
70 cm	5.9 ± 0.4^a	4.8 ± 0.3^b	5.9 ± 0.2^a
pH at 06:00 hours	8.5 ± 0.0	8.4 ± 0.0	8.5 ± 0.0
pH at 18:00 hours	8.9 ± 0.0	8.7 ± 0.0	8.9 ± 0.0
Secchi disc depth (cm)	18.2 ± 0.7	21.6 ± 2.6	20.5 ± 0.6
Total alkalinity (mg L^{-1} as $CaCO_3$)	128 ± 13	138 ± 8	129 ± 8
Chlorophyll *a* (μg L^{-1})	56 ± 11	48 ± 20	61 ± 23
Total nitrogen (mg L^{-1})	1.43 ± 0.45	1.53 ± 0.59	1.60 ± 0.17
Total ammonia nitrogen (mg L^{-1})	0.17 ± 0.14	0.10 ± 0.03	0.14 ± 0.07
Nitrite nitrogen (mg L^{-1})	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01
Total phosphorous (mg L^{-1})	2.30 ± 0.46	1.73 ± 0.15	1.83 ± 0.23
Soluble reactive phosphorous (mg L^{-1})	2.30 ± 0.78	1.03 ± 0.21	1.53 ± 0.91
Total suspended solids (mg L^{-1})	75 ± 20	70 ± 6	58 ± 11
Total volatile solids (mg L^{-1})	43 ± 14	39 ± 4	32 ± 12

Mean values with different superscript letters in the same row are significantly different ($P<0.05$).
DO, dissolved oxygen.

Table 2 Abundance (Mean ± SD) of phytoplankton in the pond water in different treatments

Group	Genus	Treatments		
		Control (units L^{-1})	Rice straw (units L^{-1})	Kanchi (units L^{-1})
Bacillariophyceae	*Coscinodiscus*	2457 ± 827	3405 ± 2448	4233 ± 4639
	Cyclotella	6145 ± 2803	26 418 ± 21 938	9000 ± 4639
	Cymbella	67 ± 115	0 ± 0	0 ± 0
	Diatoma	257 ± 283	303 ± 316	250 ± 250
	Gomphonema	512 ± 310	473 ± 231	597 ± 650
	Melosira	6310 ± 7358	1477 ± 898	2510 ± 2181
	Fragillaria	2005 ± 841	1765 ± 1071	1348 ± 619
	Navicula	1875 ± 1797	1390 ± 863	2127 ± 1039
	Nitzschia	4853 ± 2254	2967 ± 1432	17 970 ± 21 136
	Surirella	575 ± 532	1047 ± 464	700 ± 889
	Synedra	1953 ± 1649	2080 ± 719	1345 ± 650
	Tabellaria	173 ± 152	322 ± 376	167 ± 289
	Subtotal	27 182 ± 9662	41 647 ± 21 498	40 247 ± 20 160
Chlorophyceae	*Actinastrum*	412 ± 523	1062 ± 917	1302 ± 1512
	Ankistrodesmus	423 ± 405	743 ± 1094	597 ± 406
	Centritractus	78 ± 136	0 ± 0	1000 ± 1000
	Chlamydomonas	0 ± 0	513 ± 208	710 ± 648
	Chlorella	13 087 ± 9901	12 305 ± 6053	57 668 ± 84 742
	Chodatella	228 ± 395	0 ± 0	0 ± 0
	Closterium	125 ± 109	1557 ± 1939	1017 ± 1087
	Coelastrum	1253 ± 1846	712 ± 798	472 ± 640
	Crucigenia	4692 ± 4356	3843 ± 3761	1696 ± 838
	Gonatozygon	350 ± 312	72 ± 124	375 ± 327
	Mougeotia	2225 ± 2927	2798 ± 2325	1440 ± 1276
	Oedogonium	0 ± 0	72 ± 124	167 ± 288
	Oocystis	6695 ± 1858	4483 ± 580	17 107 ± 10 501
	Pediastrum	2598 ± 1440	933 ± 275	2127 ± 1056
	Scenedesmus	9593 ± 7694	10 213 ± 5375	8082 ± 4720
	Selenastrum	268 ± 263	140 ± 242	2832 ± 4673
	Sphaerocystis	5457 ± 5924	2253 ± 998	10 047 ± 9486
	Spirogyra	67 ± 115	0 ± 0	0 ± 0
	Staurastrum	95 ± 165	212 ± 210	83 ± 144
	Tetraedron	543 ± 587	503 ± 472	250 ± 433
	Tetraspora	290 ± 254	783 ± 916	313 ± 372
	Treubaria	95 ± 165	233 ± 214	167 ± 289
	Ulothrix	1025 ± 631^{a}	142 ± 123^{b}	142 ± 128^{b}
	Volvox	75 ± 130	70 ± 121	167 ± 287
	Subtotal	49 675 ± 21 291	43 643 ± 10 318	107 759 ± 99 027
Cyanophyceae	*Anabaena*	75 ± 130	0 ± 0	0 ± 0
	Aphanocapsa sp.	0 ± 0	140 ± 242	167 ± 289
	Aphanozomenon	0 ± 0	75 ± 130	0 ± 0
	Chroococcus	1527 ± 1233	2445 ± 599	1633 ± 1886
	Gloecapsa	1507 ± 1754	952 ± 303	1380 ± 1777
	Gomphosphaeria	275 ± 152	238 ± 254	1325 ± 1211
	Merismopedia	467 ± 808	528 ± 162	0 ± 0
	Microcystis	78 ± 136	70 ± 121	0 ± 0
	Oscillatoria	875 ± 1277	412 ± 375	400 ± 529
	Subtotal	4803 ± 1309	4860 ± 765	4905 ± 4773
Euglenophyceae	*Euglena*	9678 ± 4937	41 310 ± 51 261	88 363 ± 108 714
	Phacus	548 ± 472	1495 ± 676	672 ± 70
	Trachalomonas	1447 ± 596	1672 ± 1285	1298 ± 1202
	Subtotal	11 673 ± 5470	44 477 ± 49 373	90 333 ± 107 749
Total phytoplankton		93 333 ± 15 342	134 627 ± 62 439	243 244 ± 94 646
Number of identified genus		45	44	42

Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

Table 3 Abundance (Mean ± SD) of zooplankton in the pond water in different treatments

Group	Genus	Treatments		
		Control (units L^{-1})	Rice straw (units L^{-1})	Kanchi (units L^{-1})
Sarcodina	*Difflusia*	962 ± 523	820 ± 589	1678 ± 1458
Rotifera	*Asplanchna*	740 ± 275	837 ± 609	1833 ± 1318
	Brachionus	1343 ± 534	2027 ± 178	4477 ± 2840
	Filinia	1278 ± 912	227 ± 393	337 ± 111
	Keratella	1577 ± 932	1153 ± 73	1260 ± 176
	Lecane	200 ± 25	445 ± 438	575 ± 378
	Monostylla	0 ± 0	0 ± 0	250 ± 250
	Polyarthra	1055 ± 989	987 ± 309	2013 ± 533
	Trichocerca	577 ± 327	150 ± 130	330 ± 361
	Subtotal	6848 ± 2044	5895 ± 703	11 075 ± 4133
Crustacea	*Cyclpos*	545 ± 135	1068 ± 293	590 ± 512
	Diaptomus	235 ± 41	148 ± 129	303 ± 366
	Ceriodaphnia	58 ± 101	130 ± 114	600 ± 529
	Daphnia	75 ± 130	338 ± 118	0 ± 0
	Diaphanosoma	290 ± 182	87 ± 150	67 ± 115
	Moina	240 ± 243	450 ± 507	553 ± 224
	Nauplius	772 ± 130	1308 ± 591	1215 ± 133
	Subtotal	2215 ± 362	3530 ± 563	3328 ± 897
Total zooplankton		9947 ± 1379	10 176 ± 1158	16 082 ± 4089
Number of identified genus		15	15	15

Table 4 Abundance (Mean ± SD) of periphyton in terms of the pond surface area in the rice straw and kanchi treatments during the experimental period

Group	Genus	Treatments	
		Rice straw ($10^3 \times$ units m^{-2})	Kanchi ($10^3 \times$ units m^{-2})
Bacillariophyceae	*Coscinodiscus*	794 ± 1376	0 ± 0
	Cyclotella	3720 ± 1182[a]	174 ± 301[b]
	Cymbella	2863 ± 2481	0 ± 0
	Diatoma	34 999 ± 16 623[a]	3991 ± 795[b]
	Fragillaria	15 931 ± 7163	5553 ± 3347
	Gomphonema	7680 ± 2959[a]	521 ± 521[b]
	Melosira	7095 ± 3932	868 ± 795
	Navicula	40 196 ± 47 396	13 362 ± 7832
	Nitzschia	64 369 ± 33 405[a]	6594 ± 1828[b]
	Surirella	1589 ± 2751	0 ± 0
	Synedra	30 476 ± 12 967	12 147 ± 9547
	Tabellaria	1838 ± 1635	174 ± 301
	Subtotal	211 550 ± 30 722[a]	43 382 ± 6254[b]
Chlorophyceae	*Actinastrum*	531 ± 919	0 ± 0
	Centritractus	1592 ± 2757	0 ± 0
	Characium	2196 ± 2109	3471 ± 2568
	Chlamydomonas	0 ± 0	174 ± 301
	Chlorella	40 049 ± 7860[a]	5900 ± 3837[b]
	Closterium	1805 ± 3126	0 ± 0
	Coelastrum	0 ± 0	347 ± 601
	Cosmarium	5045 ± 2497	1215 ± 301
	Crucigenia	37 428 ± 26 208	1562 ± 1377
	Cylindrocapsa	0 ± 0	22 038 ± 22 866
	Gonatozygon	4822 ± 2329	0 ± 0
	Microspora	3839 ± 582	1041 ± 1803
	Mougeotia	7095 ± 7046	868 ± 1084

Table 4 Continued

Group	Genus	Treatments	
		Rice straw ($10^3 \times$ units m^{-2})	Kanchi ($10^3 \times$ units m^{-2})
	Oedogonium	5420 ± 7421	9718 ± 7969
	Oocystis	3592 ± 3892	4165 ± 1562
	Scenedesmus	60 020 ± 15 990[a]	5206 ± 521[b]
	Stigeoclonium	1589 ± 2751	476 160 ± 251 769
	Sphaerocystis	720 ± 1248	0 ± 0
	Staurastrum	1016 ± 1760	0 ± 0
	Tetraspora	0 ± 0	694 ± 301
	Tetradorn	0 ± 0	1041 ± 1377
	Triplocerus	5384 ± 2958	0 ± 0
	Ulothrix	0 ± 0	1735 ± 1590
	Subtotal	182 141 ± 27 784	535 332 ± 238 794
Cyanophyceae	*Chroococcus*	4800 ± 6980	2082 ± 902
	Gleocapsa	0 ± 0	3991 ± 1084
	Gomphosphaeria	1203 ± 1064	0 ± 0
	Merismopedia	1044 ± 1808	0 ± 0
	Oscillatoria	19 493 ± 12 661	2429 ± 1202
	Phormidium	25 304 ± 13 958[a]	1215 ± 1673[b]
	Subtotal	51 844 ± 24 230	9718 ± 601
Euglenophyceae	*Euglena*	5426 ± 3492	1388 ± 1084
	Phacus	720 ± 1248	0 ± 0
	Trachelomonas	2842 ± 2462	174 ± 301
	Subtotal	8989 ± 1293[a]	1562 ± 1377[b]
Sarcodina	*Diffugia*	531 ± 919	0 ± 0
Rotifera	*Asplanchna*	1589 ± 2751	694 ± 301
	Brachionus	1838 ± 1635	521 ± 521
	Conochilus	0 ± 0	1562 ± 902
	Lecane	1346 ± 2331	0 ± 0
	Subtotal	4773 ± 2107	2776 ± 795
	Total periphyton	459 826 ± 32 266	592 770 ± 233 709
Number of identified genus		41	34

Mean values with different superscript letters in the same row are significantly different ($P<0.05$).

Table 5 Periphyton biomass (Mean ± SD) in the rice straw and kanchi treatments

Parameter	Treatment	
	Rice straw	Kanchi
Dry matter (g pond^{-1})	540.4 ± 140.6	620.3 ± 60.1
Ash (%)	41.7 ± 3.7	36.9 ± 7.3
Ash-free dry matter (g pond^{-1})	280.0 ± 36.6[b]	382.8 ± 36.8[a]
Chlorophyll *a* (g pond^{-1})	0.75 ± 0.2	2.18 ± 0.9

Mean values with different superscript letters in the same row are significantly different ($P<0.05$).

ash-free dry matter was higher in the kanchi treatment than in the rice straw treatment (Table 5). Bacteria total plate count was 41 320 ± 4006 ($10^6 \times$ cfu m^{-2}) on the rice straw, which was higher than 11 780 ± 1208 ($10^6 \times$ cfu m^{-2}) on the kanchi.

Treatments with substrates had higher fish growth (Table 6). The final size of individuals and daily weight gains of rohu and common carp were higher in the substrate treatments than in the control. There was no difference between the two-substrate treatments. The final size and daily weight gain of catla were higher in the kanchi treatment than that in the control but were not different from the rice straw treatment. The total weight gains of rohu and catla were higher in the substrate treatments than those in the control, although there were no differences in total weight gains of mrigal, common carp and silver carp among treatments. Furthermore, individual final size and daily weight gains of mrigal and silver carp were not different among treatments. Combined total weight gain was significantly higher in the substrate treatments than that in the control but there were no differences between the two-substrate treatments. Silver carp made the highest

Table 6 Growth performance of carps stocked in different treatments

Treatments	Rohu	Catla	Mrigal	Common carp	Silver carp	Combined
Initial total weight (kg pond^{-1})						
Control	0.30 ± 0.01	0.20 ± 0.01	0.20 ± 0.01	0.22 ± 0.01	0.13 ± 0.01	1.05 ± 0.04
Rice straw	0.28 ± 0.02	0.21 ± 0.01	0.21 ± 0.02	0.21 ± 0.01	0.11 ± 0.01	1.01 ± 0.03
Kanchi	0.30 ± 0.01	0.21 ± 0.02	0.19 ± 0.01	0.23 ± 0.00	0.13 ± 0.01	1.07 ± 0.01
Initial mean weight (g fish^{-1})						
Control	25.10 ± 0.79	25.50 ± 1.39	24.83 ± 1.76	27.90 ± 1.04	31.40 ± 2.07	
Rice straw	23.17 ± 1.63	25.83 ± 1.37	26.13 ± 2.63	25.67 ± 1.44	28.53 ± 2.32	
Kanchi	25.33 ± 1.06	26.03 ± 2.42	24.33 ± 1.08	29.23 ± 0.21	31.43 ± 3.13	
Final total weight (kg pond^{-1})						
Control	1.19 ± 0.06^{b}	0.43 ± 0.05^{b}	0.89 ± 0.13	0.58 ± 0.06	1.35 ± 0.20	4.44 ± 0.36^{b}
Rice straw	1.66 ± 0.09^{a}	0.63 ± 0.04^{a}	1.16 ± 0.11	0.71 ± 0.08	1.53 ± 0.03	5.70 ± 0.06^{a}
Kanchi	1.90 ± 0.27^{a}	0.73 ± 0.06^{a}	1.19 ± 0.26	0.64 ± 0.09	1.60 ± 0.20	6.06 ± 0.70^{a}
Final mean weight (g fish^{-1})						
Control	105.41 ± 0.89^{b}	59.00 ± 10.36^{b}	130.49 ± 7.25	72.67 ± 8.02^{b}	406.19 ± 32.23	
Rice straw	138.72 ± 7.60^{a}	68.67 ± 21.36^{ab}	139.81 ± 38.70	90.35 ± 5.41^{a}	365.71 ± 18.78	
Kanchi	162.82 ± 16.77^{a}	99.37 ± 9.30^{a}	161.15 ± 18.88	92.01 ± 2.53^{a}	402.46 ± 51.82	
Daily weight gain (g fish^{-1} day^{-1})						
Control	0.89 ± 0.00^{b}	0.37 ± 0.13^{b}	1.17 ± 0.08	0.50 ± 0.08^{b}	4.16 ± 0.34	
Rice straw	1.28 ± 0.07^{a}	0.48 ± 0.22^{ab}	1.26 ± 0.40	0.72 ± 0.05^{a}	3.75 ± 0.18	
Kanchi	1.53 ± 0.18^{a}	0.81 ± 0.12^{a}	1.52 ± 0.22	0.70 ± 0.03^{a}	4.12 ± 0.55	
Total weight gain (kg pond^{-1})						
Control	0.89 ± 0.06^{b}	0.23 ± 0.06^{b}	0.69 ± 0.12	0.36 ± 0.06	1.22 ± 0.19	3.39 ± 0.32^{b}
Rice straw	1.39 ± 0.08^{a}	0.42 ± 0.04^{a}	0.96 ± 0.08	0.50 ± 0.08	1.44 ± 0.04	4.69 ± 0.06^{a}
Kanchi	1.60 ± 0.26^{a}	0.52 ± 0.08^{a}	0.99 ± 0.27	0.41 ± 0.09	1.47 ± 0.19	4.99 ± 0.70^{a}
Survival (%)						
Control	94.7 ± 4.6	96.0 ± 6.9	96.0 ± 6.9	100.0 ± 0.0	83.0 ± 14.4	
Rice straw	100.0 ± 0.0	96.0 ± 6.9	96.0 ± 6.9	96.0 ± 6.9	100.0 ± 0.0	
Kanchi	97.3 ± 4.6	92.0 ± 6.9	91.7 ± 14.4	87.7 ± 12.5	100.0 ± 0.0	

Mean values with different superscript letters in the same column among treatments are significantly different ($P < 0.05$).

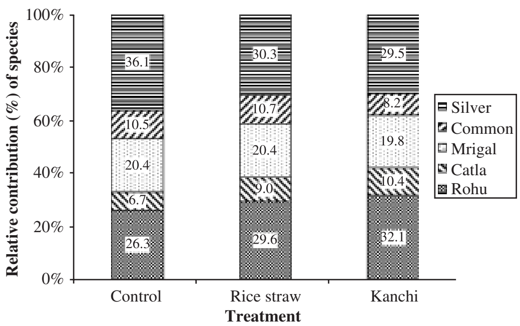

Figure 1 Relative contribution (%) of five species on combined total weight gains in different treatments.

contribution (30–36%) to the total weight gains in all three treatments although they represented only 10% of the total population, while catla contributed the least (7–10%). Rohu, mrigal and common carp contributed 26–32%, 20% and 8–11%, respectively, to the total weight gains (Fig. 1). There were no differences in the survival rates among all five species across treatments ($P > 0.05$).

Gross margin analysis showed that all treatments were profitable; however, there was no significant difference in gross margin among all treatments (Table 7).

Discussion

Generally, water quality remained within the normal range during the experiment. Significantly lower DO in the rice straw treatment was probably due to increased biological oxygen demand (Dharmaraj, Manissery & Keshavnath 2002), which is common in the water with predominantly heterotrophic food production (Moriarty 1997).

Plankton density did not differ among all treatments, indicating that the added substrates did not affect plankton growth. Lower ash-free dry matter of periphyton in the rice straw treatment than that in

Table 7 Gross margin analysis of different treatments based on 40 m^2 pond in Bangladeshi currency Taka (1 US$ = 67 Taka)

Item	Unit	Taka/unit	Treatments: Control Quantity	Control Taka	Rice straw Quantity	Rice straw Taka	Kanchi Quantity	Kanchi Taka
Gross return								
Rohu	kg	60	1.19	72 ± 4[b]	1.66	100 ± 5[a]	1.90	114 ± 16[a]
Catla	kg	60	0.43	26 ± 3[b]	0.63	38 ± 2[a]	0.73	44 ± 3[a]
Mrigal	kg	60	0.89	53 ± 8	1.16	70 ± 6	1.19	71 ± 16
Common	kg	60	0.58	35 ± 4	0.71	42 ± 5	0.64	39 ± 5
Silver	kg	60	1.35	81 ± 12	1.53	92 ± 2	1.60	96 ± 12
Total gross return				267 ± 21[b]		342 ± 4[a]		364 ± 42[a]
Variable cost								
Fingerlings								
Rohu	Pcs	3.5	12	42	12	42	12	42
Catla	Pcs	3.5	8	28	8	28	8	28
Mrigal	Pcs	3.5	8	28	8	28	8	28
Common	Pcs	3.5	8	28	8	28	8	28
Silver	Pcs	3.5	4	14	4	14	4	14
Fertilizer								
Urea	kg	8	0.9	7	0.9	7	0.9	7
TSP	kg	15	0.4	7	0.4	7	0.4	7
Cow dung	kg	0.4	35.0	14	35.0	14	35.0	14
Lime	kg	12	1.0	12	1.0	12	1.0	12
Kanchi	Pcs	1		–	–	–	390 for 4 crops	98
Bamboo	Pcs	130	–	–	2 for 9 crops	29	–	–
Wire						20		
Interest on working capital		10%		4		6		7
Total variable cost				184 ± 0		235 ± 0		285 ± 0
Gross margin				83 ± 21		107 ± 4		79 ± 42

Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).
TSP, triple superphosphate.

the kanchi treatment was probably due to mixing of rice straw fragments with the periphytons. Keshavnath, Gangadhar, Ramesh, Van Rooij, Beveredge, Baird, Verdegem and Van Dam (2001) had also reported a similar problem using sugarcane bagasse as a substrate. Rice straw had more bacteria than kanchi probably because rice straw provided more surface area. Bacteria total plate count in rice straw in the present experiment was higher than that obtained by Ramesh *et al.* (1999) in sugarcane bagasse, paddy straw and *Eichhornia*.

The two substrate treatments gave better fish yield than the control, probably due to the provision of additional foods in terms of periphyton (Miller & Falace 2000) and bacterial biofilm (Ramesh *et al.* 1999). Total weight gains of rohu and catla increased significantly in the substrate treatments over the control similar to the findings of Azim, Rahman, Wahab, Asaeda, Little and Verdegem (2004). Higher total weight gain of rohu in the substrate treatments could be explained by its periphyton grazing habit (NFEP 1997). Periphyton feeding habit of rohu benefited catla because of reduced interspecific competition. In ponds without substrates, rohu and catla tend to compete with each other for planktons (Azim *et al.* 2002b). Generally, catla is faster growing compared with other Indian major carp (Chakrabarty 1998). They did not grow faster in this experiment possibly due to insufficient zooplanktons in the pond water. Most probably, highly efficient grazer silver carp affected catla growth negatively through removal of zooplankton and by reducing food availability for zooplankton (Kadir, Wahab, Milstein, Hossain & Seraji 2007). Higher daily weight gain and larger mean final size of common carp in the rice straw treatment could be attributed to high organic matter (2.0%) deposited to the pond bottom and to its bottom-feeding habit. Substrates did not have a significant effect on the growth and production of mrigal. An earlier report also found that a periphyton-based pond polyculture system with bamboo substrates resulted in lower growth (Azim *et al.* 2004). Silver carp grew equally well in all three treatments independent of substrates.

The rice straw treatment had the highest economic return, due to the low cost of rice straw and high fish yield in the rice straw treatment. Despite the highest gross return, the kanchi treatment was less profitable than the rice straw treatment, mainly due to the relatively higher cost of kanchi. Comparatively less profit in the control was due to the lower fish yield.

The substrates (rice straw and kanchi) added to the ponds increased fish yield substantially and did not affect the water quality negatively; thus, the substrate treatments were better than the treatment without a substrate (control). Periphyton and bacterial biofilm have driven higher fish yield in the substrate treatments. Considering economics, rice straw is a cheaper substrate than kanchi. Partial harvesting is also easier in rice straw ponds because rice straw mats can be removed easily from the ponds. This simple technique has potential application in the periphyton-based rural aquaculture. As rice straw decomposes gradually, further research is needed on using rice straw as a substrate for long-term fish culture.

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