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Research Article

Production Characteristics and Changes in Fatty Acids Profiles of Nile Tilapia (*Oreochromis niloticus*) Using Algae as a Food Source in Partitioned Aquaculture System

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Abstract: Small (57.56 ± 0.03 g) and large (172.46 ± 1.14 g) Nile tilapia fingerlings (*Oreochromis niloticus*) were stocked in six 0.15 ha partitioned aquaculture system (PAS) units on May 1 1997 at a rate of 100 kg/0.15 ha (low density) and 200 kg/0.15 ha (high density) in triplicate to determine the growth rates and production characteristics and the changes in fatty acid profiles of the fish. The primary food source for the 152-day rearing period available to the fish confined within the raceway sections was planktonic algae and to a lesser extent zooplankton and possibly drifting invertebrates. At harvest the mean net production was 2.017 ± 212.4 kg/ha for the high density and 2.298 ± 178.9 kg/ha for the low density treatment. The average weight (g) of the small tilapia was significantly larger in the low density treatment. Total fat content decreased from 11.6% to 6.2% in the large fish and from 8.6% to 6.2% in the small fish and fatty acid profiles changed in the fish flesh during the study. The percentage of both Omega-3 and Omega-6 fatty acids increased over the sampling months. The ratio of Omega-3 to Omega-6 fatty acids also increased from 0.35 to 0.56 in the large fish and from 0.44 to 0.60 in the small fish during the study.

Key Words: Tilapia, *Oreochromis niloticus*, fatty acids, partitioned aquaculture system (PAS), stocking rate

Bölünmüş Yetiştirme Sisteminde Algleri Besin Kaynağı Olarak Kullanan Nil Tilapia'larının (*Oreochromis niloticus*) Üretim Özellikleri ve Yağ Asidi Profili Değişimleri

Özet: Küçük (57,56 ± 0,03 g) ve büyük (172,46 ± 1,14 g) boy Nil tilapia fingerlingleri (*Oreochromis niloticus*) 1 Mayıs 1997 tarihinde, altı adet 0,15 ha'lık bölünmüş yetiştirme sistemine 100 kg/0,15 ha (düşük yoğunluk) ve 200 kg/0,15 ha (yüksek yoğunluk) oranında üç tekerrürlü stok edilerek balıkların büyüme oranları, üretim özellikleri ve yağ asitlerindeki değişimin tespiti amaçlanmıştır. Kanallarda tutulan balıkların 152 günlük kültür periyodunda ana besin kaynağı ağırlıklı olarak planktonik alg türleri ve daha az miktarda zooplankton ve muhtemelen sürüklenerek sisteme giren omurgasız türleri olmuştur. Hasattaki ortalama net üretim miktarı yüksek yoğunluk için 2017 ± 212,4 kg/ha ve düşük yoğunluk için 2298 ± 178,9 kg/ha'dır. Küçük boy tilapiaların ortalama ağırlıkları (g) düşük yoğunluk uygulamasında önemli derecede yüksek olmuştur. Çalışma süresince balık etindeki toplam ham yağ oranı büyük boy balıklarda % 11,6'dan % 6,2'ye ve küçük boy balıklarda % 8,6'dan % 6,2'ye düşmüştür. Örnekleme ayları boyunca Omega-3 ve Omega-6 yağ asitleri % oranları artmıştır. Çalışma süresince Omega-3'ün Omega-6 yağ asitine oranı büyük boy balıklarda 0,35'den 0,56'ya ve küçük boy balıklarda 0,44'den 0,60'a çıkmıştır.

Anahtar Sözcükler: Tilapia, *Oreochromis niloticus*, yağ asitleri, bölünmüş yetiştirme sistemi, stoklama oranı

Introduction

The partitioned aquaculture system (PAS) is a combination of conventional pond culture and high density raceway culture, maintaining fish in divided sections of two raceways, separate from the bulk pond water (1).

The PAS used in this study has three fish sections per unit, offering the opportunity to raise different cohorts within the same unit while keeping cohorts separated. By dividing the primary fish raceways into sections, it is possible to stock different sizes of fingerlings at different times to achieve harvest consistency (2). These sections allow producers to stock different size fingerlings, in separate sections therefore reducing variability, competition, and feed conversion ratios. This system will also eliminate the need to sort at harvest (2,3). The PAS has been designed to increase the fish carrying capacity through improved waste management and confinement culture of the target aquatic organism. The unique design of the system offers the opportunity for increased production through intensive cohort (3,4) and stock management (4,5). The important processes in the PAS are controlled gas exchange (NH_3, CO_2, and O_2), semi-controlled algal culture, solids settling and removal, high density culture of the target fish species, and the use of a control algorithm (computer model). This computer model is capable of using dynamic input variables such as pH, temperature, dissolved oxygen concentration, and ammonia concentration while outputting control signals affecting pond mixing and gas exchange rates.

Since the Nile tilapia can utilize algae as a food source, changes in body composition could result if their diet is restricted to algae. Algae produce alpha linolenic Omega-3 fatty acids, which is an essential polyunsaturated fatty acid in human nutrition. The 22 carbon Omega-3 fatty acid, docosahexaenoic acid, which has six double bonds, is important in the membranes of brain cells, heart muscle cells, spermatozoa, and the rods and cones of the retina. Docosahexaenoic acid is found only in foods such as fish and other aquatic organisms that consume phytoplankton (6). The Omega-3 fatty acids from fish and fish oil tend to reduce the development of atherosclerosis (7). The consumption of fish prolongs the survival of those afflicted with coronary heart disease and reduces the number of subsequent heart attacks (7). Omega-3 fatty acids interfere with abnormal clotting of the blood, which leads to coronary thrombosis (8). Omega-3 fatty acids may also be active against certain immunological diseases, hypertension and hyperlipidemic conditions (8). Human populations that include fish and other sources of Omega-3 fatty acids in their diets generally seem healthier. Japanese, the Dutch, and Greenland Eskimos are less affected by coronary disease despite a high fat, high cholesterol diet (8). The high intake of the Omega-3 fatty acids from seals, whales, and fish appears to decrease coronary disease. Intake of eicosapentaenoic and docosahexaenoic acids (which are 20 and 22 carbons in length) can only be obtained by eating fish and seafood, which are rich in these fatty acids.

The objectives of this study were to:

1) determine the growth rates and production characteristics of two different sized tilapia stocked at two densities within the PAS.

2) evaluate the accumulated biomass outside the confined raceway due to reproduction and subsequent growth.

3) determine the change in fatty acid profiles of fish changed from 36% crude protein floating catfish feed to algae.

Materials and Methods

This study was conducted in six 0.15 ha partitioned aquaculture system (PAS) units at the Clemson University Aquaculture Research Facility, Clemson, South Carolina, USA. The units consisted of high density fish raceways, followed by a solids settling basin, low speed paddle wheel mixer (2.5 – 10.2 cm/s) and shallow (60 cm) algal oxidation channels (400 m x 4 m) (Figure).

Tilapia were stocked at a rate of ≅ 200 kg/unit (high density) and a rate of ≅ 100 kg/unit (low density) in triplicate PAS units, on May 1 1997. There were two sizes stocked in each unit into separate sections (5.6 m^3) of the alternate raceway, small (57 ± 0.03 g) and large (172 ± 1.14g) individual weight (mean ± SD). The average stocking rate for high density treatment was 89 kg of small fish/unit (n = 1545) and 110 kg of large fish/unit (n = 640). The average stocking rate for the low density treatment was 44 kg of small fish/unit (n = 720) and 55 kg of large fish/unit (n = 320). The average stocking rate was 14,500 fish/ha and 6950 fish/ha for the high density and low density treatment, respectively. The tilapia were harvested on October 29, 152 days after stocking. The tilapia were fed 36% crude protein, 10% fat commercial floating catfish feed before the study, tilapia were not offered any supplemental feed during the study. The primary food source available to the fish within the raceways was planktonic algae species and to a lesser extent zooplankton and possibly drifting invertebrates species.

The fish within the confined section of the raceways were sampled monthly to determine average size and estimated growth rate. The samples were collected during the first week of each month by using a cast net to catch the fish. Fish were weighed and counted and average weight calculated. Monthly samples were also collected to determine fatty acids content and profile. Three fish from each section were collected monthly and samples were pooled for composite fatty acids analysis. The fish were deheaded, eviscerated and scaled, and then stored at –20 °C for analysis. Fish were thawed and then, using a meat grinder, ground into a paste in preparation for fatty acid analysis. Total raw fat content was

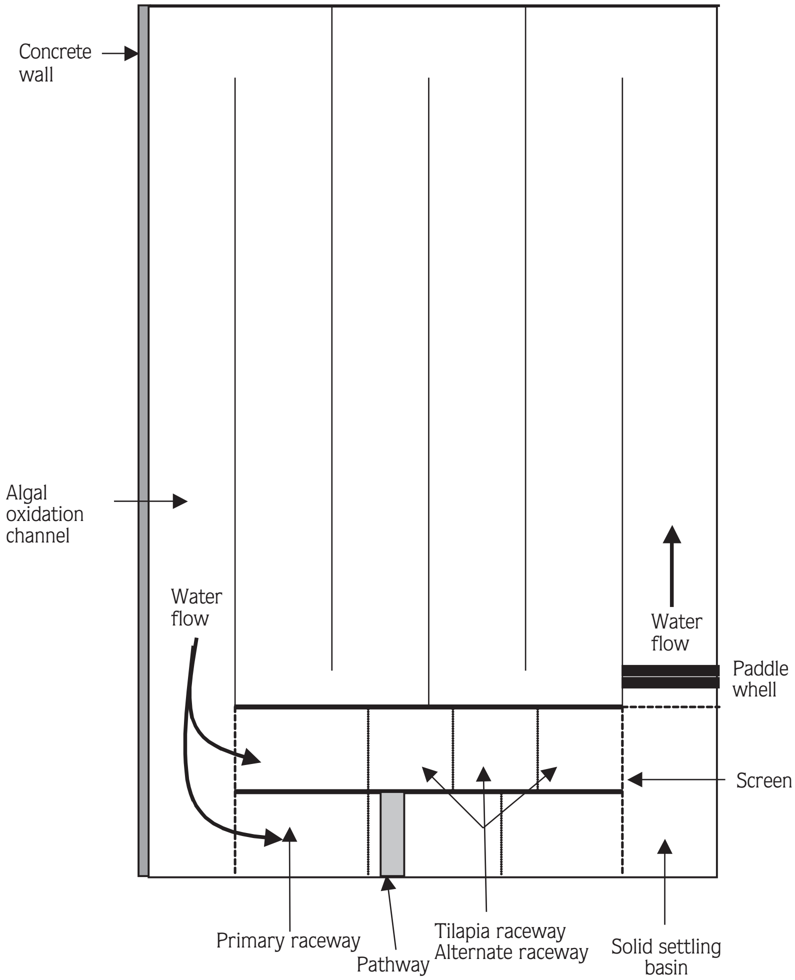

Figure. Schematic drawing of a PAS unit.

determined by proximate analysis. Fatty acids were methylated and separated by gas liquid chromatography to quantify fatty acid composition according to Jenkins and Thies (9).

To evaluate reproduction and production outside the raceways samples were collected monthly using 0.25 cm mesh seine. The tilapia were seined from the first algal oxidation channel of each unit using a block net to confine the fish within the channel. Fish collected were separated into size groups (< 1 g, 1-5 g, 5-10 g, 10-20 g, 20-40 g, 40-80 g) weighed and counted.

Water quality was monitored throughout the study including dissolved oxygen, pH, temperature, alkalinity, nitrite and total ammonia and maintained within acceptable parameters for tilapia and catfish. Two floating 3/4 hp aerators (Power House, Owings Mills, MD, USA) were used in each PAS unit to maintain oxygen levels at or above 4.0 mg/l.

All data were analyzed using one-way analysis of variance (SAS / PC statistical software, SAS Institute Inc., Cary, NC). Means of average weights, percent gain, biomass and reproduction outside and net production of large and small tilapia within treatments were compared using Student's t-test. Differences were considered significant at $P < 0.05$.

Results

Tilapia biomass in the high density treatment remained significantly higher at 285 ± 8.3 kg/0.15 ha (n = 6) compared to the low density treatment 170 ± 7.1

kg/0.15 ha (n = 6)(mean ± SE) within the confined sections of the raceways (Table 1). The biomass outside the confined raceway due to reproduction resulted in 216 ± 5.5 kg/0.15 ha in the high density unit, which was significantly lower than the low density unit at 273 ± 11.5 kg/0.15 ha. The total biomass at the end of study was 505 ± 3.4 kg/unit for high density and 440 ± 19.8 kg/unit for low density with no significant difference (Table 1). The average daily production over a 152 day growing season, inside the raceway was 0.564 kg/unit/day and 0.455 kg/unit/day and outside the raceway was 1.425 kg/unit/day and 1.801 kg/unit/day for high density and low density treatments, respectively (Table 1).

Tilapia production (harvest weight – stock weight), inside the raceway was 85.85 ± 8.3 kg/0.15 ha for the high density treatment and 69.2 ± 6.3 kg/0.15 ha for the low density treatment with no significant difference. The production of the small fish was 51.7 ± 6.9 kg/0.15 ha for the high density treatment and 43.7 ± 3.5 kg/0.15 ha for low density treatment. The production of the large fish was 34.2 ± 1.4 kg/0.15 ha for the high density treatment and 27.2 ± 3.7 kg/0.15 ha for the low density treatment, with no significant differences (Table 2).

Specific growth rate (SGR) (calculated as ($\log_e$Finalw – $\log_e$Initialw)/ duration (days) x100) over the culture period was 0.28% for small and 0.17% for large fish in

Table 1. Mean ± SE harvest biomass (kg/unit), production (kg/unit) and mean daily production (kg/unit/day) for each treatment in the PAS units. Values in the same column with the same superscripts are not significantly different (P > 0.05).

Treatment	Inside the Raceway	Outside the Raceway	Total (inside & outside)
		Tilapia biomass (kg/unit)	
High Density	285.13 ± 8.27 ^{a}	216.71 ± 5.57 ^{a}	505.48 ± 3.36 ^{a}
Low Density	170.61 ± 7.15 ^{b}	273.93 ± 11.45 ^{b}	440.90 ± 19.74 ^{a}
		Tilapia production (kg/unit)	
High Density	85.84 ± 8.25 ^{a}	216.71 ± 5.57 ^{a}	302.55 ± 13.00 ^{a}
Low Density	69.17 ± 6.28 ^{a}	273.93 ± 11.45 ^{b}	344.81 ± 10.96 ^{a}
		Mean daily production (kg/unit/day)	
High Density	0.564	1.425	1.990
Low Density	0.455	1.801	2.268

Table 2. Mean ± SE production (kg/unit) and percent gain (% gain) for each treatment in the PAS units by size at stocking inside the raceway. Values in the same column with the same superscripts are not significantly different (P > 0.05).

Treatment	Small tilapia	Large tilapia	Total tilapia
		Tilapia production*	
High Density	51.69 ± 9.85 ^{a}	34.16 ± 1.95 ^{a}	85.84 ± 8.25 ^{a}
Low Density	43.65 ± 5.01 ^{a}	27.19 ± 5.24 ^{a}	69.17 ± 6.28 ^{a}
		Percent gain**	
High Density	57.92 ± 11.05 ^{a}	31.04 ± 1.76 ^{a}	44.48 ± 11.06 ^{a}
Low Density	97.81 ± 11.10 ^{a}	49.35 ± 9.65 ^{a}	73.58 ± 17.93 ^{a}

* Tilapia production calculated as harvest weight – stock weight.
**Percent gain calculated as (harvest weight – stock weight) / stock weight X 100.

the high density treatment and 0.45% for small and 0.26% for large fish in the low density treatment.

The percent gain for the fish [(harvest weight – stock weight) / stock weight x 100] within the raceway, in small and large tilapia and for large and small combined was not significantly different between treatments. The percent gain of the small tilapia was 57.9 ± 11.0 for the high density treatment and 97.8 ± 11.1 for the low density treatment. The large tilapia had a 31.0% ± 1.7% gain for the high density treatment and 49.3% ± 9.6% gain for the low density treatment. The percent gain for the total group (small and large fish) was 44.5 ± 11.02 for the high density treatment and 73.5 ± 17.9 for the low density treatment (Table 2).

The average weight (g) of the small tilapia was significantly different between treatments on all the sampling dates except September (Table 3).

Total fat and fatty acids profile of tilapia changed during the growth out period (Table 4). Total fat was 11.6% in the large and 8.6% in the small fish at stocking, and decreased to 6.2% in both sizes by the end of the study. The percentage of saturated fatty acids remained about the same during the study period. The percentage of monounsaturated fatty acids decreased from 39.7% to 28.8% in the large and from 37.7% to 29.3% in the small fish. The percentage of

Table 3. Average weights (mean ± SE) for tilapia in the PAS units by month and treatment. Values within the same column and size class followed by the same superscript are not significantly different (P > 0.05).

		Weight (g)	
Months	Treatment	Small Tilapia	Large Tilapia
Stock	High Density	60.88 ± 2.52 ^{a}	171.59 ± 8.55 ^{x}
(May)	Low Density	63.94 ± 2.88 ^{a}	179.70 ± 4.42 ^{x}
June	High Density	62.96 ± 1.46 ^{a}	180.6 ± 4.82 ^{x}
	Low Density	69.70 ± 1.63 ^{b}	187.93 ± 7.55 ^{x}
July	High Density	70.93 ± 1.93 ^{a}	181.93 ± 9.11 ^{x}
	Low Density	86.76 ± 3.55 ^{b}	216.66 ± 10.00 ^{x}
August	High Density	96.10 ± 4.52 ^{a}	229.66 ± 3.83 ^{x}
	Low Density	125.30 ± 8.30 ^{b}	259.10 ± 8.68 ^{x}
September	High Density	98.50 ± 7.05 ^{a}	235.66 ± 11.74 ^{x}
	Low Density	125.96 ± 8.16 ^{a}	268.76 ± 21.48 ^{x}
Harvest	High Density	94.46 ± 2.36 ^{a}	224.76 ± 10.54 ^{x}
(October)	Low Density	126.53 ± 9.81 ^{b}	276.20 ± 20.35 ^{x}

Table 4. Fatty acids profiles in whole dressed tilapia by fish size and sampling date.

Fish Size	Sampling Month	Total[a]	SFA[b]	USFA[c]	PUFA[d]	O-3[e]	O-6[f]	O-3/O-6[g]
Large	May	11.6	36.5	39.7	24.0	5.8	16.6	0.35
	June	8.6	38.2	36.6	25.2	7.0	16.6	0.42
	July	5.3	38.2	34.5	27.2	8.7	16.9	0.51
	August	10.3	37.4	35.4	27.3	8.3	17.5	0.47
	September	9.8	37.3	31.2	31.3	8.9	20.8	0.43
	October	6.2	38.4	28.8	32.8	11.2	20.0	0.56
Small	May	8.6	35.6	37.7	26.8	7.7	17.5	0.44
	June	6.0	38.3	34.5	27.3	8.9	16.5	0.54
	July	5.7	37.1	34.2	28.9	10.5	16.2	0.65
	August	8.5	36.9	31.1	32.0	10.8	19.4	0.56
	September	6.9	38.6	27.7	33.7	11.0	21.6	0.51
	October	6.2	36.1	29.3	34.5	12.3	20.6	0.60

(a) Total fat (g /100 g whole dressed fish)
(b) Saturated fatty acids (% of total fat)
(c) Monounsaturated fatty acids (% of total fat)
(d) Polyunsaturated fatty acids (% of total fat)
(e) Omega-3 fatty acids (% of total fat)
(f) Omega-6 fatty acids (% of total fat)
(g) Ratio of Omega-3 to Omega-6

polyunsaturated fatty acids increased from 24.0% to 32.8% in the large fish, and from 24.0% to 32.8% in the large fish, and from 26.8% to 34.5% in the small fish. The percentage of Omega-3 fatty acids increased from 5.8% to 11.2% in the large fish and from 7.7% to 12.3% in the small fish. The percentage of Omega-6 fatty acids was 16.6% in the large and 17.5% in the small fish in May and reached 20% in both fish sizes by harvest. The ratio of Omega-3 to Omega-6 fatty acids also increased in both fish sizes during the study.

Discussion

The low density treatment is recommended since the high density of tilapia had an insignificant ($P < 0.05$) increase in production within the raceways. Density strongly influences food consumption of the fish, which in turn is linearly related to the relative growth rate (10). The total amount of feed available was assumed to be about the same for both the high density and the low density treatments; consequently the feed available per fish was higher for the low density treatment. The combination of algae was similar in both the high and the low density treatment (11). The poor growth of the high density tilapia likely resulted from limited nutrient inputs.

The over-wintered tilapia in this study spawned shortly after stocking as evidence of small tilapia fry in the algal oxidation channels in the June samples. Tilapia offspring grew outside the raceways in the algal oxidation channels. The mean outside production in the high density and in the low density treatments were 1444.71 ± 37.16 kg/ha and 1826.25 ± 76.34 kg/ha, respectively. This significant difference in production may have resulted from more food being available in the low density treatment. Competition for feed and natural pond production between the stocked tilapia and their young can reduce growth rate of stocked fish and results in stunted populations (12). This observation explains the poor growth of the high density tilapia especially in September and October. The low density treatment had consistently higher percent gain than high density treatment at both sizes of fish inside the raceway. The average weights of the small tilapia were significantly larger in low density treatment. Increased stocking density had an adverse affect on the average weights for the small fish. Many fish species show an inverse relationship between growth rate and stocking density (13-15), although the reverse has also been observed (16). Stocking density had no significant effect on average weights for large fish. This observation indicated that large fish grew just as well in the high stocking density as in the low stocking density.

The fatty acids composition of freshwater fish is markedly influenced by the lipids in their food (8). Freshwater algae, crustaceans, and aquatic insects are, as a rule, rich in linoleic acid (18:2 Omega-6), linolenic acid (18:3 Omega-3) and eicosapentaenoic acid (20:5 Omega-3). In the present study, by changing the diet of the Nile tilapia from 36% crude protein commercial floating feed to algae, a change in the body composition with respect to fatty acids was observed. The Omega-3 fatty acids were increased in both sizes of fish. The increase in Omega-6 fatty acids remained lower than the increase in Omega-3 fatty acids. In a balanced diet for humans the Omega-3 / Omega-6 polyunsaturated fatty acids ratio should be approximately 0.1(7). The Omega-3 to Omega-6 fatty acids ratio in the total lipid of freshwater fish is in the range of 0.5-3.8 and that of marine fish is 4.7-14.4, with the lowest values being in tropical fish (8). The ratio of total Omega-3 to Omega-6 fatty acids of tilapia in this study was about 0.60 at harvest, which is considered a well-balanced diet for human consumption.

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