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Combined effects of water temperature and salinity on growth and feed utilization of juvenile Nile tilapia *Oreochromis niloticus* (Linneaus)

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Abstract

Juvenile Nile tilapia, *Oreochromis niloticus* (Linneaus) (average weight 4.60 to 4.83 g) were raised in 36 75-l glass tanks at a stocking density of 15 fish per tank and fed a 50% protein diet for 56 days. Combined effects of temperature (24, 28, and 32°C) and salinity (0, 8, 12, and 16 g l^{-1}) on growth and feed utilization under a 12L:12D photoperiod were studied. Significant ($P < 0.05$) effects of temperature, salinity, and their interaction on growth were observed. Final mean weights were significantly ($P < 0.05$) higher at 32 and 28°C than 24°C at 12 g l^{-1} salinity, where fish increased their weights seven-fold and four-fold, respectively. Feed conversion efficiencies and protein efficiency ratios were highest at 32°C and 8 g l^{-1} salinity, and lowest at 28°C and 16 g l^{-1} salinity. At all salinities, growth increased with temperature, but at all temperatures an increase in salinity generally inhibited growth. At 32°C and 16 g l^{-1} salinity, fish developed body lesions. The study suggested that growth rates of juvenile *O. niloticus* may be comparably high at 28 or 32°C in waters of 0 and 8 g l^{-1} salinity.

Keywords: Temperature; Salinity; Growth; *Oreochromis niloticus*; Tilapia

1. Introduction

Nile tilapia *Oreochromis niloticus* (Linneaus) is one of the most important freshwater finfish in aquaculture. It grows fast but is less salt-tolerant than *Oreochromis aureus* (Steindachner) (Watanabe et al., 1985b; Avella et al., 1993), *Oreochromis mossambicus*

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(Peters), and *Tilapia zillii* (Gervais) (Stickney, 1986). Although both *O. mossambicus* and *T. zillii* are highly salt-tolerant (Bayoumi, 1969; Stickney, 1986), they are not popular species for culture (Suresh and Lin, 1992). Chervinski and Zorn (1974) indicated that *T. zillii* is not popular because it is small, rarely attains commercial size, and spawns vigorously. Suresh and Lin (1992) have shown that both *O. niloticus* and *O. aureus* are suitable for low salinity brackish water. Payne and Collinson (1983) reported that upper estimates for salinities giving unimpeded growth of *O. niloticus* ranged from 5 to 10 g l^{-1} salinity, suggesting that the distribution of *O. niloticus* may be limited by salinity range. Cataldi et al. (1988) also reported that *O. niloticus* survived only for brief periods in seawater. Several studies and reviews on salinity tolerance of tilapias have been published (Chervinski, 1961; Fryer and Iles, 1972; Chervinski and Hering, 1973; Whitfield and Blaber, 1976; Coleman et al., 1977; Assem and Hanke, 1979; Chervinski, 1982; Wohfarth and Hulalta, 1983; Stickney, 1986; Prunet and Bornancin, 1989; Jennings and Williams, 1992; Suresh and Lin, 1992); however, very little information is available on combined effects of water temperature and salinity on growth and feed utilization of Nile tilapia, except the work of Watanabe et al. (1993) which showed that salinity modified effects of temperature on the growth of Florida red tilapia. Beamish (1970) studied the temperature preferenda of *O. niloticus* in relation to acclimation temperature and salinity, rather than the combined effects of temperature and salinity on growth. Salinity has been shown to influence tilapia reproduction. Watanabe and Kuo (1985a) observed spawning of *O. niloticus* in salinities ranging from freshwater to full seawater (32 g l^{-1} salinity) but eggs spawned in full seawater resulted in extremely poor hatching success. Egg and fry production per unit weight was greater in yearling females in 5 to 15 g l^{-1} salinity than in older females in freshwater. Research has also shown that salinity tolerance of fishes is influenced by size and several environmental factors including temperature. Watanabe et al. (1985b) reported that in *O. niloticus* salinity tolerance was more closely related to size than to chronological age. Salinity tolerance may also be influenced by hybridization. Watanabe et al. (1985b) indicated that the hybrids of *O. mossambicus* and *O. niloticus* have higher salinity tolerance than *O. niloticus*, and suggested that hybridization may enable the production of progeny which can be transferred to seawater at very small sizes, thus reducing freshwater requirements. Watanabe et al. (1985c) demonstrated that early exposure through spawning and incubation to elevated salinities can effectively enhance salinity tolerance levels in *O. niloticus* fry. Very little is known about the combined effects of water temperature and salinity on reproduction of *O. niloticus*.

Tilapias are known to tolerate high temperatures, but salinity has been reported to modify effects of temperature on growth (Stauffer, 1986; Watanabe et al., 1993). Salinity affects temperature preference (Stauffer et al., 1984), and temperature may also influence salinity selection (Miller et al., 1983). In nature, temperature and salinity may fluctuate together, and considering the wide range of habitats that are used worldwide to raise *O. niloticus* commercially, it is important to understand the interactive influence of water temperature and salinity on growth and feed utilization of this fish. The objective of the present study was to investigate combined effects of temperature (24, 28, and 31°C) and salinity (0, 8, 12, and 16 g l^{-1}) on growth, feed conversion and protein utilization of juvenile tilapia, *O. niloticus*, under controlled laboratory conditions.

2. Materials and methods

Nile tilapia were obtained as fry from Clearwater Aquaculture Farms, Alabama, USA. Upon arrival at Penn State University on November 16, 1993, the fry were held at 27 ± 1°C. The study was conducted in 36 75-l glass tanks, each of which was stocked with 15 fish. Using a 3 × 4 factorial design, three temperatures (24, 28, and 32 ± 1°C) and four salinity levels (0, 8, 12, and 16 ± 1 g l^{-1}) were randomly assigned to triplicate tanks. Each tank was filled with well water and supplied with compressed air. A 300-W immersion heater and a gravel-lined biofilter were installed in each tank to control water temperature and ammonia, respectively. Insulation was used to prevent heat transfer between tanks. Tanks were covered with plastic screen to prevent fish from escaping. Light was supplied by four 40-W timer-regulated fluorescent bulbs to provide a 12L:12D photoperiod.

To begin an experiment, fish were captured from a holding tank, anaesthetized, and weighed and measured to the nearest 0.1 g and 0.1 cm, respectively. Initial mean weights did not differ significantly ($P > 0.05$) among treatments. During the acclimation period, experimental water temperatures were attained by gradually heating water at 1°C day^{-1}. Salinity was increased by 2 g l^{-1} day^{-1} using Instant Ocean synthetic sea salts (Aquarium Systems).

Fish were hand-fed on a restricted ration once daily at 3% body weight using a 50% protein pellets manufactured by Zeigler Bros. Inc. Feed allowance was adjusted fortnightly following sampling, and at any other time a dead fish was observed. At the end of the study, triplicate fish samples were taken and dried in a laboratory oven at 80°C for 24 h to determine dry matter. Feed samples were also dried for the same time and temperature. Tank temperatures were checked daily using a combined temperature/dissolved oxygen meter (YSI Model 58). Salinity levels were monitored using salinity–conductivity–temperature meter (YSI Model 33). Twice weekly, water samples were taken for pH and total ammonia measurements using a pH/ISE meter, Model 720A (Orion Laboratory Products Division) using electrodes for both variables.

Fish mortality was checked every day, and about a third of the water in each tank was replaced twice weekly. Water was completely renewed once during the experimental period, using pre-heated water of correct salinity. Data were collected for treatment water temperatures (ranges: 23.93 to 24.15°C; 27.97 to 28.07°C; 31.95 to 31.99°C), dissolved oxygen (range: 5.38 to 6.86 mg l^{-1}), total ammonia (range: 0.29 to 6.89 mg l^{-1}) and pH (range: 7.04 to 7.57). At the end of the study, all surviving fish were weighed and measured. Final mean weight and length measurements were used for calculation of coefficients of condition (K), from: $K = 100$ (mean weight/length^3). Initial and final mean weights were used for calculation of specific growth rates (SGRs) from: SGR (%body weight per day) = 100(Log_e final weight − Log_e initial weight)/$t_2 - t_1$, where $t_2 - t_1$ = experimental period in days. Percentage weight gain (%WG) was calculated from: %WG = 100 (final weight (g) − initial weight (g)/initial weight (g)). Feed conversion efficiency (FCE) was determined from: FCE (%) = $100(Wf - Ws)/R$, where Wf = total final wet weight (g) of fish, Ws = total initial wet weight (g) of fish, and R = total dry weight of feed (g). Protein efficiency ratios (PERs) were determined from PER = weight gain (g)/protein fed (g).

The effects of water temperature and salinity on growth and feed utilization were compared by two-way analysis of variance. When ANOVA was found to be significant, multiple comparisons among means were made using Duncan's multiple range test. Level of significance in all tests was $P < 0.05$. Multiple regression analysis was used to determine linear relationship between water temperature and growth, or salinity and growth. Simple linear regression analyses were used to establish relationships among growth, temperature, and salinity.

3. Results

3.1. Effects of temperature and salinity on growth

Growth was significantly ($P < 0.05$) influenced by water temperature, salinity, and their interaction. Specific growth rates, final mean weights, and percentage weight gains were significantly ($P < 0.05$) greater at 28 and 32°C than at 24°C. Growth rates were not significantly ($P > 0.05$) different among the following treatments: T28/S0, T28/S8, T28/S12, T32/S0, T32/S8, and T32/S12, where the number following T equals temperature (°C) and that following S equals salinity (g l^{-1}). Growth rates were highest at 32°C and 8 g l^{-1}, and lowest at 24°C and 12 g l^{-1} salinity. The fastest-growing and slowest-growing fish increased their weights seven-fold and four-fold, respectively. The temperature that produced the highest growth rates differed with changing salinity. At 0 g l^{-1} and 8 g l^{-1} salinity, specific growth rates (range: 1.9 to 2.8% day^{-1}), final mean weights (range: 18 to 33.6 g), and percentage weight gains per fish (range: 284.7 to 601.2%) were highest at 32°C; at 12 g l^{-1}, specific growth rates, final mean weights, and percentage weight gains were highest at 28°C. At 24°C, growth rates were highest in freshwater (< 0.5 g l^{-1} salinity) (Table 1).

Table 1
Specific growth rate (SGR), mean harvest weight (WT), percentage weight gain per fish (%WG), and mean harvest length (L) of *Oreochromis niloticus* raised at 24, 28, and 32°C (T) and 0, 8, 12, and 16 g l^{-1} salinity (S). At the start of the experiment, mean weight = 4.75 g and mean length = 6.48 cm

Treatment	SGR (% day^{-1})	WT (g)	%WG^2	L (cm)
T24/S0	2.24 ± 11fde	24.4 ± 9.51bc	369.65 ± 35.0c	10.9 ± 1.52bc
T24/S8	2.03 ± 0.03fe	18.8 ± 6.55c	299.22 ± 11.04c	10.4 ± 1.19cd
T24/S12	1.90 ± 0.26f	18.0 ± 7.12c	284.68 ± 84.80c	10.2 ± 1.29d
T24/S16	1.94 ± 0.49fe	18.3 ± 8.27c	297.16 ± 141.7c	10.2 ± 1.44d
T28/S0	2.68 ± 0.02abc	30.8 ± 9.02a	538.77 ± 11.47a	12.1 ± 1.19a
T28/S8	2.67 ± 0.10abc	30.2 ± 8.78a	532.77 ± 43.80a	11.9 ± 1.19a
T28/S12	2.72 ± 0.14ab	30.8 ± 13.88a	555.66 ± 61.20a	12.0 ± 1.57a
T28/S16	2.32 ± 0.36cde	21.0 ± 5.10bc	406.2 ± 13.7bc	10.7 ± 0.95cd
T32/S0	2.74 ± 0.05a	31.5 ± 10.65a	565.64 ± 23.10a	12.0 ± 1.27a
T32/S8	2.82 ± 0.10a	33.6 ± 10.89a	601.18 ± 47.20a	12.2 ± 1.25a
T32/S12	2.62 ± 0.23abcd	28.9 ± 8.19a	510.11 ± 10.6ab	11.5 ± 0.99ab
T32/S16	2.29 ± 0.23cdef	23.9 ± 7.33b	391.0 ± 77.6bc	10.9 ± 1.07c

Means in a column followed by the same letter are not significantly ($P > 0.05$) different (Duncan's multiple range test).

Table 2
Regression equations for effects of temperature and salinity on growth of *O. niloticus* raised in tanks for 56 days

Variable	Regression equation	r^2
Where Y = weight gain (g) and X = temperature (°C)		
0 g l^{-1}	$Y = -4.16 + 1.16X$	0.746
8 g l^{-1}	$Y = -24.3 + 1.86X$	0.833
12 g $^{-1}$	$Y = -13.1 + 1.39X$	0.544
16 g l^{-1}	$Y = 6.70 + 0.55X$	0.114
Where Y = weight gain (g) and X = salinity (g l^{-1})		
24°C	$Y = 21.7 - 0.246X$	0.164
28°C	$Y = 32.2 - 0.351X$	0.227
32°C	$Y = 33.90 - 0.490X$	0.411

Growth generally increased with temperature, but generally decreased as salinity was increased above 8 g l^{-1}. Regression equations showing effects of temperature and salinity on growth are shown in Table 2. Final mean weights were positively correlated with temperature ($r^2 = 0.742$), feed conversion efficiencies ($r^2 = 0.853$), protein efficiency ratios ($r^2 = 0.854$), but negatively related to salinity concentration ($r^2 = -0.413$) (Table 3). Feed conversion efficiencies ($r^2 = 0.683$), and protein efficiency ratios ($r^2 = 0.684$) were positively correlated with temperature, but both variables were negatively correlated with salinity ($r^2 = -0.576$).

3.2. Effects of temperature and salinity on feed utilization, coefficient of variation, and survival

Feed conversion efficiencies (range: 10.0 to 30.0%), and protein efficiency ratios (range: 0.20 to 0.60) were highest at 32°C and 8 g l^{-1} salinity, and differences were significant ($P < 0.05$) (Table 4). Both feed conversion efficiencies and protein efficiency ratios increased with temperature, and were generally higher at 28 and 32°C than at 24°C (Table 4). The highest survival was 95.5% at 32°C and 0 g l^{-1} salinity, and the lowest was 44.4% at 28°C and 16 g l^{-1} salinity, and differences were significant ($P = 0.054$). At 28°C and 16 g l^{-1} salinity, total ammonia rose suddenly in one of the

Table 3
Pearson correlation for mean harvest weight (g) (WT), feed conversion efficiency (%) (FCE), and protein efficiency ratio (PER) for *O. niloticus* raised at 24, 28, and 32°C (TEMP) and 0, 8, 12, and 16 g l^{-1} salinity (SAL) in tanks for 56 days

	WT	FCE	PER	TEMP
FCE	0.853			
PER	0.854	1.00		
TEMP	0.742	0.683	0.684	
SAL	−0.413	−0.576	−0.576	0.001

Table 4
Feed conversion efficiency (FCE), protein efficiency ratio (PER), and survival of *O. niloticus* raised in tanks at 24, 28, and 32°C (T) and 0, 8, 12, and 16 g l^{-1} salinity (S) for 56 days

Treatment	FCE (%)	PER	Survival (%)
T24/S0	16.99 ± 0.274cde	0.34 ± 0.005cde	82.20 ± 7.70ab
T24/S8	16.10 ± 2.36cde	0.32 ± 0.047cde	84.40 ± 10.18ab
T24/S12	13.24 ± 4.52de	0.26 ± 0.090de	77.80 ± 10.18ab
T24/S16	10.38 ± 2.66e	0.21 ± 0.053e	66.70 ± 11.55b
T28/S0	23.16 ± 4.78abc	0.46 ± 0.098abc	73.30 ± 13.33ab
T28/S8	25.54 ± 2.91ab	0.51 ± 0.058ab	82.20 ± 20.40ab
T28/S12	17.31 ± 7.43cde	0.35 ± 0.148cde	62.20 ± 16.75b
T28/S16	10.00 ± 1.05e	0.20 ± 0.021e	44.40 ± 32.90b
T32/S0	29.93 ± 2.36a	0.59 ± 0.047a	95.50 ± 3.85a
T32/S8	30.00 ± 2.99a	0.60 ± 0.060a	93.30 ± 6.67a
T32/S12	20.32 ± 5.39bcd	0.41 ± 0.108bcd	75.50 ± 16.78ab
T32/S16	19.64 ± 6.99bcd	0.39 ± 0.139bcd	86.70 ± 11.55ab

Means in a column followed by different letters are significantly ($P < 0.05$) different (Duncan's multiple range test).

triplicate tanks, and almost all fish died in that tank. That tank was eliminated from statistical analysis, so the following data reported for 28°C and 16 g l^{-1} are based on the results from two tanks. Total ammonia developed more rapidly in salt water treatments than in the controls (< 0.5 g l^{-1} salinity). Effects of temperature at all salinities, and of salinity at all temperatures on growth, survival, feed conversion efficiency, protein efficiency ratio, and coefficient of condition are shown in Tables 5 and 6. At all salinities, growth was significantly ($P < 0.05$) higher at 28 and 32°C than at 24°C (Table 5). Feed conversion efficiencies, protein efficiency ratios and the coefficients of condition were significantly ($P < 0.05$) different at all three temperatures. Survival was

Table 5
Effects of 24, 28, and 32°C water temperatures at 0, 8, 12, and 16 g l^{-1} salinity on specific growth rate (SGR), mean harvest weight (WT), mean harvest length (L), percentage weight gain per fish (%WG), percentage survival, food conversion efficiency (FCE), protein efficiency ratio (PER), and coefficient of condition (K) of *O. niloticus* raised in tanks for 56 days

Variable	Temperature (°C)		
	24	28	32
SGR (% day^{-1})	2.03 ± 0.152b	2.60 ± 2.67a	2.62 ± 0.233a
WT (g)	19.4 ± 2.06b	28.2 ± 4.83a	29.5 ± 4.17a
%WG	312.70 ± 38.5b	508.5 ± 68.5a	517.0 ± 92.0a
L (cm)	10.4 ± 0.373b	11.7 ± 0.648a	11.6 ± 0.583a
Survival (%)	77.78 ± 7.88ab	65.53 ± 16.29b	87.20 ± 9.99a
FCE (%)	14.18 ± 2.99a	18.82 ± 7.25b	24.97 ± 5.77c
PER	0.28 ± 0.06a	0.38 ± 0.139b	0.50 ± 0.115c
K	1.612 ± 0.013a	1.695 ± 0.019b	1.800 ± 0.027c

Means in a row followed by the same letter are not significantly ($P > 0.05$) different (Duncan's multiple range test).

Table 6
Effects of 0, 8, 12, and 16 g l^{-1} salinity at 24, 28, and 32°C on specific growth rate (SGR), mean harvest weight (WT), percentage weight gain/fish (%WG), mean harvest length (L), percentage survival, food conversion efficiency (FCE), protein efficiency ratio (PER), and coefficient of condition (K) of *O. niloticus* raised in tanks for 56 days

Variable	Salinity (g l^{-1})			
	0	8	12	16
SGR (% day^{-1})	2.55 ± 0.273a	2.51 ± 0.420a	2.41 ± 0.447a	2.18 ± 0.211a
WT (g)	28.2 ± 5.06a	27.5 ± 7.77a	25.9 ± 6.94a	21.06 ± 2.81a
%WG	491.40 ± 106.3a	477.70 ± 158.3a	450.10 ± 145.1b	365.0 ± 59.2b
L (cm)	11.7 ± 0.611a	11.5 ± 0.99a	11.2 ± 0.93a	10.58 ± 0.39a
Survival (%)	83.7 ± 11.17a	86.60 ± 5.88a	71.10 ± 8.03a	65.90 ± 21.20a
FCE (%)	23.36 ± 6.47a	23.88 ± 7.09a	16.96 ± 3.55b	13.09 ± 5.70b
PER	0.47 ± 0.129a	0.48 ± 0.142a	0.34 ± 0.071b	0.27 ± 0.109b
K	1.703 ± 0.090a	1.67 ± 0.090a	1.707 ± 0.119a	1.703 ± 0.047a

Means in a row followed by the same letter are not significantly ($P > 0.05$) different (Duncan's multiple range test).

also significantly ($P < 0.05$) influenced by temperature ($P < 0.05$). When the data were analyzed irrespective of temperature, percentage weight gain was higher at 0 and 8 g l^{-1} than at both 12 and 16 g l^{-1} salinity (Table 6). Similar trends were observed for feed conversion efficiencies and protein efficiency ratios. The coefficients of condition were not significantly ($P > 0.05$) influenced by salinity (Table 6). Differences in mean lengths among treatments were not significant ($P > 0.05$).

4. Discussion

Water temperature, salinity, and their interaction significantly ($P < 0.05$) influenced growth of juvenile Nile tilapia, *O. niloticus*. Growth rates increased with water temperature, and were significantly higher at 28 and 32°C than at 24°C, but at all temperatures, salinity levels higher than 8 g l^{-1} depressed growth. Salinity modified temperature effects on growth at 0, 8, and 16 g l^{-1} salinity. Growth was highest at 32°C at all temperatures except at 12 g l^{-1} salinity, where the highest growth was observed at 28°C. Watanabe et al. (1993) also reported that salinity modified the effects of temperature on growth of Florida red tilapia. They found that at 0 g l^{-1} salinity, feed consumption and growth reached a maximum at 27°C, while at 18 and 36 g l^{-1} salinity, consumption and growth were highest at 32°C. Stauffer et al. (1984) showed that salinity influenced lethal temperatures of *Sarotherodon melanotheron* (Rüppell), but did not affect preferred temperatures. In the present study, growth was lowest at 24°C at 16 and 12 g l^{-1} salinity. Although the highest growth rate was found in fishes exposed to 32°C and 8 g l^{-1} salinity there was no significant difference ($P > 0.05$) among fishes raised at 0, 8, and 12 g l^{-1} salinity at either 28 or 32°C, suggesting that any one of these six treatments could produce fast growth of Nile tilipia.

In the present study, juvenile Nile tilapia cultured at 32°C and 16 g l^{-1} salinity developed body lesions in the trunk behind the operculum and in the caudal peduncle. Vine (1980) cited by Suresh and Lin (1992) also reported that *O. niloticus* lost appetite and developed lesions on the flanks after 2 months of rearing in the sea. In the present study, factors that led to the development of body lesions were unknown, but Kutty et al. (1980) have indicated that the interactions between two or more ecological factors can modify the effect of factors acting individually.

The energetic cost of ion regulation is lowest in an isotonic environment, where ionic gradients between blood and water are minimal, and this energy saving is substantial enough to increase growth (Morgan and Iwama, 1991). Growth was lowest at 24°C, indicating that low temperature detrimentally affected metabolic rate, and implies that energy expenditure for osmoregulation may have occurred at the expense of growth. A slight growth retardation in freshwater was probably caused by energy expenditure for elimination of excess water from the tissues in a hypotinic environment. Combinations involving 24°C or 16 g l^{-1} salinity were amongst those that retarded growth most. It may be possible that when juvenile *O. niloticus* are raised in a static environment, low temperature and 50% seawater (16 g l^{-1} salinity), are stressful.

Feed conversion efficiencies and protein efficiency ratios were highest at 32°C and 8 g l^{-1} salinity, where growth was maximum, indicating the most efficient feed utilization for growth at that temperature–salinity combination. Feed conversion efficiency increased with temperature, an observation also made by others (Watanabe et al., 1993), but higher salinity levels generally adversely affected feed conversion efficiency.

5. Conclusion

The study showed that a combination of 32°C and 8 g l^{-1} salinity was most conducive to maximum growth of *O. niloticus*. The study also suggested that generally, the temperature range of 28 to 32°C and the salinity range of 0 to 12 g l^{-1} could result in rapid growth of juvenile Nile tilapia, because there were no significant differences ($P > 0.05$) in growth of fish in these water temperature–salinity combinations (Table 1). In a static environment with salinity close to 16 g l^{-1} (about half-strength seawater) combined with elevated water temperature (32°C) may be injurious to the health of juvenile Nile tilapia. Comparable effects of this temperature–salinity combination on growth and feed utilization of *O. niloticus* in nature are unknown. Worldwide, Nile tilapia is raised under a wide variety of environmental conditions and further studies are needed to understand the combined effects of temperature and salinity on growth of *O. niloticus* and other tilapiine fishes.

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