Growth efficiency of juvenile barramundi, Lates calcarifer, at high temperatures

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Abstract

Temperature is recognized to be the most important environmental factor affecting growth in fish. Barramundi are cultured over a wide range of temperatures and extreme high temperatures which they can experience under culture approach the upper thermal tolerance limit for this species. A growth trial was conducted on juvenile barramundi to examine the effects of high temperatures ranging from the minimum optimal temperature (27 °C) for growth efficiency to the extreme upper thermal limits (39 °C) for feed intake, growth and growth efficiency. Juveniles (4.87 ± 0.32 g) were held at four different temperatures 27, 33, 36 and 39 °C and fed twice daily to satiation (503.5 g kg^{-1} crude protein, 182.5 g kg^{-1} lipid, 150.1 g kg^{-1} ash, 20.52 GE MJ kg^{-1}). Feed intake ($g \cdot d^{-1}$) and SGR ($\% \cdot d^{-1}$) increased with increasing temperature up to 36° C. At 39 °C feed intake, growth, feed efficiency ratio, protein efficiency ratio and productive energy value were significantly lower than at the other temperatures. This demonstrates that growth was optimized at temperatures from 27 to 36 °C and that barramundi have a much wider range for maximum growth efficiency than preciously thought.

Keywords: barramundi; Asian sea bass; Lates calcarifer; temperature; growth efficiency; feed intake

1. Introduction

Temperature has a marked effect on many key physiological processes in fish (Brett and Groves, 1979) and there have been numerous studies (Jobling, 1981; McCarthy, et al., 1998; Jonassen, et al., 1999) and reviews (Elliott, 1982) which have

examined the effects of temperature on growth. Every species has a range of temperatures over which it survives and where growth occurs. However, growth is maximized at an optimal temperature within this thermal tolerance range (Jobling, 1997). As temperature increases, feed intake will increase to a maximum and then decrease rapidly prior to the upper limit for thermal tolerance (Jobling, 1994). Maximum feed intake will occur at a temperature which is generally a few degrees above the optimal temperature for growth. Metabolic rate increases exponentially as the temperature increases and, at any given temperature, the difference between feed intake and metabolic rate will determine the energy available for growth (Brett and Groves, 1979; Jobling, 1994). For cultured species, these parameters are extremely important in order to understand and maximize the efficiency with which the consumed food is converted into growth (Jobling, 1994; Carter, et al., 2001).

Barramundi or Asian sea bass is a commercially important aquaculture species in Australia and southeast Asia. Production of these fish in Australia has steadily increased for the past 15 years and this trend is expected to continue (Boonyaratpalin and Williams, 2002). Barramundi have an extremely wide thermal tolerance range (15-40°C) and they are cultured in temperatures from 22-35°C (Tucker et al., 2002). However, the more extreme temperatures under which they are cultured approach the thermal tolerance for this species. Recent research has focused on determining optimal feeding practices (Williams and Barlow, 1999) and nutritional requirements for juvenile barramundi (Catacutan and Coloso, 1997; Boonyaratpalin, et al., 1998; Coloso et al., 1999; Williams and Barlow, 1999; Murillo-Gurrea et al., 2001). However, studies have not examined temperatures above 30°C. Previous research has shown that growth efficiency had an

optimal range of 27 to 33°C (Katersky and Carter, unpublished data). However, the highest temperature examined was 33°C and the full temperature range for maximum growth efficiency was not determined. This study examines feed intake and growth efficiency at temperatures which range from the minimum optimal temperature (27°C) for growth efficiency to the extreme upper thermal limits (39°C) for juvenile barramundi in order to determine the entire range of temperatures where growth is optimized.

2. Materials and Methods

2.1 Experimental diet

A standard diet (2-mm pellets) was formulated according to known dietary requirements for barramundi (Boonyaratpalin and Williams, 2002). The diet was formulated to contain 50% crude protein and 19.7 MJ kg^{-1} gross energy (Table 1). Fish meal and fish oil were supplied by Skretting (Cambridge, TAS, Australia). Vitamins and minerals were supplied by Sigma-Aldrich Pty. Ltd (Sydney, NSW, Australia), Vitamin C was supplied as Stay-C (Roche Vitamins Australia Ltd., Sydney, NSW, Australia).

2.2 Growth experiment

Juvenile barramundi, *Lates calcarifer,* (1 g) were obtained from WBA Hatcheries (West Beach, SA, Australia). Fish were maintained at the University of Tasmania under constant environmental conditions (salinity: 10 ‰; photoperiod: 24h light (Barlow et al., 1995); temperature: 27.0°C). Fish were initially stocked into 4 150-l aquaria and maintained at 27.0°C. Temperature was adjusted 1°C d^{-1} towards the experimental temperatures of 33.0, 36.0 and 39.0°C, with the exception of the 27.0°C aquarium which was maintained at a constant temperature. After 12 days all fish were at their experimental temperature. The experiment was conducted in four identical recirculating

93 systems each consisting of 3 19-l carboys with a trickle biofilters on each system. Each
94 system was held at a constant temperature (either 27, 33, 36 or 39°C) with submersible
95 heaters each controlled with an individual thermostat. The system was modified from that
96 used by (Engin and Carter, 2001). The fish were fed to satiation twice daily during this
97 acclimation period. The standard diet was fed to all fish at all times (Table 1).
98 At the start of the experiment, 60 fish from each treatment were anesthetized (100
99 mg l^{-1}, benzocaine) and individual weight (g) was measured. These fish were then
100 randomly separated into 3 19-l recirculating tanks to give 20 fish per experimental tank.
101 Ten fish were killed with an overdose of benzocaine (400 mg l^{-1}) and frozen in liquid
102 nitrogen for whole-body chemical analysis. Water quality was monitored 3 times $week^{-1}$
103 and water changes (~50%, with preheated water) were performed as necessary to keep
104 water quality within the limits for barramundi (Tucker et al., 2002). Dissolved oxygen
105 was maintained at >80 % saturation with constant aeration in all temperature treatments.
106 Temperature was recorded twice daily with a mercury thermometer.
107 Fish were fed to satiation twice daily at 0900 and 1800 for 20 d. A pre-weighed
108 ration was provided to each tank, and if completely consumed additional pellets were
109 counted out and provided until feeding ceased. Any uneaten pellets were siphoned out
110 after 10 min and counted in order to determine total daily food consumption. On day 20,
111 fish from 1 replicate from each of the four temperature treatments were starved for 24 h.
112 Following this starvation period, individual weight (g) and total length (mm) were
113 measured for all fish. Five fish from each tank were killed with an overdose of
114 benzocaine (400 mg l^{-1}), autoclaved and freeze-dried to a constant weight in order to
115 determine whole-body chemical composition. On days 21 and 22 fish from the

remaining 2 replicates of each treatment were starved for 24 h and sampled as described above.

2.3 Calculations

The following equations were used to calculate specific growth rate (SGR), feed efficiency ratio (FER), protein efficiency ratio (PER), productive protein value (PPV) and productive energy value (PEV):

$$SGR\ (\%\cdot d^{-1}) = [(\ln BW_F - \ln BW_I)/d]*100 \quad (1)$$

FER (%) = BW gain, g (wet) / Mass of food consumed, g (dry) (2)

PER (%) = BW gain (wet) / Mass of protein fed (dry) (3)

PPV = (fish protein gain (g CP)/total protein consumed (g CP)]*100 (4)

PEV = (fish energy gain (g MJ)/ total energy consumed (g MJ))*100 (5)

2.4 Chemical anaylsis

Standard methods were used to determine dry weight (freeze drying to a constant weight); crude protein (Kjeldahl); total lipid (Bligh and Dyer, 1959); energy (bomb calorimeter); ash by combustion at 550°C for 16 h (AOAC, 1995).

2.5 Statistical analysis

Data are presented as mean ± standard error. The normality and homogeneity of data were explored by examining the residual plots. Results were analyzed using a one-way ANOVA (SPSS, version 11.5) and significant results were compared using Tukey's HSD. Growth data were analyzed using ANCOVA (SPSS, version 11.5) between the initial and final weight measurements as significant differences in mean weights of fish were found between treatments at the start of the experiment.

3. Results

Feed intake ($g \cdot d^{-1}$) was significantly higher at 33 and 36°C than at 27 and 39°C (F=29.40; df=3,8; P<0.001), which were not significantly different from one another (Table 2). At 33 and 36°C feed intake was 10.48 ± 0.50 and 9.74 ± 0.99 $g \cdot d^{-1}$, respectively. This was approximately double the intake at 27 and 39°C. Significant differences found among initial weights (F=21.64; df= 3,236; P<0.001) did not have a significant effect on final weights (F=1.31; df= 3,225; P=0.253). Body weight gain (g) (F=63.40; df=3,8; P<0.001) and specific growth rate (SGR)(F=72.38; df=3,8; P<0.001) were both significantly higher at 33 and 36°C than at 27 and 39°C. Fish reared at 39 °C had significantly lower growth than at the other temperatures. Overall, as temperature increased there was an increase in both feed intake and SGR up to 36°C. At 39°C a sharp decrease in feed intake and growth was observed (Table 2).

Whole-body crude protein was significantly (F=9.35; df=3,20; P<0.001) lower in the 39°C treatment than the other temperatures which were not significantly different from one another. Crude lipid was also significantly (F=4.70; df= 3,22; P=0.011) lower at 39°C than at 33 and 27°C but not different from the 36°C treatment. Ash content at 39°C was significantly (F=8.03; df=3,20; P=0.001) higher than at the 33 and 27°C groups but not different from the 36°C. Energy did not differ among the temperature treatments (F=2.89; df=3,20; P=0.061), (Table 3).

Growth efficiency expressed as feed efficiency ratio (FER), protein efficiency ratio (PER) and productive energy value (PEV) were significantly lower for fish held at 39°C, than the remaining treatments (FER, F=68.72; df=3,8; P<0.001: PER, F=68.25; df=3,8; P<0.001, Table 2: PEV, F=84.23; df=3,8; P<0.001, Fig. 1). Productive protein value (PPV) was also significantly lower for fish held at 39°C than the remaining

treatments, however the 27°C was significantly lower than the 33°C treatment ($F=148.36$; $df=3,8$; $P<0.001$, Fig. 1).

5. Discussion

The present study was the first to examine feed intake, growth and growth efficiency in juvenile barramundi over a wide range of high temperatures. The results show that feed intake and SGR were highest at 33 and 36°C. However, when growth efficiency (PEV, PER and FER) was examined there was no significant difference from 27 to 36°C. It was only when temperatures exceeded 36°C that a decline in efficiency was observed.

Previous research on the feed intake and growth of juvenile barramundi at different temperatures (Williams and Barlow, 1999) examined temperatures ranging from 20 to 29°C and observed a plateau in food conversion ratio (FCR) and feed intake from 26°C to 29°C. This is consistent with previous results (Katersky and Carter, unpublished data), where feed intake ($\%BW \cdot d^{-1}$) remained constant between 27 and 30°C but there was a significant increase between 30 and 33°C. In the present study, feed intake was significantly higher at 33°C than at 27°C.

There is an inverse relationship between SGR and fish weight, SGR decreases as fish weight increases (Jobling, 1994). The majority of research on barramundi has been on larger slower growing juvenile fish, this partly explains the higher SGR's found in the present study. Williams and Barlow (1999) determined SGR of different size barramundi at 29°C and found SGR decreased from 3.6 $\%\cdot d^{-1}$ for 40 g fish, through 1.7 for 100g fish and 1.5 for 170g fish to 1.1 for 270g fish. A few studies have looked at growth rates of small juvenile barramundi, Eusebio and Coloso (2000) determined SGR to be 4.1 $\%\cdot d^{-1}$

for 40g fish raised at 27-28°C and Catacutan and Coloso (1997) found SGR of 5.0 $\%\cdot d^{-1}$ when water temperatures ranged from 26.5 to 29°C for 57 g fish. In the present study, using 5 g fish, SGR was 5.6 $\%\cdot d^{-1}$ at 27°C and increased to 7.1 $\%\cdot d^{-1}$ at 33 and 36°C.

Temperature has been shown to have an effect on the biochemical composition of fish (Cui and Wootton, 1988; Koskela et al., 1997; Bendiksen et al., 2003; Tidwell et al., 2003). In the present study, as temperatures exceeded the optimal range for growth efficiency there was a significant decrease in whole-body protein. This differs from Baltic salmon reared at high temperatures where protein did not change with increasing temperature (Koskela et al., 1997). However, whole-body lipid levels peaked at optimal growth temperatures for Baltic salmon (Koskela et al., 1997) and then significantly decreased as the temperature continued to increase. In the present study, lipid levels remained elevated up to 36°C and then significantly declined. The decrease in both protein and lipid at the high temperatures can be attributed to the increased metabolism which is encountered at temperatures nearing the upper limits of thermal tolerance (Jobling, 1997).

Growth efficiency has been shown to remain constant over a wide range of temperatures (Forseth et al., 2001). The present study showed this to be the case for juvenile barramundi, with maximum growth efficiency occurring between 27 and 36°C. As temperatures approached the upper limit for thermal tolerance (39°C), growth efficiency declined due to an increase in metabolism and a decrease in feed intake (Jobling, 1997). Previous research on barramundi has been focused on temperatures between 27 and 30°C (Williams and Barlow, 1999; Murillo-Gurrea et al., 2001; Tian and Qin, 2003; Williams et al., 2003) as this was believed to be the extent of the optimal

range for growth efficiency, however, this research shows that juvenile barramundi have a much wider optimal range for culture than previously believed. This is possibly a biological adaptation that barramundi have developed based on their wide geographical distribution around northern Australia and southeast Asia. Barramundi are an incredibly robust fish thus allowing them to grow and thrive in a wide range of environmental conditions.

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Table 1. Ingredient and chemical composition of experimental diet

Ingreadient compostion (g kg^{-1})	
Fish meal	730
Fish oil	70
Starch	119
CMC	10
Choline chloride	10
Phosphorus ($NaPO_4$)	10
Vitamin C (Stay-C)	20
Ytterbium-oxide	1
Vitamin premix[a]	15
Mineral premix[b]	15
Chemical compostion (g kg^{-1} DM)	
Dry matter (g kg^{-1})	946.9
Crude protein	503.5
Crude lipid	182.5
Ash	150.1
Energy (MJ kg^{-1})	20.52

[a]Vitamin premix (mg kg^{-1}): Vitamin A (7.50), Vitamin D (9.00), Rovimix E50 (150.00), Menadone sodium bisulphate (3.00), Riboflavin (6.00), Calcium D-pantothenate (32.68), Nicontinic Acid (15.00), Vitamin B-12 (0.015), d-biotin (0.23), Folic acid (1.50), Thiamin HCL (1.68), Pyridoxine HCl (5.49), myo-Inositol (450.00), α-cellulose (817.91).

[b]Mineral premix (mg kg^{-1}): $CuSO_4$ $5H_20$ (35.37), $FeSO_4$ $7H_2O$ (544.65), $MnSO_4$ H_2O (92.28), Na_2SeO_3 (0.99), $ZnSO_4$ $7H_2O$ (197.91), KI (2.16), $CoSO_4$ $7H_2O$ (14.31), α-cellulose (612.33).

Table 2. Survival, feed intake, growth and growth efficiency (mean ± standard error) of juvenile barramundi at four different temperatures.

Temperature (°C)	27	33	36	39
Measured temperature (°C)	26.98 ± 0.04	33.16 ± 0.13	35.36 ± 0.32	38.86 ± 0.05
Mean body weight$_{initial}$ (g)	4.23 ± 0.13	5.06 ± 0.19	4.49 ± 0.12	5.69 ± 0.17
Mean body weight$_{final}$ (g)	13.11^{b} ± 0.45	22.47^{a} ± 1.71	20.09^{a} ± 1.76	10.33^{c} ± 0.14
Survival (%)	98.33 ± 1.67	96.67 ± 1.67	98.33 ± 1.67	95.00 ± 2.89
Feed intake(g·d^{-1})	5.58^{b} ± 0.14	10.48^{a} ± 0.50	9.74^{a} ± 0.99	4.32^{b} ± 0.08
SGR (%·d^{-1})	5.38^{b} ± 0.19	7.10^{a} ± 0.07	7.11^{a} ± 0.42	2.84^{c} ± 0.09
FER (g·g^{-1})	1.41^{a} ± 0.05	1.46^{a} ± 0.01	1.46^{a} ± 0.02	0.86^{b} ± 0.04
PER (g·g^{-1})	2.80^{a} ± 0.09	2.91^{a} ± 0.02	2.82^{a} ± 0.05	1.72^{b} ± 0.08

Means with similar superscripts were not significantly different ($P<0.05$, $n=3$).

Table 3. Body composition (mean ± standard error) of juvenile barramundi at four temperatures.

Temperature (°C)	27	33	36	39
Dry Matter ($g \cdot kg^{-1}$)	$262.5^{b} \pm 0.17$	$275.8^{a} \pm 0.14$	$275.6^{a} \pm 0.08$	$263.0^{b} \pm 0.23$
Crude Protein ($g \cdot kg^{-1}$WW)	$154.9^{b} \pm 1.01$	$164.2^{a} \pm 1.25$	$163.8^{a} \pm 1.54$	$147.4^{c} \pm 1.29$
Crude Lipid ($g \cdot kg^{-1}$WW)	$63.5^{a} \pm 1.27$	$63.1^{a,b} \pm 2.42$	$64.4^{a} \pm 2.96$	$54.0^{b} \pm 2.39$
Ash ($g \cdot kg^{-1}$WW)	$37.8^{b} \pm 0.37$	$39.6^{b} \pm 0.78$	$42.1^{a,b} \pm 1.31$	$44.2^{a} \pm 1.53$
Energy ($MJ \cdot kg^{-1}$ WW)	$5.76^{a,b} \pm 0.07$	$5.96^{a} \pm 0.09$	$6.09^{a} \pm 0.08$	$5.48^{b} \pm 0.09$

Initial group (mean ± SD: n=10): Dry matter, 245.3 $g \cdot kg^{-1}$, Crude protein, 153.3 ± 0.54 $g \cdot kg^{-1}$ WW, Total lipid, 56.0 ± 3.19 $g \cdot kg^{-1}$ WW, Ash, 34.1 ± 1.20 $g \cdot kg^{-1}$WW, Energy, 5.14 ± 0.01 $MJ \cdot kg^{-1}$ WW. Means with similar superscripts ($P<0.05$, n=3) were not significantly different between temperatures.

Figure 1. Growth efficiency (mean ± standard error) of juvenile barramundi expressed as productive protein value (PPV %) and productive energy value (PEV %). Means with similar letters were not significantly different ($P<0.05$, $n=3$).

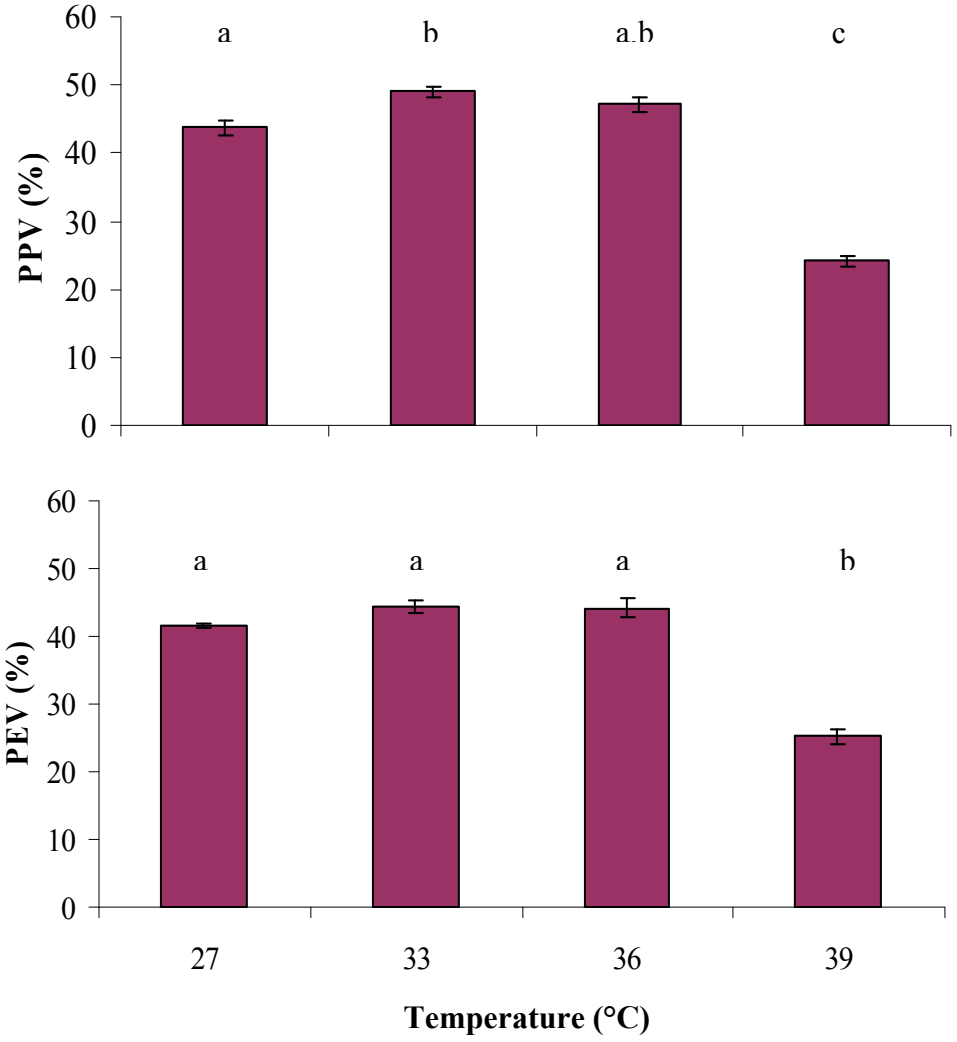

Figure 1. Katersky and Carter