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Effect of temperature on growth and energy budget of juvenile cobia (*Rachycentron canadum*)

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Abstract

Growth and energy budget of juvenile cobia (initial body weight ~22 g) at various temperatures (23, 27, 31 and 35 °C) were investigated in this study. Maximal ration level (RL_{max}, %/day) increased as temperature (T, °C) increased from 23 °C to 31 °C but decreased at 35 °C, described as a quadratic equation: $RL_{max}=-0.023T^2+1.495T-17.52$. Faecal production ($f$, mg g^{-1} day^{-1}) increased with increased temperature (T, °C), described as a power function: $\ln f=0.738\ln T-0.806$. As temperature increased, feed absorption efficiency in dry weight (FAE_d, %), protein (FAE_p, %) and energy (FAE_e, %) all increased first and then decreased, but the variation of feed absorption efficiency was small, with ranges of 89.59–91.08%, 92.91–94.71%, 93.92–95.32%, respectively. Specific growth rate in wet weight (SGR_w, %/day), dry weight (SGR_d, %/day), protein (SGR_p, %/day) and energy (SGR_e, %/day) showed a domed curve relative to temperature (T, °C), described as quadratic equations: $SGR_w=-0.068T^2+3.878T-50.53$, $SGR_d=-0.079T^2+4.536T-59.64$, $SGR_p=-0.084T^2+4.783T-63.08$ and $SGR_e=-0.082T^2+4.654T-60.99$, and SGR_w, SGR_d, SGR_p and SGR_e maximized at 28.5 °C, 28.6 °C, 28.4 °C, 28.5 °C, respectively, as calculated from the regression equations. The relationships between feed conversion efficiency in wet weight (FCE_w, %), dry weight (FCE_d, %), protein (FCE_p, %), energy (FCE_e, %) and temperature (T, °C) also took on a domed curve described as quadratic equations: $FCE_w=-0.726T^2+39.71T-473.8$, $FCE_d=-0.276T^2+15.31T-190.6$, $FCE_p=-0.397T^2+22.05T-277.9$ and $FCE_e=-0.350T^2+19.39T-239.9$, and FCE_w, FCE_d, FCE_p and FCE_e maximized at 27.4 °C, 27.8 °C, 27.7 °C and 27.7 °C, respectively, as calculated from the regression equations. Energy budget of juvenile cobia fed satiation was $100C=5F+67(U+R)+28G$ at water temperature 27 °C and $100C=5F+70(U+R)+25G$ at water temperature 31 °C, where C is food energy, F is faeces energy, $(U+R)$ is excretion energy and metabolism energy, and G is growth energy.

Keywords: Juvenile cobia (*Rachycentron canadum*); Temperature; Growth; Energy budget

1. Introduction

Cobia, *Rachycentron canadum*, is a large, carnivorous, coastal pelagic species distributed worldwide in tropical and subtropical seawaters except the eastern Pacific (Briggs, 1960; Smith, 1995). In many countries, cobia has been regarded as an excellent game fish and highly prized by recreational fishers (Shaffer and Nakamura, 1989). In recent years cobia has been considered as a prime candidate for large-scale offshore cage-culture because of its advantages of high economic

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value, rapid growth, adaptability to cage-culture and strong resistance to diseases. Cobia has now become one of the key species for cage-culture in the coastal waters of the southern China Sea. However, the seedlings are scarce, so large numbers of seedlings provided for large-scale aquaculture of cobia are from artificial breeding.

Water temperature is an important factor for fish growth and energy budget (Sun et al., 1999, 2001; Russell et al., 1996; Ruyet et al., 2004). In the aquaculture for cobia at Daya Bay, China, the breeding period lasts from the late April to early October, so the water temperature in outdoor breeding ponds is affected strongly by air temperature because of the restricted water volume. How to adjust water temperature to meet the demand of normal feeding and fast growth is one of the key issues in cobia artificial breeding. Therefore, it is important to investigate growth and energy budget relative to temperature and to provide useful knowledge for the aquaculturist engaged in cobia artificial breeding.

Many aspects of cobia biology have been investigated ((Dawson, 1971; Ditty and Shaw, 1992; Franks et al., 1996; Brown-Peterson et al., 2001; Chou et al., 2001; Zhou et al., 2004; Liao et al., 2004; Wang et al., 2005; Turner and Rooker, 2005; Faulk and Holt, 2005; Lunger et al., 2006; Resley et al., 2006; Sun et al., 2006), but little information is available on the growth–temperature relationship and the energy budget. This study investigated the effect of temperature on growth and energy budget of juvenile cobia. The results from the study may provide fundamental information for the adjustment of temperature in large-scale artificial breeding of cobia.

2. Materials and methods

2.1. Experimental fish and diet

Juvenile cobia for the experiment were from those artificially bred by the cobia-study group in Marine Biology Research Station at Daya Bay (MBRS), Chinese Academy of Sciences.

The experimental diet for juvenile cobia was a commercial eel feed (Grobest brand, Quanxing aquatic feed L.T.D., Shunde, China) with white fish meal from Peru, α-starch, barm powder, $FeSO_4$, $ZnSO_4·7H_2O$, $CuSO_4·5H_2O$, $MnSO_4$, Na_2SeO_3, Vitamin A, Vitamin D3, Vitamin E, Vitamin K3, Vitamin C, Vitamin B1, Vitamin B2, Vitamin B6, Vitamin B12, niacin, folic acid, inositol, etc. And the chemical composition of this diet was 8.92% water, 44.44% protein, 11.21% lipid, 12.31% ash and gross energy content was 16.64 kJ g^{-1}. Before the start of feeding the diet was mixed with a fixed proportion of water (water:eel feed = 1:2) and made into pellets suitable for fish feeding.

2.2. Fish acclimation

The experimental containers were rectangular transparent plastic tanks (60 cm × 45 cm × 40 cm). The groups requiring heating were equipped with WMZK-01 temperature controllers, temperature probes and insulating quartz heating coils, whereas the groups requiring cooling were placed in two constant-temperature rooms.

Juvenile cobia belonging to the same batch with good health and even body weights were captured randomly from outdoor breeding ponds at MBRS and transferred randomly into the indoor plastic tanks (water volume 90 L). At the start of acclimation fish were marked with the method described by Russell et al. (1996). During the period of acclimation, fish were initially held at room temperature for 3∼4 d, and then water temperature was decreased or increased at a rate of 1–2 °C/day to the individual desired experimental temperature. Subsequently, fish continued to be acclimated at each constant temperature for one more week.

During the whole period, water in each tank was entirely replaced twice a day by fresh, filtered and well-aerated seawater of the desired experimental temperature (obtained from the seawater being heated or cooled). Fish were hand-fed to satiation twice a day (about 08:00 and 17:00). Aeration was provided continuously except during feeding to maintain dissolved oxygen above 5 mg l^{-1}. Water quality parameters were monitored daily. During this period salinity ranged from 31.2 to 33.4 and fish were subjected to a natural photoperiod regime (light periods ranging from 13 h to 14 h) with similar light conditions for all tanks.

2.3. Growth experiments

The growth experiment for juvenile cobia was carried out at four temperatures: 23, 27, 31 and 35 °C and there were four replicates with two fish in each tank at each temperature. Another sixteen fishes were sampled for estimates of initial body composition and energy content.

Immediately prior to the start of the growth experiment, fish were starved for 36 h, then captured, blotted of excess water and weighed. During the growth experiment, fish were hand-fed to satiation twice a day (about 08:00 and 17:00). An excess of feed was offered and any uneaten was collected 30 min after feeding by pipetting and then oven-dried at 70 °C. Potential loss of uneaten feed was determined by placing feed in water for 30 min and then collecting, drying and weighing. The proportion

Table 1
Body chemical composition (g g^{-1} W.W.[a]) and energy content (kJ g^{-1} W.W.[a]) of juvenile cobia at different temperatures (*T*, °C) at the end of the 21 days growth experiment

T	23	27	31	35
Moisture content	74.35±0.41 c	73.16±0.47 b	72.09±0.63 a	74.94±0.73 c
Protein content	16.16±0.38 b	17.00±0.50 c	17.55±0.52 c	14.88±0.38 a
Lipid content	5.72±0.17 a	6.00±0.19 ab	6.26±0.44 b	5.80±0.31 a
Ash content	2.90±0.13 a	2.96±0.14 a	3.68±0.17 c	3.48±0.05 b
Energy content	5.89±0.09 a	6.23±0.14 b	6.43±0.15 b	5.67±0.22 a

Values (mean±SD) in the same row with different letters are significantly different ($P<0.05$).
[a] W.W.=wet weight.

remaining was calculated and this value was used to adjust the amount of the feed intake. Faeces were collected twice a day by pipetting, oven-dried at 70 °C, weighed, homogenized and stored at −20 °C for chemical analysis and energy determination. Water in each plastic tank was replaced by fresh, filtered and well-aerated seawater of the desired experimental temperature once a day with 80% water replacement each time. Aeration was provided continuously except in the period of feeding and faecal collection to maintain dissolved oxygen above 6 mg l^{-1}. Water quality parameters were monitored daily. During this period salinity was 31.4–34.2 and fish were subjected to a natural photoperiod regime (light periods ranging from 13 h to 14 h) with similar light conditions for all tanks.

The whole experiment lasted 21 days and no fish died. At the end of the experiment, fish were killed after starvation for 36 h and then weighed. Fish from the same tank were pooled, chopped, dried, reweighed, homogenized and stored at −20 °C for later chemical analysis and energy determination.

2.4. Chemical analysis

All chemical and caloric analyses were conducted according to the methods described by Cui (1989). Moisture contents of fish and feed were determined after oven-drying to a constant weight at 105 °C for diet and 70 °C for fish. Protein contents of fish, faeces and feed were measured by the Kjeldahl method using an auto Kjeldahl system (model BÜCHI K-370/K-437, Switzerland). Lipid contents of fish and feed were measured by ether extraction. Ash contents of fish and feed were determined by a muffle furnace at 550 °C for 8–10 h. Gross energy contents of fish, faeces and feed were measured by oxygenic bomb calorimetric (model 1341EE, U.S.A., calibrated by benzoic acid). For each variable, at least duplicate samples were determined and the mean of duplicate determinations was taken as the result when the relative deviation was less than 2%.

2.5. Statistical analysis

A one-way ANOVA followed by a multiple range test (Newman–Keuls) was used for four temperatures to examine significant differences ($P<0.05$) among various treatments. The least squares regression was performed to evaluate the relationships between specific growth rate, maximal ration, faecal production and ration level, and judged by coefficient of determination (R^2) and residual analysis. Analysis of covariance was made to estimate the effect of fish body weight on growth. Data were expressed as the mean±SD of four replicate groups. Statistical analyses were performed using SPSS 11.0 for windows.

Table 2
Maximal ration level (RL_{max}, %/day), faecal production (f, mg g^{-1} day^{-1}) and feed absorption efficiency in dry weight (FAE_d, %), protein (FAE_p, %) and energy (FAE_e, %) of juvenile cobia at different temperatures (*T*, °C) in the 21 days growth experiment

T	23	27	31	35
RL_{max}	4.752±0.230 a	5.915±0.469 b	6.881±0.361 c	6.572±0.675 bc
f	4.505±0.206 a	5.131±0.139 b	5.590±0.398 b	6.188±0.516 c
FAE_d	89.59±0.36 a	90.44±0.56 bc	91.08±0.47 c	89.63±0.71 ab
FAE_p	92.91±0.22 a	94.26±0.37 bc	94.71±0.40 c	93.75±0.58 ab
FAE_e	93.92±0.12 a	94.97±0.53 bc	95.32±0.51 c	94.43±0.33 ab

Values (mean±SD) in the same column with different letters are significantly different ($P<0.05$) for each feed type.
FAE_d=100×(feed intake×dry matter content−faecal production)/feed intake×dry matter content.
FAE_p=100×(feed intake×protein content−faecal production×protein content)/feed intake×protein content.
FAE_e=100×(feed intake×energy content−faecal production×energy content)/feed intake×energy content.

3. Results and discussion

3.1. Body chemical composition and energy content

The contents of moisture, protein, lipid, ash and energy in the body of juvenile cobia at different temperatures are listed in Table 1. The contents of protein, lipid and energy at 31 °C were not significantly different than those at 27 °C but obviously higher than those at 23 °C and 35 °C. However, the moisture content at 23 °C and 35 °C was much higher than that at 27 °C and 31 °C. The ash content was lowest at 23 °C but highest at 31 °C.

3.2. Maximal ration level

Maximal ration for fish usually increases at lower temperatures, peaks at an optimal temperature, and then decreases at higher temperatures when feed is abundant (Brett and Groves, 1979). As temperature increased, the maximal ration of juvenile cobia also had the same tendency with a peak at 31 °C and a vale at 23 °C (the maximal ration level at 23 °C was 69% of that at 31 °C), described as a quadratic equation (Tables 2 and 3).

3.3. Faecal production and feed absorption efficiency

Faecal production of juvenile cobia at different temperatures increased significantly with increased temperature, described as a power function (Tables 2 and 3), which was consistent with the study on south catfish (Xie and Sun, 1993).

Feed absorption efficiency in dry matter, protein and energy increased first, peaked at 31 °C and then decreased as temperature increased (Table 2). The effect of temperature on feed absorption efficiency showed a significant difference ($P<0.05$) though the variation of feed absorption efficiency were small within the temperature range of 23–31 °C. In contrast, the study on young grass carp by Cui et al. (1995) showed that temperature did not affect feed absorption efficiency significantly. The discrepancy probably resulted from interspecific differences, or from the reason that the designed temperature in the experiment of a given species was not beyond its suitable temperature range.

3.4. Specific growth rate and feed conversion efficiency

Specific growth rate in wet weight (SGR_w, %/day), dry weight (SGR_d, %/day), protein (SGR_p, %/day) and energy (SGR_e, %/day) for juvenile cobia increased first, peaked at 27 or 31 °C and then decreased as temperature increased, and there were no significant differences of SGR_w, SGR_d, SGR_p and SGR_e between 27 and 31 °C temperatures (Table 4). The relationship between specific growth rate and temperature was a domed curve, described as a quadratic equation (Table 3), which was consistent with the studies on hybrid striped bass × white bass (Woiwode and Adelman, 1991) and juvenile turbot (Imsland et al., 1996). However, the growth–temperature relationship was also reported to be a decelerating curve described as a logarithm function (Russell et al., 1996), a cubic equation (Ruyet et al., 2004) or a power function (Wurtsbaugh and Cech, 1983), and a linearity described as a simple equation (Allen and Wootton, 1982), in some papers. Interspecific differences or a narrow temperature range not beyond a species suitable temperature range in experiments, in part, may explain the discrepancy among these studies.

As temperature increased, feed conversion efficiency in wet weight (FCE_w, %), dry weight (FCE_d, %), protein (FCE_p, %) and energy (FCE_e, %) increased, peaked at 27 °C, and then decreased at higher temperatures (Table 4). The relationships between feed conversion efficiency and temperature were also described as quadratic equations (Table 3), which was similar with the studies on three-spined stickleback (Allen and Wootton, 1982), juvenile mosquitofish (Wurtsbaugh and Cech, 1983), *Pagrosomus major* (Sun et al., 1999) and *Sparus macrocephalus* (Sun et al., 2001).

As calculated from the regression equations, the maximum of SGR_w, SGR_d, SGR_p and SGR_e occurred at 28.5, 28.6, 28.4 and 28.5 °C, respectively, and the maximum of FCE_w, FCE_d, FCE_p and FCE_e occurred at 27.4, 27.8, 27.7 and 27.7 °C, respectively.

Table 3
Coefficients of the regression equations, $\ln Y=a+b\ln T$, relating to faecal production (f, mg g^{-1} day^{-1}) to temperature (T, °C) and the regression equation, $Y=aT^2+bT+c$, relating to specific growth rate in wet weight (SGR_w, %/day), dry weight (SGR_d, %/day), protein (SGR_p, %/day), energy (SGR_e, %/day) and feed conversion efficiency in wet weight (FCE_w, %), dry weight (FCE_d, %), protein (FCE_p, %), energy (FCE_e, %) as well as maximal ration level (RL_{max}, %/day) to temperature (T, °C) for juvenile cobia in the 21 days growth experiment

Y	a	b	c	n	R^2	P
RL_{max}	−0.023	1.495	−17.52	16	0.788	<0.01
f	−0.806	0.738		16	0.823	<0.01
SGR_w	−0.068	3.878	−50.53	16	0.946	<0.01
SGR_d	−0.079	4.536	−59.64	16	0.953	<0.01
SGR_p	−0.084	4.783	−63.08	16	0.965	<0.01
SGR_e	−0.082	4.654	−60.99	16	0.953	<0.01
FCE_w	−0.726	39.71	−473.8	16	0.930	<0.01
FCE_d	−0.276	15.31	−190.6	16	0.943	<0.01
FCE_p	−0.397	22.05	−278.0	16	0.964	<0.01
FCE_e	−0.350	19.39	−239.9	16	0.942	<0.01

Table 4
Specific growth rate in wet weight (SGR_w, %/day), dry weight (SGR_d, %/day), protein (SGR_p, %/day), energy (SGR_e, %/day) and feed conversion efficiency in wet weight (FCE_w, %), dry weight (FCE_d, %), protein (FCE_p, %), energy (FCE_e, %) of juvenile cobia at different temperatures (*T*, °C) in the 21 days growth experiment

T	23	27	31	35
IBW (g/fish)	22.25±2.60 a	21.87±2.84 a	22.09±1.89 a	23.93±2.94 a
FBW (g/fish)	39.23±5.17 b	56.82±10.14 c	55.30±3.53 c	35.10±2.21 a
SGR_w	2.70±0.17 b	4.52±0.38 c	4.38±0.29 c	1.84±0.35 a
SGR_d	2.71±0.11 b	4.75±0.35 c	4.79±0.24 c	1.74±0.42 a
SGR_p	2.51±0.08 b	4.57±0.31 c	4.58±0.23 c	1.26±0.36 a
SGR_e	2.94±0.12 b	5.02±0.35 c	5.02±0.24 c	1.89±0.46 a
FCE_w	55.57±5.67 b	70.17±7.18 c	59.44±1.16 b	27.61±3.58 a
FCE_d	15.68±1.21 b	21.31±2.31 c	19.23±0.96 c	7.21±1.29 a
FCE_p	19.09±1.10 b	27.02±2.48 d	24.15±1.33 c	6.63±1.41 a
FCE_e	20.90±1.63 b	27.95±3.06 c	24.92±0.74 c	9.54±1.78 a

Values (mean±SD) in the same row with different letters are significantly different ($P<0.05$).
SGR_w = 100 × [ln(final body weight) − ln(initial body weight)] / days of the experiment.
SGR_d = 100 × [ln(final body weight × final dry matter content) − ln(initial body weight × initial dry matter content)] / days of the experiment.
SGR_p = 100 × [ln(final body weight × final protein content) − ln(initial body weight × initial protein content)] / days of the experiment.
SGR_e = 100 × [ln(final body weight × final energy content) − ln(initial body weight × initial energy content)] / days of the experiment.
FCE_w = 100 × (final body weight − initial body weight) / feed intake.
FCE_d = 100 × [(final body weight × final dry matter content) − (initial body weight × initial dry matter content)] / (feed intake × dry matter content).
FCE_p = 100 × [(final body weight × final protein content) − (initial body weight×initial protein content)] / (feed intake × protein content).
FCE_e = 100 × [(final body weight × final energy content) − (initial body weight × initial energy content)] / (feed intake × energy content).

3.5. Energy budget

Partial energy budget of juvenile cobia at each temperature is shown in Table 5. Faeces energy only accounted for 4.99–6.38% of food energy. The proportion of food energy allocated to growth was 9.54–27.95% and highest at 27 °C. A large portion of food energy was spent in two unmeasured terms (nitrogenous excretion and metabolism) of energy budget, and the proportion of food energy allocated to them was 66.70–84.56% and lowest at 27 °C.

In the present study on the energy budgets of juvenile cobia, the estimates of faeces energy and growth energy might be affected by nutrient leaching problems and the estimation of initial energy content of experimental fish from the mean values of the control fish. The remainder two components of the energy budget were estimated indirectly by difference $(U+R)=C-F-G$ and the pooled errors associated with directly determined terms were added to $(U+R)$. However, the effect of the errors from both terms might not be great for Elliot (1976) reported that only <4% of faecal organic matter was lost in 24 h and enough fish were sampled as the control in the growth experiment.

Tang et al. (2003) established a uniform energy budget of seven marine fish species at their maximal ration level as:

$$\begin{aligned}100C &= 3.6F + 7.8U + 63.3R + 25.3G \\ &= 3.6F + 71.1(U+R) + 25.3G\end{aligned}$$

Moreover, Tang et al. (2003) partitioned the mode of energy partition into three styles: (1) low metabolism and high growth; (2) high metabolism and low growth; (3) moderate metabolism and moderate growth.

Table 5
Energy budgets[a] of juvenile cobia at different temperatures (*T*, °C) in the 21 days growth experiment

T	23	27	31	35
C ($kJ\ g^{-1}\ day^{-1}$)	0.791±0.038 a	1.002±0.074 b	1.145±0.060 c	1.094±0.112 bc
As a percentage of *C* (%)				
F	6.38±0.12 c	5.35±0.57 ab	4.99±0.51 a	5.90±0.25 bc
G	20.90±1.63 b	27.95±3.06 c	24.91±0.74 b	9.54±1.78 a
R+*U*	72.72±1.74 b	66.70±3.22 a	70.10±0.35 b	84.56±1.89 c

Values (mean±SD) in the same row with different letters are significantly different ($P<0.05$).
[a] $C=F+(U+R)+G$ (Brett and Groves, 1979), where *C* is food energy, *F* is faeces energy, $(U+R)$ is excretion energy and metabolism energy, calculated by difference $(U+R)=C-F-G$, and *G* is growth energy.

The partial energy budgets of juvenile cobia fed to satiation at 27 °C and 31 °C were:

$$27\ °C \quad 100C = 5F + 67(U + R) + 28G$$
$$31\ °C \quad 100C = 5F + 70(U + R) + 25G$$

The proportion of food energy allocated to growth at 27 °C or 31 °C for juvenile cobia was close to the average value. By comparison, the energy partition mode for juvenile cobia is a pattern of moderate metabolism and moderate growth during a suitable growth temperature range.

In general, for carnivorous fish species, faeces and nitrogenous excretion only account for a small portion of food energy and do not greatly influence the proportion of food energy allocated to growth, so it is the metabolism that plays an important role in influencing the proportion of energy intake allocated to growth for usually a large portion of food energy that is spent in it. For juvenile cobia, the proportion of food energy stored as growth at 35 °C was smallest, which indicated that a much higher metabolism impacting normal growth might occur as temperature further increased. Furthermore, feeding was still active and could not be a major affecting factor, so the slowest growth at 35 °C was mainly due to a higher metabolism; the proportion of energy absorption spent in growth at 23 °C was slightly lower than that at 27 or 31 °C, but feed consumption decreased obviously, so it was feeding decrease, not metabolism increase, that might be the reason of the slow growth at 23 °C.

4. Conclusion

In the present study both growth and feed conversion efficiency maximized at an intermediate temperature range of 27–29 °C, which could be thought of as the optimum growth temperature of juvenile cobia at this growth stage with the experimental diet. Furthermore, based on the data of growth and feed conversion efficiency, it could be concluded that for juvenile cobia a higher temperature was more unsuitable than a lower temperature within the experimental temperature range of 23–35 °C.

However, it is possible that ration level (Cui and Wootton, 1988; Woiwode and Adelman, 1991; Russell et al., 1996), feed type or composition (Jobling, 1994), body size (Imsland et al., 1996; Jones et al., 1981), photoperiod (Woiwode and Adelman, 1991), etc. will influence fish energy budget and growth–temperature relationship. So, further researches are worth performing to investigate how the energy budget and growth–temperature relationship of juvenile cobia are affected by those factors and accordingly to adjust the optimum growth temperature.

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