Low optimal temperatures for food conversion and growth in the big-headed turtle, *Platysternon megacephalum*

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ABSTRACT

We held juvenile big-headed turtles, *Platysternon megacephalum*, from eastern China, at temperatures from 20 to 29.4 °C to determine effects on feeding, growth and food conversion. Food intake increased significantly from 20 to 22.4 °C, remained high until 27.1 °C, and then decreased dramatically at 29.4 °C. Digestive efficiency for energy decreased as temperature increased, whereas the digestive efficiency of protein increased from 20 to 25 °C, and decreased at higher temperatures. The relationships between specific growth rate (SGR), food conversion coefficient (Cf) and temperature (T) were curvilinear, and could be described by quadratic equations: SGR = −0.01 T^2 + 0.47 T − 5.24 and Cf = −0.37 T^2 + 17.20 T − 181.85. Maximum growth was estimated to occur at 23.9 °C, with 90% of the maximum being achieved within the range of 21.9–25.8 °C; maximal food conversion occurred at 23.2 °C, with a 90% range from 21.0 to 25.4 °C. The temperature range (22–25 °C) found to promote best growth and food conversion in juvenile *P. megacephalum* is lower than for many other freshwater turtles. Temperatures of 22–25 °C are recommended for use in culture of this species to maximize growth and food conversion.

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1. Introduction

Food intake and digestion may significantly affect energy acquisition and, in turn, growth and reproduction in animals (Sibly, 1981). In ectothermic vertebrates, food intake and growth largely depend on body temperatures, which are considerably influenced by environmental conditions (Congdon, 1989; Jobling, 1994). They maximize food intake and growth at moderate temperatures, but decrease these physiological performances at higher or lower temperatures (Jobling, 1994; Du et al., 2000; Hofmann and Fischer, 2003; Zhang and Ji, 2004). In reptiles, squamates rather than turtles have been the main subject of many studies on thermal dependence of physiological performances (e.g., Huey and Kingsolver, 1989; Ji et al., 1996; Du et al., 2000; Zhang and Ji, 2004; Du et al., 2007). Consequently, little is known about thermal sensitivity of food intake and growth in many turtles. Recently, a number of turtle species have been artificially cultured for food and pets in China. Turtle farmers usually apply those traditional rules derived from widely cultured species, such as the Chinese soft-shelled turtle (*Pelodiscus sinensis*), to new species of turtles. However, simply adapting aquaculture practice from species to species may be sometimes detrimental, because the optimal temperature of physiological processes differs dramatically among species (Du and Ji, 2003; Pan et al., 2003). Therefore, exploring the digestive physiology such as food intake, thermal dependence of digestion and growth of Chinese turtles is largely needed and would provide direct guidelines for their aquaculture.

The big-headed turtle (*Platysternon megacephalum*), the only species in Platysternidae, is a small (up to 160 mm carapace length) freshwater turtle (Zhang, 1998). The turtle is endemic to Southeast Asia including southern China, Myanmar, Thailand and Vietnam where the wild populations are currently threatened by over-exploitation and habitat loss as well (Wang and Zhao, 1998; Cheung and Dudgeon, 2006). Although some general principles of artificial culture are available for this creek-dwelling turtle (Wei et al., 2005), detailed information on food digestion and growth, which may provide important implications for aquaculture practice, remains unknown. In the present study, we held juvenile *P. megacephalum* at different temperatures to determine effects on food intake, food digestion, specific growth rate and food conversion coefficient. Our aims are to (1) quantify the thermal sensitivity of food intake and digestion as well as specific growth rate; and (2) determine the optimal range of temperatures for aquaculture in this species.

2. Materials and methods

2.1. Experimental procedures

In October 2006, we collected a total of 27 juveniles from a private farm in the Zhejiang province of eastern China. These wild-caught turtles had been kept in captivity for more than 3 months before they...
were brought to our laboratory at Hangzhou Normal University. Upon arrival, the animals were weighed (ranging from 79 to 129 g), housed individually in a 30 × 50 cm (diameter × height) bucket with 500 ml water, and then placed into a room at 27 °C and with a 10-h light:14-h dark cycle (light period between 0800 and 1800). Food of raw pork, containing 24.2% dry matter, and 85.1% protein, 12.5% lipid and 25.01 kJ of energy in each gram of dry food, were provided ad libitum.

After 2 weeks, we carried out feeding trials in temperature-controlled rooms to maintain water temperature in the buckets at 20, 22.5, 25, 27.5, or 30 °C. We randomly assigned nine individuals to each trial. In the total of five trials, we used 27 turtles with some individuals being re-used (average of 1.7 trials per turtle, ranging from one to two). The animals were exposed to the same light:dark cycle that they had experienced during acclimation. Throughout the trials, we monitored the water temperatures everyday, and if necessary, adjusted the room temperature to keep the water temperature as it was originally set. The body (cloacae) temperatures of the animals were measured every 2 days during the trials using a DM6801A electronic thermometer (±0.1 °C, Shengzhen Meter Instruments, Shengzhen, China). The mean body temperatures for the animals at the five test temperatures were 22, 22.4, 25, 27.1, and 29.4 °C.

The animals were acclimated to the test temperatures for 2 weeks prior to each trial. At the beginning of each trial, food was withheld for 3 days to standardize post-absorptive states and, at the end of which time, these animals were individually weighed to record their initial body mass. We then provided pre-weighed pork (ca. 5% of animal mass) to each animal at 0800 of each day, and collected the residual food 2 h later. We collected faeces with a spoon every 2 h from 0800 to 2200, and filtered the bucket water every morning to collect faeces produced during the night. Each trial lasted for 15 days to enable us to collect enough faeces samples for subsequent determination of digestive efficiency and to quantify the growth of juveniles. Afterwards, the turtles again had food withheld for 3 days and weighed again to determine final body mass.

Faeces and residual pork were oven dried at 65 °C for 24 h and weighed. The energy densities of these samples were determined by burning them in a GR-3500 S adiabatic calorimeter (Changsha Instruments, Changsha, China). Protein content was determined using a KJELTEC 2300 Analysis Unit (FOSS, Sweden).

2.2. Data analysis

The digestive efficiency of energy (DEE) was calculated as

$$DEE = \frac{(I_e - F_e)}{I_e} \times 100\%,$$

where $I_e$ = total energy consumed and $F_e$ = energy in faeces (Avery et al., 1993). The digestive efficiency of protein (DEP) was calculated as

$$DEP = \frac{(I_p - F_p)}{I_p} \times 100\%,$$

where $I_p$ = total intake of protein and $F_p$ = protein in faeces. The specific growth rate (SGR) and food conversion coefficient ($C_c$) were respectively calculated as

$$SGR = \frac{\ln W_t - \ln W_i}{t},$$

$$C_c = \frac{W_t - W_i}{I_p \times t}.$$
\[ \ln(W_f)/T \times 100\% \] and \( C_c = (W_f - W_i)/C_w \times 100\% \), where \( W_f \) = initial wet body mass, \( W_i \) = final wet body mass, \( T \) = duration of experiment and \( C_w \) = wet weight of food consumed (Tan et al., 1999; Hofmann and Fischer, 2003). These percentages were ArcSin transformed before further analysis. One-way ANOVA was employed to analyze the effects of temperature on food intake, DEE, DEP, SGR and \( C_c \). Nonlinear regression was used to estimate the relationships between temperature and food intake, SGR or \( C_c \). The thermal performance breadth (TPB) of the physiological performances was calculated as body temperature ranges in which the animals showed more than 90% of maximum performance.

3. Results

The mean body mass of turtles did not differ among treatments \((F_{4,40} = 0.03; P > 0.05)\). Body temperatures significantly affected food and energy intake in juvenile \( P. \) megacephalum (food consumption: \( F_{4,40} = 15.79; P < 0.0001 \); energy intake: \( F_{4,40} = 15.76; P < 0.0001 \)). Food and energy intake increased significantly from 20 to 22.4 °C, remained at a higher level from 25 to 27.1 °C, and then decreased dramatically at 29.4 °C (Fig. 1). The relationship between energy intake (EI) and body temperature (\( T \)) could be estimated by a quadratic equation: \( EI = 2.04 T^2 + 101.50 T - 1119.98, r^2 = 0.998, P < 0.0001 \). The maximum food intake was estimated to occur at 24.9 °C, and the TPB of food intake was 4.9 °C (22.2–27.1 °C).

Not only food intake but also food digestion was significantly influenced by body temperature. The digestive efficiency of protein was higher at temperatures between 20 and 27 °C than at 29.4 °C \((F_{4,40} = 7.16, P < 0.001)\) (Fig. 2a). The digestive efficiency of energy decreased with increasing body temperature \((F_{4,40} = 6.16 P < 0.001)\), with a higher DEE at temperatures between 20 and 25 °C than at 29.4 °C (Fig. 2b).

Body temperature significantly affected specific growth rate \((F_{4,40} = 3.86 P = 0.012)\), with greater SGRs at 22.4, 25 and 27.1 °C than at 20 and 29.4 °C (Fig. 3a). The relationship between SGR and body temperature \((T)\) could be best described by a quadratic equation: \( SGR = -0.01 T^2 + 0.47 T - 5.24, r^2 = 0.989, P < 0.0001 \). According to this equation, the estimated maximum SGR was 0.38% per day, occurring at 23.9 °C. The TPB of specific growth rate was 3.9 °C \((21.9–25.8 °C)\). The food conversion coefficient was lower at 29.4 °C than other temperatures \((F_{4,40} = 2.82 P = 0.037)\) (Fig. 3b). A quadratic equation \( (C_c = -0.37 T^2 + 17.20 T - 181.85, r^2 = 0.988, P < 0.00001)\) could be used to describe the relationship between \( C_c \) and body temperature. The maximum \( C_c \) (17.56%) was estimated to occur at 23.2 °C, with a TPB of 4.4 °C (21.0–25.4 °C).

4. Discussion

Our results demonstrated a significant thermal dependence of food intake, food conversion and growth in juvenile \( P. \) megacephalum. The juveniles showed greater food intake, specific growth rates and food conversion coefficient at moderate temperatures than at both high and low temperatures. Such patterns of thermal dependence of physiological performances are common in reptiles, but the optima of physiological performances may differ significantly among turtle species as well as other reptiles (Kepenis and McManus, 1974; Avery et al., 1993; Du et al., 2000; Zhang and Ji, 2004). Most freshwater turtles that are currently widely cultured attain maximum food intake and/or growth at high temperatures (>30 °C). For example, juvenile \( P. \) sinensis attains its highest food intake and growth rate at 31 °C (Tan et al., 1999; Lei, 2006); \( Trachemys \) scripta shows the greatest food intake at 34 °C (Avery et al., 1993); \( Chinemys \) reevesii reached a maximum of food intake and growth rate at 30 °C (You et al., 1993). In contrast, juvenile \( P. \) megacephalum reached its maximum food intake and specific growth rate at 24.9 and 23.9 °C, which is significantly lower than those of the abovementioned turtle species. Similarly, the optimal temperature for food conversion is also lower in juvenile \( P. \) megacephalum (23.2 °C) than in juvenile \( P. \) sinensis (30 °C) (Lei, 2006). Accordingly, our results indicate that simply following traditional aquaculture methods developed for turtle species such as \( P. \) sinensis and \( T. \) scripta is improper for the artificial culture of \( P. \) megacephalum, at least in terms of their thermal environment.

The difference in the optimal temperature between \( P. \) megacephalum and other freshwater turtles may reflect the difference in their habitat. The big-headed turtle, occupying mountain creeks with heavy canopy, have low field body temperatures (22–27 °C in summer, 17–21 °C in autumn) and selected body temperature (25.5 °C) (Du et al., unpublished). By contrast, \( P. \) sinensis and \( C. \) reevesii, the two sympatric species to \( P. \) megacephalum, living in open plain rivers (Zhang, 1998), have high selected body temperatures (30.3 °C for \( P. \) sinensis (Sun et al., 2002), 31 °C for \( C. \) reevesii (Du et al., unpublished)). As a result of adaptation to their respective thermal environments, these two types of turtles (closed-habitat species vs open-habitat species) shift their selected body temperatures and optimal temperature for digestive physiology and growth close to their active body temperatures in field. This phenomenon fits well with the evolutionary theory of acclimation (Huey and Berrigan, 1996), and has also been found in several sympatric species of lizards, with closed-habitat species having lower selected body temperatures and optimal temperatures for physiological performances than open-habitat species (Du et al., 2000; Zhang and Ji, 2004).

In summary, juvenile \( P. \) megacephalum may attain their best food conversion coefficient and growth within the temperature range of...
22–25 °C. This range of optimal temperatures for digestive physiology and growth of *P. megacephalum* is much lower than that of other freshwater turtles in open habitats. We thus recommend that these temperatures, rather than the temperatures around 30 °C that are widely used in the current turtle farming industry, should be adopted in the aquaculture practice of this species.

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**References**


