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Effects of acclimation temperatures on the respiration physiology and thermal coefficient of Malabar blood snapper

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ABSTRACT

This study tested the oxygen consumption rates (OCR), energy, and thermal coefficient of juvenile *Lutjanus malabaricus* (60 fish, size: 4.53 ± 1.14 g) at four temperatures of 22, 26, 30 and 34 °C. During 30 days of experimental period 5 fish tank^{-1} were reared at four temperatures with three replicates in intermittent flow respirometers in a recirculatory system under laboratory conditions. As expected, oxygen consumption rates increased significantly ($P < 0.05$) from 1.39 ± 0.07 to 3.11 ± 0.09 ml O_2 h^{-1} with an increase in the exposed temperature from 22 to 34 °C. The corresponding respired energy values also increased from 27.59 ± 1.03 to 61.78 ± 0.66 Jh^{-1} at 22 and 34 °C respectively. The maximum and minimum temperature quotients (Q_{10}) were observed between 22–26 °C (2.02) and 26–30 °C (1.82) respectively. Final preferred temperature (thermal coefficient) estimated between 26 and 30 °C. This bioengineering information can be used for designing and sizing a rearing facility for the intensive culture of *L. malabaricus*.

1. Introduction

Global warming and climate change is expected to increase ocean temperatures by 3 °C within the next century, with yet higher local temperatures expected periodically (He et al., 2014; Mazumder et al., 2015a, 2015b). As even minor increases of 0.2 °C can cause severe bleaching and death of many tropical coral reef species (Hoegh-Guldberg et al., 2007), the threat to coral reef biodiversity is considered severe. Therefore, understanding how tropical marine fishes cope with and potentially acclimate to shifting environmental conditions is paramount in determining the impact of climate change on their populations (Munday et al., 2012).

Fish oxygen consumption rate in intensive aquaculture is a very important parameter to determine optimum water flow and the oxygenation requirements for a sustained fish biomass at certain temperature (Randall, 1982). It allows the estimation of the energy costs associated with the physiological stress that these factors impose on organisms (Brougher et al., 2005). Oxygen consumption rate (OCR) is often used to examine energy utilization to determine the environmental conditions that result in maximal utilization of input energy for weight gain in an organism (Shi et al., 2011).

Measurement of the energy available for growth provides a rapid and quantitative assessment of the energy status of the animal as well as insight into the individual components (and mechanism of toxicity) which affect changes in growth rate (Widdows, 1985). There are possible energetic costs associated with modifications for which the energy used could have been spent on other functions (Angilletta et al., 2003). For example, physiological acclimation to increased temperature may reduce the energy available for growth or reproduction.

Most fishes exhibit a direct relationship between temperature and metabolic rates and a 10 °C increase in ambient temperature usually translates into a doubling of physiological rate functions (Schmidt-Nielsen, 1997). The temperature coefficient (Q_{10}) represents the degree of sensitivity of an organism to temperature (Diaz, 1988) and an evaluation of oxygen consumption at different temperatures allows the calculation of the thermal coefficient of poikilothermic organisms from aquatic habitats (Carvalho and Phan, 1997). When Atlantic cod (*Gadus morhua*) and sockeye salmon (*Oncorhynchus nerka*) are exposed to a

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progressive increase in temperature, Q_{10} increases with a Q_{10} of 2–2.5 until it reaches a plateau corresponding to the fish's optimum temperature and then declines just prior to the fish reaching it's critical thermal maximum (Steinhausen et al., 2008).

Among the several species of marine reef fish, one that stands out is the Malabar blood snapper (*Lutjanus malabaricus* Bloch & Schneider, 1801), for its commercial interest, economic importance and extensive consumption as food source. This species shows many biological aspects that are favourable for aquaculture: it is a euryhaline fish has extroverted habits and it is tolerant to high densities, so it is one of the major tropical species produced by the aquaculture industry (Rosenlund and Skretting, 2006; Mazumder et al., 2018b). The development of culture techniques suitable for this species has been on-going for many years in countries such as Malaysia, Thailand, Australia and Canada (Rosenlund and Skretting, 2006). In the previous experiments, the authors measured growth forms, condition factors, pepsin enzyme activities, and growth rate of *L. malabaricus* at different temperature and diets (Mazumder et al., 2015a, 2015b, 2016, 2018a, 2018b). However, questions on the metabolic traits of the species and its ability to cope with environmental stressors have received little attention. Taking all these issues into consideration, the objectives of this study were to investigate the rate of oxygen consumption, physiological energetics, and thermal coefficient of *L. malabaricus* acclimatized at four different temperatures (22, 26, 30 and 34 °C). Knowledge obtained from this study will aid in aquaculture inland based facility designs or site selection for cages deployment and also help in the development of oxygen management strategies.

2. Methods

2.1. Fish

A total of 120 *L. malabaricus* (total length: 6.37 ± 0.46 cm, body weight: 4.53 ± 1.14 g) samples were obtained from local hatchery of Pulau Ketam (03° 01' 20" N and 101° 15' 20" E), Selangor, peninsular Malaysia and transported to the marine science laboratory of UKM Bangi, Malaysia (Fig. 1). The 120 *L. malabaricus* were then randomly distributed among three stocking tanks (size: 1.96 × 1.02 × 0.61 m^3, capacity: 1200 L) and kept for 15 days at 26 °C and salinity 30 ppt.

2.2. Diet

Fish were fed by commercial pellet manufactured by CP Group, Malaysia (Table 1) at 5–10% of their body weight of fish twice daily (09:00 and 16:00 h) (Donelson et al., 2010) until apparent satiation was observed. The feeding rate was adjusted every week based on 5–10% of the body weight. Satiation was determined as the point when fish stopped feeding actively and feeds settled at the bottom of the tanks for more than 2 min. During feeding it was closely monitored that each fish in each replicate tank has fed until satiation then the leftover food was collected, dried, and weighed (the weight of the dried left-over food was about 71% of the wet food); and the total consumption was determined accordingly. The proximate composition of the experimental feed were protein (46.44 ± 0.82%), lipid (8.02 ± 0.76%), carbohydrate (7.18 ± 0.58%), ash (12.26 ± 1.04%), and moisture (10.03 ± 0.48%) determined by using standard methods (Soundarapandian, 2008).

2.3. Experimental setup

Following acclimation and observation of feeding and defecation, the fish samples were randomly transferred to 24 experimental tanks (5 fish $tank^{-1}$, tank size: 123 × 63 × 46 cm) and temperature was maintained at 26 °C for one week and fed similar pellet diet. Subsequently, 12 tanks were randomly selected for oxygen consumption and the remainings were for gill morphology experiments (60 fish for each experiment: 5 fish × 12 tanks). Among the 24 thanks, 3 tanks were assigned for each temperature as a replicate (3 tanks × 4 temperatures: 22, 26, 30 and 34 °C). Changes in temperature for the experimental groups were initiated at 2 °C day^{-1} by using a heater (E-JET Heater 200 W, Penang, Malaysia) and a chiller (HS-28A 250–1200 L/H, Guangdong Hailea Group Co. Ltd., China) until the experimental temperature reached a minimum of 22 °C and a maximum 34 °C. Fish was maintained at 12 h light and 12 h dark photoperiod. Water was exchanged 20% per day during the period of experiment.

2.4. Water quality measurements

During the 30-d experimental period, the water quality parameters viz., temperature, salinity, and pH were monitored daily, whereas the total ammonia nitrogen ((NH_3-N) and total hardness were measured weekly. All measurements were taken at 09:00 h. Temperature, pH, and salinity were monitored using a YSI 59 Multiparameter Water Quality Probe (Yellow Springs Instrument Company OH, USA). NH_3-N was measured using the salycilate method (Hach™ method 8155), and total hardness was measured by titration (La Motte Chemical test kit, model WAT-DR).

2.5. Oxygen consumption rate measurements

The automated respirometer developed by Steffensen et al. (1984) to perform intermittent-flow respirometry on fish (Fig. 2) was used. Tubular Plexiglas respirometers (length: 15 cm; diameter: 9.6 cm; volume: 1.04 L) were used for this experiment. Respirometers were submerged in a 90 l tank filled with seawater and the temperature of the whole system was kept constant (± 0.2 °C) by recirculating water through a heat pump. Oxygen partial pressure (pO_2) was measured by a Radiometer oxygen electrode (SA7-530-200) connected to a four-channel Fire Sting oxygen analyser logger software version > 3.0. Oxygen uptake was measured over the 20 min. The electrodes were installed into Plexiglas flow-through reading cells (Strathkelvin Instruments, model FC100). Respirometry experiments consisted of a succession of one-hour cycles. Each cycle began when respirometers were closed. A recirculating pump (March, model 1CMD) brought water to an oxygen microcathode and back to the respirometer (~0.14 l min^{-1}), thus providing continuous oxygen readings and mixing of the water in the respirometer (Fig. 2).

Prior the beginning of an experiment, oxygen electrodes were calibrated, and the temperature, salinity and barometric pressure were noted for calculations of oxygen solubility and concentration. For each treatment, identical control blanks were run without fish to assess background respiration. All necessary measures were taken to minimize visual disturbances of the experimental fishes. Oxygen consumption was measured at the end of rearing period (30 days) in different exposed temperatures (22, 26, 30 and 34 °C). The rate of oxygen consumption (MO_2, mg $O_2\,h^{-1}$) for individual fish was calculated using the formula of Widdows and Johnson (1988):

$$MO_2 = 60[C_{(t0\ -\ t1)}]\ (V_r - V_a)/(t_1 - t_0) \quad (1)$$

Where, t_0, t_1 = start and finish times (min) of the measurement period, $C_{(t0\ -\ t1)}$ = consumption of total oxygen in the water (mg $O_2\,h^{-1}$) at time t, V_r = volume of respirometer, V_a = volume of the animal.

Oxygen solubility tables were used to convert pO_2 values to oxygen concentration in mg $O_2\,h^{-1}$. At the experiment, each animal length (TL ± 0.01 cm) and volume (W_w ± 0.001 ml) was measured.

2.6. Calculating respired energy

The values of energy respired was calculated using the conversion factor of 19.9 $J.mg^{-1}$ O_2 (Elliott and Davison, 1975):

Energy respired (Jh^{-1}) = Oxygen consumption rate (mg $O_2\,h^{-1}$) ×

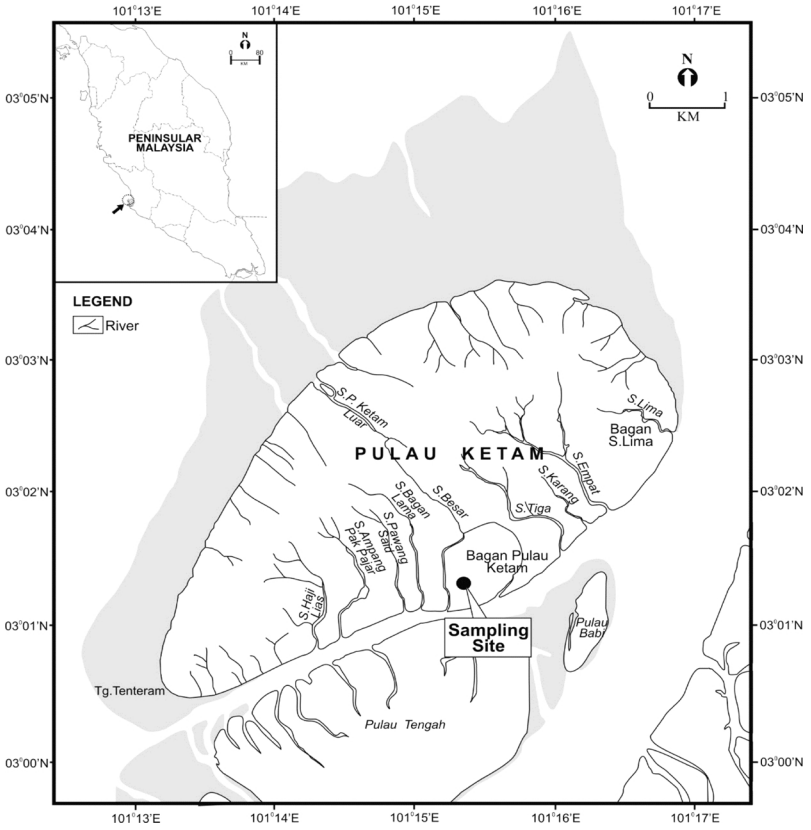

Fig. 1. Map depicting location of hatchery Pulau ketam, Selangor, Malaysia.

19.9 (2)

Where, 19.9 J.mg^{-1} O_2 is the heat equivalent of oxygen uptake.

2.7. Calculating thermal coefficient (Q_{10})

Using the calculated values of oxygen consumption rate, the thermal coefficient (Q_{10}), which represents the sensitivity of an organism to temperature variations, was estimated for the species. Q_{10} values was calculated according to Schmidt-Nielsen (1997):

$$Q_{10} = (MO_2{}^{t}{}_1 / MO_2{}^{t}{}_0)^{10 / (t_1 - t_0)} \quad (3)$$

Where, $MO_2{}^{t}{}_1$ and $MO_2{}^{t}{}_0$ are the oxygen consumption rates at temperatures t_1 and t_0 respectively, t_0 is the lower of the two temperatures used to determine oxygen consumption and t_1 is, the higher of the two temperatures used to determine oxygen consumption.

All laboratory protocols followed and complied in this study were approved by Animal Ethics Committee of Universiti Kebangsaan Malaysia [approval code no: FST/2016/SIMON/27-JULY/763-JULY-2016-MAY-2017].

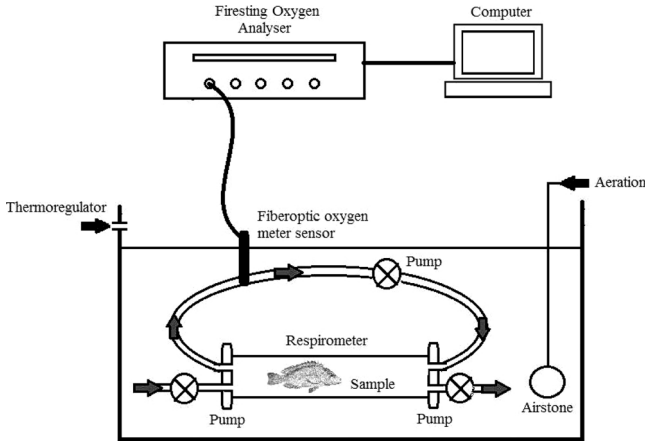

Fig. 2. Experimental setup for measurement of oxygen consumption in *L. malabaricus*. Respirometers were flushed periodically with air-saturated water from the surrounding temperature-controlled tank. Water from respirometer was continuously circulated through a Plexiglas reading chamber housing the tip of an oxygen microcathode and then pumped back to the respirometer. The five-channel oxymeter monitored five respirometers simultaneously. Only one respirometer is represented here.

Table 1
Physico-chemical parameters measured during the period of experiment. Values are mean ± S.E.

Parameters	22 °C	26 °C	30 °C	34 °C
Temperature (°C)	22.13 ± 0.56	26.07 ± 0.14	30.20 ± 0.29	34.04 ± 0.29
Salinity (psu)	30.23 ± 0.45	30.12 ± 0.34	30.06 ± 0.36	30.03 ± 0.12
TH (mg L^{-1})	119.33 ± 22.33	108.07 ± 18.41	125.4 ± 16.49	97 ± 3.89
NH_3-N (mg L^{-1})	0.25 ± 0.20	0.25 ± 0.20	0.33 ± 0.24	0.42 ± 0.24
pH	7.47 ± 0.09	7.07 ± 0.31	7.27 ± 0.17	6.87 ± 0.17

*TH: total hardness and NH_3-N: ammonical nitrogen.

2.8. Statistical analysis

No significant differences were found among any of the replicate means ($P > 0.05$), and the data for the different replicates were therefore averaged (Dean et al., 2017). Differences in oxygen consumption rate and respired energy inside the respirometer with different temperatures, quadrative regressions were used based on previous findings (Brett and Groves, 1979) whereas logistic model was used for the amount of oxygen decreased and oxygen demand increased with time inside the respirometer at different temperatures. Prior to the statistical analysis, all data were tested for normality and homogeneity of variance among the different groups using a Kolmogornov-Smirnov (K-S) test on residuals and Bartlett's test for homogeneity of variance (Sokal and Rohlf, 1995). Statistical comparisons among all temperature treatments were accomplished using a parametric analysis of variance (ANOVA). In cases where the ANOVA reported significant differences, a pairwise *post-hoc* Tukey test was used to determine specifically which groups were different (Zar, 1984). Data presented in the text, figures, and table are means ± SE and $P < 0.05$ was used as the level of statistical significance. All statistical analyses were performed using OriginTM Version 9.0 and Minitab version 17 computer software (Mazumder et al., 2016).

3. Results

3.1. Water quality parameters

Mean values ± SE of physico-chemical parameters recorded in experimental tanks during this study are presented in Table 1. They were adequately stable at the nominal treatment levels of 22, 26, 30, and 34 °C and there was no significant difference ($P > 0.05$) in all the parameters.

3.2. Dissolved oxygen concentration

At comparable intermediate times of exposure, dissolved O_2 (dO_2, mg h^{-1}) concentration was significantly higher at 22 °C ($P < 0.05$) than that for other temperatures as the O_2 consumption was significantly lower than others. The logistic model fit the relationship between dO_2 and time (t) (Fig. 3).

3.3. Oxygen consumption and oxygen demand into the respirometer

Oxygen consumption (mg O_2 h^{-1}) by individual fish was decreasing with increasing time in the respirometer but their decreasing rates are fluctuated with temperature. We measured the oxygen consumption (mg O_2 h^{-1}) in the respirometer every 5 min and found significant difference ($P < 0.05$) among the temperatures (Table 2).

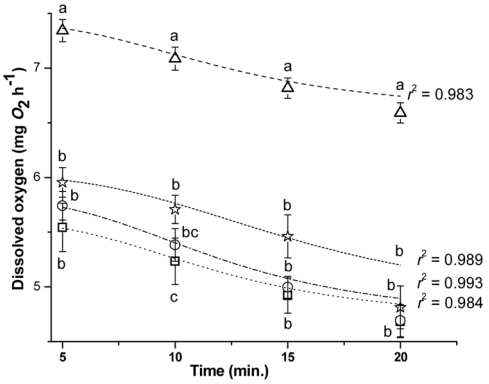

Fig. 3. Relationships between dissolved oxygen concentration (dO_2) and time of *L. malabaricus* at different time interval of exposure into the respirometer. The open triangles represent 22 °C, open squares represent 26 °C, open circles represent 30 °C and open stars represent 34 °C.

The relationship between O_2 consumption and O_2 demand for all temperatures used in this study are shown in Fig. 4. When the data are displayed as a scatter plot, it appears that the relationship between O_2 consumption and O_2 demand is opposite; a conclusion supported by the regression coefficients followed by the logistic non-linear relationships (r^2 close to 1.0).

3.4. Oxygen consumption rate and respired energy

The oxygen consumption rates, their corresponding respired energy and thermal coefficient (Q_{10}) obtained from this research reveals a valuable insight in oxygen consumption rates. Malabar blood snapper oxygen consumption rate data have been pooled for each tested temperature (Fig. 5). Physiological responses data of *L. malabaricus* have been pooled for each tested temperature in Table 3 and Fig. 5. The respirometry data for the *L. malabaricus* showed, as expected, that rate of oxygen consumption increased concomitantly with the increasing water temperatures ($P < 0.05$). The average oxygen consumption at 22 °C was 3.07 mg O_2 h^{-1}, while at 26 °C it increased to 4.29 mg O_2 h^{-1}, at 30 °C goes to 4.78 mg O_2 h^{-1} and 5.56 mg O_2 h^{-1} at 34 °C ($P < 0.05$, Table 3). The polynomial cubic relationship between MO_2 and temperature (T) could be described as $MO_2 = 62.647 + 6.790T\text{-}0.232T^2 + 0.003T^3$ and showed that the relationship between water temperature and MO_2 is highly significant ($r^2 = 0.996$, $P < 0.05$). The corresponding respired energy rate also increased markedly ($P < 0.05$) as the exposed temperature was increased from 22 to 34 °C, reaching from a minimum of 183.31 Jh^{-1} at 22 °C to a maximum of 332.17 Jh^{-1} at 34 °C (Table 3, Fig. 5). The respired energy values also fitted by polynomial cubic model and could be described as $RE = 3740.048 + 405.373T\text{-}13.840T^2\text{-}0.160T^3$ and also the relationship significantly different from each other ($r^2 = 0.998$; $P < 0.05$).

3.5. Thermal coefficient (Q_{10})

Thermal coefficient (Q_{10}) was used to describe the difference of oxygen consumption at different temperature ranges. Q_{10} based on the change of MO_2 with temperature was found to take a different course as presented in Table 3 and Fig. 5. It reached a peak of 2.30 between 22 and 26 °C falling to 0.78 between 26 and 30 °C and again increased to 2.37 between 30 and 34 °C. Thus, the drop in Q_{10} was apparent above 26 °C. Using the point where a drop in the Q_{10} becomes apparent (Kita et al., 1996), these results suggest that the final preferred temperature of juvenile *L. malabaricus* is between 26 and 30 °C.

4. Discussion

For aquaculture purposes, it is sometimes recommended to use the average oxygen consumption rates for calculating oxygen requirements for a fish farm (Nerici et al., 2012). In poikilothermic animals, the metabolic responses that are quantified in terms of oxygen consumption show a direct relation to temperature due to its direct effect on the kinetics of the enzyme reactions involved (Hochachka and Somero, 1971; Mazumder et al., 2018a; Zeng et al., 2010). Similar observations were made for Indian major carps (*L. rohita*, *C. catla*, and *C. mrigala*) (Das et al., 2004), *P. pangasius* (Debnath et al., 2006), early fingerlings of *L. rohita* and *C. carpio* (Chatterjee et al., 2004), crucian carp *Carassius carassius* and *C. auratus* (Sollid et al., 2005), and *M. salmoides* juveniles (Díaz et al., 2007).

This study is the first to assess oxygen consumption rate and thermal coefficient of *L. malabaricus* over most of its general temperature range where it is found in the wild. In the present study, in *L. malabaricus* juveniles, the OCR continued to increase throughout the entire temperature range (22–34 °C) to which they were exposed, and the relationship between the OCR and temperature clearly fit a polynomial cubic model. The increase in the oxygen consumption rate of juvenile *L.*

Table 2
Oxygen consumption in juveniles of *L. malabaricus* at 22, 26, 30 and 34 °C after introduction to the respirometer. Values are mean ± S.E.

Temperature °C)	Oxygen consumption (mg O_2 h^{-1})			
	5 min	10 min	15 min	20 min
22	0.299 ± 0.047^{c}	0.276 ± 0.060^{b}	0.266 ± 0.029^{b}	0.152 ± 0.041^{bc}
26	0.783 ± 0.073^{a}	0.405 ± 0.020^{a}	0.372 ± 0.017^{a}	0.116 ± 0.024^{c}
30	0.442 ± 0.052^{b}	0.366 ± 0.035^{a}	0.257 ± 0.044^{b}	0.245 ± 0.037^{a}
34	0.562 ± 0.070^{b}	0.284 ± 0.026^{b}	0.253 ± 0.031^{b}	0.184 ± 0.013^{ab}

*Significant temperature-dependent changes in the mean values for oxygen consumption at the different temperatures, are indicated by an ANOVA ($P < 0.05$). The superscripted letters (a,b,c) denote significant differences ($P < 0.05$) between groups (22, 26, 30 and 34 °C).

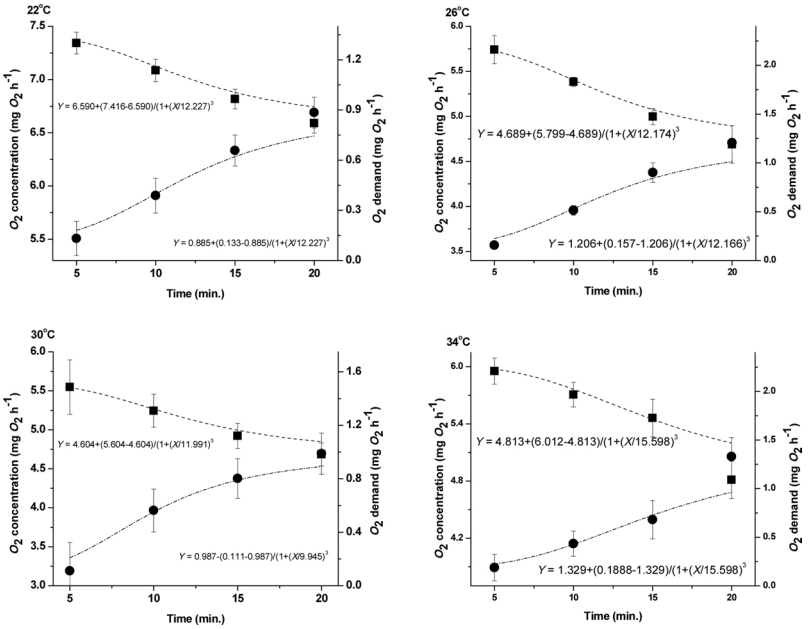

Fig. 4. Relationship between O_2 consumption and O_2 demand with temperature (22, 26, 30 and 34 °C) of *L. malabaricus* at different time interval of exposure into the respirometer. The solid square represents O_2 consumption and solid circle represents O_2 demand whether, the broken lines define the logistic regressions that were fitted to the mean data to show the general trends in O_2 consumption and O_2 demand. Values are mean ± SE recorded at different time interval (min.) at a particular temperature.

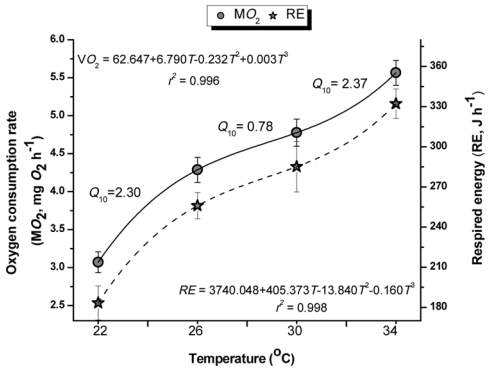

Fig. 5. Rate of oxygen consumption (MO_2, ml O_2 h^{-1}) and respired energy (RE) values of juvenile *L. malabaricus* acclimated to four different temperatures (22, 26, 30 and 34 °C). Values are expressed as mean ± SE (n = 15). Trends with different letter vary significantly (Tukey's multiple comparison test, $P < 0.05$). Numbers in parenthesis are Q_{10}s between acclimation temperatures (22–26, 26–30 and 30–34 °C).

malabaricus with increasing temperatures agrees with the profiles mentioned in other studies performed with different species (De la Gándara et al., 2002; Chatterjee et al., 2004; Das et al., 2004; Zheng et al., 2008), which was expected, as all metabolic processes are directly regulated by temperature (Jobling, 1983).

In the present study, it was shown that the OCR of the *L. malabaricus* increased with increasing of water temperature when the water temperature ranged from 22 °C to 34 °C, but expensing more energy for their metabolism when the water temperature was out of that range, indicating that juvenile *L. malabaricus* may adapt to the water temperature to some extend. Similar to previous studies (Miklos et al., 2003; Neer et al., 2006), oxygen consumption rates increased with increasing temperature.

A knowledge of the oxygen consumption and ventilatory frequency of the *L. malabaricus* in situations of gradual hypoxia should provide information on suitable oxygen concentration for its culture. Generally, fish respond to a decrease in the levels of dO_2 by increasing their ventilation volume (McArley et al., 2018), and since ventilation is energetically costly, any increase will reduce the energy available for other metabolic processes such as growth (Norin and Clark, 2016). Furthermore, when dO_2 decreased as shown in Fig. 3, the animals were not able to meet their oxygen requirements (critical oxygen level) and their vital functions were affected. This suggested why the dO_2 concentration was significantly higher at 22 °C than that for other temperatures.

The standard metabolism of fish refers to the basic metabolism with being inactive, fasting and undisturbed. Jobling (1995) suggested that the standard metabolism is comprised of components: the energy of organization repair and renovation; the second one is the energy of maintaining the inner environment stable. The OCR, tested in the present study, is only an approximation of the standard metabolism, since fish showed some swimming activity in the test chambers (Zhang and Xie, 2003). Fish maintained under fluctuating temperatures allocated more energy for growth and reproduction, and less energy in respiration than fish under constant temperature (Pilditch and Grant, 1999). The pronounced increase in the metabolic processes of respiration was related with the high rates of growth.

A marine fish demonstrates physiological plasticity when it is able

Table 3
Physiological responses in *L. malabaricus* exposed to 4 different temperatures. Values are mean ± S.E.

Parameters	Temperature (°C)			
	22	26	30	34
MO_2 (mg O_2 h^{-1})	3.07 ± 0.04[d]	4.29 ± 0.07[c]	4.78 ± 0.0.08[b]	5.56 ± 0.16[a]
Energy value (J h^{-1})	183.31 ± 12.70[c]	255.99 ± 9.81[b]	285.13 ± 18.85[b]	332.17 ± 10.99[a]
Energy value (J d^{-1})	4399.50 ± 82.03[c]	6143.74 ± 38.11[b]	6843.10 ± 54.17[b]	7972.03 ± 112.21[a]
Energy value (J g^{-1} h^{-1})	28.20 ± 4.74[b]	39.38 ± 4.82[ab]	35.64 ± 1.37[b]	50.33 ± 3.02[a]
Thermal coefficient (Q_{10})	2.30 between 22–26 °C, 0.78 between 26–30 °C and 2.37 between 30–34 °C			

*Significant temperature-dependent changes in the mean values for oxygen consumption rate (MO_2), Energy value (J h^{-1}), Energy value (J d^{-1}), Energy value (J g^{-1} h^{-1}), Thermal coefficient (Q_{10}) at the different temperatures, are indicated by an ANOVA ($P < 0.0001$). The superscripted letters (a,b,c,d) denote significant differences ($P < 0.05$) between groups (22, 26, 30 and 34 °C) as indicated by post hoc Tukey Test analysis.

to regain, or approach, its metabolic set point within the context of thermally fluctuating environments (Dent and Lutterschmidt, 2003). This process can be quantified, in part, by comparing temperature coefficient (Q_{10}) effects in a species across acclimation regimes. The Q_{10} represents the degree of sensitivity of an organism to temperature, and it is a measure of the metabolic capacity of aquatic organisms to make adjustments after temperature changes. The Q_{10} of juvenile *L. malabaricus* reached to the 2.02, the highest Q_{10} when the fish was exposed to the water temperature from 22 to 26 °C. Probably, the basic metabolism of juveniles was unstable during this water temperate range. It has been reported that the juvenile *L. malabaricus* could not survive when the water temperature was below 22 °C (Deguo et al., 2008). However, when the water temperature increased from 26 to 30 °C, the Q_{10} was 1.82, which reaches to the lowest value. The decrease in Q_{10} indicates that the metabolic rate of the fish has decreased and that more energy is potentially available for growth (Díaz et al., 2007). Thus, the final preferred temperature may be estimated indirectly based on the relationship between Q_{10} for oxygen consumption rates and the acclimation temperatures (Das et al., 2004). The second lowest Q_{10} appeared when the water temperature varied from 30 to 34 °C, indicating that from 30 to 34 °C, the basic metabolism of juveniles little changed. The present results may provide theoretical evidence of the most suitable temperature for raising and protecting juvenile *L. malabaricus*. Das et al. (2004) and Shi et al. (2011) hypothesized that the point at which the Q_{10} decreases related to the acclimation temperature, corresponds to the optimal temperature for growth, as the decrease in Q_{10} indicates that the metabolism of the fish has decreased and that more energy is available for growth, similar to what was observed for *L. malabaricus* exposed to different acclimation temperatures. The observation that the optimal temperature coincided with the temperature range in which *L. malabaricus* juveniles exhibited lower Q_{10} values may be explained by the fact that fish possess enzyme systems with specific temperature optima, as noted by Kita et al. (1996). The final preferred temperature may be estimated indirectly from the relationship between oxygen consumption and exposed temperature (Kita et al., 1996). In our study, the final preference temperature for *L. malabaricus* juvenile was found to be between 26 and 30 °C based on the Q_{10} value. Thus, estimation of Q_{10} and thermal optima estimation can serve as a preliminary and convenient method to screen candidate species used for aquaculture before a growth study is being performed.

The determinations of oxygen consumption, and preferred temperature in this research for *L. malabaricus* in laboratory conditions provide valuable information of the oxygen requirement of these fish in an aquacultural setting. This bioengineering information can be used for designing and sizing of a rearing land based or cage facility for the intensive culture of *L. malabaricus*.

5. Conclusion

The oxygen consumption, respired energy, as well as preferred temperature for *Lutjanus malabaricus* juveniles proved to be dependent upon temperature in this experiment, as expected. Although, due to the lack of references from the species, this study appears to be the first to investigate metabolic rates on *L. malabaricus*, allowing further investigations to determine optimum conditions for the culture of this species leading towards a commercial aquaculture scale.

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