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Effects of temperature on growth performance, survival rate, digestive enzyme activities and physiological parameters of striped snakehead *(Channa striata)* at fry stage

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ABSTRACT

The effects of temperature on growth performance, survival rate, digestive enzymatic activities, and physiological responses of striped snakehead (Channa striata) at fry stage were evaluated. The study consisted of two trials including (1) determination of temperature threshold and (2) effects of different temperatures (24 ℃, 27 ℃ (control), 30 ℃, 33 ℃ and 36 ℃) on growth performance, survival rate, digestive enzyme activities and physiological parameters of striped snakehead fry stage for 90 days. The growth experiment was conducted in 500-L tank (250-L water) with triplicates. The stocking density was 300 individuals per tank. Striped snakehead at fry stage showed a high tolerance to temperature ranging from 10 to 40°C. After 90 days, fish reared in 30 ℃ performed the greatest weight and survival rate (13.1±3.12 g/fish and 15.5±4.63%, respectively). The number of red blood cells and hemoglobin concentrations increased with the increase in temperature. It was discovered that different temperatures (from 27 to 36 ℃) did not significantly influence the number of white blood cells, osmolality, and ion concentration of fish. Glucose and cortisol concentrations increased with temperature rises and peaked in fish reared at 36 ℃, while temperatures of 30°C and 33°C showed higher digestive enzyme activities. It proves that 30 ℃ is the optimal level for striped snakehead fry rearing.

1. INTRODUCTION

Striped snakehead *(Channa striata)* is popularly distributed in Vietnam and several countries in Asia such as Bangladesh, India, Pakistan, Sri Lanka, south of China, Thailand, and Vietnam (Talwar & Jhingran, 1991). In nature, striped snakehead can be found in many types of water bodies including ponds, streams, and rivers, preferring stagnant and muddy water of plains and swamps. This species was also reported to be able to tolerate slightly brackish water (Talwar & Jhingran, 1991) and high temperature above 30°C (Long et al., 2017). In Vietnam, striped snakehead has been one of the species contributing to the increased national freshwater aquaculture production and popularly farmed in the Mekong Delta. The total production has increased rapidly from 15,958 t in 2006 to 62,906 t in 2018 and was planned to scale up to 104,662 t in 2020

(compiled by Hien, 2019). However, the aquaculture industry has been predicted to be greatly impacted by climate change related risk factors such as salinity, temperature, and CO_2 (Seggel and De Young, 2016). Intergovernmental Panel on Climate Change (IPCC, 2018) revealed that the average temperature of the Earth surface and ocean was increased 0.87°C (from 0.75 to 0.99°C); and it will be warmer around 3-4°C than the average one of Earth surface. The Mekong Delta of Vietnam, the biggest aquaculture area in Vietnam, is projected as one of three deltas in the world to be heavily affected by climate change (IPCC, 2007). The average temperature in Vietnam is currently 27°C (Gasparrini et al., 2017) that is predicted to increase to 33°C in the 21st century (IPCC, 2014). As a poikilothermic vertebrate, fish has been reported to be influenced by water temperature, dissolved oxygen concentration (DO) and photoperiod on feed consumption, metabolic rate, energetic cost, and growth (Brett, 1979; Elliott, 1982; Dutta, 1994; Bhikajee & Gobin., 1998). In *Channa striata*, a previous study on the fingerling stage under different temperatures indicated that temperature of 31ºC reported the highest growth rate with a significantly reduced food conversion rate, whereas the growth performance tended to decrease at 34ºC (Chinh, 2014). Fish at fry stage is sensitive with environmental changes. However, the growth and physiological responses of striped snakehead fry exposed to temperature changes have not been documented in details. Therefore, it appears to be necessary to study on the effects of temperature on physiological parameters, digestive enzymatic activities, and growth performance of snakehead from fry to fingerling stage. The main objective of this study was to elucidate the growth and physiological responses of larval snakehead to different temperatures.

2. MATERIALS AND METHODS

2.1. Animals and experimental conditions

Fertilized striped snakehead eggs were obtained from a fish hatchery in Can Tho city. Eggs were then held in a 1-m^3 composite tank in normal condition (temperature 27-28°C, oxygen 5-6 mg/L and pH 7-8) with approximate density of 150 eggs/L until hatching in the wet laboratory of the College of Aquaculture and Fisheries, Can Tho University. After 24-hour post-hatching, the actively swimming fries were collected and transferred into rearing tanks.

2.2. Experimental designs

2.2.1. Identifying thermal tolerance thresholds of striped snakehead at fry stage

Upper temperature threshold

The experiment was set up in 35-L round plastic containers (containing 20-L water). Stocking density was 20 fries per container with four replicates. The initial temperature was around 27-28°C, then increased in a stepwise, 1°C per 3 hours by heater (EHEIM professional 4+ 350T – Germany) and the temperature of water were increased until the mortality was around 50%. This level was considered as the upper-temperature threshold.

Lower temperature threshold

The experiment was designed as described above (upper temperature threshold) and conducted in an air-conditioned room. The initial temperature was around 27-28°C and decreased 1°C per 3 hours using the plastic ice bags and cooler (TECO SeaChill TR10) to maintain the temperature during 3 hours before decreasing temperature to the lower level. The experiment was stopped as the mortality was around 50%. This level was considered as the lower-temperature threshold.

2.2.2. Investigating effects of temperature on growth, survival, digestive enzymatic activities and physiological parameters of fish at fry stage

In Vietnam, the average temperature is currently around 27°C (Gasparrini et al., 2017), which was predicted to increase up to 33°C in the 21st century (IPCC, 2014). This estimated temperature was combined with the results of upper and lower temperature threshold experiments (40°C and 10°C, respectively) for choosing five temperature levels including 24°C, 27°C (control), 30°C, 33°C and 36°C for this study. The experiment was carried out in 500-L round composite tanks (111 cm x 75 cm) for a period of 90 days from the day that all treatments reached the experimental temperature levels. Actively swimming fry (24-hour post-hatching) was randomly exposed to the five different temperatures with the density of 300 ind./250-L water. Three replicates were applied for each temperature. For 24°C treatment, the temperature was decreased in a stepwise of 1°C per 12 hours and maintained at the target level by cooler (TECO SeaChill TR10), while the higher temperatures were increased 1°C per 12 hours by

heaters starting from ambient temperature 27°C. The treatments with higher temperature levels were elevated before the lower ones to ensure all treatments reaching the desirable temperatures at the same time.

During the experiment, fish were fed to satiation, four times daily at 7:00, 11:00, 14:00, and 18:00 o' clock. After completely consuming their yolk sac (2-day post-hatching), the fish were fed with *Moina* (16-20 ind./mL). Moina were used to feed the fish until day 10th. From 11th day to 30th day; the fish were fed with *Moina* and commercial powder feed (42% of crude protein); the density of *Moina* was reduced gradually from 10-16 ind./mL to 5-10 ind./mL and then 0-5 ind./mL, while the percentage of commercial feed was increased gradually until the 30th day (Huong et al., 2020). From the 30th day to the 60th day, fish were completely fed commercial powder feed (42% of crude protein) with a feeding rate of 15%-25% body weight. From the 60th day onwards, fish were fed with floating commercial pellets (40% of crude protein, d=0.8 mm) to satiation, uneaten pellets were collected 30- minute post-feeding to prevent water pollution. The mortality was recorded for determining the survival rate. Water in tanks was refreshed every three days in a ratio of 30% of total volume in combination with bottom cleaning.

Water quality parameters

The experiment was conducted indoor to keep the environmental parameters stable. Water temperatures of experimental tanks were controlled at desirable levels throughout the rearing period. pH (WTW Multi 3510 IDS) was checked daily and fluctuated from 7.55 to 7.80. Levels of nitrite and total ammonia nitrogen were weekly recorded using Griess llosvay and Diazonium and Indophenol blue methods and fluctuated from 0.19 to 0.52 and from 0.18 to 0.50 mg/L, respectively. These parameters were kept within accepted ranges for aquatic species (Boyd, 1990).

Sample collection

a. Survival rate and growth performance

Growth parameters were calculated based on fish weight. Initial fish weight was determined by weighing three samples of 30 individuals using analytical balance (Sartorius, CP2245, accuracy of 0.0001 g). Every 30 days, the individual fish each tank were weighed. Additionally, the number of remaining fish in each tank were recorded for determining survival rates at different samplings.

$$\text{Survival rate (SR, \%)} = \frac{Number\ of\ survival\ fish\ at\ the\ end\ of\ experiment}{Numbers\ of\ initial\ fish} x\ 100$$

$$\text{Daily weight gain (DWG, g/day)} = \frac{Wf-Wi}{t}$$

$$\text{Specific growth rate (SGR, \%/day)} = \frac{\text{Ln(Wf)-Ln(Wi)}}{\text{t}} \text{x100}$$

In which: Wi: the initial weight (g); Wf: the final weight (g); and t: the experimental time (day)

b. Physiological responses

Blood samplings were conducted at the end of the experiment. Three fish per tank were carefully captured by a hand-net, and an amount of approximately 0.3 mL of blood was immediately withdrawn from the caudal vein using a 1 mL pre-heparinized syringe. To minimize stress, the individuals' heads were covered with a cool moist towel (Snellgrove & Alexander, 2011). The number of red blood cells (RBCs), white blood cells (WBCs), and hemoglobin concentration (Hb) in the blood was quickly evaluated. Besides, the remaining blood samples were centrifuged at 6,000 rpm for 6 min at 4˚C to collect serum for analyzing glucose, cortisol, osmolality, sodium (Na^+) and chloride ion (Cl^-) concentrations.

The total RBCs count was determined manually in a 1:200 dilution of the blood sample in Natt-Herrick's solution as a diluent stain using a Neubauer haemacytometer (Natt & Herrick, 1952). Hb (g/dL) was determined using the cyanohemoglobin method; a 10 µL blood sample was mixed with 2.5 mL of Drabkin reagent (Hawk, 1965). Hb of samples were determined at 540 nm using a spectrophotometer (Cary 50 Conc). WBCs were determined according to the unified methods for hematological examination of fish (Hrubec et al., 2000). The plasma osmolality of fish was measured by using a Micro Osmometer (Advanced Instruments Model 3300, Advanced Instruments Inc, USA); Cl^- was measured by a chloride titrator (Sherwood model 926S MK II Chloride analyzer, Sherwood Scientific Ltd., Cambridge, UK); Na^+ was measured by a Flame Photometer 420 (Sherwood Scientific Ltd., Cambridge, UK). Glucose was analysed by following the method of Hugget and Nixon (1957). [Cortisol] was measured by Elisa kit (DRG Instruments GmbH – Germany).

c. Enzymatic activity

After the blood collection, the three sampled fish per tank were dissected on a glass plate placed on ice. Stomach and intestine were collected to analyze

digestive enzymatic activities. Samples were thawed on ice and homogenated with the buffer KH_2PO_4 20 mM and NaCl 6 mM, pH 6.9. The mixture was centrifuged in 30 min at 4,200 rpm and 4˚C and then supernatant was collected and stored at -80°C for further analyses. Chymotrypsin and pepsin activities were performed by specific method of Worthington (1982), while trypsin and amylase were analyzed by the methods of Tseng et al. (1982) and Bernfeld (1951), respectively. Protein was determined by using Biorad protein assay. Specific activities are expressed as U mg protein^{-1}min^{-1}.

2.3. Statistical analysis

All the data were subjected to statistical treatment involving standard deviation (stdev) and mean using Excel 2016. One-way analysis of variance (ANOVA) together with Duncan tests were used to test for significant differences (at a significant level of 0.05) by using SPSS 16.0.

3. RESULTS

3.1. Temperature threshold

The mortality occurred when the temperature in containers was reduced to 13˚C. Such a rate increased to 4% as the temperature reached the level of 12˚C. When the temperature dropped to 10˚C, the mortality rate increased to 52.5% from 20% recorded at 11˚C. In the upper temperature threshold experiment, the first dead fish (2.5%) were monitored at 37˚C, and this rate increased to 5% at 38˚C. The mortality of fry was 18.8% at the temperature of 39˚C, then increased up to 52.5% as the temperature reached 40˚C. The results of two experiments showed that the temperature threshold range of striped snakehead fry was quite wide. The upper temperature threshold was up to 40ºC, while the lower temperature threshold was 10ºC.

Table 1. Average number and percentage of fry dead at the upper and lower temperature threshold experiments

Temperature	Average number of fry dead/tank	Mortality (%)
Upper temperature threshold		
37˚C	0.50	2.50
38˚C	1.00	5.00
39˚C	3.75	18.75
40˚C	10.5	52.5
Lower temperature threshold		
13˚C	0.5	2.5
12˚C	4.00	20.0
11˚C	4.00	20.0
10˚C	10.5	52.5

Data presented as mean of four replicates.

3.2. Effect of temperature on growth and physiological responses of fry stage after 90 days

a. Physiological parameters

The size of fish (1.20±0.34 g/fish) in 24ºC treatment was too small to collect blood for hematological parameter analysis. Therefore, the results of hematological parameter analysis in this study were for 27°C, 30°C, 33°C and 36°C treatments. The number of WBCs of fish was not significantly different among experimental temperatures. It is noted that the number of RBCs of fish increased with the temperature rises. The lowest RBCs were found in 27°C treatment (2.61±0.66 x 10^6 cell/mm^3), which was significantly lower than 33 and 36°C treatments (3.42±0.16x10^6 and 3.78±0.06x10^6 cell/mm^3, respectively). Hb markedly increased at 36°C (13.0±1.39 g/100 mL) compared to 10.1±0.25 g/100 mL at 27°C.

Table 3. Red blood cells (RBCs), white blood cells (WBCs) and hemoglobin concentration (Hb) of fish reared in different temperatures

Treatment	RBCs (x10^6 cell/mm^3)	WBCs (x10^3 cell/mm^3)	[Hb] (g/100 mL)
27ºC	2.61±0.66^a	124±13.3^a	10.1±0.25^a
30ºC	2.87±0.26^{ab}	101±10.9^a	11.3±1.15^{ab}
33ºC	3.42±0.16^{bc}	121±9.6^a	11.8±1.17^{ab}
36ºC	3.78±0.06^c	129±21.1^a	13.0±1.39^c

Data presented as mean ± std. Values with different letters in the same column is significantly different ($p<0.05$).

b. Glucose and cortisol concentrations

The glucose and cortisol increased with the temperature rise. The lowest values were recorded in 27°C treatment (66.5±10.3 mg/100 mL and 258±21.7 ng/mL, respectively), which were significantly lower than those of the 36ºC treatment (122±9.67 mg/100 mL and 386±31.4 ng/mL, respectively) ($p<0.05$). However, it has been shown that there was no significant difference in cortisol and glucose

concentrations among 27, 30 and 33°C treatments (Table 4).

Table 4. Cortisol and glucose concentrations of snakehead fry observed under different temperatures

Treatments	Cortisol (ng/mL)	Glucose (mg/100 mL)
27°C	258±21.7[a]	66.5±10.3[a]
30°C	269±26.9[a]	77.1±6.46[a]
33°C	257±16.4[a]	97.1±17.3[ab]
36°C	386±31.4[b]	122±9.67[b]

Data presented as mean ± std. Values with different letters in the same column is significantly different (p<0.05).

c. Osmolality, chloride and sodium ion concentrations

The results showed that the osmolality and Na^+, Cl^- were not significantly different among temperature levels (p>0.05). The osmolality of fish ranged between 290±0.76 and 298±3.17 mOsm/kg. Na^+ was from 136±0.77 to 143±2.48 mmol/L and Cl^- fluctuated from 101±1.04 to 109±8.93 mmol/L.

Table 5. Osmolality, chloride and sodium ion concentrations of fry stage after 90 days

Treatment	Osmolality (mOsm/kg)	Na^+ (mmol/L)	Cl^- (mmol/L)
27°C	290±0.76[a]	143±2.48[a]	109±8.93[a]
30°C	298±3.17[a]	136±0.77[a]	101±1.04[a]
33°C	296±2.84[a]	142±4.54[a]	105±2.59[a]
36°C	292±2.05[a]	142±1.84[a]	104±3.44[a]

Data presented as mean ± std. Values with different letters in the same column is significantly different (p<0.05).

d. Digestive enzymatic activities

The digestive enzymatic activities of the fish at high temperature treatments 30, 33, and 36°C showed significantly higher than those of the treatments 24°C. Specially, the amylase enzymatic activity in the intestine of fish increased with temperature rise while the trypsin, chymotrypsin, and pepsin enzyme activities increased as the temperature rose from 24 to 30°C and tended to decrease at the higher temperatures. There was no significant difference in the four digestive enzymatic activities among 30, 33, and 36°C treatments (p>0.05).

Table 6. Amylase, trypsin, chymotrypsin and pepsin activities of striped snakehead after rearing 90 days under different temperatures

Treatment	Amylase (U/min/mg protein)	Trypsin (mU/min/mg protein)	Chymotrypsin (U/min/mg protein)	Pepsin (U/min/mg protein)
24°C	2.20±0.45[a]	2.19±0.43[a]	61.5±8.69[a]	0.28±0.09[a]
27°C	2.79±0.44[ab]	2.93±0.59[ab]	75.7±11.5[ab]	0.40±0.08[a]
30°C	3.30±0.64[bc]	4.20±0.07[b]	95.0±12.1[b]	0.65±0.22[b]
33°C	3.82±0.69[bc]	3.44±0.65[ab]	95.0±12.9[b]	0.43±0.07[ab]
36°C	4.55±1.33[c]	4.07±1.26[b]	81.7±9.30[ab]	0.46±0.04[ab]

Data presented as mean ± std. Values with different letters in the same column is significantly different (p<0.05).

e. Growth performance

There were significant differences in the weight of fish after 30 and 60 days of culture. The 24°C treatment showed the lowest weight at these sampling times (0.11±0.02 and 0.52±0.16 g/ind., respectively) and the highest weight of fish was found at 30°C (0.20±0.04 and 4.90±2.12 g/ind., respectively). After 90 days, fish showed the greater capacity to grow at 27, 30, and 33°C, which was significantly higher than those in 24 and 36°C. The highest weight of fish was found at 30°C (13.1±3.12 g/ind.), but there was no significant difference compared to weight of fish reared at 27, 30, and 33°C. The study indicated that the temperature dropped to 24°C or increased up to 36°C, the growth performance of fish were very low (Fig. 1).

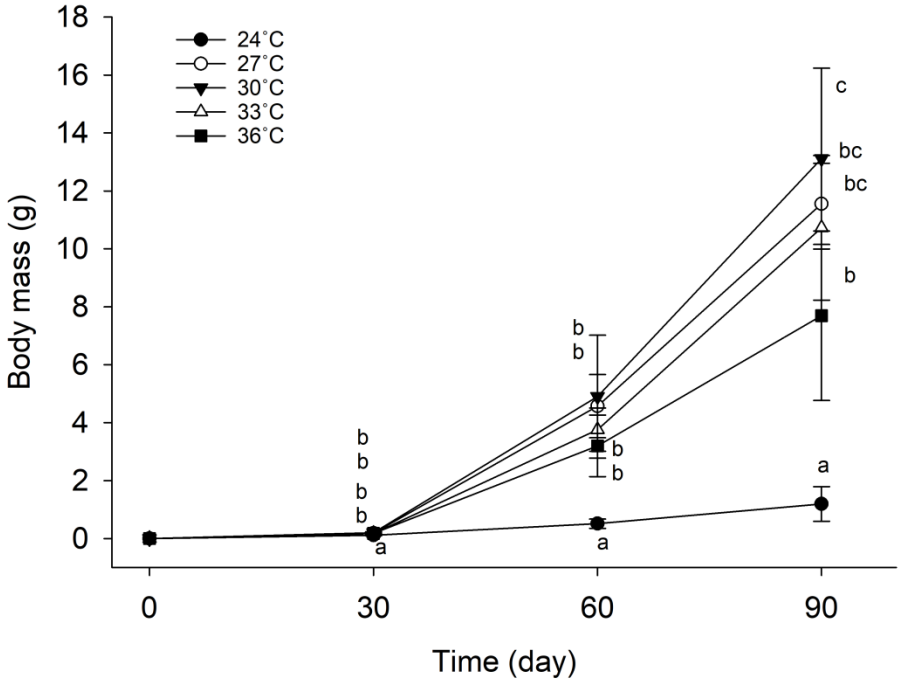

Fig. 1. The body mass of snakehead under different temperatures

Data shown in mean ± SD. The same letter (a,b,c) in the same line were not significantly different (p>0.05)

The specific growth rate (SGR) and daily weight gain (DWG) of snakehead after rearing 90 days were highest in the 30ºC treatment (7.34±0.23 %/day and 0.14±0.03 g/day, respectively), while the lowest values were recorded at the 24ºC treatment (5.13±0.42 %/day and 0.01±0.006, respectively). The results show that the growth of fish increases in a range from 24°C to 33°C and decreased as the temperature exceeds 30ºC (Table 7).

Table 7. Specific growth rate (SGR) and daily weight gain (DWG) of fish reared at different temperatures for 90 days

Treatment	SGR (%/day)	DWG (g/day)
24ºC	5.13±0.42^{a}	0.01±0.006^{a}
27ºC	7.24±0.11^{b}	0.13±0.02^{bc}
30ºC	7.34±0.23^{b}	0.14±0.03^{c}
33ºC	7.16±0.22^{b}	0.12±0.03^{bc}
36ºC	6.83±0.37^{b}	0.08±0.05^{b}

Data are presented as mean ± std. Values with different letters in the same column is significantly different (p<0.05).

f. Survival rate

The survival rate of fish gradually decreased throughout the sampling times. At day 30, the survival rate of fish was not significantly different among treatments (p>0.05) that ranged between 36.9 and 49.4%. However, the survival rate of fish continued to decrease, at the day 90th, the higest survival rate was in 30°C treatment (15.5%), which was not significantly different in the treatment of 33 and 36°C (p>0.05) (Fig. 2).

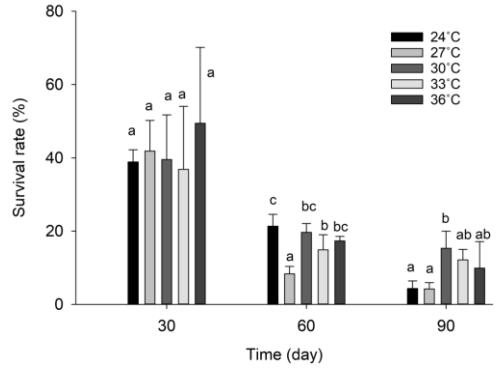

Fig. 2. Survival rate of fish reared at different temperatures

Data shown in mean ± SD. The column with the same letter (a,b,c) in figure were not significantly different (p>0.05)

4. DISCUSSION

4.1. Temperature threshold

The temperature threshold range of striped snakehead fry was quite wide. This species was able to tolerate temperature of 10-40ºC. This finding is similar to the paper by Lee and Ng (1994). Sarma et al. (2010) reported that the critical thermal maxima (CTmax) and minima (CTmin) of Climbing perch *(Anabas testudineus)* fingerling (17.03 ± 1.2 g) after acclimating to three preset temperatures (25, 30, and 35ºC) were 40.15, 41.40, 41.88ºC and 12.43, 13.06, 13.94ºC, respectively. Thermal tolerance Ctmax and CTmin of *Pangasius pangasius* fingerling after acclimating at 30, 34 and 38 °C were 42.68, 43.67, 44.05 and 12.37, 14.48, 17.22, respectively (Debnath et al. 2006).

4.2. Hematological parameters

In this study, the number of RBCs increased with rising temperature. The increase in the number of RBCs showed a response for the rising demand for oxygen consumption resulted from increasing metabolism and osmoregulation (Martinez-Alvarez et al., 2002). Huong and Tu (2010) stated that RBCs play a vital role in oxygen transfer, and fish exposed to rising temperatures become more active and metabolic, leading to an increase in oxygen demand thereby increase of RBCs. Increased RBCs and Hb are also common responses dealing with stress (Carvalho & Fernandes, 2006). The result of this study is in agreement with the study by Hao (2015) on giant gourami (*Osphronemus goramy*) juveniles, which suggested that the RBCs increased with elevated temperatures from 22°C to 34°C. Similarly, the hematological parameters in eel including RBCs and Hb tended to increase at high temperatures (Thinh, 2019). A study on *Chitala ornata* also showed that RBCs also increased when the temperature rose from 27 to 34°C (Gam, 2018). Fish cultured in unfavorable conditions, WBCs play a role to protect the fish from pathogen infection (Heath, 1995; Huong & Tu, 2010). In the current study, WBCs of *Channa striata* tended to increase when the temperature increased up to 36°C although there was no significant difference among treatments ($p>0.05$). Nhu (2010) reported that WBCs of striped catfish (*Pangasianodon hypophthalmus*) increased with temperature from 28°C to 42°C.

4.3. Glucose, cortisol and Na^+, Cl^- concentration

In addition to hematological parameters, plasma glucose and cortisol levels are also useful indicators to assess the capacity of fish to perform under temperature change or other stresses (Boyd & Tucker, 1998; Pacheco & Santos, 2001). This study indicated that the plasma glucose and cortisol significantly increased in fish reared at 36°C compared to the control treatment. Rising temperatures have been reported to resulted in the increases in cortisol and glucose levels of striped catfish (Thinh et al., 2013), giant gourami (Hao, 2015), and basa catfish (Ha et al., 2017). Kiilerich and Prunet (2011) reported that the cortisol concentration in blood of healthy fish ranged from 5 to 10 ng/mL and increased up to 10-100 times when fish got stressful. In fresh water teleost, the plasma Na^+ and Cl^- often decreased at low temperature. The explaination for this could be a reduced ability to osmoregulate in the lower temperature (Umminger, 1969). This also could be the decrease in the metabolic cost of osmoregulation when metabolism is reduced (Prosser et al., 1970). According to Houston (1968), Na^+ and Cl^- in freshwater fish usually either rise with increasing temperature or are little affected, and other patterns of variation do also occur. However, in the present study these parameters were not significantly different among temperatures in ranges 24 to 36°C. These finding are similar in goldfish that the plasma Na^+ and Cl^- was constant in fish acclimated to temperatures between 10 and 30°C (Mackay, 1974).

4.4. Growth and survival rate

Growth is a specific physiological function and also a continuous process which depends on several factors (Bœuf & Payan, 2001) such as light (Bœuf & Le Bail, 1999), temperature (Carriquiriborde et al., 2009), salinity (Peters & Boyd, 1972; Peterson et al., 1999; Tipsmark et al., 2004; Phuc et al., 2014) and the interaction of temperature and salinity (Phuc, 2015). In this study, within the temperature range from 27 to 33°C, fish performed a higher growth rate, compared to 24 and 36°C. This indicates that both increase and decrease in temperature could have impact on the growth performance of snakehead fry. The fish growth performance of the present study is in accordance with findings by Andrews and Stickney (1972); Cox and Coutant (1981); Cuenco et al. (1985) and Requena et al. (1997). The relationship between temperature and growth was also illustrated in a trial carried out by Buentello et al. (2000), in which weight gain was greatest for channel catfish (*Ictalurus punctatus*) juveniles held at 3°C above mean water temperature. Britz and Hecht (1987) reported that *Clarias gariepinus* performed a higher growth rate at temperatures from 25 to 33ºC, with the highest being shown at 33ºC. This

confirms the studies which the growth of fish increased with raised temperatures (Hao, 2015; Thinh, 2013; Chinh, 2014). The explanation for this could be that increasing temperature within the thermal tolerance range of the fish results in increases in metabolic processes, enzymatic activity levels, appetite, and foraging efficiency, and thus, in biochemical reaction rates (Brett & Groves, 1979; Cossins & Bowler, 1987; Taylor et al., 1997; Huong & Tu, 2010; Biro et al., 2010). However, the growth of fish dramatically dropped at 36°C since at this temperature, fish use much more energy for their increasing metabolic processes and swimming activity. It was revealed that the food consumption of magur (*Clarias batrachus*) was seen to decrease once the optimal temperature exceeds (Ahmad et al., 2014). The other study on magur also showed that this species grew well up to 32°C and were under stress at 35°C with mortality being started at 38°C (Dehadrai et al., 1985). This has been confirmed by the results of the current study, in which glucose and cortisol significantly increased at 36°C and the energy was possibly dedicated to stress responses. Besides, the activities of trypsin and chymotripsin decreased at 36°C, which could result in a decrease in the growth rate of fish.

On the other hand, low temperature (24°C) seems to be a stressful condition for fish. Due to feeding behavior that snakehead fry mostly use *Moina* and powder feed in most of the experimental period, therefore, the data of feed consumption rate could not be achieved in this study. However, common observations suggested that fish might have less appetite for feed at this temperature, resulting in a decrease in the growth rate. Goolish and Adelman (1984) stated that the feed conversion efficiency of common carp (*Cyprinus carpio)* decreased with lower temperatures. The same result was found by Ahmad et al. (2014), in which the rate of food consumption gradually fell as the temperature decreased from 25°C to 10°C. The survival rate of striped snakehead fry in this study was decreased at low temperature (24°C). During the experiment, the fish in this treatment showed a low appetite and less active. The enzymatic activities were also low at the treatment of 24°C, resulting in the decrease in food digestion and absortion which finally caused higher motality rate.

The findings of this study indicated that the growth of fish was greater in a range from 27°C to 33°C. However, 30°C could be considered as the optimal temperature for striped snakehead nursing, in which fish showed high growth performance, survival rate, and digestive enzymatic activities with no significant difference in hematological parameters of fish reared at 27°C (normal temperature). The fish growth was increased in the range 27-33°C , and it was reduced as temperature exceeds this range. Therefore, it could be assumed that striped snakehead can tolerate with global warming situation predicted by IPCC (2014).

5. CONCLUSIONS

Striped snakehead at fry stage showed a high tolerance to temperatures ranging from 10 to 40ºC. At the temperatures approaching the upper limitation level, the hematological parametter tended to increase as a response for the temperature stressor. The optimal temperature for striped snakehead nursing could be 30°C that the fish show better growth and survival. Snakehead fry development was dramatically impacted as temperature significantly dropped reaching 24ºC or increased up to 36ºC.

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