Int Aquat Res (2020) 12:209–218
https://doi.org/10.22034/IAR.2020.1900150.1053

ORIGINAL RESEARCH

Effect of water temperature on the physiological responses in *Betta rubra*, Perugia 1893 (Pisces: Osphronemidae)

Firman M. Nur . Agung S. Batubara . Kartini Eriani . Usman M. Tang . Abdullah A. Muhammadar . Mohd N. Siti-Azizah . Martin Wilkes . Nur Fadli . Syamsul Rizal . Zainal A. Muchlisin

Received: 18 May 2020 / Accepted: 06 August 2020 / Published online: 30 September 2020

Abstract Water temperature is a limiting factor in fish health and plays a crucial role, especially in endemic species that are more sensitive to ambient temperature changes. The objective of the present study was to examine the effects of temperature on growth patterns, survival, blood glucose, gill histology, and erythrocyte cell abnormality of *Betta rubra*, an endemic species in Aceh and Northern Sumatra, Indonesia. The fish sample was collected from Nagan Raya, Aceh Province, Indonesia. The fish were acclimatized for three days prior to experimental trials at five temperature levels, 24, 26, 28, 30 and 32 °C for 14 days. Fish were taken randomly from every treatment to measure blood glucose levels and gill samples were taken at the start and end of the experiment. The results showed the highest survival at a temperature of 28 °C (83.33%). The lowest blood glucose level was also found at a temperature of 28 °C. In addition, an increase and decrease in temperature exceeding 28 °C caused gill damage. Higher temperatures caused an increase in the abnormality of erythrocyte cells, with the highest percentage of abnormality found at 32 °C. Overall, this study confirmed that exposure to lower and higher temperature than the optimal is stressful to *B. rubra*.

Keywords Gill abnormality . *Betta rubra* . Blood glucose . Ambient temperature

Introduction

Indonesia is one of the most biodiverse countries in the world. According to Fishbase (2019), at least 4,878 species of fish have been recorded from Indonesian waters, of these 1,258 species are freshwater fish. However, these numbers are underestimated since many locations have never been explored and therefore many new species are being described every single year. Sumatera island is one of the most biodiverse regions in Indonesia (Muchlisin and Azizah 2009). According to Kottelat et al. (1993) there were 272 species of freshwater fish reported from Sumatra, including 30 species endemic to the island. Wargasasmita (2002) reported 589 species of freshwater fish in Sumatra, including 58 endemic species with 14 of these threatened by ecological perturbation and climate change (Booth and Evans 2011; Oczkowski et al. 2015;

Firman M. Nur
Graduate School of Mathematics and Applied Sciences, Universitas Syiah Kuala, Banda Aceh, Indonesia

Agung S. Batubara, Abdullah A. Muhammadar, Nur Fadli, Syamsul Rizal, Muchlisin Z. Abidin ✉
Department of Aquaculture, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Jl. Tgk. Syech Abdul Rauf, Banda Aceh, Indonesia
e-mail: muchlisinza@unsyiah.ac.id

Kartini Eriani
Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala, JL. Syech Abdurrauf, Banda Aceh, Indonesia

Usman M. Tang
Department of Aquaculture, Faculty Fisheries and Marine Sciences, Universitas Riau, Pekanbaru, Indonesia

Mohd N. Siti-Azizah
Institute Marine Biotechnology, Universiti Malaysia Terengganu, Malaysia

Martin Wilkes
Center for Agroecology, Water and Resilience, Conventry University, United Kingdom

Kano et al. 2016).

Global warming that triggers an increase in the average temperature of the air temperature (Nguyen et al. 2011; Lineman et al. 2015). Based on the Climatology, Meteorology and Geophysics Agency of Republic of Indonesia, the earth temperature has been increasing approximately 0.03 °C annually (Bmkg 2019). Climate change may affect fish directly through at least two mechanisms. Firstly, acidification occurs as atmospheric CO_2 increases (Cole and Prairie 2009), a process which threatens the fish populations (Orr et al. 2005; Doney et al. 2009; Pachauri et al. 2014). Secondly, increases in water temperature associated with climate change negatively impact fish communities, for example through changes in species composition (Caldeira and Wickett 2003; Xu et al. 2009; Bezuijen 2011; Oczkowski et al. 2015), distribution and abundance (Gupta et al. 2012; Kjelland et al. 2015).

Fish are poikilothermic animals which adjust their body temperature to the ambient water temperature (Bowden 2008 ; Abram et al. 2017; Frick et al. 2018). However, there are limits to fish physiological adaptation to changes in ambient temperature, and therefore the water temperature can be a limiting factor for fish health (Viadero 2005; Simpson et al. 2013). Tang et al. (2017) and Nyanti et al. (2018) reported that changes in water temperature and pH can cause stress, decrease feeding activity, reduce growth and survival rates and lead to erythrocytic abnormalities such as echinocytic and elongated shape (Ashaf-Ud-Doulah et al. 2019; Shahjahan et al. 2019; Shahjahan et al. 2020). Moreover, the changes in water temperature also cause damage to gill cells (Mohammadi et al. 2019). Indeed, this impact is highly significant in endemic species (Leuven et al. 2011; Davis et al. 2019). According to Ficke et al. (2007), endemic fish typically have narrow tolerance to environmental changes including temperature, pH and dissolved oxygen, and therefore are very susceptible to extinction due to climate change.

Betta rubra, locally referred to as *cupang* fish, is one of the endemic fish species found in Aceh waters. This species is distributed from the Southwestern part of Aceh to Sibolga in North Sumatra (Hui 2013). *Betta rubra* has an important role both ecologically and economically. This species is a highly economically important ornamental fish and plays a crucial trophic role in the freshwater ecosystem. Besides, *B. rubra* is an invaluable germplasm, because of its endemicity in Sumatra island. However, the population of *B. rubra* has been decreasing over the years due to habitat destruction, over-exploitation of the wild population, introduction of alien fish species and climate change (Muchlisin 2008). Therefore, this species has been listed as an endangered species in the IUCN Redlist database (Low 2019)

Research on *B. rubra* is scarce. The two documented studies in the literature have been limited to the description and taxonomic status of the *B. rubra* (Schindler and Van Der Voort 2011; Hui 2013). However, studies on the physiological response due to temperature change have never been published. This information is important to predict the effects of climate change and to plan a better mitigation strategy for this species. Therefore, the objective of the present study was to examine the effects of water temperature changes on the growth performance, survival, gill morphology and blood profiles of *B. rubra,* an endemic species in Sumatra.

Materials and methods

Experimental fish

Adult *B. rubra* with mean bodyweight of 0.5±0.10 g and mean total length of 3.90±0.30 cm were used in this experiment. The fish were collected from Nagan Raya, Aceh, Indonesia during the dry season (27.8-28.7 ºC) using scoop nets and acclimatized for three days in the Laboratory of Ichthyology, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh. During acclimatization, the fish were fed twice a day up to satiation with commercial feed (Hi-Pro-Vite 888 with 42 % crude protein).

Experimental design and research procedure

A completely randomized experimental design with one tested factor (univariate) was used in this study. The tested factor was differences in water temperature at five levels, modified from Hassanen et al. (2014), namely; 24, 26, 28, 30 and 32 °C. Each temperature treatment was conducted with three replications. During the procedure, a fish was taken randomly one at a time from the acclimatized tank

and measured for initial length and weight, then stocked into 15 plastic containers (45 cm x 35 cm x 30 cm in size) with 5 L of water at a stocking density of 15 fish per container (Niazie et al. 2013). The experiment was conducted in the laboratory temperature-controlled room. The water temperature in the containers was adjusted to room temperature (24 °C) with a heater (Amara HT-100). The temperature was increased gradually at 1 ℃ per 12 hours until it reached the testing point (Shahjahan et al. 2019). The fish were reared at the treatment temperature for 14 days (Shahjahan et al. 2020).

Weight gain and survival rate analysis

Weight gain was calculated as follows: Wg = Wt – Wo, where Wg = weight gain (g), Wt = average body weight of fish at the end of the experiment (g), Wo = average body weight of fish at the start of the experiment (g). The survival rate (SR) of the fish was calculated based on Muchlisin et al. (2016) and Muchlisin et al. (2017) as follows: Survival (%) = (No – Nt)/No x100, where No is total fish at the start of the experiment, Nt is total fish mortality during the experiment.

Blood glucose analysis

The blood glucose was examined on five occasions: firstly, in the field when the fish was sampled; secondly, upon reaching the laboratory from the field; thirdly, after three days acclimated in the laboratory; fourthly, at day-7 of the experiment; and fifthly, at day-14 of the experiment. The blood was collected from three randomly sampled fish from each treatment. The fish was anesthetized using MS-222 and euthanised. Immediately after collection of blood from caudal peduncle of experimental fish, blood glucose level was estimated using glucose strips by Easy-Touch GCU.

Erythrocyte abnormality analysis

For erythrocyte abnormality analysis, each blood sample was smeared onto a clean glass slide and dried at room temperature for 10 min. The sample was then fixed using 98% methanol for another 10 min. After a further 10 min the sample was stained using 5% Giemsa solution, and then the sample was washed using distilled water and dried at room temperature for 24 h. The sample was observed using a stereomicroscope (Primo Star Zeeis, Germany) with 100x objective lens. The erythrocyte abnormality was observed by random sampling of 900 erythrocyte cells. The abnormality was categorized into two categories; erythrocytic nuclear abnormalities (ENA) and erythrocytic cellular abnormalities (ECA) (Shahjahan et al. 2018). The ENA is classified as: binucleated and nuclear bridge while ECA is classified as: fusion, teardrop, and twin shaped cells (Carrasco et al. 1990).

Histological snalysis of gill morphology

Gill morphology was observed using histological analysis after the experiment. Four fish samples were taken randomly from each treatment and the fish anesthetized using MS-222 and euthanised (Nugroho et al. 2017). The mouth was then dissected from the *cavum oris* to the lower area of the operculum. The gill arch was separated and the whole gill was removed from the gill cavity and fixed in Bouin solution for 24 h. The second gill arch was dehydrated in an increasing alcohol series and then cleared using a combination of xylene and alcohol, embedded in paraffin and sectioned (4-5 µm) using a microtome (HM 325 Rotary Microtome, Thermo Scientific™). The sections were attached to a glass slide and dried in a stove (37 ℃) for 24 h and followed at 60 ℃ for one hour. The sample was stained with Ehrlich hematoxylin-eosin (Muchlisin et al. 2010). The gill morphological abnormalities were observed in primary lamella and secondary lamella using a stereo microscope (Primo Star Zeeis, Germany, 100x objective lens). The criteria for defining gill cell abnormalities were based on Bernet et al. (1999).

Data analysis

The data on blood glucose, Erythrocyte Abnormality and survival rate were subjected to one-way Analysis of Variance (one-way ANOVA) followed by Duncan's multiple range test with 95% confidence limits. Data on gill cell abnormality were analyzed descriptively.

Results

Weight gain and survival rate

The experimental fish exposed at 28 °C showed a weight gain of 0.02 g, while fish exposed to 26 °C did not gain weight and in fact even lost weight during the experiment (Table 1). The highest survival rate was recorded for treatment at 28 °C (83.3%), while the lowest survival was recorded at 24 °C (0%, all fish died). The mortality starts to occur at day-1 and all fish died at day-6 at 24 °C. At day-14, the lowest survival rate was found for fish reared in 26 °C (3.33%). The rate increased to 83.33% for fish reared at the water temperature of 28 °C, then decreased gradually at a temperature above 30 °C (Table 1).

Table 1 Growth and survival rates of *Betta rubra* exposed to different water temperatures for 14 days

Parameter	Exposed temperature				
	24 °C	26 °C	28 °C	30 °C	32 °C
Initial weight (g)	0.48±0.02	0.50±0.01	0.50±0.02	0.49±0.02	0.49±0.02
Final weight (g)	-	0.33	0.52±0.03	0.62±0.03	0.50±0.02
Weight gain (g)	-	-0.17	0.02	0.13	0.01
Survival rate (%)	0	3.33 ± 0.33^{a}	83.3 ± 0.33^{c}	70.00 ± 5.77^{bc}	53.33 ± 13.33^{b}

Note: Mean±SD in same row with different superscript are significantly different (P< 0.05)

Table 2 Blood glucose concentration (Mean±SD) of *Betta rubra* in the field, laboratory and post acclimatization

Tank No.	At the field (*in situ*)	At laboratory post transportation	At laboratory three-days post acclimatization
1	1.40±0.0 mmolL^{-1}	4.05±0.07 mmolL^{-1}	2.80±0.10 mmolL^{-1}
2	1.50±0.14 mmolL^{-1}	4.10±0.0 mmolL^{-1}	2.75±0.05 mmolL^{-1}
Average	1.45±0.10 mmolL^{-1}	4.08±0.50 mmolL^{-1}	2.77±0.07 mmolL^{-1}

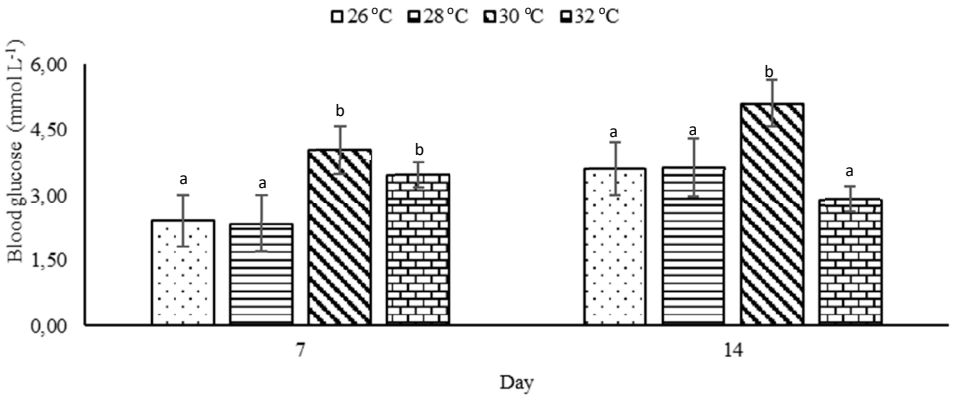

Fig. 1 Changes in blood glucose concentration post-exposure to different temperatures. Values accompanied by different letters indicate statistically significantly difference (P< 0.05).

Blood glucose

The blood glucose levels of the fish in the field just after sampling was 1.4-1.5 mmolL^{-1}. These values increased to 4.05-4.1 mmolL^{-1} post transportation from the field to the laboratory and then decreased to 2.75-2.80 mmolL^{-1} after acclimation for three days (Table 2). We assume that the fish had already adapted to the laboratory conditions at the initiation of the experiment. All the fish at the treatment temperature of 24 °C died before day-7, and therefore there is no data from this treatment. At day-7, the blood glucose ranged from 2.23 mmol L^{-1} to 4.03 mmol L^{-1} and at day-14 the blood glucose ranged from 2.90 mmol L^{-1} to 5.10 mmol L^{-1}, the highest concentration of blood glucose was observed at the temperature of 30 °C (Figure 1).

Erythrocyte cell abnormalities

Seven types of erythrocyte abnormalities were observed at the end of the experiment (Figure 2). Erythrocyte abnormalities of echinocytic was highest at 32 °C, and was significantly different from other treatments ($P< 0.05$). The fusion, elongated shape, and twins were also highest at 32 °C. These values were significantly different from 28 °C, but were not significantly different from 30 °C ($P> 0.05$). Binucleated, nuclear bridge and tear-drop shape were not significantly different among the treatments ($P> 0.05$) (Table 3).

Gill abnormalities

Based on histological analysis, four types of gill abnormalities were identified, namely; shortening of secondary lamella (SH), fused secondary lamella (F), aneurysm (A), and blood congestion (CB) (Figure 3). Secondary fusion was observed at 26 °C, while congested blood primer lamellae were recorded at 30°C and 32 °C. At 28 °C, the gill histology showed normal conditions without any abnormalities.

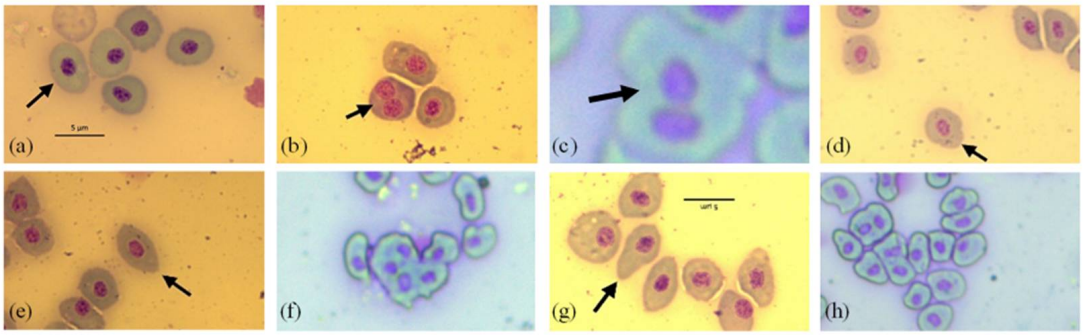

Fig. 2 Erythrocyte abnormality (a) regular cell, (b) *binucleated*, (c) *nuclear bridge*, (d) *echinocytic*, (e) *elongated shaped*, (f) *fusion*, (g) *tear drop shaped*, and (h) *twin*.

Table 3 Erythrocyte abnormalities of *Betta rubra* after 14 days exposed at different temperatures

Temp.	Binucleated (%)	Nuclear bridge (%)	Echinocytic (%)	Fusion (%)	Elongation shaped (%)	Tear drop shaped (%)	Twins (%)
28 °C	0±0^{a}	1.33±0.19^{a}	2.22±0.22^{a}	1.78±0.29^{a}	1.67±0.19^{a}	0.89±0.48^{a}	1.56±0.29^{a}
30 °C	0.11±0.11^{a}	1.56±0.29^{a}	5.89±0.48^{b}	2.56±0.29^{ab}	2.56±0.59^{ab}	2.00±0.19^{a}	2.67±0.19^{b}
32 °C	0.11±0.11^{a}	2.22±0.29^{a}	8.89±0.40^{c}	3.89±0.59^{b}	4.00±0.51^{b}	2.00±0.19^{a}	3.44±0.29^{b}

Mean±SD followed with different superscript in the same column are significantly different ($P< 0.05$).

Discussion

The current study revealed that *B. rubra* grows optimally at a temperature of 28 °C. Previous studies in the Siamese fighting fish, *B. splendens* showed that the best maintenance temperature range was 20-30 °C (Reyes-Bustamante and Ortega-Salas 2002). Our study showed that the survival rate of *B. rubra* decreased gradually when the water temperature rose from 28°C to 30 °C and 32 °C while there was 100% mortality within seven days at 24 °C. This study indicates that *B. rubra* cannot tolerate decreasing or increasing temperatures.

Several studies have reported that temperature is an abiotic factor that most influences the survival and distribution of fish (Kestemont et al. 2003; Martínez-Álvarez et al. 2005). At low temperatures, fish cannot produce enough heat for their bodies to tolerate the thermal conditions (Acharya and Mohanty 2014; Giannetto et al. 2014; Maisano et al. 2016). At temperatures of 26°C, 30°C and 32 °C, decreases in the body weight of fish were observed at the end of the experiment. In contrast, the body weight increased in fish reared at 28 °C. However, changes in temperature that exceed the tolerance limit trigger stress which can have negative impacts on fish (Dominguez et al. 2004), for example; stunted growth in meagre, *Argyrosomus regius* (Chatzifotis et al. 2018), late gonad maturation in Atlantic salmon, *Salmo salar* (King and Pankhurst 2007) and disease susceptibilty in blueback salmon, *Oncorhynchus nerka* (Fish and Rucker 1945), inhibited growth, even death in Bull trout, *Salvelinus confluentus* (Selong et al. 2001), and negatively impacts fish metabolism in Brond snout, *Chondrostoma regium* (Mohammadi et al. 2019).

Hastuti et al. (2003) explained that the mechanism underlying the increase in blood glucose levels begins when the receptor organ receives a stressor, then this information is conveyed to the hypothalamic by the nervous system. The hypothalamus secretes the Corticoid Releasing Factor (CRF) which stimulates the pituitary gland to secrete Adrenocorticotropic hormone (ACTH), Melanophore-Stimulating hormone (MSH) and β-endorphin (β-End). These hormones regulate inter renal cells to secrete the cortisol hormone. The presence of the cortisol triggers an increase in the production of enzymes involved in gluconeogenesis. This will have an impact on increasing blood glucose which is an early indicator of fish experiencing stress (Mommsen et al. 1999; Beyea et al. 2005; Islam et al. 2019). This mechanism is linked to energy demand for maintaining the metabolic activity in tissue cells (Deslauriers and Kieffer 2012).

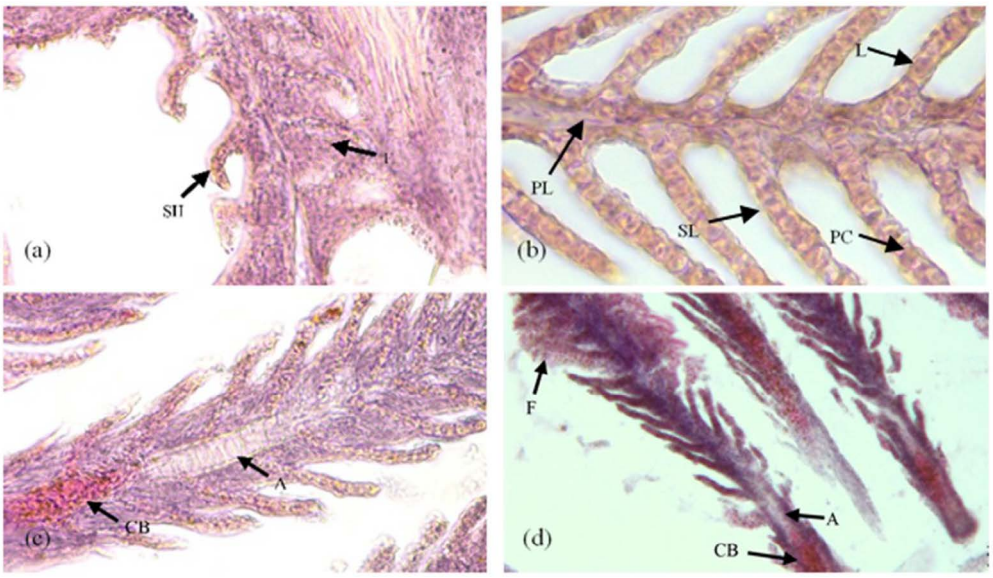

Fig. 3 Gill abnormalities of Betta rubra (a) at 26 oC showed shortening of secondary lamella (SH) and fusion of secondary lamella (F); (b) at 28 oC, the gill histology showed normal conditions, PL: primary lamella, SL: Secondary lamella, PC: Pillar cell, L: Lacuna; (c) at 30 oC blood congestion (CB); and (d) at 32 oC blood congestion (CB), fusion (F), and aneurysm (A).

According to Polakof et al. (2012), the average blood glucose level in Perciformes fish is about 3.7-4 mmolL^{-1}; therefore the blood glucose levels of *B. rubra* fish passed the tolerance limit except at treatment 28 °C. This indicates that *B. rubra* is physiologically disturbed due to stress. At 26 °C the fish also experienced an increase in blood glucose levels by up to 140% (3.6 mmolL^{-1}). This is an indication that the fish was experiencing stress due to low temperature shock, while the average level of glucose in wild *B. rubra* (no stress conditions) is 1.5 mmolL^{-1}. Similar results were reported in previous studies on several species such as in Channel catfish, *Ictalurus punctat* (Strange 1980), rohu, *Labeo rohita*, common carp, *Cyprinus carpio* (Chatterjee et al. 2004), Hong Kong grouper, *Epinephelus akaara* (Cho et al. 2015) and striped wallago catfish, *Wallago leeri* (Tang et al. 2017). However, the blood glucose decreased to 2.23 mmolL^{-1} at a temperature of 28 °C; not much deviated from normal level of blood glucose of the species in the wild. The survival rate was also higher (83.33%). The highest blood glucose concentration (above 4.0 mmol L^{-1}) was found at 30 °C, indicating that the fish was in a stressed condition (Cech and Brauner 2011). The increase in glucose level in this treatment could be caused by the alteration of glycogen to glucose to meet the increased energy demand needed to reduce stress due to temperature shock (Xie et al. 2017). However, in *B. rubra*, the negative impact of temperature decrease is more severe than temperature increase as recorded in this study. Tang et al. (2017) reported optimum blood glucose level in the striped wallago, *Wallago leeri* maintained at 29 °C, while an increase or decrease of 3 °C of water temperature impacted blood glucose levels. A similar finding was also reported in the pacu, *Piaractus mesopotamicus* reared at a temperature of 18 °C to 30 °C (Pinto et al. 2019).

Several studies have shown that the effects of thermal stress can cause changes in hematological parameters in response to hypoxia or anoxia (Carvalho and Fernandes 2006). Erythrocyte abnormalities such as elongated, fusion, tear-drop shaped and twin shaped cells in fish exposed to high temperatures has been attributed to increased lipid peroxidation in erythrocytes as recorded in this study. Echinocytic is caused by erythrocyte membrane lipid solubility which leads to apoptosis (Walia et al. 2013), while binucleated is because of failure of cytokinesis at the stage of cell nucleus division but which is not followed by cytoplasmic division (Pera and Schwarzacher 1968). The results of this study indicate that in general, the abnormality of red blood cells increases with an increase in temperature. Similar findings were also reported in the rohu, *Labeo rohita* (Ashaf-Ud-Doulah et al. 2019), common carp *Cyprinus carpio* (Shahjahan et al. 2020), zebrafish *Danio rerio* (Shahjahan et al. 2018) and striped catfish *Pangasianodon hypophthalmus* (Islam et al. 2019).

The zero to low survival rates at temperature of 24 °C was probably due to the low temperatures affecting metabolic decline (Mohammadi et al. 2019), which is associated with gill damage (Leino and Mccormick 1993; Mohammadi et al. 2019). Therefore, the decrease in metabolism, and subsequent gill damage caused most of the fish to die. This phenomenon was also found at higher temperature of 32 °C.

Conclusion

Betta rubra is unable to tolerate changes in the ambient water temperature of its habitat, causing an increase in blood glucose levels, abnormal red blood cells, and damage to the gill cells, and subsequently resulting in mortality.

Conflict of interest The authors declare that they have no conflict of interest.

Authors' contributions FMN and ASB: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodolog, Resources, Software, Validation, Visualization, Writing – Original Draft Preparation; KE, UT and AAM: Conceptualization, Methodology, Supervision, Writing – Original Draft Preparation; MNS, MW, NF and SR: Conceptualization, Formal Analysis, Supervision, Writing – Original Draft Preparation; MZA: Conceptualization, Funding Acquisition, Supervision, Writing – Review & Editing. All authors read and approved the final manuscript.

Acknowledgements This study was supported by Ministry of Research, Technology and Higher Education through World Class research (Contract Number: 91/UN11.2/PP/SP3/2018). Therefore, the authors would like to thank the Ministry of Research, Technology & Higher Education for supporting this study.

References

Abram Q, Dixon B, Katzenback BA (2017) Impacts of low temperature on the teleost immune system. Biology 6:39. https://doi.org/10.3390/biology6040039

Acharya G, Mohanty PK (2014) Comparative haematological and serum biochemical analysis of catfishes *Clarias batrachus* (Linnaeus, 1758) and *Heteropneustes fossilis* (Bloch, 1794) with respect to sex. J Entomol Zool Stud 2:191-197

Ashaf-Ud-Doulah M, Shahjahan M, Islam SM, Al-Emran M, Rahman MS, Hossain MAR (2019) Thermal stress causes nuclear and cellular abnormalities of peripheral erythrocytes in Indian major carp, rohu *Labeo rohita*. J Therm Biol 86:102450. https://doi.org/10.1016/ j. jtherbio.2019.102450.

Beyea MM, Benfey TJ, Kieffer JD (2005) Hematology and stres physiology of juvenile diploid and triploid shortnose sturgeon (*Acipenser brevirostrum*). Fish Physiol Biochem 31:303-313. https://doi.org/10.1007/s10695-005-1552-y

Bezuijen MR (2011) Wetland biodiversity and climate change briefing paper: rapid assessment of the impacts of climate change to wetland biodiversity in the Lower Mekong Basin. Victoria: ICEM

BMKG (2019) Tren suhu. https://www.bmkg.go.id/iklim/?p=tren-suhu Accessed 13 September 2019

Booth DT, Evans A (2011) Warm water and cool nests are best. How global warming might influence hatchling green turtle swimming performance. PLoS One 6e23162. https://doi.org/10.1371/journal.pone.0023162

Bowden T (2008) Modulation of the immune system of fish by their environment. Fish Shellfish Immunol 25:373-83. https://doi.org/10.1016/j.fsi.2008.03.017

Caldeira K, Wickett ME (2003) Anthropogenic carbon and ocean pH. Nature 425:365-365. https://doi.org/10.1038/425365a

Carrasco KR, Tilbury KL, Myers MS (1990) Assessment of the piscine micronucleus test as an in situ biological indicator of chemical contaminant effects. Can J Fish Aquat Sci 47:2123-2136. http://dx.doi.org/10.1139/f90-237

Carvalho C, Fernandes M (2006) Effect of temperature on copper toxicity and hematological responses in the neotropical fish *Prochilodus scrofa* at low and high pH. Aquaculture 251:109–117

Cech JJ, Brauner CJ (2011) Respiration: an introduction. In: Farrell, A.P. (Ed.), Encyclopedia of Fish Physiology: From Genome to Environment. Academic press, United States

Chatterjee N, Pal A, Manush S, Das T, Mukherjee S (2004) Thermal tolerance and oxygen consumption of *Labeo rohita* and *Cyprinus carpio* early fingerlings acclimated to three different temperatures. J Therm Biol 29:265–270. https://doi.org/10.1016/j.jtherbio.2004. 05.001

Chatzifotis S, Clavero S, Kounna C, Soumalevris A, Feidantsis K, Antonopoulou E (2018) Effects of long-term feed deprivation on body weight loss, muscle composition, plasma metabolites, and intermediate metabolism of meagre (*Argyrosomus regius*) under different water temperatures. Fish Physiol Biochem 44:527-42. https://doi.org/10.1007/s10695-017-0451-3

Cho HC, Kim JE, Kim HB, Baek HJ (2015) Effects of water temperature change on the hematological responses and plasma cortisol levels in growing of red spotted grouper, *Epinephelus akaara*. Dev Reprod 19:19-24. https://doi.org/10.12717/devrep.2015.19.1.019

Cole JJ, Prairie YT (2009) Dissolved CO2. In: Gene E. Likens, (Editor) Encyclopedia of Inland Waters. Elsevier, Oxford

Davis BE, Cocherell DE, Sommer T, Baxter RD, Hung TC, Todgham AE, Fangue NA (2019) Sensitivities of an endemic, endangered California smelt and two non-native fishes to serial increases in temperature and salinity: implications for shifting community structure with climate change. Conserv Physiol 7:coy076. https://doi.org/10.1093/conphys/coy076

Deslauriers D, Kieffer JD (2012) The effects of temperature on swimming performance of juvenile shortnose sturgeon (*Acipenser brevirostrum*). J Appl Ichthyol 28:176–181. https :// doi.org/10.1111/j.1439-0426.2012.01932.x

Dominguez M, Takemura A, Tsuchiya M, Nakamura S (2004) Impact of different environmental factors on the circulating immunoglobulin levels in the Nile tilapia, *Oreochromis niloticus*. Aquaculture 241:491-500. https://doi.org/10.1016/j.aquaculture.2004.06.027

Doney SC, Fabry VJ, Feely RA, Kleypas JA (2009) Ocean acidification: the other CO2 problem. Ann Rev Mar Sci 1:169-192. https://doi.org/10.1146/annurev.marine.010908.163834

Ficke AD, Myrick CA, Hansen LJ (2007) Potential impacts of global climate change on freshwater fisheries. Rev Fish Biol Fish 17:581–613. https ://doi.org/10.1007/s11160 007-9059-5

Fish F, Rucker R (1945) Columnaris as a disease of cold-water fish. Trans Am Fish Soc 73:32-36. https://doi.org/10.1577/1548-8659(1943)73[32:CAADOC]2.0.CO;2

Fishbase (2019) Spesies list genus *Betta*. https://www.fishbase.se/identification/SpeciesList. php?genus=Betta. Accessed 30 August 2019

Frick C, Vierheilig J, Linke R, Savio D, Zornig H, Antensteiner R, Baumgartner C, Bucher C, Blaschke A, Derx J, Kirschner A, Ryzinska-Paire G, Mayer R, Seidl D, Nadiotis-Tsaka T, Sommer R, Farnleitne AH (2018) Poikilothermic animals as a previously unrecognized source of fecal indicator bacteria in a backwater ecosystem of a large river. Appl Environ Microbiol 15:e00715-18. https://doi.org/10.1128/AEM.00715-18

Giannetto A, Fernandes JM, Nagasawa K, Mauceri A, Maisano M, De Domenico E, Cappello T, Oliva S, Fasulo S (2014) Influence of continuous light treatment on expression of stres biomarkers in Atlantic cod. Dev Comp Immunol 44:30-34. https://doi.org/10.1016/j.dci. 2013.11.011

Gupta BK, Sarkar UK, Bhardwaj SK (2012) Assessment of habitat quality with relation to fish assemblages in an impacted river of the Ganges basin, northern India. Environmentalist 32:35-47. https://doi.org/10.1007/s10669-011-9363-4

Hassanen G, Salem M, Younes M, Heba EAE (2014) Combined effects of water temperature and salinity on growth and feed utilization of juvenile red tilapia (*Oreochromis niloticus* x *O. aureus*). World J Zool 9:59-70

Hastuti S, Supriyono E, Mokoginta I, Subandiyono (2003) Blood glucose response of giant gouramy (*Osphronemus gaouramy*, Lac.) to the stres of environmental temperature changes. J Akua Indo 2:73-77. https://doi.org/10.19027/jai.2.73-77

Hui TH (2013) The identity of *Betta rubra* (Teleostei: Osphronemidae) revisited, with description of a new species from Sumatra, Indonesia. Raffles Bull Zool 61:323-330

Islam MA, Uddin MH, Uddin MJ, Shahjahan M (2019) Temperature changes influenced the growth performance and physiological functions of Thai pangas *Pangasianodon hypophthalmus*. Aquacult Rep 13:100179. https://doi.org/10.1016/j.aqrep.2019.100179

Kano Y, Dudgeon D, Nam S, Samejima H, Watanabe K, Grudpan C, Grudpan J, Magtoon W, Musikasinthron P, Nguyen PT,

Praxaysonbath B, Sato T, Shibukawa K, Shimatani Y, Suvarnaraksha A, Tanaka W, Thach P, Tran DD, Yamashita T, Utsugi K (2016) Impacts of dams and global warming on fish biodiversity in the Indo-Burma hotspot. PloS One 11: e0160151:https://doi.org/10.1371/journal.pone.0160151

Kestemont P, Jourdan S, Houbart M, Mélard C, Paspatis M, Fontaine P, Cuvier A, Kentouri M, Baras E (2003) Size heterogeneity, cannibalism and competition in cultured predatory fish larvae: biotic and abiotic influences. Aquaculture 227:333-356. https://doi.org/10.1016/S0044-8486(03)00513-1

King HR, Pankhurst NW (2007) Additive effects of advanced temperature and photoperiod regimes and LHRHa injection on ovulation in Atlantic salmon (*Salmo salar*). Aquaculture 273:729-738. https://doi.org/10.1016/j.aquaculture.2007.07.008

Kjelland ME, Woodley CM, Swannack TM, Smith DL (2015) A review of the potential effects of suspended sediment on fishes: potential dredging-related physiological, behavioral, and transgenerational implications. Environ Syst Decis 35:334-350. https://doi.org/10.1007/ s10669-015-9557-2

Kottelat M, Whitten A, Katikasari S, Wirjoatmodjo S (1993) Ikan air tawar Indonesia bagian Barat dan Sulawesi. Periplus Edition, Jakarta

Leino RL, McCormick JH (1993) Responses of juvenile largemouth bass to different pH and aluminum levels at overwintering temperatures: effects on gill morphology, electrolyte balance, scale calcium, liver glycogen, and depot fat. Can J Zool 71:531-543. https://doi.org/10.1139/z93-074

Leuven RS, Hendriks AJ, Huijbregts MA, Lenders HJ, Matthews J, Velde GV (2011) Differences in sensitivity of native and exotic fish species to changes in river temperature. Curr Zool 57:852-62

Lineman M, Do Y, Kim J, Joo GJ (2015) Talking about climate change and global warming. PloS One 10:e0138996. doi: 10.1371/journal.pone.0138996

Low B (2019) The IUCN Red List of Threatened Species. http://dx.doi.org/10.2305/IUCN.UK. 2019-2.RLTS.T91310582A91310586.en. Accessed 14 September 2019

Maisano M, Cappello T, Oliva S, Natalotto A, Giannetto A, Parrino V, Battaglia P, Romeo T, Salvo A, Spanò N, Mauceri A (2016) PCB and OCP accumulation and evidence of hepatic alteration in the Atlantic bluefin tuna, *T. thynnus*, from the Mediterranean Sea. Mar Environ Res 121:40-48. https://doi.org/10.1016/j.marenvres.2016.03.003

Martínez-Álvarez RM, Morales AE, Sanz A (2005) Antioxidant defenses in fish: biotic and abiotic factors. Rev Fish Biol Fish 15:75-88. https://doi.org/10.1007/s11160-005-7846-4

Mohammadi M, Mahboobi-Soofiani N, Farhadian O, Malekpouri P (2019) Metabolic and NH4 excretion rate of fresh water species, *Chondrostoma regium* in response to environmental stresors, different scenarios for temperature and pH. Sci Total Environ 648:90-101. https://doi.org/10.1016/j.scitotenv.2018.08.131

Mommsen TP, Vijayan MM, Moon TW (1999) Cortisol in teleosts: dynamics, mechanisms of action, and metabolic regulation. Rev Fish Biol Fish 9:211-268. https://doi.org/ 10. 1023/ A:1008924418720

Muchlisin ZA (2008) Ikan depik yang terancam punah. Bull Leus 6:9-12

Muchlisin ZA, Arisa AA, Muhammadar AA, Fadli N, Arisa II, Siti-Azizah MN (2016) Growth performance and feed utilization of keureling (*Tor tambra*) fingerlings fed a formulated diet with different doses of vitamin E (alpha-tocopherol). Arch Pol Fish 24:47-52. https://doi.org/ 10.1515/aopf-2016-0005

Muchlisin ZA, Siti-Azizah S (2009) Diversity and distribution of freshwater fishes in Aceh waters, northern Sumatra Indonesia. Int J Zool Res 5:62-79. https://doi.org/10.3923 /ijzr.2009.62.79

Muchlisin ZA, Murda T, Yulvizar C, Dewiyanti I, Fadli N, Afrido F, Siti-Azizah MN, Muhammadar AA (2017) Growth performance and feed utilization of keureling fish *Tor tambra* (Cyprinidae) fed formulated diet supplemented with enhanced probiotic. F1000Research 6:1-9. https://doi.org/10.12688/f1000research.10693.1

Muchlisin ZA, Musman M, Siti-Azizah MN (2010) Length-weight relationships and condition factors of two threatened fishes, *Rasbora tawarensis* and *Poropuntius tawarensis*, endemic to Lake Laut Tawar, Aceh Province, Indonesia. J Appl Ichthyol 26:949-953. https://doi.org/10.1111/j.1439-0426.2010.01524.x

Nguyen KDT, Morley SA, Lai CH, Clark MS, S TK, Bates AE, Peck LS (2011) Upper temperature limits of tropical marine ectotherms: global warming implications. PLoS One 6:e29340. https://doi.org/10.1371/journal.pone.0029340

Niazie EHN, Imanpoor M, Taghizade V, Zadmajid V (2013) Effects of density stress on growth indices and survival rate of goldfish (*Carassius auratus*). Glob Vet 10:365-371

Nugroho RA, Manurung H, Nur FM, Prahastika W (2017) Terminalia catappa L. extract improves survival, hematological profile and resistance to Aeromonas hydrophila in *Betta* sp. Arch Pol Fish 25:103-115. https://doi.org/10.1515/aopf-2017-0010

Nyanti L, Soo CL, Danial-Nakhaie MS, Ling TY, Sim SF, Grinang J, Ganyai T (2018) Effects of water temperature and pH on total suspended solids tolerance of Malaysian native and exotic fish species. AACl Bioflux 11:565-575

Oczkowski A, McKinney R, Ayvazian S, Hanson A, Wigand C, Markham E (2015) Preliminary evidence for the amplification of global warming in shallow, intertidal estuarine waters. PloS One 10:e0141529. https://doi.org/10.1371/journal.pone.0141529

Orr JC, Fabry VJ, Aumont O, Bopp L, Doney SC, Feely RA, Gnanadesikan A, Gruber N, Ishida A, Joos F, Key R (2005) Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437: 681. https://doi.org/10.1038/nature04095

Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, Church JA, Clarke L, Dahe Q, Dasgupta P, Dubash NK (2014) Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change IPCC, Switzerland

Pera F, Schwarzacher HG (1968) Formation and division of binucleated cells in kidney cell cultures of Microtus agrestis. Humangenetik 6:158-162. https://doi.org/10.1007/bf00297724

Pinto D, Pellegrin L, Nitz LF, da Costa ST, Monserrat JM, Garcia L (2019) Haematological and oxidative stres responses in *Piaractus mesopotamicus* under temperature variations in water. Aquac Res 50:3017-3027. https://doi.org/10.1111/are.14260

Polakof S, Panserat S, Soengas JL, Moon TW (2012) Glucose metabolism in fish: a review. J Comp Physiol B 182:1015-1045. https://doi.org/10.1007/s00360-012-0658-7

Reyes-Bustamante H, Ortega-Salas AA (2002) Initial sexual maturity and fecundity of two anabantids under laboratory conditions. N Am J Aquac 64:224-227. https://doi.org/10.1577/ 1548-8454(2002)064

Schindler I, van der Voort S (2011) Re-description of *Betta rubra* Perugia, 1893 (Teleostei: Osphronemidae), an enigmatic fighting

fish from Sumatra. Raffles Bull Zool 13:21-32
Selong JH, McMahon TE, Zale AV, Barrows FT (2001) Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Trans Am Fish Soc 30:1026-1037. https://doi.org/10.1577/1548-8659(2001)130
Shahjahan M, Mun MM, Islam S, Uddin M, Badruzzaman M, Khan S (2020) Nuclear and cellular abnormalities of erythrocytes in response to thermal stress in common carp *Cyprinus carpio*. Front Physiol 11:543
Shahjahan M, Rahman MS, Islam SM, Uddin MH, Al-Emran M (2019) Increase in water temperature increases acute toxicity of sumithion causing nuclear and cellular abnormalities in peripheral erythrocytes of zebrafish *Danio rerio*. Environ Sci Pollut Res Int 26:36903-36912
Shahjahan M, Uddin MH, Bain V, Haque MM (2018) Increased water temperature altered hemato-biochemical parameters and structure of peripheral erythrocytes in striped catfish *Pangasianodon hypophthalmus*. Fish Physiol Biochem 44:1309-1318
Simpson SD, Blanchard JL, Genner MG (2013) Impacts of climate change on fish. MCCIP Science review 13:113-124. https://doi.org/10.14465/2013.arc13.113-12
Strange RJ (1980) Acclimation temperature influences cortisol and glucose concentrations in stresed channel catfish. Trans Am Fish Soc 109:298-303. https://doi.org/10.1577/1548-8659(1980)109
Tang UM, Muchlisin ZA, Syawal H, Masjudi H (2017) Effect of water temperature on the physiological stres and growth performance of tapah (*Wallago leeri*) during domestication. Arch Pol Fish 25:165-171. https://doi.org/10.1515/aopf-2017-0016
Viadero RC (2005) Factors affecting fish growth and production. Water Encyclo 3:129-133. https://doi.org/10.1002/047147844X.sw241
Walia G, Handa D, Kaur H, Kalotra R (2013) Erythrocyte abnormalities in a freshwater fish, *Labeo rohita* exposed to tannery industry effluent. Int J Pharm Biol Sci 3:287-95
Wargasasmita S (2002) Ikan air tawar Endemik Sumatra yang terancam punah. J Ikti Indo 2:41-49. https://doi.org/10.32491/jii.v2i2.276
Xie H, Lü X, Zhou J, Shi C, Li Y, Duan T, Li G, Luo Y (2017) Effects of acute temperature change and temperature acclimation on the respiratory metabolism of the snakehead. Turk J Fish Aquat Sci 17:535–542. https://doi.org/10.4194/1303-2712-v17_3_10
Xu J, Grumbine RE, Shrestha A, Eriksson M, Yang X, Wang YUN, Wilkes A (2009) The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. Conserv Biol 23:520-530. https://doi.org/10.1111/j.1523-1739.2009.01237.x

Publisher's Note