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1 **Effects of temperature on the zootechnical performances and physiology of**
2 **giant gourami (*Osphronemus goramy*) larvae**

3

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18 **Abstract**

19 The influence of temperature on zootechnical performances and physiology was
20 assessed in giant gourami (*Osphronemus goramy*) larvae. Larvae aged ten days
21 post-hatching were reared at five temperature treatments (22.5, 25.0, 27.5, 30.0
22 and 32.5 °C, three replicated per treatment) in indoor closed recirculating systems
23 until they reached, at least, the commercial size of 2.5 cm in total length (i.e.
24 rearing time of 21 to 42 d depending on the temperature). Samples of larvae were
25 collected every week. Survival, growth, and feed intake were used as main
26 indicators of zootechnical performances. In addition, concentration of glucose and
27 cortisol and proximate composition of the young life-stages giant gourami were
28 compared to assess effects of temperature on their physiology. Results showed
29 that temperature strongly affected growth of giant gourami larvae with
30 significantly increased observed at the increasing tested temperatures (from $57.2 \pm$
31 9.3 mg to 431.9 ± 64.2 mg of body weight after three weeks, $p < 0.05$). The
32 increased growth can be related to changes in metabolism, feed intake and feed
33 use efficiency. Based on cortisol and glucose values, we recommend to maintain
34 rearing temperature at 30.0°C for both optimizing growth and avoid physiological
35 impairments in giant gourami larvae. The consequences of larval rearing at stable
36 temperature (30.0°C) should be further investigated in the nursery and grow-out
37 outdoor phases.

38

39 **Keywords:** Fish larval rearing, Temperature, Survival, Growth, Cortisol, Glucose

40 **1. Introduction**

41 Giant gourami (*Osphronemus goramy*; Lacepède, 1801) is one of the most
42 popular freshwater fish species in Southeast Asia and particularly in Indonesia,
43 the main producing country in aquaculture (113,396 tons in 2015; FAO, 2017).
44 Over the past 15 years, the Indonesian giant gourami aquaculture production has
45 grown exponentially with an annual increase of 16% (FAO, 2017). As for other
46 freshwater species, Indonesian giant gourami aquaculture is mainly ensured by
47 micro and small-scale farms (more than 100,000 fish farmers mainly in Java
48 Island; BPS, 2013; Maskur et al., 2013). Currently, there are still some obstacles
49 to the production of gourami related to gaps of knowledge on the biology of this
50 species (Arifin et al., in press). One of the main impediments in giant gourami
51 aquaculture is ensuring availability of fry for fish farmers through the
52 improvement of larval rearing methods (Amornsakun et al., 2014a, 2014b).
53 Commercial scale propagation of giant gourami in hatcheries is yet to be
54 standardized (Amornsakun et al., 2014a). Thus, although Indonesian National
55 Standard recommends indoor larval rearing allowing to limit variations of
56 environmental conditions (SNI, 2000), an on-farm inquiry carried out on about 40
57 small-scale farms of the West Java province revealed that the current practices for
58 giant gourami larval production consisted to rear larvae for the first days post-
59 hatching (dph) in plastic basins and then transferred to outdoor small ponds. In
60 such practices, larvae have to deal with fluctuations of environmental conditions
61 that could not be controlled, especially for water temperature changes. For these
62 reasons, the impacts of environmental conditions on giant gourami larval rearing,
63 especially temperature, is thus become limiting factor for fish farmers.

64 Water temperature is one of main environmental factors affecting physiology of
65 aquatic ectotherm organisms such as fish even before hatching (Kamler, 2002;
66 Pauly and Pullin, 1988; Teletchea et al., 2009). Temperature changes affect
67 physiological conditions, such as oxygen consumption, metabolism, digestion,
68 growth, and reproduction (Wendelaar Bonga, 1997). When temperature tolerance
69 ranges are exceeded, it results negative impacts, such as physiological
70 disturbances, increased sensitivity to disease, and potentially mortality (Singh et
71 al., 2013). Temperature is therefore a key environmental parameter in aquaculture
72 contributing for successful outcome of larvae production (Blaxter, 1991;
73 Pankhurst and King, 2010; Réalis-Doyelle et al., 2016). Effects of temperature on
74 the larval and fry rearing have been extensively studied in freshwater fish (e.g.
75 Desai and Singh, 2009; El-Gamal, 2009; Pandit and Nakamura, 2010; Rodkhum
76 et al., 2011; Singh et al., 2009; Zeng et al., 2018).

77 Effects of temperature in fish larval and fry rearing may be diverse. As an
78 example, Desai and Singh (2009) have shown that growth and food efficiency of
79 common carp *Cyprinus carpio* fry was significantly increased by higher
80 temperature (32°C vs. 28°C). Nevertheless, feed efficiency and protein efficiency
81 ratio decreased at the highest temperature as already demonstrated for Asian
82 catfish *Clarias batrachus* fry (Singh et al., 2009). Temperature can also affect the
83 sensibility of fish to pathogens (Rodkhum et al., 2011) through, in particular,
84 effects the ontogeny of mucous cells (El-Gamal, 2009). In addition, temperature
85 affects deformity rate during fish larval rearing (Wang and Tsai, 2000). Such
86 results emphasize the importance of assessing temperature effects on giant
87 gourami larvae.

88 The objectives of this study were therefore (1) to assess the zootechnical
89 performances of giant gourami (*O. goramy*) larvae reared until they reached, at
90 least, the commercial size of 2.5 cm in total length (i.e. rearing time of 21 to 42 d
91 depending on the temperature) in closed aquaculture recirculating systems (RAS)
92 at five rearing temperatures (22.5-32.5°C according to preliminary tests and
93 current practices) through their survival, growth and food intake and (2) measure
94 the impacts of temperature changes on the physiology of the larvae through the
95 measurements of glucose and cortisol concentrations and their chemical
96 composition.

97

98 **2. Materials and methods**

99 2.1. Origin of larvae

100 Giant gourami larvae used in this experiment came from the same broodfish pair
101 at the same natural spawning event. The 3-4 years old broodfish (“Galunggung”
102 strain, Arifin et al., 2018) were reared in an outdoor pond at the Research
103 Installation of Germplasm Freshwater Aquaculture (RIFAFE, Cijeruk, West Java,
104 Indonesia). Broodfish were fed leaves of giant taro (*Alocasia macrorrhiza*) and
105 commercial feeds (floating pellets: 32% proteins, 5% lipids) at a feeding rate of
106 2% and 1% of fish biomass per day, respectively. Bamboo nest supports and palm
107 tree fibres were provided for nest building. The buoyant eggs were then incubated
108 in the experimental room for 20 hours (20-L plastic basin; daily water change,
109 temperature: $29.0 \pm 0.6^\circ\text{C}$; light:dark cycle: 12:12 h). After hatching, larvae were
110 kept unfed in the incubation basin (following fish farming practices), until the

111 beginning of the experiment, which was 10 dph (i.e. postflexion larva, approx. 6 d
112 after the mouth opening, Morioka et al., 2013).

113

114 2.2. Live prey maintenance

115 According to the current practices (SNI, 2000) and Lucas et al. (2015) who
116 demonstrated the benefits of this feed for survival rate and growth of giant
117 gourami larvae, in this study, fish were fed tubifex worms (*Tubifex tubifex*)
118 throughout the experiment. Live tubifex worms were purchased weekly and stored
119 in the experimental room (100-L aquarium; daily water change, temperature: 29.0
120 \pm 0.6°C; light:dark cycle: 12:12 h) and kept unfed. Proximate analyses of tubifex
121 worms were conducted to obtain nutritional quality based on the procedures
122 described in AOAC (1999) giving the following results (dry matter basis): 52.87%
123 crude proteins, 22.09% crude lipids, 4.09% ash, 1.23% crude fibre and 19.72%
124 nitrogen free extract (NFE).

125

126 2.3. Temperature experiment

127 2.3.1. Experimental design

128 Zootechnical performances and physiology of giant gourami *O. goramy* larvae
129 were studied under five temperature conditions (22.5, 25.0, 27.5, 30.0 and
130 32.5°C). Experiment was carried out in five identical indoor RAS (1 per
131 temperature condition) under natural photoperiod (light:dark cycle: 12:12 h,
132 daylight intensity: 60-4500 lux). At 10 dph, larvae were individually counted and
133 measured (mean body weight: 12.4 \pm 1.4 mg; mean total length: 9.8 \pm 0.3 mm)

134 then randomly assigned to the experimental tanks (n=3 per temperature condition,
135 stocking density of 2.4 larvae L⁻¹) placed in RAS.

136 Larvae were acclimated into targeted temperatures by gradual temperature
137 changes (2.5°C h⁻¹). The experimental tanks were 30-L glass aquaria 40 × 30 × 30
138 cm (L × W × H), aerated by bubbling, with sides covered by isolating black
139 polyethylene foam and top closed by transparent polycarbonate sheet in order to
140 limit temperature exchanges. The experiment continued until the larvae reached,
141 at least, 2.5 cm of total length (i.e. after 21 to 42 days of rearing depending on the
142 temperature condition). The choice of this experimental protocol was made in
143 accordance with the “BPPSIGN” Centre (West Java Centre for the Development
144 of Giant Gourami Culture) which mentioned 2.5 cm as one of segmentation
145 market size for local fish farmers (called “Nguku”; Adida, 2014).

146

147 2.3.2. Feeding protocol and water quality monitoring

148 Larvae were fed every day, except on the sampling days, in large excess for all the
149 temperature treatments (9.1 ± 0.6 g aquarium⁻¹ day⁻¹ throughout the experiment)
150 in order to ensure non-limiting food conditions for larvae and facilitate the
151 accurate estimation of ingestion. Thus, the same quantity of live tubifex worms
152 was spread in the bottom of each aquarium twice a day at 8:00 and 16:00. Prior to
153 distribution to giant gourami larvae, tubifex worms were collected, rinsed and
154 drained on a 50-µm mesh and weighed (nearest 0.1 g). In order to define food
155 intake, unconsumed tubifex worms were collected in each aquarium and weighed
156 before the addition of the new ration of tubifex. Water inlet flow into rearing
157 tanks was maintained at 33 L h⁻¹ for the first 5 days of the experiment and then at

158 78 L h⁻¹. Temperature was monitored in each aquarium three times a day (at
159 08:00, 12:00 and 16:00) while water quality was checked once a week with direct
160 measurements using a multi-parameter probe (HI 9829 Hanna) for pH, dissolved
161 oxygen (DO) and conductivity. In addition, alkalinity, Total ammoniacal nitrogen
162 (TAN), NO₂⁻ and NO₃⁻ were measured by spectrophotometry analysis (n=6-15 per
163 treatment). NH₃ concentrations were calculated from TAN, temperature and pH
164 values. Results are provided in Table 1.

165

166 2.4. Observations and measurements of larvae

167 Fish (n=20 for each aquarium) were sampled every seven days in each aquarium,
168 transferred in a plastic basin containing water from their aquarium in order to
169 keep them in the same water temperature. The sampling frequency was selected in
170 order to limit stress for the larvae caused by handlings. Larvae were anaesthetized
171 (Eugenol, 50 µL L⁻¹) and their size (total body length, TL, mm) was measured
172 under a stereomicroscope with a micrometre (accuracy ranging from 0.05 to 0.1
173 mm, depending on fish size and magnification). Meanwhile, body weight (BW,
174 mg) was measured using a digital scale with an accuracy of 0.1 mg. After
175 individual measurements, fish were returned into their respective rearing
176 structures. No mortality was observed following samplings.

177 At the end of the experiment (i.e. after 21 to 42 d depending on the temperature
178 treatment, see Section 2.3.1), for each treatment, the aquaria were emptied and
179 remaining living larvae were counted allowing survival rate determination. Two
180 times during the experiment (after 4 h and at the end), fish from each treatment
181 were sampled to quantify whole-body cortisol and glucose concentrations. Whole-

182 body cortisol level was analysed by anesthetizing and grinding the larvae or
183 juveniles (n=3 pools of 20 fish). Afterwards, the samples were centrifuged
184 (10,000 rpm for 10 min at 25°C) and cortisol levels were analysed in the
185 supernatants by using Cortisol ELISA kit (DRG International, Inc., Germany) and
186 microplate photometer (Biosan HiPo MPP-96, Latvia). At the beginning of the
187 experiment, samplings for glucose analyses were carried out as described above
188 (n=3 pools of 20 fish). Methodology was adjusted for juveniles at the end of the
189 experiment. Thus, one drop of blood was collected on each anesthetised fish (n=3
190 fish). After collection, the blood samples were put on glucose reader (Accu-Chek
191 Active, Roche, Germany) for analysis. At the end of the experiment, 35-40 fish
192 from each treatment were collected for the whole-body proximate analyses (i.e.
193 protein, lipid, ash, and NFE). Anesthetizing fish from each treatment were taken
194 and pooled (n=3), autoclaved, homogenized, and dried to a constant weight at
195 105°C and then analysed following the methods described by AOAC (1999).

196

197 2.5. Data treatment and statistical analysis

198 Temperature effects on survival, growth and feed intake were determined by
199 calculating the following parameters for each experimental treatment. Survival
200 rates (SR), expressed as a percentage, were calculated by comparing the final
201 number (N_f) with the initial number of larvae (N_i): $SR (\%) = (N_f / N_i) \times 100$.

202 The specific growth in body weight (SGR_{BW} , %) was calculated according to the
203 following equation: $SGR_{BW} = (\ln BW_f - \ln BW_i) / ED) \times 100$, where BW_i and
204 BW_f are the initial and final body weight of larvae (mg) respectively, and ED is
205 the duration of the experiment in days.

206 The specific growth in total length (SGR_{TL} , %) was calculated using the same
207 calculation by substituting BW with LT: $SGR_{TL} = (\ln LT_f - \ln LT_i) / ED) \times 100$.
208 Heterogeneity of larval size (in body weight or total length) was assessed using
209 the coefficient of variation (CV, %) calculated as: $CV_{BW} = SD_{BW} / BW$ and
210 $CV_{TL} = SD_{TL} / TL$, where SD is the standard deviation and BW is the average body
211 weight (mg) and TL the average body length (mm).

212 The Fulton's condition factor (K) was calculated according to the relationship $K =$
213 BW_f / TL_f^3 (Froese, 2006). The equation was multiplied by 100 to bring the value
214 close to one.

215 Food intake per treatment (FI_{total} , %) was calculated as follows: $FI_{total} = (Food$
216 $distributed\ in\ g - Food\ remaining\ in\ g) / Food\ distributed\ in\ g) \times 100$.

217 Ingestion rates (IR) of fish (expressed as $g\ g^{-1}\ d^{-1}$) exposed to the different
218 temperature were calculated according to the equation: $IR = TFi / (N_f BW_f - N_i$
219 $BW_i) / ED$, where TFi is the total food consumed by the fish (g) during the
220 duration of the experiment (ED, d).

221 Feed conversion ratio (FCR) was calculated using the following equation: $FCR =$
222 $F / (N_f BW_f - N_i BW_i)$, where F is the total quantity of food intake in wet weight
223 during the whole rearing period. F was determined as the total amount of uneaten
224 food subtracted from the total amount of food provided (g).

225 Protein efficiency ratio (PER) was calculated for each experimental treatment
226 according to the following equation: $PER = (N_f BW_f - N_i BW_i) / PI$ where PI is the
227 total protein ingested by the larvae (g).

228 Statistical comparisons were done for each parameter described above. Data were
229 first assessed to confirm normality (Shapiro's test) and homogeneity of variances

230 (Levene's test) and, where necessary, data expressed were arcsine-square root
231 prior to analysis. One-way ANOVA following by Tukey's test were used to
232 determine significant differences among temperature treatments. When
233 assumptions of normality and homogeneity of variances were unable to be
234 achieved, data were analyzed using Kruskal-Wallis and Siegel and Castellan non-
235 parametric tests.

236 The growth kinetics of the larvae, both for body weight (BW) and total length
237 (TL), reared at the five different temperature were best fitted using exponential
238 model: BW or $TF = BW_i$ or $TF_i \times e^{at}$ where a was the growth rate (d^{-1}) and t the
239 time (d). Model constants were estimated by iterative adjustment of the model
240 using the least square regression method. In order to statistically assess the effects
241 of temperature on larval growth, for each experimental treatment, growth data
242 (BW and TL) were linearized using natural logarithmic transformation and
243 ANCOVA following by Tukey's test were then applied to identify differences
244 between the regression slopes. The level of significance for statistical analyses
245 was always set to $\alpha = 0.05$. All statistics were performed using R freeware version
246 3.3.0 (R Development Core Team, 2016).

247

248 **3. Results**

249 3.1. Water parameters

250 The targeted temperatures were kept constant throughout the experiment (Table 1)
251 and significant differences were confirmed between each treatment ($\chi^2 = 1100$, p
252 < 0.001 , Table 1). Regular monitoring indicated that water quality was similar
253 between each treatment. Dissolved oxygen saturation was maintained above 85%

254 in all treatments ($\chi^2 = 4.015$, $p = 0.400$) with average DO concentration of 6.21 to
255 7.40 mg L⁻¹. Total ammoniacal nitrogen was not significantly different between
256 the five experimental treatments ($\chi^2 = 5.207$, $p = 0.267$) and NH₃ was kept very
257 lower 0.05 mg L⁻¹.

258

259 3.2. Survival

260 The larval survival rates measured at the end of the experiment ranged from 61.6
261 \pm 15.4% (treatment 22.5°C) to 75.5 \pm 5.6% (treatment 32.5°C) without any
262 significant differences between the five temperatures tested ($\chi^2 = 4.196$, $p = 0.380$,
263 Table 2).

264

265 3.3. Growth and size heterogeneity

266 The growth of giant gourami larvae reared at five different temperatures is
267 indicated in Table 2. At the end of the experiment (i.e. after 21 to 42 days
268 depending on the temperature), the average body weight (BW) and total length
269 (TL) of larvae ranged from 270.2 \pm 95.4 mg and 24.7 \pm 2.6 mm and 431.9 \pm 64.2
270 mg and 30.3 \pm 1.4 mm when they reared at 22.5°C and 32.5°C respectively (Fig. 1
271 and Table 2). Growth significantly increase with an increase of temperature ($F =$
272 568.3, $p < 0.001$ and $F = 496.0$, $p < 0.001$ for BW and TL respectively), with the
273 lowest growth observed for the larvae reared at 22.5°C (Fig. 1 and Table 2) and
274 the highest growth observed for the larvae reared at 32.5°C. No significant
275 difference was found for the larvae reared at intermediate temperature (i.e. 27.5°C
276 and 30.0°C). This trend was confirmed by the specific growth rate calculated from
277 body weight (SGR_{BW}) and total length (SGR_{TL}). Significant increases in SGR_{BW}

278 ($F = 360.4$, $p < 0.001$) and SRG_{TL} ($F = 351.5$, $p < 0.001$) were observed when
279 temperature increased, with values varying from $7.3 \pm 0.6\%$ for SGR_{BW} and $2.2 \pm$
280 0.2% for SRG_{TL} at 22.5°C to $17.0 \pm 0.2\%$ for SGR_{BW} and $5.4 \pm 0.1\%$ SRG_{TL} at
281 32.5°C (Table 2).

282 Interpolation from exponential growth curves (Table 3) indicated that, in this
283 experiment, the fry commercial size (i.e. 2.5 cm in total length) was reached after
284 17 days (i.e. 27 dph) of rearing larvae reared at 32.5°C while 42 days (i.e. 52 dph)
285 are needed for larvae reared at 22.5°C to reach similar size (Fig. 1).

286 Size heterogeneity of larvae as a function of temperature was assessed through the
287 calculation of coefficients of variation for body weight (CV_{BW}) and total length
288 (CV_{TL}) at the end of experiment for each temperature. Thus, CV_{BW} ranged from
289 12.1 ± 1.9 (treatment 25.0°C) to $24.2 \pm 10.4\%$ (treatment 22.5°C) and CV_{TL}
290 ranged from $3.8 \pm 0.7\%$ (treatment 25.0°C) to $8.0 \pm 3.4\%$ (treatment 22.5°C). For
291 CV_{BW} and CV_{TL} , no significant differences were found between the five tested
292 temperatures ($F = 2.3$, $p = 0.128$ and $F = 2.7$, $p = 0.089$ for CV_{BW} and CV_{TL}
293 respectively, Table 2). Statistical analysis revealed a slight significant decrease in
294 K with increased temperature ($F = 88.7$, $p < 0.001$) with K ranging from 1.7 ± 0.1
295 at 22.5°C and 1.5 ± 0.1 at 32.5°C (Table 2).

296

297 3.4. Food intake and feed efficiency

298 The proportion of the total distributed tubifex worms effectively ingested in each
299 aquarium was affected by temperature ($F = 105.7$, $p < 0.0001$) with higher feed
300 intake (45-59%) observed in the highest temperatures (27.5 - 32.5°C) compared to
301 low temperature treatments (22.5°C and 25.0°C) where ingestion was 26-30%

302 (Table 4). FCR and ingestion rate (IR) were not affected by the temperature (FCR:
303 $\chi^2 = 9.459$, $p = 0.051$ and IR: $\chi^2 = 6.767$, $p = 0.149$) but remained more variable in
304 the larvae reared at the lowest temperature (i.e. 22.5°C, FCR = 11.1 ± 5.6 and IR
305 = $0.26 \pm 0.13 \text{ g g}^{-1} \text{ d}^{-1}$). Regarding protein use efficiency, PER was significantly
306 lower at 22.5°C (3.1 ± 1.4) compared to the higher temperature treatments ($F=7.4$,
307 $p = 0.005$, Table 4).

308

309 3.5. Chemical composition

310 The results presented in Table 5 showed that the moisture content in fish is stable
311 and does not differ between different temperatures. However, chemical
312 composition (% dry matter basis) of giant gourami juveniles was significantly
313 affected by the rearing temperature especially for the lowest temperature
314 treatment (i.e. 22.5°C). Indeed, crude lipid content was clearly significantly higher
315 at 22.5°C with values of $26.05 \pm 1.06\%$ ($F = 198.0$, $p < 0.001$; Table 5).
316 Nevertheless, significant, but less pronounced differences were also observed in
317 the other temperature treatments with minimal values of crude lipid content of
318 $15.88 \pm 0.22\%$ observed at 27.5°C. Meanwhile, NFE content was lowest at 22.5°C
319 ($6.88 \pm 0.85\%$) and maximal values ($14.17 \pm 0.32\%$ and $13.86 \pm 0.28\%$) were
320 observed at 25.0°C and 27.5°C respectively ($F = 96.1$, $p < 0.001$). Crude protein
321 increased significantly up to 30.0°C and were lower for the treatment at 32.5°C (F
322 = 165.6 , $p < 0.001$; Table 5). Ash content was significantly lower for the treatment
323 at 22.5°C and tended to be stable for the other temperature treatments although
324 some significant differences were observed ($F = 92.8$, $p < 0.001$). For crude fibre

325 content, slight significant increase was observed between the five tested
326 temperatures ($F = 4.5$, $p = 0.025$; Table 5).

327

328 3.6. Glucose and cortisol blood concentrations

329 Glucose and cortisol blood concentrations were measured in giant gourami at the
330 beginning and at the end of each temperature treatments. Initial concentrations of
331 glucose were not significantly different in all the treatments ($F = 0.4$, $p = 0.817$)
332 with values ranging from 31.0 ± 14.0 mg dL⁻¹ to 39.0 ± 3.6 mg dL⁻¹ (Fig. 2). At
333 the end of each treatment, no change was observed in glucose concentrations for
334 juveniles reared at 22.5°C. Nevertheless, a significant increase was observed for
335 juveniles reared in higher temperature conditions (i.e. from 25.0°C to 32.5°C)
336 with values ranging from 96.0 ± 12.2 mg dL⁻¹ to 133.7 ± 52.5 mg dL⁻¹ ($F = 5.6$, p
337 $= 0.013$) up to 32.5°C where a decrease of glucose concentration was observed
338 (Fig. 2). Cortisol was not detected in larvae at the beginning of the experiment
339 (Fig. 3). After the larval rearing period, cortisol was detected in juveniles coming
340 from each temperature conditions. Significant higher cortisol concentrations ($F =$
341 67.7 , $p < 0.001$) were observed in the intermediate temperatures (25.0°C and
342 27.5°C). Indeed, cortisol concentrations reached 72.0 ± 5.8 ng mL⁻¹ and 45.9 ± 8.0
343 ng mL⁻¹ at 25.0°C and 27.5°C respectively, while for other treatments, cortisol
344 concentrations ranged from 12.3 ± 4.2 ng mL⁻¹ to 17.3 ± 3.4 ng mL⁻¹ (Fig. 3).

345

346 **4. Discussion**

347 4.1. Water quality

348 Aerobic metabolism predominates in fish, so dissolved oxygen (DO) can be a
349 limiting environmental factor in fish rearing (Fry, 1971), especially at high
350 temperature (Jobling, 1997). In the present study, DO was kept high with values
351 never under 6 mg L⁻¹ and saturation >85%. Such conditions prevent effects on fish
352 health, growth and feed intake (Kestemont and Baras, 2001). Depending on
353 temperature, oxygen and pH, non-lethal concentrations of NH₃ may cause toxic
354 effects on fish especially for young-life stages (El-Greisy et al., 2016) and affect
355 their feeding behaviour (Kestemont and Baras, 2001). Although some statistical
356 differences have been highlighted between the five experimental treatments, NH₃
357 concentrations was always very lower 0.05 mg L⁻¹ following the
358 recommendations of Francis-Floyd et al. (2009). Based on these findings, we can
359 reasonably assume that the results obtained in this study are solely related to
360 temperature and not to water quality degradation.

361

362 4.2. Effects of temperature on survival

363 The present study provides evidence for the effects of rearing temperature on
364 larvae production in the giant gourami (*O. goramy*). The range of temperatures
365 used in this study was based on prior measurements done in the larval rearing
366 structures of fish farms in the West Java province showing that temperatures may
367 vary from 22.9-33.1°C although pikes up to 42.1°C were observed (data not
368 shown). Furthermore, preliminary experimental observations performed over 15 d
369 from hatching have shown that despite a relatively high survival rate (80%), the
370 proportion of deformed larvae was very high above 34°C (77.6% with
371 deformation of vertebral axis, particularly lordosis). Under 21°C, the proportion

372 of deformed or abnormal larvae reached 64.1% (anomaly of vitellus aspect,
373 haemorrhagic areas at vitellus surface, pericardial oedema). The targeted
374 temperatures were thus selected in order to avoid the occurrence of abnormality in
375 larvae. In this experiment, we demonstrated that temperatures ranging from
376 22.5°C to 32.5°C did not significantly affect the survival of giant gourami.
377 Observed survival rates of 62-76% are similar (Verawati et al., 2015) or lower
378 (Sarah et al., 2009; Arifin et al. in press) to other experimental studies on this
379 species. We found a higher heterogeneity in the survival rates of the larvae reared
380 at 22.5°C ($61.6 \pm 15.4\%$). Based on these findings, we reasonably assumed that
381 22.5°C seems to be close to the low tolerance limit of the young life-stages of
382 giant gourami.

383

384 4.3. Effects of temperature on growth

385 Successful larval rearing of fish species in aquaculture depends on several factors,
386 among them, the temperature and feed are the most significant ones (Kolman et
387 al., 2018). In the present study, the growth of giant gourami larvae stocked at
388 different temperatures was estimated from weekly measurements of body weight
389 (BW), total length (TL) and specific growth rate (SGR) until the larvae reached
390 the commercial size of 2.5-cm total length (called “Nguku”; Adida, 2014). For all
391 the experimental conditions, exponential growth were observed. At comparable
392 temperatures ($29.0 \pm 0.6^\circ\text{C}$ vs. $30.01 \pm 0.31^\circ\text{C}$) and at the same stocking density,
393 the growth performances were similar to another recent study (i.e. 288.8 ± 19.3
394 vs. 354.32 ± 70.19 mg after 21 d, Arifin et al. in press). We found that increasing
395 temperatures up to 32.5°C have positive effects on the growth of giant gourami

396 larvae. Previous studies have also highlighted the positive influence of increasing
397 temperatures, within their tolerance limits in the growth of several tropical fish
398 young life-stages, such as African catfish *Clarias gariepinus* (Britz and Hecht,
399 1987), blue tilapia *Oreochromis aureus* (Soderberg, 1990), Nile tilapia *O.*
400 *niloticus* (Azaza et al., 2008; El-Sayed and Kawanna, 2008; Pandit and Nakamura,
401 2010) and striped catfish *Pangasianodon hypophthalmus* (Baras et al., 2011). In
402 this study, giant gourami larvae reared at 32.5°C reached the size of “Nguku”
403 after only 17 days while between 30-98 days are needed in traditional fish farms
404 suggesting that better temperature control provides significant gains in larval
405 production of giant gourami.

406

407 4.4. Effects of temperature on food intake and chemical composition

408 Brett (1979) stated that the temperature influence on growth depends on food
409 consumption and metabolic scope. The energy amount from feeding is used to
410 cover metabolic cost for somatic growth. Following this pattern, larvae exposed to
411 the highest temperature treatment (32.5°C) is likely to have higher feed
412 consumption and metabolism compared with lower temperature treatments (22.5-
413 30.0°C), which resulted on faster growth. Indeed, we found that increasing
414 temperatures led to an increase in the feed consumption with highest ingestions
415 observed in the fish reared at 32.5°C. Interestingly, no significant difference was
416 observed in the IR and FCR among the five temperatures tested. Nevertheless,
417 young life-stages of giant gourami reared at 22.5°C have more variable value on
418 FCR and significant lower PER compared to the other experimental treatments.
419 Such findings are in accordance with previous studies on the African catfish *C.*

420 *gariiepinus* (Degani et al., 1989) and the hybrid Red Florida tilapia (Watanabe et
421 al., 1993). These findings point out that the less efficient feed utilization on giant
422 gourami larvae occurred at 22.5°C, which resulted in the slowest growth observed
423 at this temperature.

424 In addition, in the present study, we found that proximate composition of giant
425 gourami juveniles changed with temperature. Various effects of temperature on
426 proximate composition have been shown by previous studies carried out in several
427 fish species. Indeed, in some cases, no influence of temperature on proximate
428 composition was observed (e.g. Martinez-Palacios et al., 1996). Conversely, other
429 authors found temperature-dependent changes in proximate body composition
430 especially for protein content (e.g. Hidalgo et al., 1987; Van Ham et al., 2003).
431 The latter findings are in accordance with the statement of Jobling (1997) who
432 mentioned that changes in proximate composition at high temperatures could be
433 associated with increasing metabolism until it reaches the upper tolerance limits in
434 poikilotherm organisms such as fish. In the present study, we found a higher lipid
435 and a lower carbohydrate (i.e. NFE) contents in the fish exposed to the lowest
436 temperature treatment. We assume that such results can be related to the lowest
437 metabolism in fish reared at 22.5°C. Indeed, most freshwater fish species do not
438 attempt to maintain a body temperature which is different from their environment.
439 When water temperature declines, body temperature of the fish also declines and
440 metabolic rate is reduced and, as consequence, the energy requirements is reduced
441 too (FAO, 1980). Thus, excessive carbohydrates, a non-negligible energy source
442 for fish can be stored as form of lipids (Tacon, 1987).

443

444 4.5. Physiological responses to temperature

445 Changes in temperatures can be a source of stress for fish larvae, affecting larval
446 rearing performances, and imply different physiological responses (Blaxter, 1991).
447 In this study, glucose and whole-body cortisol levels, recognized as primary
448 indicators of stress in young-life stages fish (Rudneva, 2013), were measured at
449 the beginning of the experiment and when the giant gourami larvae from each
450 temperature treatments reached the commercial size of “Nguku”. Interestingly, we
451 found similar effects of rearing temperatures on blood glucose and plasma cortisol
452 levels in giant gourami larvae. Indeed, both for glucose and cortisol,
453 concentrations measured were higher at intermediate temperatures (25°C and
454 27.5-30.0°C) and significantly lower at the extreme temperatures (22.5°C and
455 30.0-32.5°C). Several studies have shown contrasting results regarding the effects
456 of temperature on glucose and cortisol concentrations in other tropical fish species
457 such as blue tilapia *O. aureus* (Chen et al., 2002), common carp *Cyprinus carpio*
458 (Tanck et al., 2000), Mozambique tilapia *O. mossambicus* (Zaragoza et al., 2008),
459 zebrafish *Danio rerio* (Long et al., 2012), and Tapah *Wallago leeri* (Tang et al.,
460 2017). Most previous studies, however, agree that cold/heat temperature exposure
461 that exceeds the tolerance limits modified blood glucose or plasma cortisol levels.
462 In giant gourami fingerlings, Hastuti et al. (2003) reported that cold shock to 26-
463 27°C, 23-24°C, and 20-21°C led to changes in blood glucose level with highest
464 values observed at 20-21°C (~80 mg dL⁻¹). In fish, Selye (1974) and Barton and
465 Iwama (1991) stated that the exposure of low or high temperatures beyond the
466 tolerance limits lead to negative impact on their physiology depending on each
467 species tolerance level. In the present study, we found that glucose concentrations

468 are the highest at the intermediate temperatures (25.0, 27.5 and 30.0°C) and
469 decreased at the extreme rearing temperatures (22.5 and 32.5°C). Based on our
470 main findings, we can reasonably assume that the extreme temperatures tested are
471 closed to the tolerance limit of this species and affected the metabolism of the
472 larvae. Thus, although, the most efficient temperature for larval growing (i.e.
473 32.5°C) does not cause serious impairment in larvae, a slightly lower rearing
474 temperature (~30.0°C) should be maintained as a precaution.

475 The physiological responses measured in this study, in addition to the
476 zootechnical performances observed, reinforce the interests of an optimization of
477 the giant gourami larval rearing based on a better control of the temperature. Such
478 improvements are currently required to support micro- and small-scale fish
479 farmers who provide the bulk of gourami production in Indonesia.

480

481 **5. Conclusion**

482 We highlighted that temperature strongly affects the larval growth. Thus, we
483 observed that 10-dph larvae reared at 22.5°C needed 42 days of production before
484 reaching the commercial size of “Nguku” while only 17 days is needed at 32.5°C.
485 Based on all our findings, maintaining a stable temperature at 30°C seems to be
486 the best compromise to significantly improve the zootechnical and economic
487 performance of giant gourami larval rearing. Nevertheless, control of lower
488 temperatures is not always easy in traditional fish farming due to the limited
489 access to electricity and its cost. Thus, further investigations are needed to (1)
490 determine the performances of larvae reared at constant temperatures on the

491 nursery and grow-out outdoor phases and (2) assess effects of daily thermal
492 fluctuations on the performances of giant gourami larvae.

493

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498 XXX.

499

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681 **Captions to figures**

682

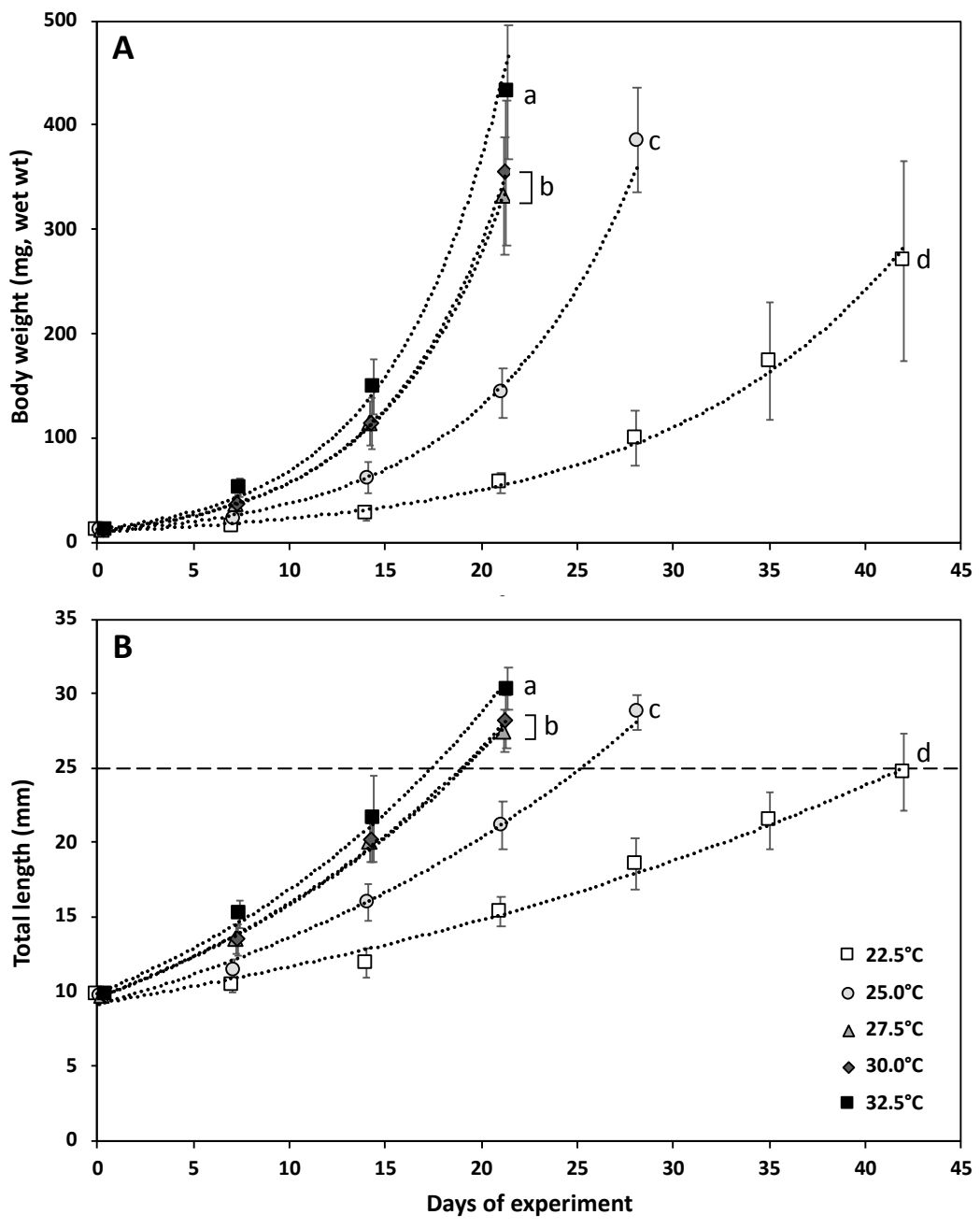
683 **Figure 1.** Growth in (A) body weight and (B) total length of giant gourami (*O.*
684 *goramy*) larvae (n=60) reared at five temperatures from 8 dph. The horizontal
685 dotted line represents the commercial size (i.e. called “Nguku”, 2.5 cm of total
686 length). Values are Means \pm SD. Letters denote significant differences ($p < 0.05$)
687 between treatments.

688

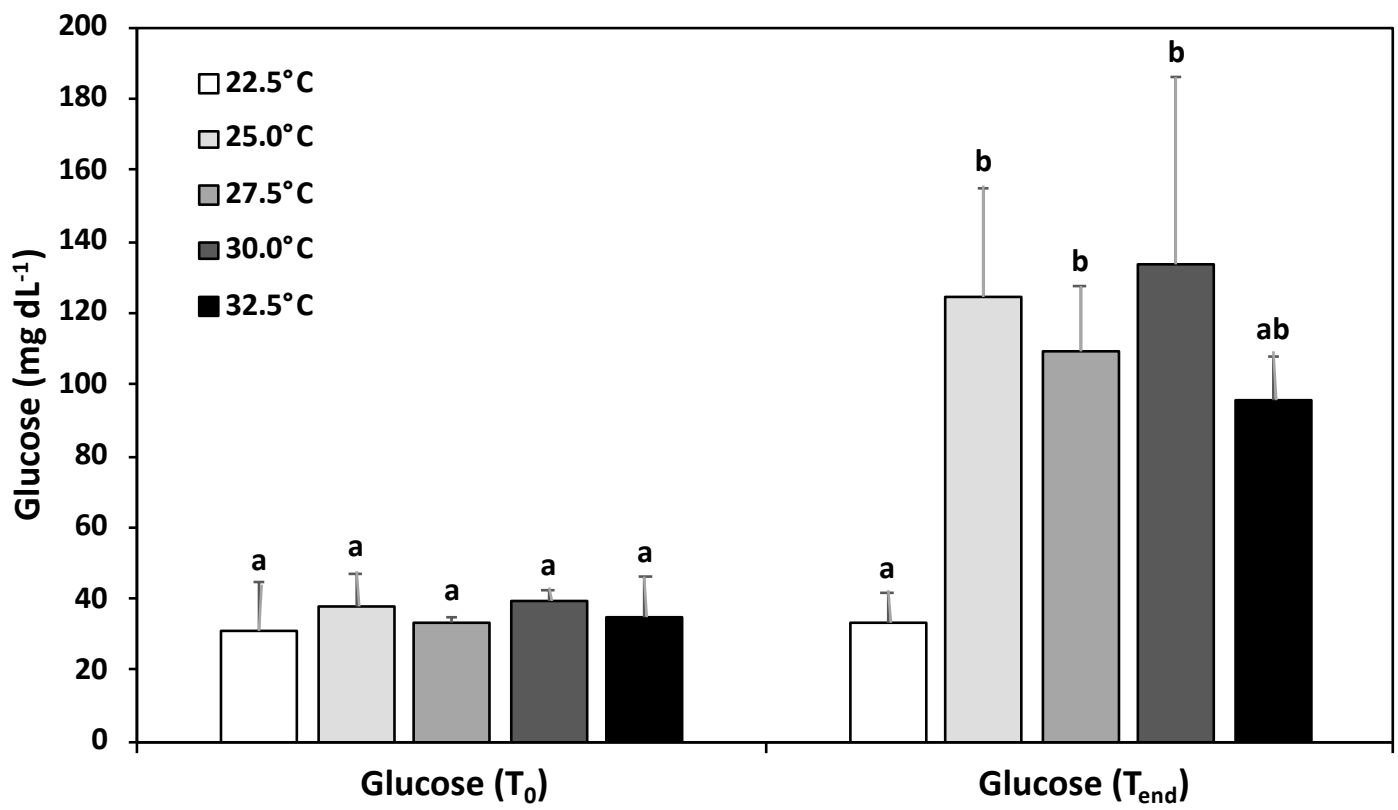
689 **Figure 2.** Concentration of glucose in the blood of giant gourami (*O. goramy*)
690 larvae (n=3 pools of 20 larvae) reared at five temperatures from 10 dph (T_0) up to
691 their reached 2.5-cm total length (T_{end}). Values are Means \pm SD. For Letters
692 denote significant differences ($p < 0.05$) between treatments.

693

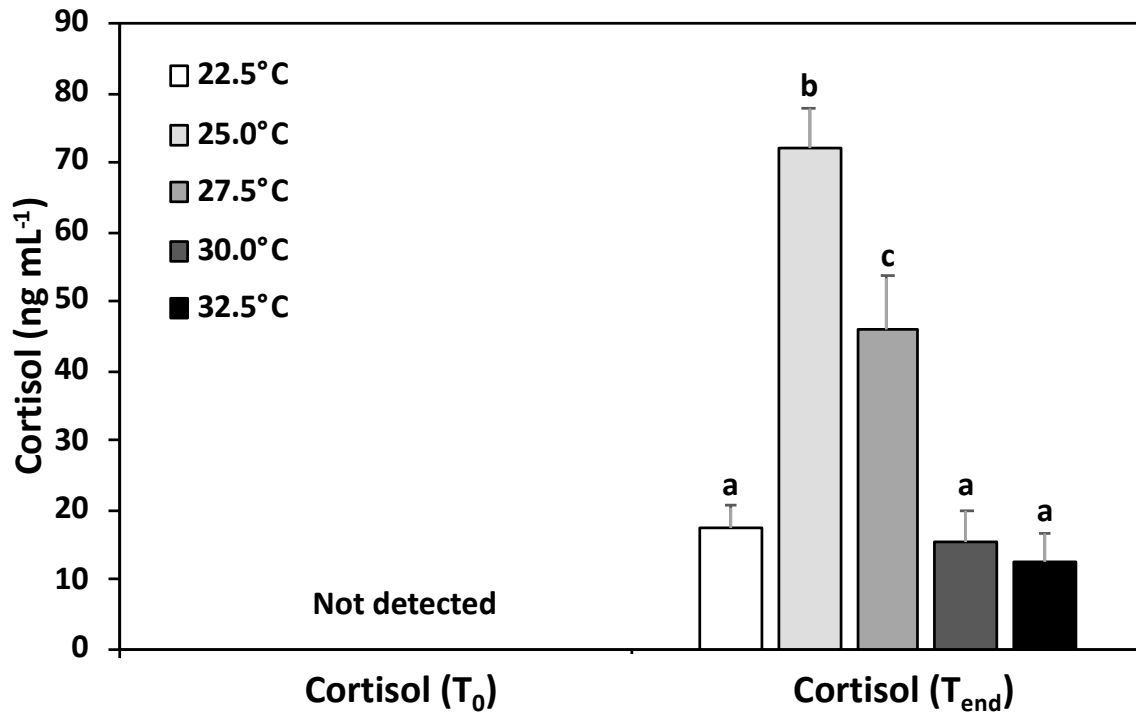
694 **Figure 3.** Concentration of cortisol in the blood of giant gourami (*O. goramy*)
695 larvae (n=20) reared at five temperatures from 10 dph (T_0) up to their reached 2.5-
696 cm total length (T_{end}). Values are Means \pm SD. Letters denote significant
697 differences ($p < 0.05$) between treatments.



698 Figure 1



699 Figure 2



700 Figure 3

701 Table 1. Summary of water quality parameters measured for the five temperature
 702 conditions during the experiment. Values are Means \pm SD. For each parameter,
 703 letters denote significant differences ($p < 0.05$) between treatments.

Parameters	Experimental treatment				
	22.5°C	25.0 °C	27.5°C	30.0°C	32.5°C
Temperature (°C)	22.57 \pm 0.43 ^a	25.24 \pm 0.53 ^b	28.17 \pm 0.68 ^c	30.01 \pm 0.31 ^d	32.45 \pm 0.74 ^e
DO (mg L ⁻¹)	7.40 \pm 0.37 ^a	7.05 \pm 0.39 ^{ab}	6.67 \pm 0.25 ^b	6.55 \pm 0.15 ^b	6.21 \pm 0.18 ^c
O ₂ saturation (%)	85.6 \pm 4.3 ^a	85.7 \pm 4.7 ^a	85.5 \pm 3.2 ^a	86.7 \pm 2.0 ^a	85.7 \pm 2.5 ^a
pH	6.58 \pm 0.19 ^a	6.77 \pm 0.21 ^b	7.04 \pm 0.05 ^b	6.98 \pm 0.28 ^b	7.05 \pm 0.04 ^b
Conductivity (μS cm ⁻¹)	208.8 \pm 13.3 ^a	263.9 \pm 15.2 ^b	215.0 \pm 6.1 ^a	327.0 \pm 16.2 ^c	347.0 \pm 7.2 ^c
Alkalinity (mg L ⁻¹)	130.4 \pm 45.2 ^a	124.1 \pm 23.4 ^a	135.4 \pm 19.1 ^a	124.6 \pm 26.0 ^a	142.2 \pm 15.2 ^a
TAN (mg L ⁻¹)	0.12 \pm 0.08 ^a	0.12 \pm 0.06 ^a	0.09 \pm 0.05 ^a	0.07 \pm 0.02 ^a	0.12 \pm 0.03 ^a
NH ₃ (mg L ⁻¹)	0.0003 \pm 0.0003 ^a	0.0011 \pm 0.0019 ^{ab}	0.0002 \pm 0.0001 ^{ac}	0.0007 \pm 0.0003 ^{abc}	0.0015 \pm 0.0004 ^{bd}
NO ₂ ⁻ (mg L ⁻¹)	0.08 \pm 0.138 ^a	0.02 \pm 0.02 ^a	0.01 \pm 0.003 ^a	0.02 \pm 0.004 ^a	0.02 \pm 0.0017 ^a
NO ₃ ⁻ (mg L ⁻¹)	4.25 \pm 3.15 ^a	5.48 \pm 2.85 ^a	4.15 \pm 0.75 ^a	12.30 \pm 2.46 ^a	7.54 \pm 2.01 ^a

704 DO: dissolved oxygen; TAN: total ammoniacal nitrogen

705 Table 2. Growth and survival of giant gourami larvae reared at five temperature
706 conditions (22.5, 25.0, 27.5; 30.0, 32.5°C) in a closed recirculating system for 21
707 to 42 days (i.e. until they reached, at least, the commercial size of 2.5 cm of total
708 length). See Section 2.5 for details of the parameters. Values are means \pm SD. For
709 each parameter, letters denote significant differences ($p < 0.05$) between
710 treatments.

Parameters	Experimental treatment				
	22.5°C	25.0°C	27.5°C	30.0°C	32.5°C
Rearing duration (d)	42	28	21	21	21
BW _i (mg)	12.3 \pm 1.5 ^a	12.1 \pm 1.5 ^a	12.4 \pm 1.4 ^a	11.8 \pm 1.1 ^a	12.2 \pm 1.4 ^a
BW _{21d} (mg)	57.2 \pm 9.3 ^a	143.7 \pm 23.6 ^b	332.0 \pm 56.0 ^c	354.3 \pm 70.2 ^c	431.9 \pm 64.2 ^d
BW _f (mg)	270.2 \pm 95.4 ^a	385.8 \pm 50.3 ^b	332.0 \pm 56.0 ^c	354.3 \pm 70.2 ^{bc}	431.9 \pm 64.2 ^d
CV _{BW} (%)	24.2 \pm 10.4 ^a	12.1 \pm 1.9 ^a	16.1 \pm 2.1 ^a	19.9 \pm 3.7 ^a	14.7 \pm 3.3 ^a
CV _{TL} (%)	8.0 \pm 3.4 ^a	3.8 \pm 0.7 ^a	4.8 \pm 1.0 ^a	6.37 \pm 1.2 ^a	4.5 \pm 0.8 ^a
K (mg mm ⁻³ x 100)	1.7 \pm 0.1 ^a	1.6 \pm 0.1 ^b	1.6 \pm 0.1 ^{bc}	1.6 \pm 0.1 ^c	1.5 \pm 0.1 ^c
SGR _{BW} (% d ⁻¹)	7.3 \pm 0.6 ^a	12.4 \pm 0.3 ^b	15.7 \pm 0.3 ^c	16.2 \pm 0.2 ^{cd}	17.0 \pm 0.2 ^d
SGR _{TL} (% d ⁻¹)	2.2 \pm 0.2 ^a	3.9 \pm 0.1 ^b	4.9 \pm 0.2 ^c	5.0 \pm 0.1 ^{cd}	5.4 \pm 0.1 ^d
SR (%)	61.6 \pm 15.4 ^a	68.5 \pm 5.3 ^a	66.7 \pm 6.4 ^a	75.0 \pm 4.8 ^a	75.5 \pm 5.6 ^a
TL _i (mm)	9.8 \pm 0.4 ^a	9.7 \pm 0.3 ^{ab}	9.8 \pm 0.4 ^a	9.9 \pm 0.19 ^{ac}	9.8 \pm 0.3 ^a
TL _{21d} (mm)	15.4 \pm 1.0 ^a	21.2 \pm 1.6 ^b	27.5 \pm 1.4 ^c	28.2 \pm 1.8 ^c	30.3 \pm 1.4 ^d
TL _f (mm)	24.7 \pm 2.6 ^a	28.8 \pm 1.2 ^b	27.5 \pm 1.4 ^c	28.2 \pm 1.8 ^{bc}	30.3 \pm 1.4 ^d

711 BW: body weight, BW_i: initial body weight, BW_f: final body weight, CV:
712 coefficient of variation, TL: total length, SGR: specific growth rate, SR: survival
713 rate, TL_i: initial total length, TL_f: final total length.

714 Table 3. Parameters (Mean \pm SE, n = 20 at each time) of the exponential growth
 715 in body weight (BW, mg) and total length (TL, mm) of giant gourami (*O.*
 716 *goramy*) larvae reared at five different temperatures. Model parameters: a: growth
 717 rate (d⁻¹). R²: determination coefficient.

Treatments	a \pm SE	R ²
Body weight (BW)		
22.5°C	0.074 \pm 0.001***	0.90
25.0°C	0.123 \pm 0.001***	0.98
27.5°C	0.157 \pm 0.001***	0.97
30.0°C	0.162 \pm 0.001***	0.96
32.5°C	0.170 \pm 0.001***	0.98
Total length (TL)		
22.5°C	0.022 \pm 0.001***	0.96
25.0°C	0.038 \pm 0.001***	0.98
27.5°C	0.050 \pm 0.001***	0.99
30.0°C	0.050 \pm 0.001***	0.99
32.5°C	0.054 \pm 0.001***	0.97

718 *** Probability of the model adjustment: p < 0.001

719 Table 4. Feed utilization of gourami reared larvae rearing in closed recirculating
 720 system at five temperature conditions. Values are means \pm SD. For each
 721 parameter, letters denote significant differences ($p < 0.05$) between treatments.

Parameters	Experimental treatment				
	22.5°C	25.0°C	27.5°C	30.0°C	32.5°C
FI _{total} (%)	25.7 \pm 2.1 ^a	30.4 \pm 1.5 ^a	45.3 \pm 2.2 ^b	51.0 \pm 3.6 ^b	58.6 \pm 1.6 ^c
IR (g g ⁻¹ d ⁻¹)	0.26 \pm 0.13 ^a	0.17 \pm 0.02 ^a	0.26 \pm 0.02 ^a	0.24 \pm 0.01 ^a	0.25 \pm 0.01 ^a
FCR	11.1 \pm 5.6 ^a	4.7 \pm 0.6 ^a	5.4 \pm 0.4 ^a	5.1 \pm 0.2 ^a	5.2 \pm 0.2 ^a
PER	3.1 \pm 1.4 ^a	6.3 \pm 0.8 ^b	5.4 \pm 0.4 ^b	5.7 \pm 0.2 ^b	5.6 \pm 0.3 ^b

722 FI: food intake, IR: ingestion rate, FCR: feed conversion ratio, PER: protein
 723 efficiency ratio.

724 Table 5. Moisture (%), dry matter (%) and proximate composition (% dry matter
 725 basis) of giant gourami juveniles reared in closed recirculating system at five
 726 temperature conditions. Values are means \pm SD. For each parameter, letters
 727 denote significant differences ($p < 0.05$) between treatments.

Composition	Experimental treatment				
	22.5°C	25.0°C	27.5°C	30.0°C	32.5°C
Moisture	77.80 \pm 1.17 ^a	78.38 \pm 0.10 ^a	79.02 \pm 0.11 ^a	78.79 \pm 0.29 ^a	78.31 \pm 0.39 ^a
Dry matter	22.20 \pm 1.17 ^a	21.62 \pm 0.10 ^a	20.98 \pm 0.11 ^a	21.21 \pm 0.29 ^a	21.69 \pm 0.39 ^a
Crude protein	57.90 \pm 0.08 ^a	58.19 \pm 0.10 ^b	59.23 \pm 0.11 ^c	59.86 \pm 0.09 ^d	58.90 \pm 0.12 ^e
Crude lipid	26.05 \pm 1.06 ^a	17.13 \pm 0.23 ^b	15.88 \pm 0.22 ^c	17.50 \pm 0.35 ^b	18.91 \pm 0.24 ^d
Ash	8.75 \pm 0.19 ^a	10.09 \pm 0.06 ^b	10.58 \pm 0.11 ^c	10.26 \pm 0.09 ^{bc}	10.27 \pm 0.15 ^{bd}
Crude fibre	0.41 \pm 0.02 ^a	0.42 \pm 0.02 ^a	0.45 \pm 0.02 ^{ab}	0.46 \pm 0.03 ^{ab}	0.48 \pm 0.01 ^b
NFE	6.88 \pm 0.85 ^a	14.17 \pm 0.32 ^b	13.86 \pm 0.28 ^b	11.93 \pm 0.38 ^c	11.45 \pm 0.14 ^c

728 NFE: Nitrogen Free Extract.