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Research Article

INFLUENCE OF ROTIFER ENRICHMENT WITH TAURINE ON LARVAL EYE DEVELOPMENT AND GROWTH PERFORMANCE OF GOLDEN RABBITFISH (*Siganus guttatus*)

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ARTICLE HIGLIGHTS

- Taurine improves eye development in golden rabbitfish larvae
- Enhanced growth performance with taurine-enriched rotifers
- Taurine positively impacts fish eye and body growth

Article Information

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ABSTRACT

Golden rabbitfish (*Siganus guttatus*) is an emerging species for aquaculture industry, despite constrains faced on commercial scale of seed production due to the high mortality during the first-feeding stage. An experiment was conducted to determine the effect of taurine through enrichment of rotifers as live-feed on eye development and growth performance of larval golden rabbitfish. Observation of eye development was carried out by measuring eye diameter of the larva and development of the retina based on histology assessment. Growth performance was measured for absolute growth and fin development of the larvae and survival rate. The results showed that taurine-enriched rotifer generally provided better performances for eye development and growth of larval golden rabbitfish compared with control (without taurine). Increase of taurine dose up to 0.050 g/L resulted in an increase of eye diameter, absolute growth, fin development and survival rate. Further increased increment of the taurine tended to decrease the values of the measured parameters. The eye diameter of larval golden rabbitfish fed with 0.050 g/L taurine-enriched rotifer was significantly wider (106.1±9.8 μm) ($P < 0.05$) compared with control (58.2±14.3 μm), but did not significantly differ from other doses of taurine ($P > 0.05$). Body width of larvae fed with 0.050 g/L taurine-enriched rotifer was significantly higher (127.3±14.6 μm) ($P < 0.05$) compared with control (98.8±18.3 μm). In regard to eye development, growth performances (total length, fin development and survival rate), dose of taurine for rotifer enrichment fed to larval golden rabbitfish *Siganus guttatus* was 0.050 g/L.

Keywords:
eye development, golden rabbitfish, growth performance, taurine

INTRODUCTION

Siganids or rabbitfish comprise many species, one of which is *Siganus guttatus* also called golden rabbitfish with local name *baronang emas* (Laining *et al.* 2021). Distribution of rabbitfish is mainly in tropical coastal waters. Production of the species is reported different based on the region. In Abu Dhabi-United Arab Emirates, *S. canaliculatus* was reported to be 149 tons in 2002 from capture (Grandcourt *et al.* 2007). The Philippines reported production of siganid reaching 150.89 tons in 2005 and increased significantly by 45% in 2014 (Gonzales *et al.* 2018). Production from aquaculture was reported in the Philippines since 2018 both from ponds and floating cages culture (Caballero *et al.* 2022). Indonesia also reported production of siganids which are mainly from capture. Demand of rabbitfish is reported in many parts of Indonesia, in particular in South Sulawesi Province, where fish are commonly served in restaurants and become a typical culinary in the region (Laining *et al.* 2017).

South Sulawesi Province reported production of 3,658.2 tonnes in 2018 and increased 37% in 2021 (https://dkp.sulselprov.go.id/page/info_berkala/kategori/24). Despite demand for rabbitfish, supply from aquaculture has yet met the demand so far.

One major constraint of golden rabbitfish culture is the unavailability of commercial scale seed production. Mortality rate of larvae is still quite high, reaching 50-90% at the age of 2-3 DAH (Days After Hatch), the time where transition period from endogenous nutrition to feeding on life-feed (Rao 2003). Survival rate during the first feeding stage of golden rabbitfish ranges from 0.2-31.6% (Juario *et al.* 1985), and survival rate of golden rabbitfish larvae was only 1%. It is argued that failures in the seed production might be caused by the feeding ineffectiveness during the early hatched stage, due to the limited eye sight of the larvae to see the feed. Golden rabbitfish demonstrates a slow growth pattern from their early life to their young juvenile period (Duray 1998). The eyes were formed on the first day, yet they were not fully developed (Juario *et al.* 1985). After 1 DAH, the eyes acquire pigmentation and become more pronounced at the age of 2 DAH (Darsiani *et al.* 2022).

Differentiation of eye is essential for larvae to see and catch the feed (Yufera *et al.* 2014). One of the contributing factors in the development of larval eyes is nutrition (Stuart 2013). The nutrition requires enrichment technique to deliver certain nutrient to support the eye. Taurine-enriched feed has been reported to have positive effects on eye, brain, and muscle development (growth) in turbot fish *Scophthalmus maximus* (Qi *et al.* 2012). Taurine is a simple protein that is easily absorbed by the body, to support the fish growth (Jusadi *et al*. 2012). Taurine also improves survival and development of white shrimp during the larval stages (Jusadi *et al.* 2011), enhances the immune system and reduces stress in zebrafish (Mezzomo *et al*. 2019) and contributes in regulating calcium metabolism, including the inside of the eye (Lombardini 1983; Lombardini 1991).

Studies on the taurine-enriched feed has been conducted on various fish, both freshwater and marine species (El-Sayyed 2013; Hernandez *et al.* 2018) and reported that marine fish have less ability to synthesize taurine (El-Sayyed 2013). Effects of taurine are different among fish depending on species, size, and nutritional content of the feed provided and ability of species to synthesize taurine with the help of enzyme CSD (*cysteinesulphinate decarboxylase*) (El-Sayyed 2013). This study aimed to evaluate the effect of different levels of taurine through rotifers enrichment on eye development and growth performances of larval golden rabbitfish *S. guttatus*.

MATERIALS AND METHODS

Experimental Design

This study was conducted at the Rabbitfish Hatchery Instalation of Research Institute for Coastal Aquaculture and Fisheries Extension (RICAFE) in Barru District, South Sulawesi. This experiment was designed in a Completely Randomized Design consisting of 4 treatments with 3 replications. The treatments were rotifers enriched with different doses of taurine, i.e., without taurine enrichment (T 0); with 0.025 g/L taurine dose (T 0.025); with 0.050 g/L taurine dose (T 0.050); and with 0.075 g/L taurine dose (T 0.075) following protocols developed by Jusadi *et al.* (2012).

Enrichment of Rotifer

Rotifers type S (*Brachionus rotundiformis*) harvested from mass culture tank with a density of 500-1,000 ind./mL (Jusadi *et al*. 2015) were enriched before being given to larvae. Enrichment was performed by preparing 10 L media, requiring 0.5 mL of fish oil A1 DHA Selco, 0.1 g of egg yolk, 0.25 of bread yeast, and taurine PA Sigma which were added according to the respective treatment doses. Taurine and other enriching materials were mixed up with 200 mL water and emulsified using a blender for three to five minutes, then poured into rotifers containers. The enriched rotifers were incubated for 2 hours and harvested by using a 50 µm plankton net then fed to the larvae (Jusadi *et al.* 2012).

Condition of Larval Rearing

Feeding trial was conducted by rearing larval in concrete tank with capacity of 6 T filled up with 3.5 T of seawater with 20-25 ppt salinity (Lante & Muslimin 2012). Water was sterilized using UV light (Yamano UV-30W) for 6 hours. During the larval rearing period, green water system was applied by adding *Nannochloropsis* sp., and maintained at a density of $1x10^5$ individual/mL (Duray & Juario 1988). Newly-hatched larvae (1 DAH) were carefully stocked with density of 20

ind./L (Duray & Kohno 1988; Lante & Muslimin 2012). Enriched rotifers were fed to the larvae with density of 10-20 ind./mL once a day. The feeding experiment was conducted for 10 days. Water quality was maintained by performing water exchanges following Duray & Kohno (1988). Water quality parameters were measured every day at 07.00 am and 17.00 pm.

Observed Variables and Data Analysis

Biological parameters observed in this study included eye development, absolute growth (length), fin development, number of rotifers consumed by larvae and survival rate. Absolute growth (length) was calculated using the formula from Jaya (2013) and Mulqan *et al.* (2017):

$$L=Lt-L0$$

where:

L = Absolute growth (mm)

L0 = Average length of test animals at the start of the experiment (mm)

Lt = Average length of test animals at the end of the experiment (mm)

Thirty larvae were taken from each rearing tank and observed using compound microscope (Olympus 40, Japan) with 4x magnification connected to a computer and camera. Histological observation was performed using the same microscope with 100x magnification. The amount of feed comsumption was determined by observing the stomach contents of the larvae.

Daily live-feed rotifer consumed by the larvae was observed by taking 30 larvae from each tank, and the stomach content was then checked using microscope. Survival rate was calculated using equation developed by Effendie (2002):

$$SR\ (\%) = \frac{Nt}{N0} \times 100\%$$

where:

SR = Survival Rate (%)

Nt = Number of larvae at final day of the experiment

N0 = Number of larvae at initial day of the experiment

Biochemical analysis was carried out for taurine content in rotifers using High Performance Liquid Chromatography (HPLC, Shimadzu 20 A, Tokyo, Japan) procedure. Due to the limited samples of the enriched rotifers, the taurine content was accommodated only for simplo analysis. Antioxidant Glutathione Peroxidase (GPx) content was analyzed spectrophotometrically using Glutathione Peroxidase Assay Kit (Abcam UK, London).

Larval size data and eye development measurement data (histology preparations) were analyzed using analysis of variance (ANOVA), with multiple comparisons evaluated using W-Tukey to compare the treatment effects (Steel & Torrie 1991). Statistical analysis was carried out using software SPSS 16.0 (SPSS, Inc., Chicago, Illinois, USA). The level of significance was defined as 0.05. Data on taurine content in rotifers after taurine enrichment were explained descriptively.

RESULTS AND DISCUSSION

Eye Development

The eye diameter of larval golden rabbitfish fed with different doses of taurine-enriched rotifers is presented in Table 1. Larvae fed with taurine-enriched rotifers had a very significant effect ($P < 0.01$) on the eye diameter compared to the T 0 treatment (control). The highest eye diameter was observed in the T 0.050 treatment, but did not significantly differ from other two taurine levels in the T 0.025 and T 0.075 groups ($P > 0.05$).

Table 1 Eye Diameter (mean±SD) of golden rabbitfish, *S.guttatus* larvae fed different doses of taurine

Dose of taurine (g/L)	Average eye diameter±sd (µm)
0	58.2±14.3[a]
0.025	94.6±7.5[b]
0.050	106.1±9.8[b]
0.075	91.7±7.8[b]

Notes: sd = standard deviation. Different letters above the numbers indicate significant differences among treatments at ($P < 0.05$).

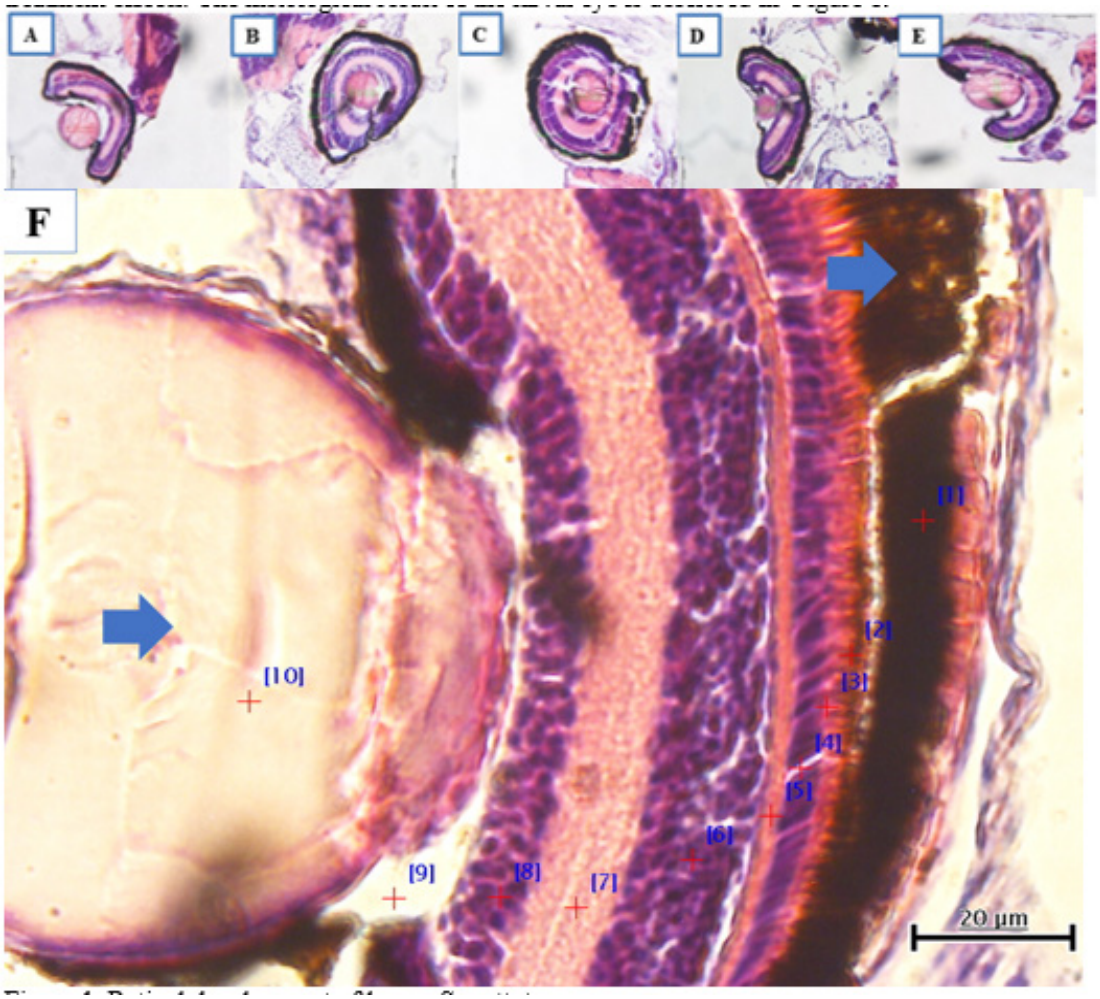

Figure 1 Retinal development of larvae *S. guttatus*

Notes: DAH = Day After Hatch. Blue arrows indicate lens and receptor cells. A presents retinal development at 2 DAH; B, C, D, E present retinal development at 10 DAH with taurine dose treatments, observed with 4x magnification. B = control (T 0 g/L); C = T 0. 025 g/L; D = T 0. 050 g/L ; E = T 0. 075 g/L; F = parts of the retina (100X magnification). Description of picture F: 1) Retinal Pigmen Epithelium; 2) Photoreseptor Layer; 3) Outer Limiting Membrane; 4) Outer Nuclear Layer; 5) Outer Plexiform Layer; 6) Inner Nuclear Layer; 7) Inner Plexiform Layer; 8) Ganglion Cell Layer; 9) Sclera; 10) Lens.

Histology of larval eye development was performed to have in-depth observation on the treatment effects. The histological result of the larval eye is described in Figure 1.

At 2 DAH, diameter of the lens was 45.4±1.0 µm, and the photoreceptor cell thickness was 1.9±0.6 µm. At 10 DAH, the lens diameter was 64.7±3.8 µm (T 0), 68.1±5.6 µm (T 0.025), 72.7±5.0 µm (T 0.050), and 69.9±0.9 µm (T 0.075), respectively and thickness of the photoreceptor cell was 4.0±0.1 µm, 4.4±0.1 µm, 5.6±3.1 µm, and 3.1±0.0 µm, respectively.

Results found in this present study indicated that rotifers enriched with taurine had positive effect on the eye development of golden rabbitfish larvae including eye diameter size, lens diameter and receptor cell thickness. In the rotifers enrichment treatment using taurine, eye development increased, and the best development was occurred when the rotifers was enriched with 0.050 g/L of taurine. Jusadi *et al.* (2012) reported that the use of taurine at a dose of 0.060 g/L on duck grouper *Cromileptes altivelis* increased the rate of feed predation, indicating that eye development had increased significantly. Banthani *et al.* (2019) also reported that taurine as an enrichment in rotifers was perceived to support eye development, leading to significant increase in the vision of coral trout larvae (*Plectropomus leopardus*). However, further increase of the taurine dose did not cause a better eye development as demonstrated in this present study. On the other hand, the excessive doses of taurine tended to have negative effect on the eyes' visibility of the larvae due to the impaired eye development. It is argued that excessive taurine in the larvae's

body might stimulate a toxic taurine-derived compounds that can damage cells. According to Watanabe *et al.* (2022) N-acetyltaurine (NAT) and N-chlorotaurine are derivatived compounds of taurine and although they are biologically less toxic, they may decrease the stability of cell.

Increased eye diameter is one of the indicators of the larva's developing ability to see objects. Fiolita *et al.* (2017) stated that eye diameter improves the eye's ability to capture light which strongly improve the ability of the larvae to see surrounding objects. Furthermore, a well-developed eye lens supports for better vision (Afitah *et al.* 2020). The eye lens functions to regulate the light entering the eye, continue the reflection the object's shadow received, then focus the image falling on the retina, and sent to the brain for translation (Rahardjo *et al.* 2011). The shadows of objects that successfully enter the eye are supported by proper lighting conditions and appropriate contrast of the container/object (Bogner *et al.* 2017; Stuart 2013). Growth has a major effect on the increase in the size of the eye lens, but the increase in lens size will stop at a certain age (Fitri 2002).

Number of Live-feed Consumption

The average number of live-feed (taurine-enriched rotifers) consumed by the larvae at the age of 3-10 DAH is shown in Figure 2. Generally, number of rotifers consumed by the larvae increased with the increase of the age of larvae. At the final day of the feeding experiment, rotifers consumption by the larvae was the highest in the T 0.050 g/L treatment, while the lowest was recorded in the T 0 g/L group.

The eyes' ability to see objects can also be determined through the amount of feed captured by the larvae (Yufera *et al.* 2014). The present study showed that the amount of live-feed rotifers captured by the larvae was significantly higher in treatments with taurine enrichment compared to that without taurine, with the highest amount of rotifers captured was found in T 0.050 g/L. This indicated that a well-developed eye can increase the number of live-feed captured. A similar finding was reported by Jusadi *et al.* (2012) and Hernandez *et al.* (2018), where the amount of feed captured by larvae increased through taurine supplementation. Subsequently, successful feed capture can support the growth and development of larvae (Stuart 2013; Miranti *et al.* 2017).

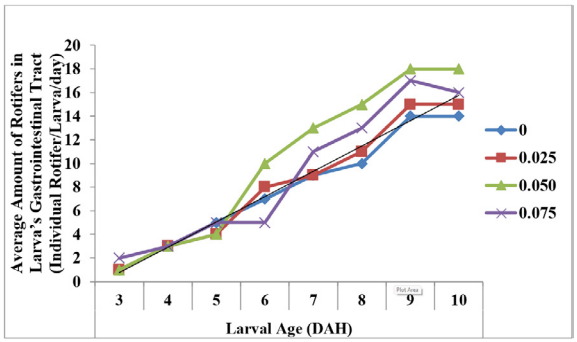

Figure 2 Amount of live-feed (rotifers enriched with taurine with different doses) consumed by golden rabbitfish larvae, *S. guttatus* at the age of 3 to 10 DAH

Figure 2 shows that the daily feed predation of golden rabbitfish larvae at 3-5 DAH in each treatment showed no significant difference, and a significant difference ($P < 0.01$) started to be detected at 6 DAH. This showed that the effect of taurine on the eye sight of larvae occurred after the larvae reached 6 DAH, or after 4 days of consuming taurine-enriched rotifers.

The increasing eye vision was presumably due to the calcium regulation in the eye, resulting in better vision in the dark. This is in agreement with studies conducted by Lombardini (1983), Lombardini (1991), and Militante dan Lombardini (2002), where taurine supports eye development through calcium regulation that occurs in the retinal pigment epithelium (RPE). The Glutamate released under dark conditions may increase the concentration of free calcium ($Ca^{2+}i$) in RPE. High concentration of free calcium can inhibit the performance of *rhodopsin kinase*, limiting individuals' vision in low light conditions. In addition, free calcium can also inhibit the performance of CGMP which is the ion channel Na^{+}. The hampered CGMP disrupts the entry of Na^{+} into RPE, where in fact the Na^{+} is an element that can bind free calcium, decreasing its concentration in the RPE. Free calcium can further hamper the performance of *guanylate cyclase*, a phototransduction that converts light into electrical signals in the brain.

Growth

Absolute growth of golden rabbitfish larvae measured in this study included body length, and width. The absolute growth of the larvae fed with different doses of taurine-enriched rotifers are presented in Table. 2. Feeding of rotifers enriched with taurine at different doses had a very significant effect ($P < 0.01$) on absolute length, but had no significant effect

(P > 0.05) detected on absolute body width of the larvae. The trend of both total length and body weight was similar where increase of taurine dose up to 0.05 g/L resulted in an increase of the both parameters.

Table 2 Absolute growth (mean±SD) of golden rabbitfish, *S. guttatus* larvae fed with rotifers at different doses of taurine

Dose of taurine (g/L)	Absolute growth	
	Total length (mm)	Body width (μm)
0	0.94±0.09[a]	98.8±18.3[a]
0.025	1.28±0.01[b]	106.5±30.0[a]
0.050	1.39±0.03[b]	127.3±14.6[a]
0.075	0.85±0.08[a]	79.6±8.2[a]

Note: different letters above the numbers indicate significant differences among treatments (P < 0.01).

The mean of absolute length of larvae fed with T 0.050 treatment was very significantly different from T 0 and T 0.075 treatments (P < 0.01), but was not significantly different from T 0.025 treatment (P > 0.05). The highest absolute growth was obtained at T 0.050 treatment and the lowest was shown at T 0.075 treatment.

In this study, an obvious response of taurine enrichment was observed on the length growth of golden rabbitfish larvae. The increase in body length in treatments fed with taurine-enriched rotifers was suspected to have a positive correlation with spinal development. Zulfahmi *et al.* (2018) revealed that spinal development is an important factor for fish growth as it supports the muscle strengthening. Similar findings were reported on humpback groupers (*Cromileptes altivelis*) and on white shrimp *Litopenaeus vannamei* (Jusadi *et al.* 2012; 2015) that the larvae growth was better in the taurine-enriched rotifers feeding treatment at a dose of 0.050 g/L. Lower growth of golden rabbitfish was observed in the treatment without taurine (T 0) and at the highest dose of taurine (T 0.075). Similar phenomena were reported by Bavi *et al.* (2022), where taurine deficiency and excessive taurine feeding decreased the growth performance of juvenile *Acipenser ruthenus*. Impaired growth in excessive taurine feeding was argued to be caused by the inhibited absorption of nutrients which is in line with Liu *et al.* (2022) who reported that excessive taurine can damage the digestive tracts and livers of *Scophthalmus maximus*.

Better growth can be achieved when the daily energy requirements are met, and one way to save energy use is the easily absorbed diets. As stated by Jusadi *et al.* (2012), taurine is one of the essential amino acids that can be used directly (absorbed) by the body to increase growth and development of fish larvae. As reported by McBean *et al.* (2017) and Tochitani (2022), taurine can be synthesized from methionine and cysteine with the help of several enzymes, such as cystathionine-β-synthetase (CßS), β-cystathionine (CTH), cysteine dioxygenase (CDO), cysteine sulfinic acid decarboxylase (CSAD), hypotaurine oxidase, and cysteic acid decarboxylase. These stages of amino acid synthesis requires a certain amount of energy to produce taurine compounds.

The role of taurine on nerve cells has also been reported by Jakaria *et al.* (2019), where taurine had the ability to regulate free calcium in cells to prevent damaging the cells (*apoptosis*) (including nerve cells), through activating the *calpain* and *caspase* enzymes. The condition of healthy nerve cells can facilitate in sending signals to the brain to perform organogenesis, which is controlled by the central nerve (Banthani *et al.* 2019). The effect of taurine on growth was further reported by Qian *et al.* (2021), stating that taurine was able to improve digestive function in the intestine and regulate *glycolipid* metabolism to increase the use of carbohydrates, to support growth. Shi *et al.* (2022) also found that taurine maintained the intestinal health of juvenile swamp eels *Monopterus albus*.

Fin Development

Development of fins including dorsal, pectoral, and caudal of golden rabbitfish larvae fed with taurine-enriched rotifers at different doses of taurine is presented in Table 3.

Table 3 Development of dorsal, pectoral, caudal fins (mean±SD) of golden rabbitfish *S. guttatus* larvae fed with different doses of taurine-enriched rotifers

Dose of taurine (g/L)	Fin development (μm)		
	Dorsal	Pectoral	Caudal
0	48.7±13.3[a]	44.0±13.4[a]	36.2±11.8[a]
0.025	79.3±15.2[ab]	76.0±24.3[ab]	52.0±10.2[ab]
0.050	84.6±14.8[b]	93.6±15.3[b]	75.5±8.9[b]
0.075	56.4±10.9[ab]	87.0±13.8[ab]	54.9±17.3[b]

Note: different letters above the numbers indicate significant differences among treatments (P < 0.05).

Development of fins was significantly affected ($P < 0.05$) by feeding of rotifers enriched with taurine at different doses. The mean of dorsal and pectoral fins of the T 0.050 treatment were significantly different ($P < 0.05$) from the T 0 treatment, but did not significantly differ ($P > 0.05$) from both T 0.025 and T 0.075 treatments. The caudal fin development of larvae in T 0 and T 0.025 treatments was significantly different ($P > 0.05$) from that in T 0.05 and T 0.075 treatments. The highest fin length (dorsal, pectoral, and caudal) was obtained at T 0.050 treatment and the lowest was at T 0 group.

This study also found that growth was directly proportional to the fin size of the larvae where larvae in T 0.050 treatment demonstrated a better fin development. Well-developed fins can result in a better fish mobility to swim in the water column. Rahardjo (2020) also found that fins can support fish mobility (swimming) including for catching preys. Better movement of fish may trigger an increase in the amount of feed predation, and result in better growth and survival (Stuart 2013). In addition, Jusadi *et al*. (2011) reported that taurine can accelerate the stadia development of white shrimp *Litopenaeus vannamei* larvae.

Survival Rate

Survival rates of rabbitfish larvae fed with rotifers enriched with different doses of taurine is presented in Table 4. Feeding rotifers enriched with taurine at different doses had a significant effect on the survival of golden rabbitfish larvae ($P < 0.05$). Only survival rate in the T 0.050 treatment was significantly different ($P < 0.05$) from the other treatments. On the other hand, survival rates in the T 0, T 0.025, and T 0.075 treatments were not significantly different ($P > 0.05$). The highest survival rate was obtained at T0.050 treatment and the lowest was shown at T 0.075 group.

Table 4 Survival rate (mean±SD) of golden rabbitfish *S. guttatus* larva fed with rotifers enriched with different doses of taurine

Dose of taurine (g/L)	Survival rate (%)
0	0.71±0.12[a]
0.025	0.75±0.21[a]
0.050	1.47±0.42[b]
0.075	0.58±0.28[a]

Note: different letters above the numbers indicate significant differences among treatments ($P < 0.05$).

The highest survival rate in this present study was observed in T0.050 taurine treatment. This is in line with the two studies reported by Jusadi *et al*. (2012; 2011) that 0.050 g/L of taurine significantly increased the survival rate of humpback grouper *Cromileptes altivelis* and white shrimp larvae *Litopenaeus vannamei*. Similarly, Banthani *et al*. (2019) reported that survival of leopard coral grouper *Plectropomus leopardus* larvae was significantly higher in taurine-enriched treatment compared to that without taurine treatment. It is presumed that at a certain stage or age, taurine supplementation will have a better effect on the growth, development, and survival of larvae *S. guttatus*. El-Sayyed (2013), Hernandez *et al.* (2018), dan Wei *et al*. (2020) reported that the effects of taurine will differ for different species, body sizes, and age levels.

Antioxidant Content (GPx) in Larvae Fed with Taurine-Enriched Rotifers

GPx antioxidant content in body of golden rabbitfish larvae after being fed with taurine-enriched rotifers is presented in Table 5. The pattern of the antioxidant GPx in the larval body linearly increased as the dose increased. The highest GPx antioxidant content was obtained at T 0.075 treatment and the lowest was found at T 0 group. However, the taurine doses had no significant effect ($P > 0.05$) on antioxidant content (GPx) on the larval body.

Table 5 Antioxidant (GPx) content in *S. guttatus* larvae

Dose of taurine (g/L)	Average antioxidant GPx content in larvae (nmol)
0	65.39±1.60[a]
0.025	70.39±5.86[a]
0.050	71.33±1.21[a]
0.075	73.29±2.78[a]

Note: different letters above the numbers indicate significant differences among treatmens ($P < 0.05$)

Other function of taurine is to increase the glutathione synthesis in the body (Miyazaki *et al.* 2022). Although no significant, effect of taurine enrichment on the antioxidant (GPx) content in the larval body was found in the present study. A clear trend was observed that increased taurine dose linearly increased the the antioxidant (GPx) in body. The presence of this antioxidant (GPx) might positively affect the healthy condition of the larvae fed with taurine-enriched rotifers.

Schaffer & Kim (2018) reported that taurine is believed to function as an antioxidant, enhance immunity (Jin *et al*. 2017), and can prevent stress (Akande & Ahmed 2017; Mezzomo *et al*. 2019) by neutralizing super oxidant derivatives produced from mitochondria (Schaffer & Kim 2018). Marcinkiwicz and Kontny (2012) demonstrated that taurine can reduce toxins of hypochrolytic acid (HoCl) and hypobromic acid (HoBr) which both of these acids are peroxide compounds. Taurine can convert these acids into chloramine taurine (TauCl) and bromamine taurine (TauBr) which are more stable or less biologically toxic compounds.

Taurine Content in Rotifers After Enrichment

Table 6 presents the taurine contents of rotifers after enrichment with various doses of taurine. The highest value was analyzed in 0.050 g/L treatment, followed by 0.025 g/L, while the lowest content was detected at the highest dose of T 0.075 g/L.

Table 6 Taurine content in rotifers after enrichment

Dose of taurine (g/L)	Taurine content in rotifers after enrichment (µg/g)
0	1.875
0.025	2.332
0.050	3.274
0.075	1.793

The content of taurine in rotifers tended to increase as the dose of taurine increased up to 0.050 g/L, and further decreased at higher level. This trend might imply that rotifers has a limited ability to accumulate taurine in the body. Similar finding was reported by Jusadi *et al*. (2011) that the addition of taurine up to 0.1 g/L increased the taurine content in rotifers; and further higher dose lead to decrease the taurine content.

Compared with the treatments of taurine-enriched rotifers, only a small amount of taurine was found in the treatment without taurine (T 0), namely 1,875.18 µg/g. Jusadi *et al*. (2011) reported similar results, the taurine content in non-taurine-enriched rotifers was 1,700 µg/g. The taurine content detected in the rotifers without taurine enrichment is presumed to come from other ingredients used in the enrichment, namely baker's yeast, egg yolks, and DHA. Baker's yeast and eggs are ingredients that contain protein and other nutrients (Oktaviani *et al*. 2012; Swari *et al*. 2019) which can also be consumed or absorbed by rotifers. Takeuchi (2001) found small amounts of taurine in unenriched rotifers ranging from 8-18 µg/g. Jusadi *et al*. (2012) and Cho *et al*. (2022) also reported lower levels of taurine content in unenriched rotifers, namely 77.7 µg/g and 310 µg/g, respectively. The difference in taurine content in rotifers is probably due to the type of nutrient fed to the rotifers before being used for the enrichment. Since, taurine content of rotifers varied according to the status of the rotifers, it is suggested to enrich the rotifers with taurine before being given to fish larvae (Li *et al*. 2017; Swari *et al*. 2019; Salsabila *et al*. 2019).

CONCLUSION

Live-feed rotifers enriched with 0.050 g/L taurine resulted in better eye development and growth performances in terms of total length, fin development and survival rate of larvae of golden rabbitfish *Siganus guttatus*.

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