The effect of yellow and red illuminations on the swimming behaviour, mortality and growth rates of yellowfin tuna juveniles (*Thunnus albacares*)

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Abstract. The breeding program for yellowfin tuna has been conducted at the Institute for Mariculture Research and Fisheries Extension (IMRAFE). The production of early juveniles in the nursery facility from egg spawned by reared tuna was unstable; the survival rate from larvae to juvenile sizes of 2.5-3.0 cm was 1-3%. This problem was suspected due to the effect of lighting system. An experiment was conducted indoor in 14 days with tanks under different illuminations, i.e. yellow and red from light emitted diodes (LED) of 3 watts and brightness of 270 lumen. Each tank contained 50 juveniles of 2.5-3.0 cm in total length (TL). The tuna juveniles were fed with fresh whole fish or fish meats, such as milkfish fries, anchovies, or minced fish, six times per day up to satiation. During the experiment, the swimming behaviour of the juveniles were observed, their body lengths were measured, and cases of mortality of the fish were recorded. The swimming activities of the yellowfin tuna juveniles and growth rate under yellow illumination were higher than under red illumination. Between the two different colours of illumination, the survival rates of the juveniles were similar.

1 Introduction

The Institute for Mariculture Research and Fisheries Extension (IMRAFE) has been successful in rearing small-sized tunas from wild [1, 2] in a circular concrete tank or in a floating net cage [3, 4, 5] to reach broodstock size that spawned in controlled environments [6, 7]. The nursery facilities for the tuna juveniles consisted of concrete tanks, fiberglass reinforced plastic tanks in indoor and outdoor systems, and floating net cages at sea [8, 9]. In contrast to the use of eggs naturally spawned in the wild [10, 11, 12, 13], the survival rates of the juveniles of 2.5-3.0 cm after 21-25 days rearing in the controlled environment were low, i.e. between 1-3% [14, 15, 16, 17]. Such low survival rates indicate the instability of the nursery facilities in producing tuna juveniles while the IMRAFE has been expected to be the main source of tuna juveniles.

Such low survival rates at the larval stages of the tuna at the IMRAFE was suspected due to the lighting system, including colour factor in the illumination and tank wall. The colour of inner wall of rearing tanks for larvae of Pacific bluefin tuna - PBT (*Thunnus orientalis*) and yellowfin tuna YFT (*Thunnus albacares*) were blue [18] while for the southern bluefin

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tuna - SBT (*Thunnus maccoyii*) were green [19]. However, we found that rearing tanks with black inner wall and grey bottom were suitable for larvae of yellowfin tuna even the larvae metamorphosed to juveniles and cannibalism was high [14]. Yellow inner wall tank was commonly used for milkfish fries [20], coral trouts [21], and YFT [14]. The PBT juveniles had better survival when were reared in clear contrast and patterned wall tanks [22].

Swimming speed, schooling, and chasing behaviours of the PBT and YFT increased rapidly from larvae to juveniles [23]. Intermittent sprint swimming from larvae to early metamorphose juveniles and continuous cruising at late juveniles were observed [24]. Findings from the behaviour of the PBT in the nurseries include scotopic visual threshold [19], photopic spectral sensitivity [25], light intensity-related-schooling behaviour [26], sensitivity related to wavelength [27], and light intensity against area coverage of illumination [28]. However, reason of a mortality of 60% of PBT juveniles is still unknown [24], and the colour of inner wall tank has not been determined yet. Considering the information from PBT, this study was carried out to describe the behaviour of YFT, survival and mortality rates under yellow and red illuminations in the nursery facilities at IMRAFE.

2 Methods

2.1 Experimental fish

The origin of the juveniles of yellowfin tuna in this study was egg naturally spawned by broodstock in floating net cage at sea, transported to land based facilities, then hatched and reared in the IMRAFE hatchery. After being reared for 22 days in hatchery, they metamorphosed to the juvenile stage, they were harvested and placed in fibreglass reinforced plastic (FRP) tanks with blue inner wall for acclimatization inside indoor nursery system. This study used 6 units of experimental tanks, each with a diameter of 2.7 m and a height of 1 m that can hold 5 m^3 of water. The inner wall of each experimental tank was painted yellow. The tanks were placed in two rows and oriented from east to west.

2.2 Experimental procedures

The water surface of each tank was exposed to continuous illumination generated by one light-emitting diode (LED) of 3 Watts and brightness of 270 lumens. There are two types of LED, i.e., one generated yellow and the other one generated red illumination. Each LED was positioned 40 cm above the center of water surface of the tank. The light intensity at the centre of water surface of the tank under the red LED was 10.03±0.70 lux while near the tank wall was o 4.28±1.80 lux. For the yellow LED, the light intensity was 19.80±3.72 lux at the centre of water surface while 5.80±0.63 lux near the tank wall. The light intensity was measured by a luxmeter type T-10Ws, Minolta Co. LTD, Japan. The assignment of illumination colour for each tank was determined randomly. Three replications were carried out for each colour of illumination.

After being acclimatized for 5 days, the tuna juveniles were transferred to the experimental tanks. Each tank contained 50 juvenile fish of 27 days old, total length-TL of 41-50 mm, standard length-SL of 36-35 mm, and body weight of 0.80-0.90 g.

The flowing seawater in each tank was filtered through a high-pressure sand filter (HPSF) to minimize the organic material content. In each tank, a 1-inch PVC pipe was installed vertically, and holes were made with a diameter of 3 mm with a distance between the holes was 5 cm and mounted on the inner wall of the tank. The position of holes is arranged parallel to the tank wall to form a counter clockwise rotation of water, according to the Coriolis effect in the southern hemisphere. Drain water was carried out at the centre of the bottom of the tank to generate additional power to develop a vortex system and simultaneously facilitate disposal of uneaten feed.

The seawater intake flow in each tank was controlled by a valve. Each tank was equipped with four aeration systems at the tank bottom near the wall to maintain oxygen level. The water in the tank was exchanged at a rate of 200-300% per day through a flow system. The experiment was conducted in 14 days and the fish juveniles were fed with fresh whole fish, such as milkfish fries, anchovies, or minced fish 6 times per day until satiation.

The swimming behaviours, growths, and survival rates of the fish juveniles were monitored during the experiment. The measurement of fish sizes (total length and standard length of the fish) was carried out using a digital calliper (Absolute Digimatic, Mitutoyo with an accuracy of up to 0.01 mm). The wet and dry weights of the juveniles were measured with digital scales (AND GX-2000) with an accuracy of up to 0.1 g. The dry weights of the juveniles were measured from fish specimen stored in a drying oven (Isuzu Drying Oven, Kosumosu, Max 260 ^{o}C Type, Isuzu Seisakhuso Co. Ltd. Japan) and set at 60 ^{o}C for 24 hours.

2.3 Data analysis

The mortality rate (MR) of the fish juveniles was calculated with:

$$MR = \frac{N_t}{N_0} \, x \, 100\% \qquad (1)$$

Where N_0: initial number of juveniles, $N_t = N_0 - d_t$ where $d_t =$ cumulative total number of dead juveniles at *t* day of rearing.

The standard length (SL), body weight (W) and survival rates of the fish juveniles under each illumination colour were regressed on rearing day. Difference in the slopes of linear regression lines was used to determine potential effects of illumination colour on the growth rate and survival rates of the fish juveniles.

3 Results

3.1 Swimming behaviour of yellowfin tuna juveniles

As soon as the fish juveniles placed in the experimental tanks (with yellow inner wall), they swam in all directions; no specific pattern was identified yet. In the following day, they started forming a fish school that swam in a circular pattern inside the tank. The swimming speed of the fish juveniles under the yellow illumination was faster than under the red illumination. The distances among the fish juveniles under the yellow illumination was closer than under the red illumination. Also, the swimming pattern was more regular under the yellow illumination than under the red illumination. The fish under the yellow illumination were more active than under the red illumination. The diameter of swimming circle made by the fish under the yellow illumination was larger than under the red illumination.

In feeding time, the fish under the yellow illumination were more responsive than under the red illumination. When someone approached the tank, the juveniles under the yellow illumination immediately formed a distinct fish school while those under the red illumination exhibited slow response and formed a vague fish school.

3.2 Growth rate of yellowfin tuna juveniles

The average body wet weight of the juveniles at the beginning of the experiment was 1.15±0.35 g (Figure 1). After being stored in a desiccator set at 60 °C for 24 hours, it was found that the average dry body weight was 0.25±0.08 g. Increase in body weight for the juveniles under the yellow illumination was higher than in the red illumminatin was observed higher after the day 7th of rearing. Increase in standard length was observed higher for the juveniles under the yellow illumination. At the end of the experiment, the average body weight of juveniles under the yellow illumination was 4.10±1.19 g whereas under the red illumination was 3.50±0.78 g. There was not significant difference in the end body weight of the fish juveniles between the two illumination types. For standard length of the juveniles at the end of experiment, no significant difference between the two illumination types is detected.

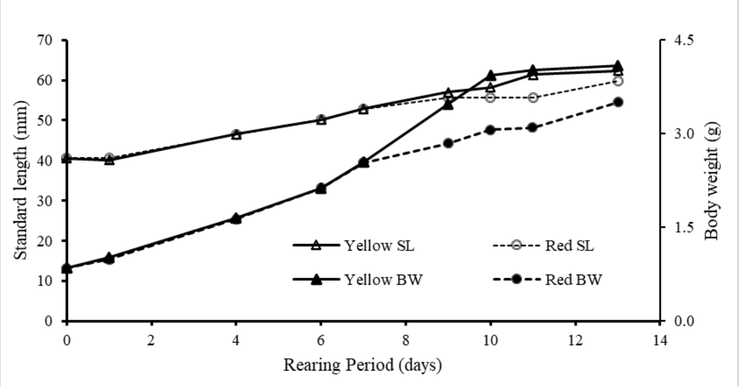

Fig. 1. Length and weight of the juveniles of yellowfin tuna (*Thunnus albacares*) during the experiments under yellow and red illuminations

Length-weight relationship of yellowfin tuna juveniles for each treatment was analysed with linear regression (Figure 2). The growth coefficient, i.e., the increase in body weight per length increase, for the juveniles under the yellow illumination was slightly higher (0.15) than under the red illumination (0.14). For the same body length, the weight of the fish in the tanks under the red illumination was lower than the fish in the tanks under the yellow illumination (Figure 2).

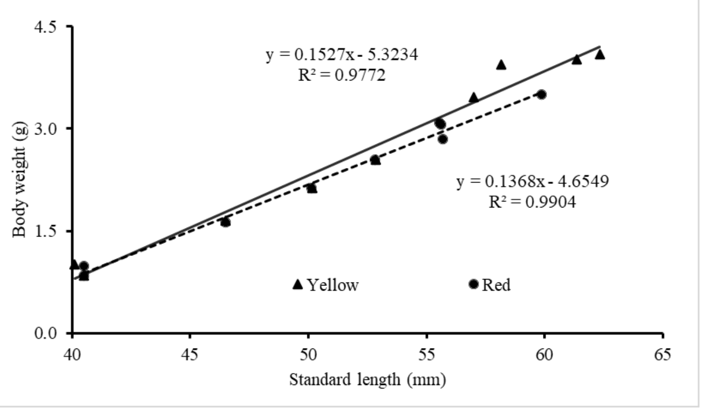

Fig. 2. Length-weight linear relationships for yellowfin tuna (*Thunnus albacares*) juveniles reared under yellow and red illuminations.

3.3 Mortality rate of yellowfin tuna juveniles

The sources of mortality of the yellowfin tuna under this experiment can be distinguished into three categories. First, mortality due to stress on environmental changes that experienced by the fish in the first two days after the transfer outdoor (i.e., exposures to high-natural illumination) to indoor nursery facilities (exposures to experimental illuminations, low illumination) and from acclimatization tanks (blue inner wall tanks with black stripes) to experimental tanks (yellow inner wall tanks). Second, mortality due to collisions fish with the tank wall when chasing food or their immediate response of rapid swimming and less controlled movement to the occurrence of sudden environmental changes such as sound, lighting, and flying objects. Third, mortality due to insufficient food leads to starvation and death.

The mortality rates during the experiment were presented in Figure 3. First, two days after transfer the mortality rates were 8-13%. The mortality rates due to collision on wall that occurred from day 3 to day 10 were 45-48%. When the experiment approached its end, the remaining fish in the tanks under the red illumination was higher than in the tanks under yellow illumination.

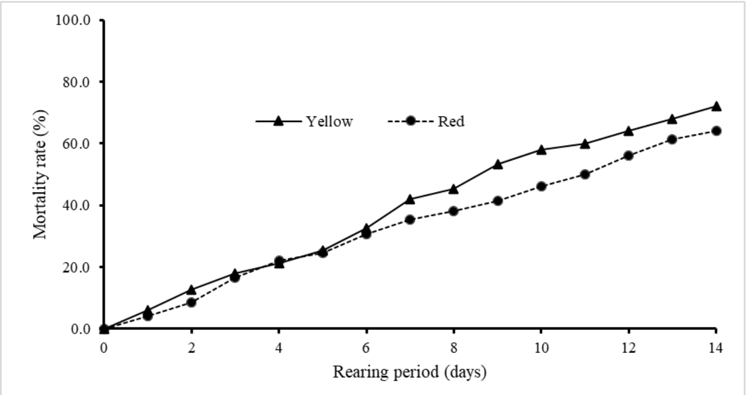

Fig. 3. Mortality pattern of yellowfin tuna (*Thunnus albacares*) juveniles during nursing period under yellow and red illuminations.

4 Discussion

The reaction of the juveniles of yellowfin tuna to light differs between the colours of illumination. According to [25], PBT juveniles reared in polyethylene net fitted in the tank without night light showed less active swimming behaviour as observed on the fish juveniles under the red illumination of this study. Prolonged low light intensity [29] was reported promote mortality rate.

The higher gain in body weight of the fish juveniles under the yellow illumination (Figure 2) was probably correlated with their more active feeding behaviour. Similar explanation was provided for the juveniles of PBT: the growth rate under the red illumination was lower than under green and white illumination. The spectrum of the wavelengths of white light covers the yellow light wavelengths [23]. Difference in the gain of body weight between the two types of illumination was observed from the 7th day of the experiment (Figure 2). The yellowfin tuna juveniles showed a rapid growth from 30 to 40 days after hatching along with development of the vertebrae ossification [16].

When the vision of yellowfin tuna juveniles has not fully developed yet [29], the illumination with low intensity is inadequate to support their vision for sensing the foods and their surroundings. The inadequate illumination may not only slow-down the growth of the tuna juveniles but also promote mortality due to collisions. Collision mortality appeared to be the most dominant source of the low survival rate of the fish juveniles in this experiment. The collision with the tank wall is likely to be correlated with an increase in the swimming speed. Development of vertebrae ossification [16] and increases in red and white muscle volumes [29] often promote the fish juveniles to hit the wall of the tank. Light at night with an intensity of 6,300-17,787 lux was provided to reduce the mortality rate of farmed PBT [30].

The mortality of the juveniles in the first two days of this experiment was lower than the mortality observed in previous experiment [17]. The reduction in this initial mortality was the outcome of better fish handling in anticipating negative effects of significant changes in water temperature, salinity, water supply, and light intensities during transfer and acclimatization process. The highest mortality in PBT juveniles was related to the scotopic visual threshold at 11.1 log photons/cm^2/s [22]. Another report mentions that fish mortality is related to the adaptability from scotopic to photopic visions [31] and found for PBT juveniles was 7.52 lux. The fish juveniles were stressed during the transition condition and swam quickly at any direction [25].

The survival rate of tuna juveniles under the red illumination was slightly higher than under the yellow illumination (Figure 3). It means that the red illumination had negative effect on the growth but promote better survival of the tuna survival than the yellow illumination.

Failure to find food was a contributing factor to slow growth rate while the collision with tank wall generated stress and physical injury that caused mortality of the tuna juveniles in this experiment. At the end of the experiment, the number of slow-grow fish juveniles under the red illumination were higher than the fish under the yellow illumination. The cause of higher survival rate of yellowfin tuna juveniles reared under red illumination in this experiment was different compared to Torisawa et. al. [27] who concluded no significant difference in survival rate of PBT juveniles among four colours of illumination. The mortality of the PBT juveniles was related to the rapid development of the swimming ability while the visual function was not fully functional [25]. Since the experiment of [27] used higher light intensity than this experiment, the light intensity was more effective in determining the survival rate of PBT juveniles than the colour of illumination. Therefore, the survival rate of the yellowfin tuna juveniles under light illumination in this experiment was related to the slow swimming activity and less success in finding the food.

5 Conclusion

LED illumination in the yellowfin tuna nursery can suppress the initial mortality of tuna juveniles during the transfer from the hatchery to a nursery tank. Under the yellow illumination the fish juveniles in the yellow inner wall tanks to grow faster than under the than the red illumination but their survival rate is lower than under the red illumination. The next experiment should investigate the effect of illumination from LEDs with higher intensity on the stress levels of yellowfin tuna juveniles during rearing period.

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