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ORIGINAL ARTICLE

High growth rates of Asian seabass (*Lates calcarifer* Bloch, 1790) fry reared using a demand feeder with an image processing system for detecting fish behaviour

Yukinori Mukai[1] | **Zahari Taha**[2] | **Khairul Muttaqin Ismail**[3] | **Nai Han Tan**[3] | **Mohd Azraai Mohd Razman**[4] | **Jessnor Arif Mat Jizat**[4]

[1]Department of Marine Science, Kulliyyah of Science, International Islamic University Malaysia, Kuantan, Malaysia

[2]Dzuki Consultancy and Training. DR67, Kampung Kuala Pahang, Pekan, Malaysia

[3]Department of Biotechnology, Kulliyyah of Science, International Islamic University Malaysia, Kuantan, Malaysia

[4]Innovative Manufacturing, Mechatronics & Sports Laboratory, Faculty of Manufacturing Engineering, Universiti Malaysia Pahang (Pekan Campus), Pekan, Malaysia

Correspondence
Yukinori Mukai, Department of Marine Science, Kulliyyah of Science, International Islamic University Malaysia, Jalan Sultan Ahmad Shah, Bandar Indera Mahkota, 25200 Kuantan, Pahang, Malaysia.
Email: mukai9166@gmail.com

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Abstract

The feeding behaviour and growth rates of Asian seabass (*Lates calcarifer* Bloch, 1790) fry were studied using a new type demand (NTD) feeder. This feeding system was equipped with a programme to detect hunger behaviour in fish and automatically dispense pellets. This system could overcome hierarchy in fish during feeding. Fish rearing experiments were conducted to compare the NTD feeder with infrared light demand (ILD) and automatic timer (AT) feeders. The specific growth rate of body weight (SGR_{BW}) was significantly higher with the use of the NTD feeder than with the ILD or AT feeders. The specific growth rate of total length (SGR_{TL}) and feed conversion ratios (FCR) showed no significant differences among the three types of feeders. Fish feeding behaviour experiments were conducted, and the feeding frequencies were compared. The average feeding frequency and feeding amount per day by the NTD feeder were significantly higher than those by the ILD feeder. In the NTD feeder, seabass ate small amounts of pellets with high frequencies at each feeding time. Therefore, high frequency feeding could be one of the reasons for the high growth rates of fish fed using the NTD feeder.

KEYWORDS
fish behaviour, images processing system, new type demand feeder, specific growth rates

1 | INTRODUCTION

Three types of feeding systems—manual, automatic (timer) and demand—are used in fish farms. Demand feeders that provide feed to fish as per their appetite (Alanärä, 1996; Kohbara et al., 2000, 2001, 2003; Paspatis and Boujard, 1996) have been developed to reduce feed loss and water pollution in fish farms. Demand feeding systems typically use a physical switch (Alanärä & Brännäs, 1993, Boujard & Leatherland, 1992; Brännäs & Alanärä, 1994; Covès et al., 2006; Paspatis and Boujard, 1996; Shima et al., 2003) or infrared light sensors (Amano et al., 2007; Mukai et al., 2016) to deliver food. Recent studies have investigated demand feeders to determine optimal fish self-selection of feed based on feed nutrients (Fortes-Silva et al., 2017) and to improve the activity of digestive enzymes through self-feeding (Reis et al., 2019). However, only a few studies have compared the growth rates of fish fed using demand feeders and other feeding systems.

Demand feeders are expected to show improved growth in fish and decrease feed loss; however, several issues hinder fish growth. For example, fish show social status and dominance hierarchies that disrupt the growth of individual fish. Moreover, a fish or a few fish may dominate the activation of the switch and monopolize the feeding area, resulting in different growth rates among the fish in a tank (Alanärä, 1996; Alanärä & Brännäs, 1993; Covès et al., 2006). Brännäs and Alanärä (1994) studied the reward levels of a demand feeder in Arctic charr (*Salvelinus alpinus*, Linnaeus, 1758) and rainbow trout

(*Oncorhynchus mykiss*, Walbaum, 1792). They found that Arctic charr showed high growth rates at higher reward levels and rainbow trout showed high growth rates at lower reward levels. They reported that these differences reflect the differences in feeding behaviour and social hierarchies.

Fish also have to learn the relationship between the activation of the switch and food delivery, and the duration of this learning period may vary depending on the fish species and population. Alanärä (1996) observed that a population of 5–100 trouts learned the demand feeding system within 10–25 days.

New technology has been developed for capturing and analysing video images, and fish behaviour can now be categorized using image processing technology. In general, when fish are hungry, they search for food and appear restless. Conversely, when they are satiated, they appear calm. Taha et al. (2018a, b) and Razman et al. (2019, 2020) addressed these problems by using fish behaviour to control a new type of demand (NTD) feeder.

In this study, we used the same methods as used in previous studies (Razman et al., 2019, 2020; Taha et al. 2018a, b) to feed Asian seabass (*Lates calcarifer*, Bloch, 1790). After determining the parameter of fish behaviour, the parameters were installed into a workstation programme. The feeding device dispensed pellets when the fish behaviour indicated that they were hungry, thereby avoiding the problem of fish hierarchy during feeding. This study was conducted to compare the growth rates obtained using NTD, AT and ILD feeders.

2 | MATERIALS AND METHODS

2.1 | The three feeding systems

2.1.1 | Automatic timer feeder (AT feeder)

The AT feeder (LCD AutoFeeder AF012, Dophin, Benoni, South Africa) was set to feed the fish three times a day at 8:00, 12:00 and 16:00 h. The feeder dispensed pellets three times (0.6 g during a 14 s interval) at each set time (1.8 g/set time, 5.4 g/day and 3.8%/fish body weight).

2.1.2 | Infrared light demand feeder (ILD feeder)

The ILD feeder was the same as that used in previous studies (Razman et al., 2019, 2020). It consisted of an infrared light sensor (CX-422, Panasonic, Osaka, Japan), a microcontroller (DFrobot, Shanghai, China), a stepper motor driver (Pololu Corporation, Las Vegas, Nevada, USA), a stepper motor (Pololu Corporation, Las Vegas, Nevada, USA), and a pellet conveyer. The infrared sensor and infrared LED (860 nm) were placed 2.5 ± 0.5 cm below the water surface. When fish came close to the infrared sensor, the infrared light beam reflected from the fish to the sensor, triggering it. The sensor then sent a signal to the microcontroller, which in turn signalled the motor to rotate the pellet conveyer. When the motor rotated, the pellet conveyor dispensed pellets into the water. Each signal moved the pellet conveyer by one pocket (0.15 g of pellets).

2.1.3 | New type of demand feeder (NTD feeder)

The NTD feeder was the same as that used in previous studies (Razman et al., 2019, 2020; Taha et al. 2018a, b). The feeding system consisted of a workstation, a Wi-Hi camera (DCS 936 L, D-Link Corp., Fountain Valley), a microcontroller, a feeding device with a pellet container and a pellet conveyor (same as in the ILD feeder). The workstation (G11CD, ASUSTeK Computer Inc., Fremont) had a computer program to control the feeding device. The Roborealm software was used for image processing. This software calculated fish group positions as the centre of gravity (COG), showing fish group positions as a given number of pixels along the x and y axes of the fish tank in the Roborealm images (Razman et al., 2020). Thus, the Wi-Hi camera and Roborealm software tracked the fish group positions continuously. In the present study, only the COG-Y axis positions, that is the distances from the tank bottom to COG-Y of the fish group, were used as parameters. The parameters of the program for the fish rearing experiment were as follows: 'H' (feed on) was 70 pixels (real distance from the tank bottom, 63%), and 'L' (feed off) was 50 pixels (real distance from the tank bottom, 45%) following a previous study (Mukai et al. unpublished data). If fish moved up to parameter 'H', then the feeder would switch on, and if fish moved down to 'L', then the feeder would turn off. Therefore, that the feeding device was turned on when the 'H' command was continuous for 10 s or more and turned off when the 'L' command was continuous for 5 s. As the pellet conveyer rotated with each command, the pellets were dispensed from each pocket (0.15 g of pellets).

2.2 | Conditions for the rearing experiment and the feeding behaviour experiment

Fish tanks of 900 × 450 × 46.5 mm (L × W × H) were filled with a water recirculation system through volume 10 litter coral pieces filtering. The tanks were illuminated at night (20:00 h to 8:00 h) with an infrared lamp (850 nm) for detecting fish behaviour through a web camera. The Asian seabass fry used for the rearing experiment and feeding behaviour experiment were obtained from a private fish farm (Johor State, Malaysia). The fish were acclimatized to laboratory conditions for 7 days. During the acclimatization period, the fish were fed pellets (Otohime EP1, Marubeni Nisshin Feed Co. Ltd. Tokyo; 48% crude protein and 12% crude lipid) twice a day. After acclimatization, the rearing experiment was initiated. The same pellets were used for all the experiments in this study. These pellets were of the sinking type. The water temperature for both experiments was 26–28°C. When the uneaten pellets were collected using a vinyl air tube with a siphon function, approximately 10% of the water was exchanged per day. The uneaten pellets were collected and dried, and their weight was measured to calculate the feed conversion ratio (FCR).

In this study, the care and use of fish were carried out as per the ethical standards stated in the 'Guidelines for the use of fishes in research' by Nickum et al. (2004). All experiments were conducted by ensuring that no experimental fish suffered.

2.3 | Fish rearing experiment

The fish rearing experiment was conducted in a laboratory in Kulliyyah of Science, International Islamic University Malaysia. The fish weighed 14.18 ± 1.27 g and were 108.7 ± 3.8 mm in length (Mean ± SD) at the beginning of the experiment. The feeding experiment was conducted with the AT, ILD and NTD feeder systems in triplicate fish tanks with one feeder and ten fish per tank. The experiment lasted for 33 days. The fish were anaesthetized with Transmore® (α-methyl quinolone; Nika Trading Co., Selangor, Malaysia), and their body weight and total length were measured. No fish died during the experiment, and after the fish were measured, they were released into the fish stock tank. The specific growth rate of body weight (SGR_{BW}) and the specific growth rate for total length (SGR_{TL}) of each fish tank were calculated using the following formulae:

$$SGR_{BW} = \frac{(\ln BW_f - \ln BW_i)}{D} \times 100$$

SGR_{BW} = specific growth rate of body weight (%/day)
BW_f = final mean body weight (g)
BW_i = initial mean body weight (g)

$$SGR_{TL} = \frac{(\ln TL_f - \ln TL_i)}{D} \times 100$$

SGR_{TL} = specific growth rate of total length (%/day)
TL_f = final mean total length (g)
TL_i = initial mean total length (g)
D = rearing time (days)

$$FCR = \frac{\text{Weight of pellets consumed by fish}}{BWtf - BWti}$$

Weight of pellets consumed by fish (g) = Weight of pellets dispensed from the pellet container – Remaining pellets on the tank bottom.

BWt_f = final body weight of total (10) fish (g)
BWt_i = initial body weight of total (10) fish (g)

2.4 | Feeding behaviour experiment

The feeding behaviour experiment was conducted with the ILD and NTD feeders to compare the feeding frequencies of these feeding systems. After the fish had acclimatized to the feeders, the amounts of pellets given to the fish during the night and day were measured for 3 days. First, the pellet container was filled with 50 g of pellets, and every day, at 8:00 h and 20:00 h, the weight of the feed inside the pellet container was measured for each feeder. The feeding frequency of the ILD and NTD feeders was calculated from the pellets remaining in the pellet container. Asian seabass fry with an average weight of 7.03 ± 1.68 g and a total length of 80.8 ± 5.5 mm were used in this experiment. Ten fish were placed in tanks with ILD and NTD feeders. The averages of feeding frequencies and feeding amounts on the 3 days were compared using Student's *t* test.

2.5 | Statistical analysis

Statistical analyses of the fish rearing test for the AT, ILD and NTD feeders were conducted using the Shapiro–Wilk test for normal distribution of the data and Levene's test of homogeneity for variance of data. After confirming the normal distribution of data and homogeneity of variance of data, the data were analysed by one-way ANOVA with Tukey's post hoc test. Statistical analysis of the feeding behaviour test for the ILD and NTD feeders was conducted using the Shapiro–Wilk test for normal distribution of the data and F test for equal variances. After confirming that the data showed normal distribution and equal variance, the data were analysed using a one-tailed Student's *t* test. These statistical analyses were conducted using a software (Ekuseru-Toukei, Version 3.20, Social Survey Research Information).

3 | RESULTS

3.1 | Fish rearing experiment

We found that the SGR_{BW}, SGR_{TL} and FCR values were normally distributed using the Shapiro–Wilk test ($p > 0.05$) and that they showed homogeneity of variances using Levene's test of homogeneity ($p > 0.05$).

One-way ANOVA test for SGR_{BW} showed significant differences among three feeder groups, $F(n, 2, 6) = 12.9308$, ($p < 0.01$). Tukey's post hoc test results showed that the NTD feeder group was significantly higher than the ILD ($p < 0.05$) and AT feeder group ($p < 0.01$) (Figure 1a). One-way ANOVA test for SGR_{TL} showed no significant differences among the three feeder groups $F(n, 2, 6) = 0.2681$ ($p > 0.05$); however, the NTD feeder showed a high tendency in SGR_{TL} (Figure 1b). Although one-way ANOVA test for FCR value showed no significant difference, $F(n, 2, 6) = 2.4693$ among the three feeders, the NTD group showed a low tendency in FCR than the other groups (Figure 1c).

3.2 | Feeding behaviour experiment

In the case of the AT feeder, fish ate the pellets when the timer feeder dispensed the pellets onto the water surface. The fish

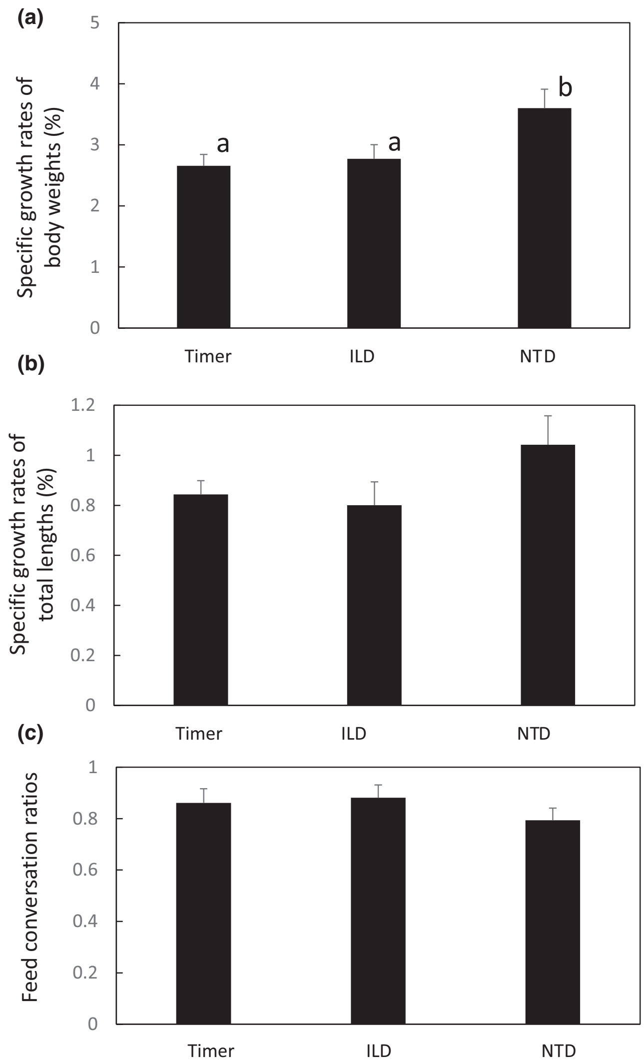

FIGURE 1 (a) Specific growth (body weight) rates (%) of Asian seabass fry reared by automatic timer (AT) feeder, infrared light feeder (ILD) and the new type of demand feeder (NTD). Different letters indicate a significant difference. (b) Specific growth (total length) rates (%) of Asian seabass fry reared by Timer, ILD and NTD feeders. (c) Feed conversion ratios of Asian seabass fry reared by Timer, ILD and NTD feeders

feeding behaviour was similar to that observed with manual feeding. The amount of pellets fed was 5.4 g per day.

Table 1 shows the feeding amounts and feeding frequencies for the ILD feeder during the 3 days of the experiment. Fish ate the pellets at a rate of 7.5 ± 1.5 g per day (mean ± SD) with the ILD feeder. The average number of pockets (frequencies of feeding) per day was 50.3 ± 10.3. The feeding frequency was higher during the day than at night. During the experiment, a few fish occupied the feeding area of the ILD feeder. When a few fish of high hierarchy stayed near the sensor, the feeder rotated to drop pellets. When other fish came to the feeding area, the high hierarchy fish sometimes attacked the smaller fish and chased them away from the feeding area, thereby keeping the other fish from switching on the feeder.

TABLE 1 Average[a] of feeding frequency (number of pocket) and amount of feeding pellets (g) for NTD feeder and ILD feeder

	Feeding frequency (number of pockets)	Amount of pellets (g)
NTD feeder (mean ± SD)	69.3 ± 6.9[b]	10.4 ± 1.04[b]
(Day)	(45.7 ± 9.6)	(6.86 ± 1.44)
(Night)	(23.6 ± 3.6)	(3.54 ± 0.54)
ILD feeder	50.3 ± 10.2	7.54 ± 1.53
(Day)	(35.5 ± 6.8)	(5.33 ± 1.02)
(Night)	(14.7 ± 6.53)	(2.21 ± 0.98)

[a]Averages were gotten from experiment periods for 3 days.
[b]Statistical analysis of one side Student's *t* test showed feeding frequency and amount of pellets were significantly higher in NTD feeders than those in ILD feeders ($p < 0.05$).

In the NTD feeder, fish ate the pellets at a rate of 10.40 ± 1.04 g per day. The data show that fish ate pellets even at night. The average number of pockets per day was 69.3 ± 6.9.

The data of feeding frequencies and feeding amounts of the ILD and NTD feeders showed normal distribution by the Shapiro–Wilk test ($p > 0.05$) and showed equal variance ($p > 0.05$). The feeding frequency of the NTD feeder was significantly higher (one-tailed Student's t test $N = 4$, $t = 2.7464$, $p < 0.05$) than that of the ILD feeder. Feeding amounts by NTD feeder were also significantly higher (one-tailed Student's t test $N = 4$, $t = 2.6764$, $p < 0.05$) than that by the ILD feeder (Table 1).

In the NTD feeder, when several fish came to the surface of the tank, the COG-Y position was more than 63% continuously, which was the parameter H, and thus, the feeder dispensed pellets into the water. When more than half of the fish stayed in the middle to bottom layers, the COG-Y position was less than 45% and the feeder ceased to dispense the pellets. No fish monopolized the feeding area.

4 | DISCUSSION

Previous reports on demand feeders have shown varying results; however, there are a few reports that compare the fish growth rates using demand feeding systems with that of other feeding systems (e.g. Azzaydi et al., 1998; Paspatis & Boujard, 1996). Other studies on demand feeders have examined fish feeding rhythms and circadian rhythms to determine the optimal timing for feeding management (Flood et al., 2011; Navarro et al., 2009; Sánchez-Vázquez & Tabata, 1998; Sunuma et al., 2007).

In the present study, the feeding frequency of the AT feeder was three times a day, while the NTD and ILD feeders had higher feeding frequencies. The feeding frequency of the NTD feeder was higher than that of the ILD feeder; this could be one of the reasons for significantly higher SGR_{BW} and SGR_{TL} in fish fed by the NTD feeder.

The advantage of the NTD feeder is that fish can get the feed easily as only a change in their position led to the release of pellets. This is much easier than the other demand feeding systems where a physical switch must be pushed or pulled by the fish (Alanärä, 1996; Covès et al., 2006; Kohbara et al., 2001; Sunuma et al., 2007) or the fish must come near a sensor to elicit an infrared light sensor response (Amano et al., 2007; Mukai et al., 2016).

An ideal fish feeding system should allow fish easy access to feed without being disturbed by other fish, such that the fish obtain optimum amounts of feed. When fish are hungry, they search for food and show nervous behaviour. The detection of this behaviour could be used for the timely delivery of feed to the fish by a feeding system. Previous demand feeders required an active declaration or indication of intention from the fish (i.e. the fish had to push a physical switch); however, the fish are disturbed by other individuals that are higher-up in the social hierarchy (Alanärä, 1996; Covès et al., 2006; Kohbara et al., 2001; Sunuma et al., 2007). In the NTD feeding system of the present study, a change in the position of fish was indicative of hunger and did not involve disturbance from other fish. The fish fed with the NTD feeder did not occupy the feeding area, and all fish could eat pellets at the water surface without aggressive behaviour. The pellets were dispensed slowly and fish ate them at the water surface as well as in the middle and at the bottom of the tank; hence, there were no fights.

As different species show different feeding behaviour, the delivery of an optimal amount of feed is crucial. In the current NTD feeding system, the feeder delivered feed to the fish until they indicated that they were not hungry, that is they were calm. This is an optimum method for determining the feeding amount. In the NTD feeding system, fish often indicated that they were not hungry. A high frequency of feeding with a small feeding amount, a characteristic of the NTD feeder, is favourable for reducing feed wastage. These characteristics might have induced high growth rates in fish at a low FCR.

When fish of the same species are reared under similar environmental conditions, all fish show similar behaviour. This means that the same parameters can be used in the NTD system with the same accuracy in any places. Hence, the NTD feeders have several beneficial features to prevent overfeeding and water pollution by unconsumed feed in the fish farms and thereby promote sustainable aquaculture.

5 | CONCLUSION

The use of the new type demand feeders showed a significantly higher growth rate of body weight in the rearing test of Asian seabass fry than the infrared light and timer feeders. The new type demand feeder showed that Asian seabass ate during the day and night and consumed small amounts of pellets at high frequencies; this could be one of the reasons for the high growth rates with the use of the new type demand feeder.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

AUTHOR CONTRIBUTIONS

Yukinori Mukai and Zahari Taha planned this experiment. Khairul Muttaqin Ismail and Yukinori Mukai conducted the fish experiments. Nai Han Tan, Mohd Azraai Mohd Razman, and Jessnor Arif Mat Jizat supported the performance of this study. Yukinori Mukai wrote the manuscript, and all authors approved the final version of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study were obtained from the corresponding authors upon reasonable request.

ORCID

Yukinori Mukai https://orcid.org/0000-0001-5379-3313

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