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APPLICATION OF FEEDING MACHINES IN EPINEPHELINAE GROUPERS GROW-OUT CULTURE: A BRIEF OVERVIEW

TAN ZI KAI[1], AU HSEIN-LOONG[2], LIM KIT GUAN[1], TEO KENNETH TZE KIN[1], RAYNER ALFRED[3], MOHAMMAD TAMRIN MOHAMAD LAL[2], ROSSITA SHAPAWI[2] AND LIM LEONG-SENG[2]*

[1]Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia. [2]Higher Institution Centre of Excellence (HICoE), Borneo Marine Research Institute, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia. [3]Advanced Machine Intelligence Research Group, Faculty of Computing and Informatics, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia.

**Corresponding author: leongsen@ums.edu.my*
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Abstract: Epinephelinae groupers are an important aquaculture species in many countries, especially in Asia. However, high feed cost has been commonly known to be a major constraint in groupers production. Appropriate feeding management is an important strategy to reduce the feed cost in grouper farming by minimising feed waste. Nevertheless, requirements by groupers juveniles such as daily feeding, frequent feeding, appropriate food ration estimation, and feeding beyond the routine working hours of the human to suit the fish feeding rhythm are hard to achieve through conventional manual hand-feeding by labour. Therefore, machine feeding is necessary for groupers grow-out farming. This study provided an overview of the applications of machine feeders in groupers grow-out culture. The applicability of this practice and future research for the way forward to improve the currently available machine feeding systems in groupers cultures were also discussed.

Keywords: Automatic feeding, demand feeder, intelligent feeding control, feeding management, feed cost.

Introduction

In aquaculture, manually feeding by hand is the most common method to deliver feed to cultured fish. Such practice is labour-intensive, especially when a farm is operating on a large scale. Besides that, farmers need to observe fish feeding responses according to their species, size, and feeding behaviour while hand-feeding to decide either to modify or retain the designated food ration for daily feeding (An *et al*., 2021). In addition to the fact that fish appetites are affected by weather, especially water temperature changes (Volkoff & Rønnestad, 2020), under or/and over-feeding can easily happen when the feeding session is conducted by inexperienced workers (Zhou *et al*., 2018; An *et al*., 2021). Over-feeding can cause a rise in production cost and increase feed wastage that can deteriorate water quality (Amirkolaie, 2011) while under-feeding can hamper fish optimal growth. For these reasons, machines have been applied in aquaculture to deliver feed to cultured fish. Up-to-date, many studies have been conducted to develop feeding machines for many fish species (Tanveer *et al*., 2018; Pratiwy *et al*., 2021). Table 1 shows examples of fish species that have been involved in the study of feeding machine development and application. Amongst these studies, the feeding machines can be generally categorised as (1) automatic feeders or (2) demand feeders (or self-feeders). Automatic feeder delivers feed according to the timing, frequency, and food amount pre-set by the farmers (Mukai *et al*., 2016; El Shal *et al*., 2021) (Figure 1) while demand feeder usually has a physical switch and delivers feed when fish on demands trigger the switch (Mukai *et al*., 2016) (Figure 2). Applications of feeding machines in aquaculture have been reported to possess several advantages in general, including promoting high fish growth and reducing feed wastage (Alanärä, 1996; Azzaydi *et al*., 1998; Kohbara *et al*., 2003; Sánchez-Muros *et al*., 2003).

Table 1: Examples of fish species involved in the studies of feeding machines development or application, with the outcomes

Fish Species	Outcomes	References
European sea bass (*Dicentrarchus labrax*, L.)	A new microcomputer-controlled demand feeder was designed and it permitted the continuous recording of the *D. labrax* feeding behaviour.	Sánchez-Vázquez *et al.* (1994)
	The Bite and Pull Trigger (BPT) was advantageous to the demand feeder as the *D. labrax* learnt how to use it in a short period and they were able to feed at night. Also, BPT prevented accidental activation, reduced feed waste, and was low in cost.	Rubio *et al.* (2004)
	The *D. labrax* group feeding behaviour was directed by the rhythm and behaviour of a few high-demand feeder-triggering fish, which were the feed demand leaders.	Millot & Bégout (2009)
	The high feeder-triggering status in the *D. labrax* was correlated with personality traits, which could be the social structure that was built around the demand-feeder device.	Ferrari *et al.* (2014)
Rainbow trout (*Oncorhynchus mykiss*)	Social interaction was found not to influence the circadian demand-feeding rhythms in the *O. mykiss*.	Chen *et al.* (2002)
	Long response intervals (≥ 15 s) of the demand-feeder with a fixed reward level can significantly restrict the *O. mykiss* from frequently activating the feeder for feed to satisfy their energy requirements.	Shima *et al.* (2003)
	This study discovered that the *O. mykiss* trigger-biting activity peaked significantly in the morning and evening when lights were on and off.	Bailey & Alanärä (2006)
	Dietary oil types can mediate the appetitive behaviour of the fish; hence, this practice can be used to train the fish (strategy of rewarding) to adapt to the demand feeder.	Geurden *et al.* (2007)

Nile tilapia (*Oreochromis niloticus*)	This study confirmed the ability of the *O. niloticus* to adapt to a demand feeder.	Benhaïm *et al.* (2017)
	The *O. niloticus* was observed to possess a dualistic capacity for demand-feeding both in light and dark phases.	Pratiwy & Kohbara (2018)
	The design of an automatic feeder for the *O. niloticus* cultured in a tank was reported.	El Shal *et al.* (2021)
Yellowtail (*Seriola quinqueradiata*)	The *S. quinqueradiata* can demand feeding in both light and dark phases.	Kohbara *et al.* (2000)
	The *S. quinqueradiata* have feeding peaks at dawn and dusk.	Kohbara *et al.* (2003)
Gilthead sea bream (*Sparus aurata*)	The peak demand-feeding activity of the *S. aurata* was in the afternoon with cold periods.	Paspatis *et al.* (2000)
	Demand feeding can improve food conversion and protein efficiency of the *S. aurata*.	Sánchez-Muros *et al.* (2003)
Tench (*Tinca tinca*)	The capability of *T. tinca* to utilise demand feeder was confirmed.	Herrero *et al.* (2005)
Senegalese sole (*Solea senegalensis*)	This study confirmed the ability of the *S. senegalensis* to use demand-feeders and it displayed a pronounced nocturnal feeding behaviour.	Navarro *et al.* (2009)
Striped knifejaw (*Oplegnathus fasciatus*)	Demand feeders can be used to improve the growth performance of *O. fasciatus* when they are cultured in high densities of 10 kg/m^3 and 15 kg/m^3.	Biswas & Takii (2017)
Pirarucu (*Arapaima gigas*)	Significantly higher feed intake, feed conversion ratio, protein efficiency ratio, and protein retention rate were observed in the *A. gigas* from the demand feeder treatment than the automatic feeder treatment.	de Mattos *et al.* (2016)

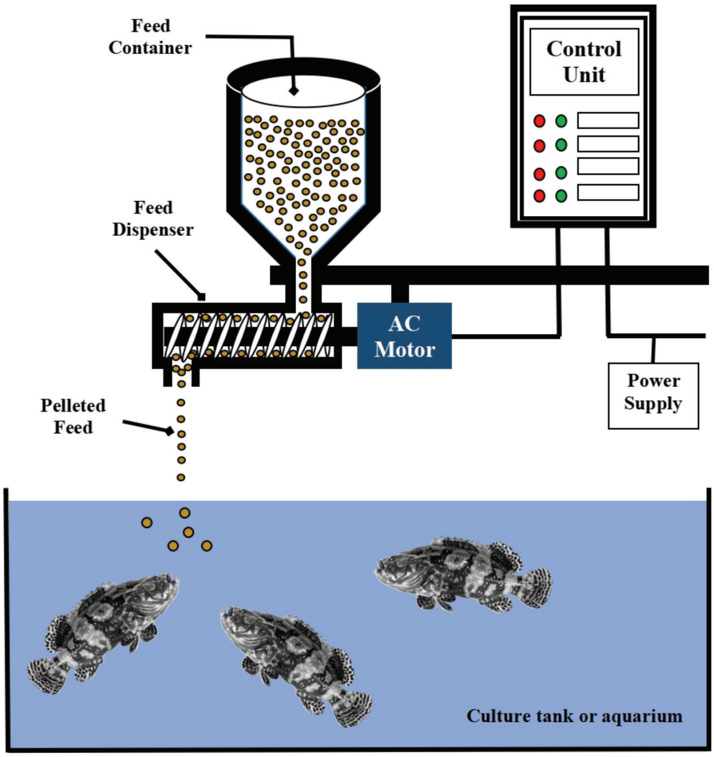

Figure 1: An example of the design of an automatic feeder

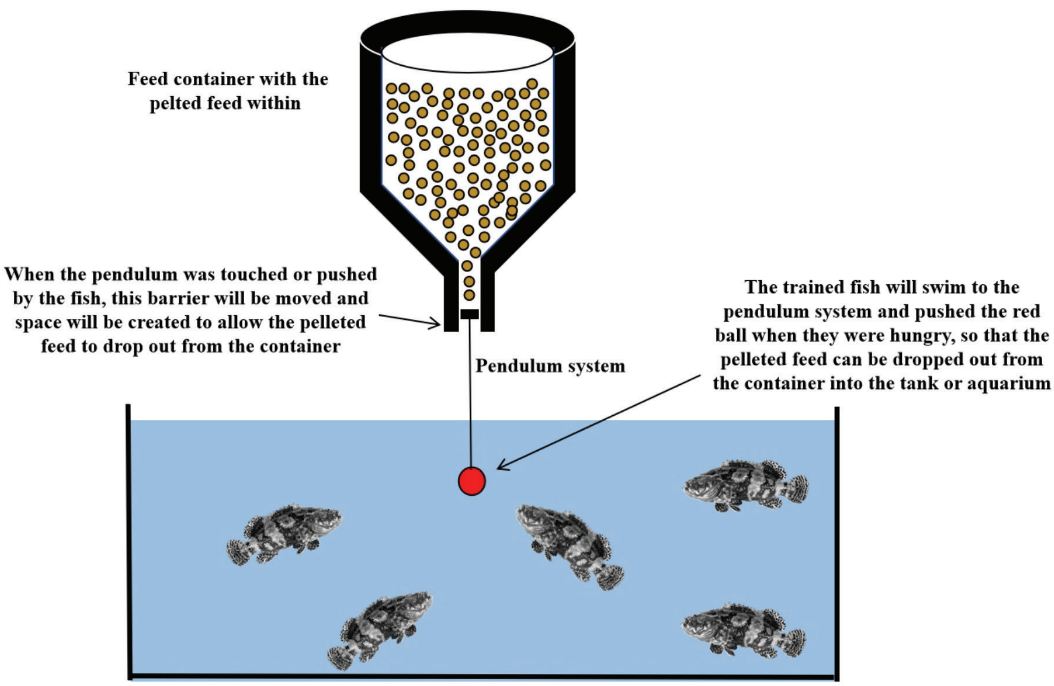

Figure 2: An example of the design of a demand feeder

Epinephelinae groupers are a high-value species in the aquaculture industry, especially in Asia. In 2015, the global grouper aquaculture production was 155,000 tonnes (worth a total value of USD 630 million) and 93% of this production volume was contributed by Asian countries (FAO, 2017). Up-to-date, at least 47 species and 15 hybrids of groupers are being cultured worldwide (Rimmer & Glamuzina, 2019). High feed cost has been commonly acknowledged as a major constraint in groupers production (Miao & Tang, 2002; Afero *et al*., 2010; Petersen *et al*., 2013). Lately, the feed cost of hybrid grouper (*Epinephelus fuscoguttatus* × *E. lanceolatus*) production in Vietnam was reported to be 86% of the total production cost (Dennis *et al*., 2020). Although much effort has been put into tackling this issue, especially in developing plant-based diets for groupers (Lim *et al*., 2014; 2015; Mohd Faudzi *et al*., 2018; 2022; Yong *et al*., 2020), appropriate feeding management is also an import strategy to reduce the feed cost in grouper farming by minimising feed waste.

According to Au *et al*. (2023), daily frequent feeding (1), providing appropriate daily food ration according to fish size and changes in environmental factors (2) and feeding according to the fish's feeding rhythm (peak hours at dawn and dusk - outside human routine working hours) (3) are necessary to promote optimum fish growth in groupers grow-out farming. As tasks (1) and (3) are labour intensive, while the decision-making in the task (2) is difficult for inexperienced workers, the need for a machinery system that can facilitate groupers demand feeding has been suggested (Au *et al*., 2023). Up-to-date, several studies have been conducted to develop or feed machines and their applications in groupers cultures, but these studies have not been reviewed to provide information that is potentially useful in the field. Therefore, the present study aimed to provide an overview of the application of feeding machines in groupers grow-out culture. Also, the applicability of this practice and future research on the way forward on this topic were discussed.

Automatic Feeders in Groupers Culture

Up-to-date, many studies have been conducted to develop automatic feeders for aquaculture, especially fish farming (Yeoh *et al*., 2010; Ogunlela & Adebayo, 2016; Uddin *et al*., 2016; Nirwan *et al*., 2017; Ojo & Benard, 2018; Abdullah *et al*., 2019; El Shal *et al*., 2021; Khater *et al*., 2021). Recently, Karningsih *et al*. (2020) also reported on their development of an automated feeding machine for the offshore aquaculture of tiger grouper *Epinephelus fuscoguttatus*. Although no fish growth data was reported in work by Karningsih *et al*. (2020) to evaluate the effect of automatic feeding on the grouper's growth, Soemarjati *et al*. (2013) reported that applying automatic feeder in the culture of humpback grouper, *Cromileptes altivelis* can increase their survival rate, although there were not much different in the fish final body weight and total length between the treatments of automatic feeding and hand feeding. In fact, groupers are well-known for their cannibalistic behaviour (Hseu *et al*., 2007; Chang *et al*., 2019) and frequent feeding is necessary to reduce cannibalism (Ismi *et al*., 2012). On the other hand, de Sousa *et al*. (2019) have demonstrated that an automatic feeder is necessary to feed 12 times daily (every two hours intervals) to promote optimum growth in the dusky grouper, *Epinephelus marginatus* cultured in tanks in a seawater re-circulation system. The application of automatic feeders in groupers culture is practicable.

Demand Feeders in Groupers Culture

Other than automatic feeders, many studies have also been conducted to develop demand feeders (also known as a self-feeding system) for fish farming and this topic has been reviewed by Pratiwy *et al*. (2021). As a demand feeder requires fish to trigger it to release feed based on fish demand, knowledge of the fish's hunger and satiation behaviour is critical to develop a functional demand feeder (Mohd Razman *et al*., 2020). For grouper species, Tan *et al*. (2013) have reported on the hunger behaviour of *E. fuscoguttatus*. The observation was conducted on fish that are maintained in an aquarium equipped with a commercial pendulum demand feeder. According to Tan *et al*. (2013), the *E. fuscoguttatus* generally dwelt or swam at the bottom layer of the water column, and when they were hungry, they swam up to close to the water surface, gathered around and bite or pushed the pendulum knob or switch to trigger the demand feeder. After satiation, the fish returned to the tank bottom and stayed idle or swam slowly. Such hunger behaviour was similar to that observed in yellowtail, *Seriola quinqueradiata* and Asian seabass, *Lates calcarifer*, as reported by Kohbara *et al*. (2000) and Mohd Razman *et al*. (2020), respectively.

As the commercial pendulum demand feeder is difficult to be physically triggered, especially by fish with small body sizes (cannot generate enough force through biting or pushing to move the knob/switch and trigger the feed release), Mukai *et al*. (2012; 2016) have developed a demand feeder with an infrared light sensor for groupers juveniles by using *E. fuscoguttatus* juveniles as the experimental fish. In this demand feeder system, the physical knob remained as a visual cue or target (Tan *et al*., 2013) to train the *E. fuscoguttatus* juveniles to swim to the designed feeding area when they were hungry. Subsequently, the infrared light sensor placed above the knob will detect the presence of the fish and release the feed. Such design has genuinely overcome the "switch-triggering" issue in the development of demand feeders for groupers juveniles. In addition, Mukai *et al*. (2016) reported that only three days were needed for the *E. fuscoguttatus* juveniles to adapt to this newly developed demand-feeding system.

In fact, a long period is generally required for fish to learn how to trigger the demand feeders [e.g., 20 days and 35 days for the gilthead seabream, *Sparus aurata*, and the rainbow trout, *Oncorhynchus mykiss*, as reported by Sánchez-Muros *et al*. (2003) and Heydarnejad and Purser (2013), respectively]. Nevertheless, the practicability of applying this new demand feeding system by Mukai *et al*. (2016) in grouper grow-out culture was tested only on a laboratory scale (10 fish/500 L tank with triplicates) while its application in the field for groupers mass production remained to be tested.

Growth Performances of Groupers Fed Using Automatic Feeder or Demand Feeder

Up-to-date, limited studies have been conducted to compare the effects of different feeding methods on the growth performances of groupers juveniles. Mukai *et al*. (2012) examined the growth performances of the *E. coioides* juveniles fed using the pendulum demand feeder, automatic feeder, or infrared light sensor demand feeder through a 20-days feeding trial. At the end of the trial, it was found that the fish Sstandard Length (SL), Total Length (TL), and Body Weight Gain (BWG) among all treatments were not significantly different, but those from the infrared light sensor demand feeder treatment tended to have the higher value than those from the other two treatments. Similar results were also obtained when Mukai *et al*. (2016) observed the growth performance of *E. fuscoguttatus* juveniles fed using an automatic feeder or the infrared light sensor demand feeder through a 25-days feeding trial. No significant difference was observed among the SL, TL, BWG, and Food Conversion Ratio (FCR) of *E. fuscoguttatus* fed using an automatic feeder or the infrared light sensor demand feeder, but the latter tended to show better results. In fact, such results were also examined in other fish species such as tambaqui and *Colossoma macropomum* (de Mattos *et al*., 2022). These findings have evidenced that both automatic and demand feeders are equally efficient when applied in groupers grow-out farming.

Potential Drawbacks and Improvements of Automatic and Demand Feeders for Groupers Culture

Based on the literature, both automatic and demand feeders are applicable in groupers grow-out culture and the application of either automatic or demand feeders will not have a significant effect on the growth performances of groupers. However, these feeding machines still have several potential drawbacks that may require improvements.

The major drawback of the automatic feeder is that this machine is not capable of self-adjusting the feeding frequency based on the real-time situation of the fish (except those that can be controlled remotely by human intervention), although it can automatically perform daily frequent feeding and feeding groupers at their known peak feeding hours (following their feeding rhythm) accordingly to the pre-set time. Such a function is essential to prevent feed wastage, especially in the case of coastal or offshore groupers cage culture, in which the fish appetite is prone to be affected by weather (especially water temperature) changes.

Demand feeder does not possess the issue like automatic feeder, as it releases feed according to fish demand. However, it is difficult to set the proper feed amount that should be released once the demand feeder is triggered (Alanärä, 1996; Mukai *et al*., 2016). When grouper juveniles were feeding near the water surface, they usually captured the pellets at the upper and middle water columns and ignored the pellets that had already sunk to the aquarium or tank bottom (Lim, personal communication). The pellets that have been released at each feeding time should be within the amount that the fish can completely capture. In other words, this ideal pellet amount is closely related to the density of fish that show up for feeding and the fish's activeness or aggressiveness during feeding (that may be related to the fish's hungriness level, which is hard to estimate).

Recently, the emergence of Artificial Intelligence (AI) has enabled a new trend in the development and application of intelligent feeding control for aquaculture. With the aid of computer vision, fish behaviour can be monitored in real-time and analysed (Li *et al*., 2020; An *et al*., 2021; Mukai *et al*., 2021; Yang *et al*., 2021), the uneaten feed can be detected and quantified (Li *et al*., 2017; Hu *et al*., 2021), and real-time water quality can be monitored (Chen *et al*., 2022) to generate precision feeding decision for the feeder to release or stop releasing feed automatically (Figure 3). This AI technology is useful for upgrading and overcoming the drawbacks of automatic and demand feeders for groupers grow-out culture. For instance, AI can be incorporated into an automatic feeder to automatically stop or skip the pre-set feeding when water quality is detected to be not favourable for feeding (such as low water temperature and dissolved oxygen level) or when a high percentage of uneaten feed has been detected. On the other hand, computer vision can be incorporated into the demand feeder to study groupers feed-capturing efficiency in relation to the density of fish that show up for feeding and their activeness during feeding to determine the proper feed amount to be released. Unfortunately, there is still no report on the application of AI in the feeding management of groupers grow-out farming. Therefore, future research on the development of feeding machines for grouper culture should be heading in this direction.

Conclusions

Automatic and demand feeders are suitable for use in groupers grow-out farming, as there is no similar growth of groupers juveniles fed using automatic or demand feeders. Although these feeding machines possess some potential functional drawbacks, these drawbacks can be overcome by incorporating AI technologies into the system designs of these feeding machines. Research on this topic is the way forward to improve the feeding machines in groupers grow-out farming.

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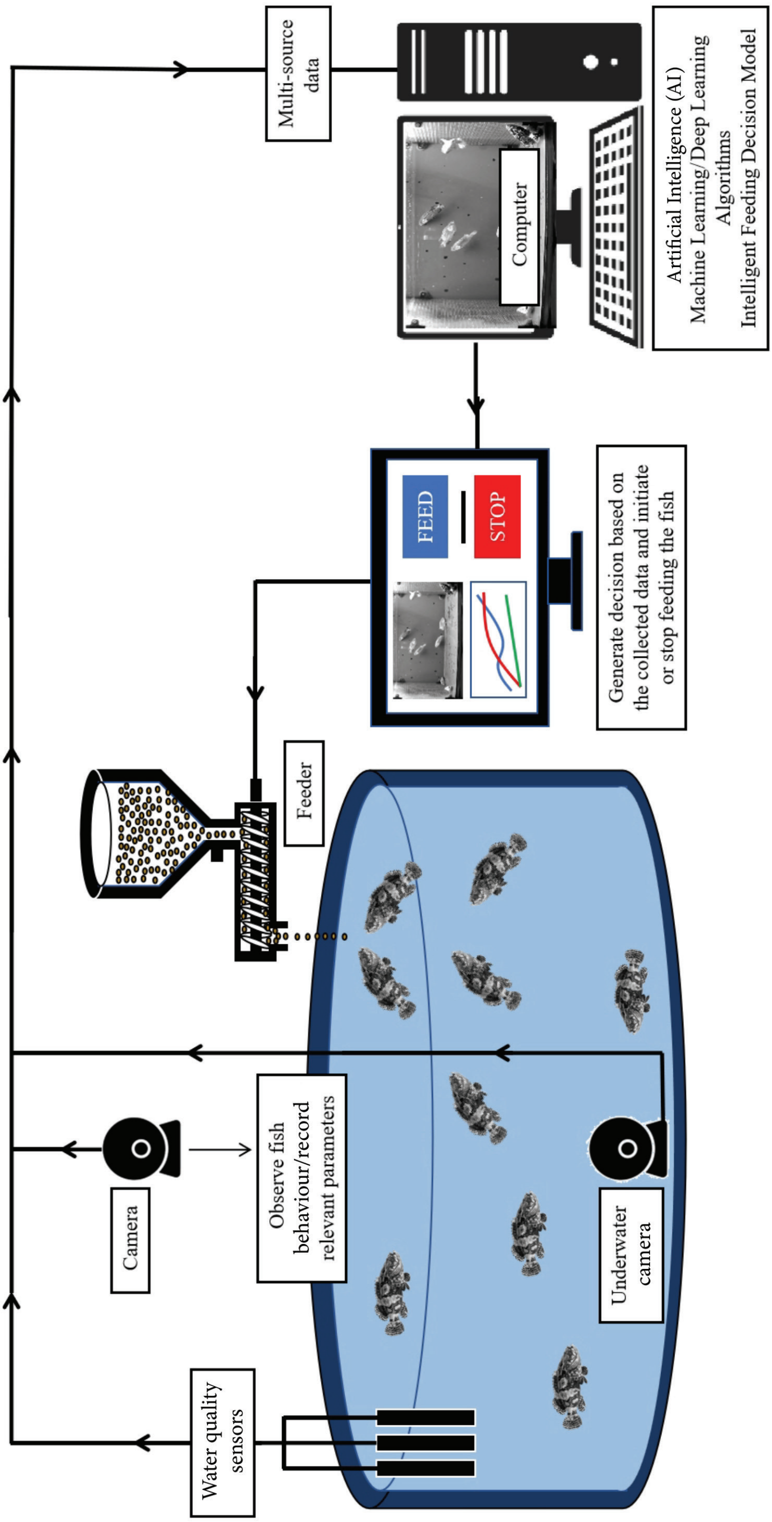

Figure 3: An example of the design of an intelligent feeding device

Conflict of Interest Statement

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