Machinery feeding development for sustainable aquaculture: Self-feeding system

Fittrie Meyllianawaty Pratiwy, Dian Yuni Pratiwi and Jun Kohbara

DOI: https://doi.org/10.22271/fish.2021.v9.i4c.2537

Abstract

Demand feeder is slightly different with an automatic feeder, it is altered to the appetite of fish because they can prefer which time they activate the feeder, also it triggered to produce a good growth performance and decrease the feed waste. Alternatively, some studies have been carried out for new method of automatic feeding system. Self-feeding system or previously familiar with the name of demand feeding system, is a system based on the learning ability of fish to activate the feeder and utilizing a feeding rhythm that may be controlled by the biological clock. At the past two decades, the development of self-feeding system is growing rapidly, from database, twenty eight studies with the most relevant data have been collected. The peak of paper published was in year 2000 with the most popular fish species was European sea bass (Dicentrarchus labrax, L.).

Keywords: Self-feeding, demand feeding, demand feeder, feeding behavior

Introduction

In most commercial fish farms scheduled hand-feeding based on a feeding chart or culture experience, has been utilized to feed the fish such as using the basic percentage of the total body weight. Nevertheless, not only low feed efficiency and growth performance but also the impact on the water environment may lead a problem in aquaculture activities [1]. At present, there are several automatic and demand feeders which have been developed to fulfill certain objectives and requirements [2, 3]. Basically, apparatus in Self-feeding system at least must have four parts: switch, a feeder with feed dispenser, a control unit and a microcomputer [1]. Specifically, the technical practice in self-feeding system works by releasing a certain amount of feed from feed dispenser into a fish tank/net cage based on trigger actuation of fish [4]. Under this circumstance, fish can eat anytime they want and this condition may provide the basic research information about learning ability [1, 4-5], nutrition [6-7, 8], and social interaction of fish [9].

Before two decades ago, self-feeding has been studied in some important aquaculture species such as Rainbow trout [10], Goldfish [11], and Tilapia [9]. Throughout the time, many studies revealed not only showed about the basic information but also the practical use of demand feeding or self-feeding system but also the improvement of feeding technology such as the utilities of machine and artificial intelligent. This paper aim to gather dozens of research about self-feeding system and summarize it into a simple understanding based on its development.

2. Data Survey

The papers were searched using the databases of Web of Science. The keywords used on the search were self-feeding, demand feeding, demand feeder, feeding behavior. The criteria for the selection of papers included original articles and short communications published within 2000-2019. Studies should be performed in field and/or laboratory (with commercially acquired organisms) and use individual or group in any species of fish. The exclusion criteria were studies related to the practical use of demand feeder or self-feeder on feeding behavior and/or growth performance, additional parameters such as circadian rhythms, loco motor activity, utilization of substitution meal, etc. were added as a supplemental data. A qualitative analysis was conducted considering the design of feeder, fish species, type of rearing condition: indoor (laboratory) or outdoor (field with or without caged organisms), number of...
sampling fish, physiological analysis such as circadian rhythms, loco motor activity, feeding behavior, sex ratio parameters and response to the environmental condition.

3. Published Studies

Considering the criteria aforementioned, 34 papers published in international scientific journals were selected, and 28 papers selected at the second screening based on the most relevant studies (Table 1). Regarding the number of publications along the years, at least 26 papers were published from 2000 to 2019. A peak of publications was reached in 2000 (5 papers) and 3 papers were published per year from 2002 and 2016 (Fig. 1). These data show that scientific publication in the field of self-feeding is stable and without tendency of increase.

### Table 1: Summary of studies using self-feeding system in chronological order

| Study | Rearing Condition | Type | Species |
|-------|-------------------|------|---------|
| [12]  | Indoor            | Individual | Rainbow trout (Oncorhynchus mykiss) |
| [13]  | Outdoor           | Group | Gilthead sea bream (Sparus aurata), Red porgy (Pagrus pagrus), and their reciprocal hybrids |
| [14]  | Diurnal and Nocturnal feeding time (Outdoor) | Group | European sea bass (Dicentrarchus labrax, L.) |
| [15]  | Laboratorium      | Group | European sea bass (Dicentrarchus labrax L.) |
| [1]   | Indoor and outdoor | Individual and group | Yellowtail (Seriola quinqueradiata) |
| [16]  | Laboratorium      | Group | Rainbow trout (Oncorhynchus mykiss Walbaum) |
| [6]   | Hand feeding and Self-feeding | Group | Juvenile Rainbow trout (Oncorhynchus mykiss) |
| [17]  | Scheduled and Self-feeding | Group | Nile tilapia (Oreochromis niloticus) |
| [18]  | Outdoor           | Group | Rainbow trout (Oncorhynchus mykiss) |
| [19]  | Indoor            | Group | European sea bass (Dicentrarchus labrax L.) |
| [20]  | Indoor and outdoor (Lab and Cage) | Group | European sea bass (Dicentrarchus labrax, L.) |
| [1]   | Indoor            | Group | Goldfish (Carassius auratus) |
| [21]  | Indoor and outdoor | Individual and group | Tench (Tinca tinca) |
| [22]  | Indoor            | Group | European sea bass (Dicentrarchus labrax, L.) |
| [23]  | Indoor (hatchery) | Group | Rainbow trout (Oncorhynchus mykiss Walbaum) |
| [24]  | Outdoor           | Group | Rainbow trout (Oncorhynchus mykiss) |
| [25]  | Indoor and Outdoor | Group | Senegalese sole |
| [26]  | Indoor            | Group | European sea bass (Dicentrarchus labrax, L.) |
| [27]  | Indoor            | Individual | Nile tilapia (Oreochromis niloticus) |
| [28]  | Laboratorium      | Individual and group | European sea bass (Dicentrarchus labrax, L.) |
| [7]   | Indoor and outdoor | Individual and group | Sevenband Grouper (Epinephelus septemfasciatus) |
| [29]  | Indoor            | Group | European sea bass (Dicentrarchus labrax, L.) |
| [30]  | Indoor            | Group | Striped Knifejaw (Oplegnathus fasciatus) |
| [31]  | Outdoor (Cage)    | Group | Tilapia (Tilapia aurea) |
| [32]  | Outdoor           | Group | Piranuca (Arapaima gigas) |
| [33]  | Laboratorium      | Individual and group | Oreochromis niloticus and Sarotherodon melanotheron |
| [3]   | Indoor and Outdoor | individual and group | Nile tilapia (Oreochromis niloticus) |
| [14]  | Indoor            | Group | Tambaqui (Colossoma macropomum) |

The European sea bass (Dicentrarchus labrax, L.) became the most common (28.57%) fish species used in self-feeding system field study and the second most common group was Rainbow trout (Oncorhynchus mykiss) with percentage of 21.43% (Table 2).
Table 2: Percentage of Fish Species used in Study of Self-feeding System

| Name of Fish Species | Number of study | Percentage (%) |
|----------------------|----------------|----------------|
| European sea bass (Dicentrarchus labrax, L.) | 8 | 28.57 |
| Rainbow trout (Oncorhynchus mykiss) | 6 | 21.43 |
| Nile tilapia (Oreochromis niloticus) | 4 | 14.29 |
| Yellowtail (Seriola quinquergadiata) | 1 | 3.57 |
| Gilthead sea bream (Sparus aurata) | 1 | 3.57 |
| Goldfish (Carassius auratus) | 1 | 3.57 |
| Tench (Tinca tinca) | 1 | 3.57 |
| Solea senegalensis (Senegalese sole) | 1 | 3.57 |
| Sevenband Grouper (Epinephelus septemfasciatus) | 1 | 3.57 |
| Striped Knifefish (Oplegnathus fasciatus) | 1 | 3.57 |
| Pirapucu (Arapaima gigas) | 1 | 3.57 |
| Blue Tilapia (Tilapia aureus) | 1 | 3.57 |
| Tambaqui (Colossoma macropomum) | 1 | 3.57 |
| | 28 | 100 |

4. Type of Studies
Feeders are not a recent technology and are widely used in various type of aquaculture production systems [35]. Mostly, the fish species used in those study are a common commercial fish species. Different type of fish species and rearing condition throughout the past twenty years make the self-feeding system is possible to apply as a suitable technology in aquaculture system. Moreover, based on the collected data, the information about the feeding behavior and learning ability of self-feeding are known now.

The most popular species was European sea bass (Dicentrarchus labrax, L.) with the study mostly about feeding activity, trigger activity, reward level, circadian rhythms, and growth performance. Other fish species were occasionally tested at the same manner. Additionally, two studies evaluated the type of sensor used in self-feeding system, namely, rod [36, 20], string [21, 25, 20], and optical/infrared [2, 32, 8, 25] sensors. The sensor is crucial component that must be specifically adapted to the feeding behavior of a given species.

5. Experimental Design
Experimental design in the study mentioned above were used different type of apparatus of self-feeding system. Between late 19th and early 20th century, the general set-up of feeders were evaluated were circadian rhythm and loco motor activity [15, 16, 21, 12, 40], feeding activity, trigger activity, reward level, circadian rhythms, and growth performance. Other parameters which commonly were evaluated were circadian rhythm and loco motor activity [15, 16, 21, 12, 40], feeding behavior [1, 4, 6, 20, 36, 38], stress condition [30, 17]. Besides that, the type of rearing condition also was assessed as shown in Table 1. Most studies were carried out in two rearing condition; 21 studies used indoor experiment and 11 studies used outdoor experiment. In indoor condition, some studies were performed in isolated room [7, 26, 33], laboratory [33, 15, 16, 25, 20], and hatchery [23]. In outdoor condition, studies were performed in outdoor tanks [4, 1, 5], net cages [21, 13, 6], and farms [25, 20, 38].

An important aspect in studies is the sample size and sample sample size may lead to inconclusive results. However, studies in present review have a wide range of sample size depends on how their analyzed the treatments. Since, the feeding behavior and circadian rhythm might be performed individually, the data analysis explained as a descriptive data. As shown in table 3, 71.43% of studies observed in the present review were performed the experiment in group sample rearing condition, 7.14% was observed individually, and 21.43% in both condition.

Table 3: Type of sampling in studies observed about Self-feeding system

| Type of sampling | Number of study | Percentage (%) |
|------------------|----------------|----------------|
| Individual       | 2              | 7.14           |
| Group            | 20             | 71.43          |
| Individual and Group | 6         | 21.43          |
|                  | 28             | 100            |

6. Result of feeding behavior
Investigation of feeding behavior in self-feeding system is to adjust the appropriate feeding time and estimation of growth performance in different rearing condition. Feeding behavior, circadian rhythm, and loco motor activity were observed using actogram data which provide the plotted data of daily feeding activity. Observation of feeding profile in some fish species mentioned in the present review shown in Table 4.

Table 4: Various feeding profiles from fish species observed in studies of the present review.

| Name of Fish Species | Feeding Profile |
|----------------------|-----------------|
| European sea bass (Dicentrarchus labrax, L.) | Nocturnal/Diurnal |
| Rainbow trout (Oncorhynchus mykiss) | Nocturnal/Diurnal |
| Nile tilapia (Oreochromis niloticus) | Nocturnal/Diurnal |
| Yellowtail (Seriola quinquergadiata) | Nocturnal/Diurnal |
| Gilthead sea bream (Sparus aurata) | Diurnal |
| Goldfish (Carassius auratus) | Nocturnal/Diurnal |
| Tench (Tinca tinca) | Nocturnal |
| Senegalese sole (Solea senegalensis) | Nocturnal |
| Sevenband Grouper (Epinephelus septemfasciatus) | Nocturnal |
| Tilapia (Tilapia aureus) | Nocturnal/Diurnal |
| Tambaqui (Colossoma macropomum) | Nocturnal |
| Pirapucu (Arapaima gigas) | Diurnal |
Even though in feeding profile in some studies as Table 4 mentioned showed a clear diurnal, nocturnal, or dual capacity, but feeding profile might be changed depends on the rearing condition (controlled or natural condition) and what treatment exposed to the object animals. Such as Sea bass shifted their daily feeding patterns from nocturnal to diurnal in winter and early spring \[14\]. Nile tilapia also has a dualistic capacity to change their feeding profile from diurnal to nocturnal when the light regime and water temperature decrease, and their growth performance also became low \[5\].

Funding
This research has received funding from Directorate of Research and Community Service Universitas Padjadjaran No. 1733/UN6.3.1/LT/2020

Authors Contribution
F.M.P. developed the theoretical formalism, performed, and wrote the manuscript. D.Y.P. Contributed to the final version of the manuscript. J.K. supervised the project relating with the manuscript.

References
1. Kohbara J, Hidaka I, Kuriyama I, Yamashita M, Ichikawa M, Furukawa K et al. Nocturnal / diurnal demand-feeding pattern of yellowtail Seriola quinqueradiata under different keeping conditions 2000, 955-962.
2. Chang CM, Fang W, Jao RC, Shyu CZ, Liao IC. Development of an intelligent feeding controller for indoor intensive culturing of eel. Aqua cultural Engineering 2005;32(2):343-353. https://doi.org/10.1016/j.aquaeng.2004.07.004
3. Velázquez M, Martínez FJ. Design and testing of a faeces-collecting device for fish digestibility studies using demand or automatic feeding. Aqua cultural Engineering 2005;33(2):126-134. https://doi.org/10.1016/j.aquaeng.2004.12.004
4. Kohbara J. Diel feeding activity of sevenband grouper. Aquaculture Science 2014;62(1):13-22. https://doi.org/10.1111/aquasci.12362
5. Pratiwy FM, Kohbara J. Dualistic feeding pattern of Nile tilapia (Oreochromis niloticus, L) reared under different self-feeding system conditions 2017. https://doi.org/10.1111/are.13544
6. Yamamoto T, Shima T, Furuita H, Suzuki N. Influence of feeding diets with and without fish meal by hand and by self-feeders on feed intake, growth and nutrient utilization of juvenile rainbow trout (Oncorhynchus mykiss) 2002;214:289-305.
7. Fortes R, Kitagawa A, Sa FJ. Dietary self-selection in fish: a new approach to studying fish nutrition and feeding behavior 2016, 39-51. https://doi.org/10.1007/s11610-015-9410
8. Fortes-Silva R, Martínez FJ, Villarroel M, Sánchez-Vázquez FJ. Daily rhythms of locomotor activity, feeding behavior and dietary selection in Nile tilapia (Oreochromis niloticus). Comparative Biochemistry and Physiology-A Molecular and Integrative Physiology 2010;156(4):445-450. https://doi.org/10.1016/j.cbpa.2010.03.031
9. Toguyen A, Faconneau B, Boujard T, Fostier A, Kuhn ER, Mol KA et al. Feeding Behaviour and Food Utilisation in Tilapia, Oreochromis niloticus: Effect of Sex Ratio and Relationship with the Endocrine Status 1997;62(2):273-279.
10. Alanarå A. The effect of time-restricted demand feeding on feeding activity growth and feed conversion in rainbow trout (Oncorhynchus mykiss). Aquaculture 1992;108(3-4):357-368. https://doi.org/10.1016/0044-8486(92)90119-6
11. Sa FJ. Selection of Macronutrients by Goldfish Operating Self-Feeders 1998;65(2):211-218.
12. Sánchez-Vázquez FJ, Iigo M, Madrid JA, Tabata M. pinealectomized does not affect the entrainment to light nor the generation of the circadian demand-feeding rhythms of rainbow trout. Physiology and Behavior 2000;69(4-5):455-461. https://doi.org/10.1016/S0031-9384(99)00250-4
13. Paspatis M, Maragoudaki D, Kentouri M. Self-feeding activity patterns in gilt-head sea bream z Sparus aurata /, red porgy z Pagrus pagrus / and their reciprocal hybrids 2000.
14. Azzaydi M, Martínez FJ, Zamora S. The influence of nocturnal vs. diurnal feeding under winter conditions on growth and feed conversion of European sea bass z Dicentrarchus labrax, L 2000.
15. Boujard T, Gélineau A, Corraze G, Kaushik S, Gasset E, Coves D et al. Effect of dietary lipid content on circadian rhythm of feeding activity in European sea bass. Physiology and Behavior 2000;68(5):683-689. https://doi.org/10.1016/S0031-9384(99)00234-6
16. Chen W, Naruse M, Tabata M. The effect of social interactions on circadian self-feeding rhythms in rainbow trout Oncorhynchus mykiss Wallbaum 2002;76:281-287.
17. Endo M, Kumahara CATY, Tabata M. Reduced stress and increased immune responses in Nile tilapia kept under self-feeding conditions 2002, 253-257.
18. Shima T, Yamamoto T, Furuita H, Suzuki N. Effect of the response interval of self-feeders on the self-regulation of feed demand by rainbow trout (Oncorhynchus mykiss) fry. Aquaculture 2003;224(1-4):181-191. https://doi.org/10.1016/S0044-8486(03)00219-9
19. Paspatis M, Boujard T, Maragoudaki D, Blanchard G, Kentouri M. Do stocking density and feed reward level affect growth and feeding of self-fed juvenile European sea bass? Aquaculture 2003;216(1-4):103-113. https://doi.org/10.1016/S0044-8486(02)00417-9
20. Rubio VC, Vivas M, Sánchez-Mut A, Sánchez-Vázquez FJ, Covès D, Dutto G et al. Self-feeding of European sea bass (Dicentrarchus labrax, L.) under laboratory and farming conditions using a string sensor. Aquaculture 2004;233(1-4):393-403. https://doi.org/10.1016/j.aquaculture.2003.10.011
21. Herrera MJ, Pascual M, Madrid JA, Sánchez-Vázquez FJ. Demand-feeding rhythms and feeding-entrainment of locomotor activity rhythms in tench (Tinca tinca). Physiology and Behavior 2005;84(4):595-605. https://doi.org/10.1016/j.physbeh.2005.02.015
22. Coves D, Gasset E, Lemarié G, Dutto G. A simple way of avoiding feed wastage in European seabass, Dicentrarchus labrax, under self-feeding conditions. Aquatic Living Resources 1998;11(6):395-401. https://doi.org/10.1016/S0979-7440(99)80050-3
23. Bailey J, Alanarå A. Mapping the demand-feeding pattern of hatchery-reared rainbow trout, Oncorhynchus mykiss (Walbaum). Aquaculture 2006;254(1-4):355-360. https://doi.org/10.1016/j.aquaculture.2005.09.027

~ 215 ~

http://www.fisheriesjournal.com
24. Geurden I, Corraze G, Boujard T. Self-feeding behaviour of rainbow trout, Oncorhynchus mykiss, offered diets with distinct feed oils. Applied Animal Behaviour Science 2007;108(3-4):313-326. https://doi.org/10.1016/j.applanim.2006.12.006
25. Navarro DB, Rubio VC, Luz RK, Madrid JA. Daily feeding rhythms of Senegalese sole under laboratory and farming conditions using self-feeding systems. Aquaculture 2007;291(1-2):130-135. https://doi.org/10.1016/j.aquaculture.2009.02.039
26. Millot S, Bégout M. Individual fish rhythm directs group feeding: a case study with sea bass juveniles (Dicentrarchus labrax) under self-demand 2009;370:363-370.
27. Fortes da Silva R, Martinez FJ, Villarroel M, Sánchez-Vázquez FJ. Daily feeding patterns and self-selection of dietary oil in Nile tilapia. Aquaculture Research 2010;42(1):157-160. https://doi.org/10.1111/j.1365-2109.2010.02599.x
28. Benhaïm D, Bégout ML, Péan S, Brisset B, Leguay D, Chatain B. Effect of fasting on self-feeding activity in juvenile sea bass (Dicentrarchus labrax). Applied Animal Behaviour Science 2012;136(1):63-73. https://doi.org/10.1016/j.applanim.2011.11.01
29. Ferrari S, Benhaïm D, Colchen T, Chatain B, Bégout ML. First links between self-feeding behaviour and personality traits in European seabass, Dicentrarchus labrax. Applied Animal Behaviour Science 2014;161(1):131-141. https://doi.org/10.1016/j.applanim.2014.09.019
30. Biswas A, Takii K. Optimal Stocking Density with the Provision of Self-feeders for Striped Knifefish, Oplgnathus fasciatus (Temminck and Schlegel 1844). Journal of the World Aquaculture Society. 2017;48(3):488-495. https://doi.org/10.1111/jwas.12354
31. Meriwether FH. The Progressive Fish-Culturist An Inexpensive Demand Feeder for Cage-Reared Tilapia An Inexpensive Demand Feeder for Cage-Reared Tilapia 2016;0779:6-9. https://doi.org/10.1577/1548-8640(1986)48<226
32. De Mattos BO, Filho ECTN, Barreto KA, Braga LGT, Fortes-Silva R. Self-feeder systems and infrared sensors to evaluate the daily feeding and locomotor rhythms of Pirarucu (Arapaima gigas) cultivated in outdoor tanks. Aquaculture 2016;457:118-123. https://doi.org/10.1016/j.aquaculture.2016.02.026
33. Benhayim D, Akian DD, Ramos M, Ferrari S, Yao K, Bégout ML. Self-feeding behaviour and personality traits in tilapia: A comparative study between Oreochromis niloticus and Sarotherodon melanoatheron. Applied Animal Behaviour Science 2017;187:85-92. https://doi.org/10.1016/j.applanim.2016.12.004
34. Da Silva Reis Y, Leite JLR, de Almeida CAL, Pereira DSP, Vidal LVO, de Araujo FG et al. New insights into tambaqui (Colossoma macropomum) feeding behavior and digestive physiology by the self-feeding approach: effects on growth, dial patterns of food digestibility, amylase activity and gastrointestinal transit time. Aquaculture 2019;498:116-122.
35. Reis J, Noviari R, Swanepeol A, Jingping G, Rhodes M, Davis DA. Optimizing feed automation: improving timer-feeders and on demand systems in semi-intensive pond culture of shrimp Litopenaeus vannamei. Aquaculture 2019, 734759. https://doi.org/10.1016/j.aquaculture.2019.734759
36. Navarro DB, Rubio VC, Luz RK, Madrid JA, Sánchez-Vázquez FJ. Daily feeding rhythms of Senegalese sole under laboratory and farming conditions using self-feeding systems. Aquaculture 2009;291(1-2):130-135. https://doi.org/10.1016/j.aquaculture.2009.02.039
37. Covès D, Beauchaud M, Attia J, Dutto G, Bouchut C, Bégout ML. Long-term monitoring of individual fish triggering activity on a self-feeding system: An example using European sea bass (Dicentrarchus labrax). Aquaculture 2006;253(1-4):385-392. https://doi.org/10.1016/j.aquaculture.2005.08.015
38. Sánchez-Muros MJ, Sánchez B, Barroso FG, Garcia-Mesa S, Rufino-Palomenas EE, Lupiáñez JA et al. Effects of culture densities on feed demand, behavioural tests and on the hepatic and cerebral oxidative status in tilapia (Oreochromis sp.). Applied Animal Behaviour Science 2016;185:137-145. https://doi.org/10.1016/j.applanim.2016.10.009
39. Valente LMP, Fauconneau B, Gomes EFS, Boujard T. Feed intake and growth of fast and slow growing strains of rainbow trout (Oncorhynchus mykiss) fed by automatic feeders or by self-feeders. Aquaculture 2001;195(1-2):121-131. https://doi.org/10.1016/S0044-8486(00)00536-6
40. Santos ADA, Lópex-olmeda JF, Sánchez-Vázquez FJ, Fortes-Silva R. Synchronization to light and mealtime of the circadian rhythms of self-feeding behavior and locomotor activity of white shrimps (Litopenaeus vannamei). Comparative Biochemistry and Physiology-Part A: Molecular and Integrative Physiology 2016;199:54-61. https://doi.org/10.1016/j.cbpa.2016.05.001