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Machinery feeding development for sustainable aquaculture: Self-feeding system

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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 fulfil 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.*)
[3]	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 .)
[1]	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	Pirarucu (*Arapaima gigas*)
[33]	Laboratorium	Individual and group	Oreochromis niloticus and Sarotherodon melanotheron
[5]	Indoor and Outdoor	individual and group	Nile tilapia (*Oreochromis niloticus*)
[34]	Indoor	Group	Tambaqui (*Colossoma macropomum*)

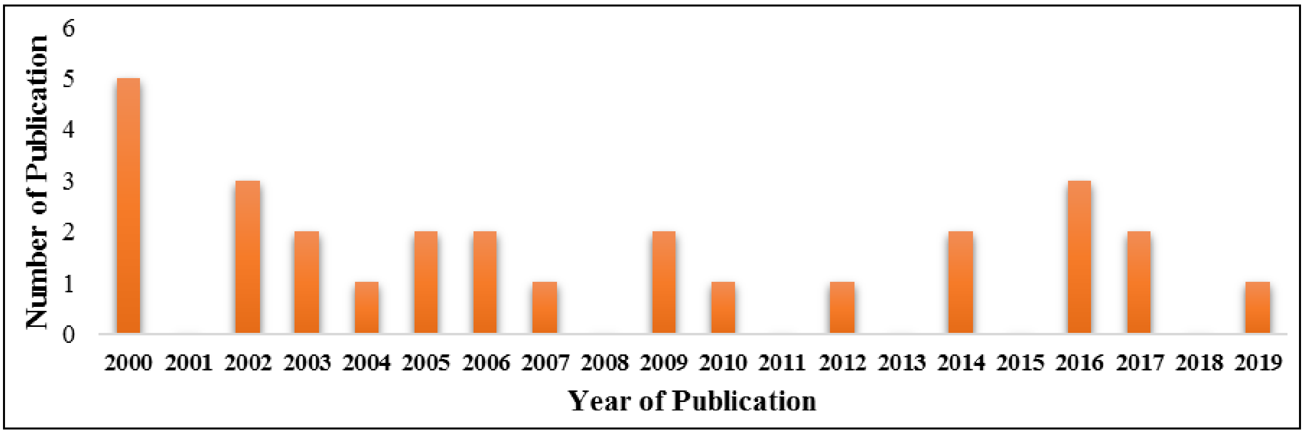

Fig 1: Number of papers published in journals within 2000-2019 regarding the utilization of Self-feeding system

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 quinqueradiata*)	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 Knifejaw (*Oplegnathus fasciatus*)	1	3.57
Pirarucu (*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 are 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 only showed lighting, feeding, flow rate and sediment trap devices [37] and by the time developed rapidly. At a recent year, basically, the apparatus consists of four parts; switch with sensor, a feeder with feed dispenser, a control unit and a microcomputer. The apparatus was modified from an automatic feeder which independently developed by an electronic switch-feed box apparatus (Adocom Electronic, Shiga, Japan; Eheim 3581, Deizisau, Germany; Food Timer Seiko, Tokyo, Japan; Yamaha Motor Co., Ltd., Shizuoka, Japan) supplied.

As a consequence of modification of automatic feeder, some studies compared the application of self-feeding system with other feeding method such as; hand-feeding [24, 38, 6], scheduled feeding [17], and automatic feeding [3, 14, 39]. In addition to use the feeding behavior approach, the assessment of more than one treatment in different sampling periods (seasonal variation) may help in the interpretation of physiological behavior responses [4, 5]. Other parameters which commonly evaluated were circadian rhythm and loco motor activity [15, 16, 34, 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 mall 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 quinqueradiata*)	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*)	Diurnal
Tilapia (*Tilapia aurea*)	Nocturnal/Diurnal
Tambaqui (*Colossoma macropomum*)	Nocturnal
Pirarucu (*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].

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

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