

Original Research Articles

Development of a microparticulate feed for the nursery rearing of the giant mottled eel (*Anguilla marmorata*)

Fredson H. Huervana^{1,2}^a, Kelee Ira B. Nodque¹, Cedric Jay A. Nantong¹, Rizza Mae T. Guyapale¹, Rex Ferdinand M. Traifalgar¹

¹ Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas, Miagao, Iloilo, Philippines, ² University of the Philippines Visayas Brackishwater Aquaculture Center, Leganes, Iloilo, Philippines

Keywords: microparticulate feed, elvers, brackishwater, eel nursery rearing, *Anguilla marmorata*

<https://doi.org/10.46989/001c.138632>

Israeli Journal of Aquaculture - Bamidgeh

Vol. 77, Issue 2, 2025

This study was conducted to develop a microparticulate feed for the nursery culture of *Anguilla marmorata*. The developed crumble-type formulated feed was evaluated through two separate feeding trials. In the first trial, the growth performance of *A. marmorata* elvers fed with dry crumble-type feed was compared to those fed the conventional moist dough-type nursery diet over a 16-day period. The results revealed that elvers fed with the crumble-type feed exhibited significant growth performance, with a specific growth rate (SGR) of 1.57 and percent weight gain (%WG) of 24.62%, ($p < 0.05$). No significant difference in survival was observed, as both dietary treatments achieved a 100% survival rate. Additionally, better water quality was observed in tanks fed with the crumble-type feed as compared to the dough-type. In the second trial, the applicability of the crumble-type feed to support elvers growth was tested on a larger scale rearing system for 120 days. Results demonstrated excellent growth and survival, with elvers exhibited an SGR of 1.52, %WG of 290.47%, and survival of 86.50%. Findings from this study underscore the successful development of a microparticulate feed that supports optimum growth and survival of *A. marmorata* elvers, while offering practical advantages in terms of ease of management and feed preparation.

INTRODUCTION

The culture of tropical anguillid eel is rapidly gaining attention as a lucrative industry in the Philippines due to its significant export potential to key markets in the East Pacific Region.¹ This particular market niche made the eel commodity emerge as one of the country's top exported fishery products, where a total volume of 23,019 MT of the commodity was exported in 2024, representing 9.0 percent of the total export volume. This translates to a value of Php 3.03B or \$ 52.8M, contributing 4.5 percent to the overall value of exported fishery products.²

However, despite its economic benefits, eel aquaculture is still heavily reliant on wild-caught glass eels, as the hatchery technologies for eel are still underdeveloped. The wild glass eels are carnivorous and are adapted to the natural food present in their environment, feeding primarily on diets such as planktonic crustaceans.³ As a predatory fish, a high-protein feed determines the success of eel culture, where the use of live feeds often accounts for 51 to 55

percent of the operation's cost and can run as high as 80 percent.⁴

Traditional feeds in the nursery culture of anguillid eels involve live feeds such as bloodworms, brine shrimp, or *Artemia* nauplii.⁵ These live diets' high acceptability, well-balanced nutritional contents, and high digestible proteins make them suitable for the early feeding of anguillid eel larvae.⁶

Feeding with live feeds, however, has always been accompanied by challenges. Live feeds are cost-intensive, and their preparation prior to feeding requires a high degree of manual work and commitment of space, adding complexities and cost of production to the hatchery facilities.^{7,8} In the European seabass, the use of *Artemia* nauplii accounts for 79% of its total production cost.⁹ The nutritional quality of live feeds such as rotifers and *Artemia* are also highly variable. Hence, the improvement of their nutritional quality through "enrichment" is imperative to meet the nutritional requirements of the cultured fish species and avoid deficiencies in essential nutrients.¹⁰ Live feeds may also be

^a Corresponding author: Fredson H. Huervana (fhuervana@up.edu.ph) Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas, Miagao, Iloilo, Philippines

a vector of pathogens, posing a risk of introducing pathogenic microorganisms to larval cultures.¹¹

Aiming to address these challenges and high costs associated with culturing live food organisms, feeding the nursery stage of anguillid eels necessitates weaning to an artificially formulated diet. Common artificial anguillid eel diets in the nursery stage are primarily prepared as moist dough-type feeds. However, dough-type feeds have low stability in water, contributing to water quality deterioration and therefore requiring more intensive management of the culture water.^{12,13} Moreover, nutrient leaching is highly observed on dough-type feeds.

Alternatively, dry feeds can be used for a more efficient eel culture due to the ease of handling, storage, and high-water stability. In the grow-out culture of eels, the utilization of dry pellet feeds showed enhanced growth performance and survival, as well as better quality of the culture water, compared to its dough-type feed counterpart.¹² However, as eel juveniles are not adept at consuming dry feeds, the abrupt transition to this type of diet can lead to low feed acceptability, consequently leading to starvation and mortality. Hence, the development of a crumble diet suitable for the nursery rearing of eels and its introduction during their early life stage can significantly improve the weaning process.

The primary goal of the study is to develop a crumble diet that is nutritionally balanced and tailored to the specific needs of eels. Specifically, the study aimed to develop a microparticulate feed that could promote improved growth performance and survival of eels during their early critical stages. The development of a crumble-type feed diet not only streamlines the feeding protocol in the early life stages of *A. marmorata*, but also prepares the eel juveniles for grow-out conditions.

MATERIALS AND METHODS

EXPERIMENTAL SITE

The experiment was conducted at the multi-species hatchery complex of the Institute of Aquaculture in the University of the Philippines Visayas.

EXPERIMENTAL ANIMAL

Anguilla marmorata elvers used in the study were sourced from a collector in General Santos, Philippines. The elvers were maintained in a 10-tonner concrete tank, acclimated to the hatchery conditions for 3 days, and were weaned for 36 days to a dough-type feed prior to the conduct of the experiment. During acclimation, water temperature was maintained at 25-28°C, and salinity gradually increased by 6 ppt per day until reaching 18 ppt. The weaning of the elvers to the formulated diets was conducted following the weaning protocol described by Huervana et al.¹⁴ On day 0, glass eels were fed *Artemia* nauplii at 15% of their body weight, then transitioned to a fish meat-based mash (FMT) until day 16. They were subsequently weaned onto a fish

meal-based mash (FML) until day 36. Elvers were not fed a day before the experiment started.

EXPERIMENTAL DIETS

Two different diets (dough-type and crumble-type) were formulated using locally available feed ingredients. The dough-type diet was formulated based on the formulation of Tomiyama & Hibiya,¹⁵ with modifications. Meanwhile, the crumble-type diet was formulated to attain the ideal protein to energy ratio for eels as described by Tibbetts et al.,¹⁶ Tibbetts et al.,¹⁷ and Okorie et al.¹⁸

The dough-type diet was prepared by mixing the dry ingredients (Table 1) and adding warm water (60-75% of the total weight of dry ingredients). The mixture was thoroughly mixed and formed into moist feed balls.

The crumble-type diet was prepared by mixing pre-weighed and sieved (< 500 µm) dry ingredients (Table 1) in a feed mixer at SEAFDEC/AQD Feed Mill. Wet ingredients (soybean oil and lecithin) were added to the dry ingredients and mixed thoroughly. The resultant mixture was passed to a low-pressure extruder (Suehiro EA-20 Extruder), with a temperature of 80-100°C to produce a 2 mm pellet feed. The extruded feed was collected and oven dried (60 °C) to achieve a moisture content of 10-12% and was ground and sieved to obtain a 500-800 µm sized feed particle.

Diets used were sent to an external laboratory for analysis of protein, lipid, moisture, and ash.

FEEDING EXPERIMENTS AND MANAGEMENT

Feeding experiments were conducted to evaluate the efficacy of a crumble-type diet on the growth performance of *A. marmorata* elvers.

In the first feeding trial, the growth performance of *A. marmorata* elvers fed with dough and crumble diet was compared. Elvers weighing an average of 198.08±0.54 mg were stocked in a 120L plastic box (1 individual L⁻¹), containing 50L UV filtered brackishwater, with a salinity of 18 ppt,¹⁹ water temperature of 28°C, and a flow rate of 7.14 mL sec⁻¹. Dissolved oxygen and ammonia are maintained at >4 mg L⁻¹ and ≤0.08 mg L⁻¹, respectively. Elvers in treatments given with either dough or crumble-type diet were fed twice a day, with a feeding rate of 15%. The experiment lasted for 16 days and treatments were done in triplicate in a completely randomized design (CRD).

In the second trial, the effectiveness of the crumble diet on a large-scale rearing system was evaluated for a 120-day rearing period. Elvers with an average body weight (ABW) and average total length (ATL) of 394.16±6.51 mg and 64.73±0.66 mm, respectively, were stocked in five 1 m³ net cages (100 individuals/m³) installed in a 200 m² brackish-water pond. A salinity of 18 ppt and water temperature of 26-30°C were maintained throughout the field trial. The eels were fed at a rate of 15% of their body weight, given three times a day (9:00 am, 12:00 noon, and 15:00 pm). Bio-mass and weight monitoring were conducted every 15 days, and the amount of allotted feeds was also adjusted based on the biomass.

Table 1. Modified formulated dough-type and crumble-type diet composition (g/100g) and proximate composition (% dry weight).

Feed Ingredients	Modified dough-type feed for eel	Formulated crumble-type feed for eel
Fish meal	70	25
Cassava flour	23	5
Shrimp meal	-	10
Squid meal	-	10
Gluten	-	17
Soybean meal	-	10
Soybean oil	-	15
Lecithin	-	3
Yeast	5	-
Vitamin C (Polyphosphate ascorbic acid)	-	1
Vitamins and minerals premix*	2	4
<i>Proximate composition (%DW)</i>		
Crude Protein	58.85	56.85
Crude Fat	4.88	11.54
Moisture	16.21	12.09
Ash	12.40	10.44

*Vitamin premix composition (per kg): Vitamin A (1,200,000 IU), Vitamin D3 (200,000 IU), Vitamin E (20,000 IU), Vitamin B1 (8,000 mg), Vitamin B2 (8,000 mg), Vitamin B6 (5,000 mg), vitamin B12 1% (2000 mcg), Niacin (40,000 mg), Calcium Pantothenate (20,000 mg), Biotin (40 mg), Folic Acid (1,800 mg), Ethoxyquin (500 mg)

*Mineral premix composition (per kg): Iron (40,000 mg), Manganese (10,000 mg), Zinc (40,000 mg), Copper (4,000 mg), Iodine (1,800 mg), Cobalt (20 mg), Selenium (200 mg)

WATER QUALITY

During the experiments, water parameters such as temperature, dissolved oxygen (DO), and ammonia were measured. Temperature and DO were measured using an oxygen meter, while ammonia was measured using an ammonia test kit.

DATA ANALYSIS

Prior to the experiment, 50 eels were separately weighed using an analytical balance. The corresponding length and mouth gape were also measured using a digital caliper.

Sampling was conducted every four days during the first experiment to monitor the growth of elvers in each treatment. Eels were counted individually for survival and batch-weighed using a top-loading balance. At the end of the experiment, eels were again counted and weighed in batches per technical replicate for each treatment. Additionally, ten (10) eels per replicate in each treatment were measured for length and mouth gape. The following growth indices at the end of the two experimental runs were measured and calculated using the following equations:

$$\text{Average body weight (ABW)} = \frac{\text{total weight}}{\text{number of samples}}$$

$$\text{Specific growth rate (SGR)} = \frac{\ln \text{Final weight} - \ln \text{Initial weight}}{\text{number of days}} \times 100$$

$$\% \text{Weight gain (\%WG)} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial weight}} \times 100$$

$$\% \text{Survival} = \frac{\text{Number of fish harvested}}{\text{Number of fish stocked}} \times 100$$

$$\text{Daily length increase} = \frac{\text{Final length} - \text{Initial length}}{\text{No. of days}}$$

Data gathered from the first experiment were tested for normality using the Shapiro-Wilk test. Data were further analyzed for statistical significance using the T-test, comparing the means of the SGR, %WG, and %Survival between elvers fed with dough and crumble-type diets. Standard error of the mean (SEM) was calculated per treatment to measure data variability.

RESULTS

The experiment comparing the growth of *A. marmorata* elvers when fed with dough-type and crumble-type diets concluded after 16 days of culture, indicating promising results for the crumble-type diet. At termination, DOC (day of culture) 16, significantly high average body weight (ABW) was recorded in elvers fed with a crumble-type diet (ABW=262.09 mg) compared to the dough-type diet (ABW=205.51 mg) ([Figure 1](#)).

[Table 2](#) summarizes the initial and final mouth gape and length of *A. marmorata* elvers fed with dough-type and crumble-type diets. After 16 days of culture, elvers fed with the crumble-type diet exhibited a wider mouth gape and a greater total length compared to those fed with the dough-type diet. A significant difference was observed in the mouth gape and total length between the two dietary treatments at the end of the experiment.

Following the trend in ABW of elvers, results showed a significant difference in the specific growth rate (SGR) of *A. marmorata* elvers between the two types of feed given. Elvers fed with the crumble feed showed a statistically higher SGR (1.57) compared to the elvers fed with a dough-type feed (0.19) ($p < 0.05$).

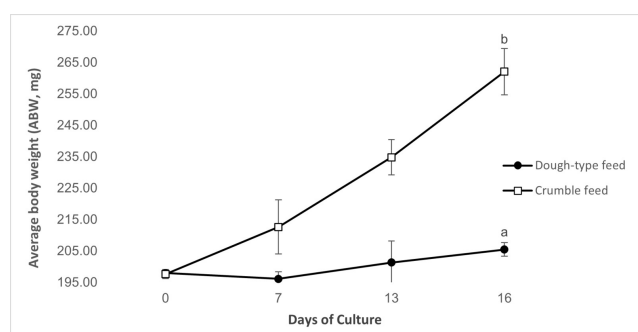


Figure 1. Average body weight (ABW, mg) of *A. marmorata* elvers fed with two types of feed after 16 days of culture. Values are means of replicates $\pm$ SEM (n=3). Values with different superscript letters are significantly different ($p < 0.05$).

Table 2. Initial and final mouth gape and length of *A. marmorata* elvers fed with two types of feed after 16 days of culture.

Growth Parameters	Modified dough-type diet for eel	Formulated crumble-type diet for eel
Initial average mouth gape (mm)	1.31 $\pm$ 0.02 ¹	1.31 $\pm$ 0.02 ¹
Final average mouth gape (mm)	1.33 $\pm$ 0.08 ^{a2}	1.56 $\pm$ 0.06 ^{b2}
Initial average total length (mm)	52.18 $\pm$ 0.43 ¹	52.18 $\pm$ 0.43 ¹
Final average total length (mm)	53.51 $\pm$ 1.15 ^{a2}	58.03 $\pm$ 1.01 ^{b2}

Values are means of replicates $\pm$ SEM (n=3). Values with different superscript letters are significantly different from each other ($p < 0.05$)

¹ 50 individuals were used for measurement/data gathering

² 60 individuals were used for measurement/data gathering

Table 3. Comparison of growth parameters between dough-type and crumble-type diet for eel.

Growth Parameters	Modified dough-type diet for eel	Formulated crumble-type diet for eel
Specific Growth Rate (SGR)	0.19 $\pm$ 0.03 ^a	1.57 $\pm$ 0.09 ^b
Percent Weight Gain (%WG)	2.71 $\pm$ 0.37 ^a	24.62 $\pm$ 1.81 ^b
Percent Survival (%Survival)	100.00 $\pm$ 0.00 ^a	100.00 $\pm$ 0.00 ^a

Values are means of replicates $\pm$ SEM (n=3). Values with different superscript letters are significantly different from each other ($p < 0.05$)

Table 4. Comparison of water parameters between dough-type and crumble-type diet for eel.

Water Parameters	Modified dough-type diet for eel	Formulated crumble-type diet for eel
Temperature (°C)	25.10-31.05	25.00-29.30
Dissolved Oxygen (mg L ⁻¹)	4.44-7.07	6.52-7.01
Ammonia (mg L ⁻¹)	0.25-1.00	0.00-0.50

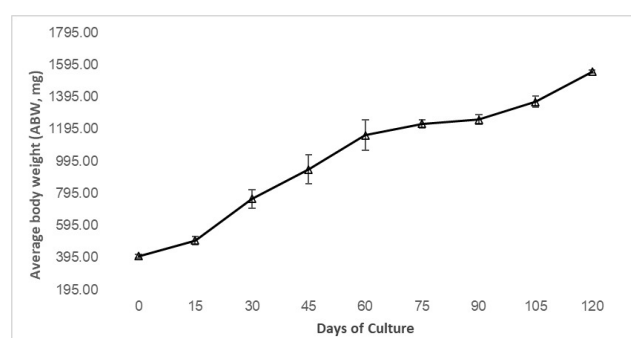


Figure 2. Growth trend of *A. marmorata* elvers fed with crumble diet in cage setup (Day 0 to Day 120).

Values are means of replicates $\pm$ SEM (n=5).

Same results were observed on the percent weight gain (%WG) of *A. marmorata* elvers fed with two types of formulated diet. Weight gain of elvers fed with a dough-type diet (2.71%) has a statistically lower %WG compared to elvers fed with a crumble diet (24.62%) ($p < 0.05$).

Meanwhile, there was no significant difference between the treatments in terms of survival after a 16-day culture. Both treatments showed 100% survival with no recorded mortality ([Table 3](#)).

Data obtained from the first experiment reveal that elvers have a better growth performance during nursery culture when formulated crumble feed is used as their main diet.

In terms of water parameters, better water quality was observed in tanks where the crumble diet was fed. Notably low ammonia levels were observed in tanks fed with a crumble diet compared to tanks fed with the dough-type diet ([Table 4](#)). Recorded dissolved oxygen in tanks fed with a crumble diet were also comparatively higher than on tanks fed with the dough-type diet.

After the experiment, the crumble diet was used in a field trial as the main nursery feed for *A. marmorata* to further assess its effectiveness on a larger scale. [Figure 2](#) shows the growth trend of elvers after 120 days of culture.

Good growth performance was observed during the nursery culture of *A. marmorata* elvers fed with the crumble diet. The effectiveness of the diet was also reflected in the growth parameters of *A. marmorata* elvers after a 120-day culture ([Table 5](#))

Table 5. Growth data of *A. marmorata* elvers fed with crumble diet in cage setup after 120 days of culture. Values are means of replicates $\pm$ SEM (n=5)

Data on growth and survival of <i>A. marmorata</i> elvers	
Specific Growth Rate (SGR)	1.52 $\pm$ 0.04
Percent Weight Gain (%WG)	290.47 $\pm$ 0.92
Daily length increase (mm)	0.47 $\pm$ 0.01
Survival (%)	86.50 $\pm$ 0.71

Results obtained from both the feeding experiment and field trial demonstrate the feasibility of using a crumble-type diet in the nursery culture of *A. marmorata*, with superior growth performance when compared to the traditional dough-type feeds.

DISCUSSION

Several diets were developed and examined in the nursery culture of Anguillid eels to effectively facilitate the weaning and diet transitioning of elvers. Weaning protocols have been developed in the larval and nursery rearing of *A. marmorata*,¹⁴ and the most common diet in nursery and grow-out culture of Anguillid eels is a dough-type feed. The results of this study suggest that the formulated crumble diet is effective and can promote better growth performance for *A. marmorata* elvers during the nursery culture in brackish-water ponds. Also, this study showed favorable effects of the formulated crumble diet on the performance of *A. marmorata* in the nursery culture.

A. marmorata elvers fed with a crumble diet have higher growth performance compared to the elvers fed with a dough-type diet. This shows that a solid diet is an effective diet for the nursery culture of *A. marmorata*. The developed crumble diet formulated for *A. marmorata* nursery significantly enhances the growth of the elvers. Fish fed with dry feeds have better performance in terms of growth compared to fish fed with moist feed.²⁰ A study conducted by Kim & Shin²¹ also demonstrated that dried feed has a better effect on fish, in terms of growth performance and feed utilization, compared to moist and semi-moist feed. Lee et al.²² also showed a better growth performance of *A. japonica* fed with extruded dry pellets during the grow-out culture. The lower growth performance of *A. marmorata* fed with dough-type feed could be attributed to high leaching and low water stability of the feed.

The positive effect of the formulated crumble diet on the growth performance of *A. marmorata* elvers is due to the extrusion process during the development of the crumble diet. Extrusion process improves the feed stability and efficiency of aquaculture feeds.²³ Welker et al.²⁴ also highlighted that the extrusion process improves the overall quality of fish feed, such as increasing the water stability, decreasing the leaching of nutrients, improving the nutrient digestibility of feed, and ensuring sufficient available energy for fish, which leads to better feed conversion and improved growth of fish. Moreover, Kannadhasan et al.²⁵

emphasized that the extrusion cooking process triggers several reactions and processes in the feed that improve the diet, such as denaturation of protein, modification of texture, partial rehydration and dehydration, killing of microorganisms, and destruction of possible toxic compounds. In the present study, the extrusion process in making the crumble diet for *A. marmorata* makes the formulated diet better and more efficient. Similarly, a study conducted by Lee et al.²² showed that extruded pellets promote better growth performance in Japanese eel, *A. japonica*.

On the other hand, the water quality in tanks was better on the treatment fed with the formulated crumble diet. Water quality has a significant effect on the production and efficiency in aquaculture. The present study showed that the formulated crumble diet can improve the water quality, which can lead to better water management and increased production. Ekanem²⁰ demonstrated that feeding moist feed increases the ammonia levels of water, and using solid feed improves the water quality. A study conducted by Kim and Shin²¹ showed that using extruded pellets as feed improves the water quality and decreases the nitrogen and phosphorus discharge. A similar study conducted by Lee et al.²² showed that the water quality in Japanese eel culture tanks is better in the treatments fed with extruded pellets. The same author suggests that dough-type feed is easily soluble in water before being consumed by the fish, and extruded feeds have a longer leaching rate, making it more stable in the water.

The survival rates of elvers in both treatments are attributed to the successful weaning in the early stage (glass eel) and the nutritional contents of both feeds tested. Successful weaning of glass eels and introduction of artificial diets during the early stage (glass eel) results in elvers having higher adaptability to more complex artificial feeds.¹⁴ In this trial, the elvers have more adaptability to artificial diets, which results in good survival on both treatments. On the other hand, the survival of elvers is also attributed to the nutritional contents of the artificial diets used in the experiment. The sufficient amount of protein content of both diets (dough-type and crumble) had a positive effect on the survival of elvers on both treatments. Cheng et al.²⁶ showed that at least 50% crude protein content is optimal for *A. marmorata* elvers, which was met by the artificial diets used in the study. However, there is a big difference in the lipid content of diets used, which can be a factor involved in the difference in the growth rate of elvers.

The better growth of elvers fed with crumble diets can also be linked to the more complex ingredients used in the development of the crumble diet. Several studies explored different feed ingredients for anguillid eels. Heinsbroek et al.²⁷ tested different diet composition of feed for *A. anguilla*, using mainly fish meal, soybean meal, fish oil, and vitamin and mineral premix. Plant-based protein diets and ingredients, such as soybean meal and oil, are also explored and tested as dietary ingredients for eel.²⁸ The addition of squid meal as an attractant in the diet also had good effects on the feed adaptability of *A. marmorata*.²⁹ The complex ingredients used in the crumble development in this

study, and utilization of squid meal as a protein source and attractant, have a positive effect on the growth of *A. marmorata* elvers, with sufficient protein content and better lipid content. The crumble diet has more lipid content than the dough-type feed, which accords with the recommended lipid content of *A. marmorata* diet.²⁶ Lipid content of diet is very important for the overall development of eel.³⁰ The development of this diet with such complex ingredients is made possible with the extrusion process. The nutritional requirement of the fish can be met through mixing necessary feed ingredients, which can be achieved through the extrusion process, and is a key step in producing good quality feed with increased digestibility and good nutrition.³¹ Thus, complex ingredients are tailored successfully through extrusion without compromising the texture and quality of feed, which is hardly possible to achieve in the traditional dough-type feed.

However, the production cost of extruded feed is greater compared to the traditional dough-type feed. A higher capital investment is needed for extrusion technology due to complex machinery and high-energy requirements, which also covers other equipment like feed drying machines.³² For some production scales, especially small-scale farming, the dough-type eel feed is a practical choice in eel nursery culture. However, the lower growth rate of eel fed with dough-type feed and higher ammonia levels in the water may increase indirect costs and economic disadvantages in the long run. Extruded feed has higher initial cost but offers better economic benefits eventually due to its stability, consistency, and efficiency, as shown in this study. The better feed conversion ratio with extruded feed lowers the cost of feed per weight of fish produced.³³ Using extruded diets in fish farming results in higher biomass produced, which promotes economic efficiency and profitability.^{34,35} The choice between the traditional dough-type feed and extruded solid diets must be based on many factors, including feed efficiency and profitability. While dough-type feed may still be a practical choice for some production scales, the crumble feed developed in this study is a promising diet that can promote better growth due to its consistency, increasing the production and economic efficiency of *A. marmorata* nursery culture.

Overall, this study demonstrated success in developing a microparticulate feed for the nursery culture of *A. marmorata* in brackishwater pond/tank systems. The findings highlight that utilizing the developed microparticulate feed effectively maintains the water quality and enhances the growth performance of *A. marmorata* elvers, thereby improving the efficiency, sustainability, and manageability of the nursery culture process.

ACKNOWLEDGMENTS

Authors extend sincere thanks to the Department of Science and Technology-Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development

(DOST-PCAARRD) for funding this study. Our gratitude also extends to the Southeast Asian Fisheries Development Center/Aquaculture Department (SEAFDEC/AQD) for their assistance in feed extrusion. Furthermore, we acknowledge the Institute of Aquaculture, College of Fisheries and Ocean Sciences, University of the Philippines Visayas for the technical assistance, use of facilities, and overall support that made this project possible.

AUTHORS' CONTRIBUTION

Conceptualization: Fredson H. Huervana (Equal), Rex Ferdinand M. Traifalgar (Equal). Methodology: Fredson H. Huervana (Equal), Rex Ferdinand M. Traifalgar (Equal). Writing – review & editing: Fredson H. Huervana (Equal), Rex Ferdinand M. Traifalgar (Equal). Funding acquisition: Fredson H. Huervana (Lead). Supervision: Fredson H. Huervana (Lead). Formal Analysis: Kelee Ira B. Nodque (Equal), Cedric Jay A. Nantong (Equal), Rizza Mae T. Guyapale (Equal). Investigation: Kelee Ira B. Nodque (Equal), Cedric Jay A. Nantong (Equal), Rizza Mae T. Guyapale (Equal). Writing – original draft: Kelee Ira B. Nodque (Equal), Cedric Jay A. Nantong (Equal). Software: Kelee Ira B. Nodque (Equal), Cedric Jay A. Nantong (Equal). Data curation: Kelee Ira B. Nodque (Equal), Cedric Jay A. Nantong (Equal). Visualization: Kelee Ira B. Nodque (Equal), Cedric Jay A. Nantong (Equal), Rizza Mae T. Guyapale (Equal).

COMPETING OF INTEREST – COPE

No competing interests were disclosed.

ETHICAL CONDUCT APPROVAL – IACUC

Ethical review and approval were not required for the animal study because this study adheres to the Philippine National Standard (PNS) on the Code of Good Aquaculture Practices (GAqP) for nursery fish culture (BAFS, 2017). Protocols on rearing, handling, and animal welfare were strictly followed based on the guidelines stipulated in Philippine Republic Act Number 8485, known as the Animal Welfare Act of 1998.

INFORMED CONSENT STATEMENT

All authors and institutions have confirmed this manuscript for publication.

DATA AVAILABILITY STATEMENT

All are available upon reasonable request.

Submitted: February 20, 2025 CST. Accepted: April 24, 2025 CST. Published: June 16, 2025 CST.



This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY-4.0). View this license's legal deed at <http://creativecommons.org/licenses/by/4.0> and legal code at <http://creativecommons.org/licenses/by/4.0/legalcode> for more information.

REFERENCES

1. Shiraishi H, Crook V. An analysis of *Anguilla* production, trade and consumption in East Asia. Published online 2015:53.
2. BFAR (Bureau of Fisheries and Aquatic Resources). *The 2023 Philippine Fisheries Profile*. Bureau Of Fisheries and Aquatic Resources Fisheries Building Complex, BPI Compound, Visayas Ave., Quezon City; 2024.
3. Van Wichelen J, Verhelst P, Perneel M, et al. Glass eel (*Anguilla anguilla* L. 1758) feeding behaviour during upstream migration in an artificial waterway. *Journal of Fish Biology*. 2022;101(4):1047-1057. doi:[10.1111/jfb.15171](https://doi.org/10.1111/jfb.15171)
4. Bardach JE, Ryther JH, McLarney WO. *Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms*. John Wiley & Sons; 1974. doi:[10.1016/0013-9327\(73\)90098-0](https://doi.org/10.1016/0013-9327(73)90098-0)
5. Cuvin-Aralar ML, Aya F, Romana-Eguia MRR, Logronio DJ. *Nursery Culture of Tropical Anguillid Eels in the Philippines*. Aquaculture Department, Southeast Asian Fisheries Development Center; 2019.
6. Keshavanath P. Role of natural food in sustaining aquaculture. *Journal of Aquatic Biology & Fisheries*. 2014;2(1):6-13.
7. Southgate PC, Partridge GJ. Development of artificial diets for marine finfish larvae: problems and prospects. In: *Tropical Mariculture*. Academic Press; 1998:151-169. doi:[10.1016/b978-012210845-7/50005-2](https://doi.org/10.1016/b978-012210845-7/50005-2)
8. Borlongan IG, Marte CL, Nocillado JN. Development of larval diets for milkfish (*Chanos chanos*). *Journal of Applied Ichthyology*. 2000;16(2):68-72. doi:[10.1046/j.1439-0426.2000.00152.x](https://doi.org/10.1046/j.1439-0426.2000.00152.x)
9. Person le Ruyet J, Fischer C, Thebaud L. Sea bass (*Dicentrarchus labrax*) weaning and on-growing onto Sevbar [55% protein-10% lipid extruded diet]. *Colloques de l'INRA (France)*. 1993;(61).
10. Kandathil Radhakrishnan D, AkbarAli I, Schmidt BV, John EM, Sivanpillai S, Thazhakot Vasunambesan S. Improvement of nutritional quality of live feed for aquaculture: An overview. *Aquaculture Research*. 2020;51(1):1-17. doi:[10.1111/are.14357](https://doi.org/10.1111/are.14357)
11. Melaku S, Geremew A, Getahun A, Mengestou S, Belay A. Challenges and prospects of using live feed substitutes for larval fish. *Fisheries and Aquatic Sciences*. 2024;27(8):475-487. doi:[10.47853/FAS.2024.e45](https://doi.org/10.47853/FAS.2024.e45)
12. Wahyudi AA, Fui CF, Senoo S. Impact of Diet Variation on Growth Performance, Feeding Efficiency, Health Condition and Water Quality of Juvenile Short-finned Eel (*Anguilla bicolor*). *Malaysian Journal of Fundamental and Applied Sciences*. 2025;21(2025):1601-1610. doi:[10.11113/mjfas.v21n1.3788](https://doi.org/10.11113/mjfas.v21n1.3788)
13. Arai S. *Eel Culture in Greece*. Food and Agriculture Organization of the United Nations; 1987.
14. Huervana FH, Nodque KIB, Nantong CJA, Vargas RP, Guyapale RMT, Traifalgar RFM. Early weaning protocols for the brackishwater nursery culture of the tropical anguillid eel *Anguilla marmorata* (Quoy & Gaimard, 1984). *Israeli Journal of Aquaculture - Bamidgeh*. 2024;76(4):87-99. doi:[10.46989/001c.124741](https://doi.org/10.46989/001c.124741)
15. Tomiyama T, Hibiya T, Japan Marine Products Photo Materials Association. *Fisheries in Japan: Eel*; 1977.
16. Tibbetts SM, Lall SP, Anderson DM. Dietary protein requirement of juvenile American eel (*Anguilla rostrata*) fed practical diets. *Aquaculture*. 2000;186(1-2):145-155. doi:[10.1016/S0044-8486\(99\)00363-4](https://doi.org/10.1016/S0044-8486(99)00363-4)
17. Tibbetts SM, Lall SP, Anderson DM. Optimum dietary ratio of digestible protein and energy for juvenile American eel, *Anguilla rostrata*, fed practical diets. *Aquaculture Nutrition*. 2001;7(4):213-220. doi:[10.1046/j.1365-2095.2001.00175.x](https://doi.org/10.1046/j.1365-2095.2001.00175.x)
18. Okorie OE, Kim YC, Lee S, et al. Reevaluation of the dietary protein requirements and optimum dietary protein to energy ratios in Japanese eel, *Anguilla japonica*. *Journal of the World Aquaculture Society*. 2007;38(3):418-426. doi:[10.1111/j.1749-7345.2007.00113.x](https://doi.org/10.1111/j.1749-7345.2007.00113.x)
19. Cadiz R, Traifalgar RF. Optimum salinity for growth of tropical eel *Anguilla marmorata* Quoy & Gaimard, 1824 in nursery culture. *Asian Fisheries Science*. 2020;33(4). doi:[10.33997/j.afs.2020.33.4.002](https://doi.org/10.33997/j.afs.2020.33.4.002)

20. Ekanem SB. Effects of feeding frequency, moist and dry feeds on the growth of *Chrysichthys nigrodigitatus* Lacepede and on pond water quality. *Aquaculture Research*. 1996;27(2):107-112. doi:[10.1111/j.1365-2109.1996.tb00974.x](https://doi.org/10.1111/j.1365-2109.1996.tb00974.x)
21. Kim JD, Shin SH. Growth, feed utilization and nutrient retention of juvenile olive flounder (*Paralichthys olivaceus*) fed moist, semi-moist and extruded diets. *Asian-australasian journal of animal sciences*. 2006;19(5):720-726. doi:[10.5713/ajas.2006.720](https://doi.org/10.5713/ajas.2006.720)
22. Lee S, Moniruzzaman M, Yun H, Park Y, Mann J, Bai SC. Comparative studies on effects of extruded pellets and dough-type diets on growth, body composition, hematology and gut histology of juvenile Japanese Eel, *Anguilla japonica* (Temminck et Schlegel). *J Fish Aqua Sci*. 2016;11:378-384. doi:[10.3923/jfas.2016.378.384](https://doi.org/10.3923/jfas.2016.378.384)
23. Chang YK, Wang SS. *Advances in Extrusion Technology: Aquaculture/Animal Feeds and Foods: Proceedings of the International Symposium on Animal and Aquaculture Feedstuffs by Extrusion Technology and the International Seminar on Advanced Extrusion Technology in Food Applications.*; 1999.
24. Welker TL, Overturf K, Snyder S, et al. Effects of feed processing method (extrusion and expansion-compression pelleting) on water quality and growth of rainbow trout in a commercial setting. *Journal of Applied Aquaculture*. 2018;30(2):97-124. doi:[10.1080/10454438.2018.1433095](https://doi.org/10.1080/10454438.2018.1433095)
25. Kannadhasan S, Muthukumarappan K, Rosentrater KA. Effect of starch sources and protein content on extruded aquaculture feed containing DDGS. *Food and Bioprocess Technology*. 2011;4:282-294. doi:[10.1007/s11947-008-0177-4](https://doi.org/10.1007/s11947-008-0177-4)
26. Cheng WT, Lai CS, Lin YH. Quantifying the Dietary Protein and Lipid Requirements of Marble Eel, *Anguilla marmorata*, with Different Body Weight. *Journal of the Fisheries Society of Taiwan*. 2013;40(2):135-142. doi:[10.29822/JFST.201306_40\(2\).0006](https://doi.org/10.29822/JFST.201306_40(2).0006)
27. Heinsbroek LT, Van Hooff PL, Swinkels W, Tanck MW, Schrama JW, Verreth JA. Effects of feed composition on life history developments in feed intake, metabolism, growth and body composition of European eel, *Anguilla anguilla*. *Aquaculture*. 2007;267(1-4):175-187. doi:[10.1016/j.aquaculture.2007.03.028](https://doi.org/10.1016/j.aquaculture.2007.03.028)
28. Kontara EKM, Suryaningrum LH, Saputra A, et al. Review of dietary strategies for glass eels (*Anguilla* sp.): impact of plant-based protein diets on growth, immunity, and intestinal development. *AACL Bioflux*. 2025;18(2).
29. Ndobe S, Rosyida E, Widiastuti IM, Mansyur K, Tantu FY. Effect of adding squid meal as an attractant to freshwater eel (*Anguilla marmorata*) feed on elver growth, feed palatability, efficiency and conversion. In: *IOP Conference Series: Earth and Enviro.* ; 2022.
30. Liu L, Li R, Zhang JM, Guo F, Zhang T. Composition and metabolizing of lipids and fatty acids in muscle of female *Anguilla japonica* during the period of artificial inducing ovarian maturation. *Acta Hydrobiologica Sinica*. 2009;33(6):1011-1019. doi:[10.3724/SP.J.1035.2009.61011](https://doi.org/10.3724/SP.J.1035.2009.61011)
31. Delgado E, Reyes-Jaquez D. Extruded aquaculture feed: a review. In: *Extrusion of Metals, Polymers and Food Products*. InTechOpen; 2018:145-163. doi:[10.5772/intechopen.69021](https://doi.org/10.5772/intechopen.69021)
32. Pennells J, Salini M, Rombenso A, Simon C, Ying D. The State-of-the-Art of Aquafeed Extrusion: Mechanisms, Challenges and Opportunities. *Reviews in Aquaculture*. 2025;17(2):e70002. doi:[10.1111/raq.70002](https://doi.org/10.1111/raq.70002)
33. Adelizi R, Rosati M, Warner D, Muench J, White L, Broen D. Evaluation of fish-meal free diets for rainbow trout, *Oncorhynchus mykiss*. *Aquaculture Nutrition*. 1998;4(4):255-262. doi:[10.1046/j.1365-2095.1998.00077.x](https://doi.org/10.1046/j.1365-2095.1998.00077.x)
34. Muyot FB, Mutia MTM, Caunan PJH. Growth performance and cost efficiency of tilapia (*Oreochromis niloticus*) and milkfish (*Chanos chanos*) fed extruded floating and non-floating feeds reared in net cages in Taal Lake. *The Philippine Journal of Fisheries*. 2015;25(2):41-56. doi:[10.31398/tjpf/25.2.2018A0008](https://doi.org/10.31398/tjpf/25.2.2018A0008)
35. Abou-Zied RM. Effect of diet extruded type on growth performance, feed utilization and economic efficiency of Nile tilapia in commercial farms. *Egyptian Journal of Nutrition and Feeds*. 2015;18(1):143-150. doi:[10.21608/ejnf.2015.104795](https://doi.org/10.21608/ejnf.2015.104795)