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*Research Article*

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# Application of IOT Technology, Sensor Networks Combined with Plasma Techniques in Seed Production and Commercial Farming of Swamp Eel (Monopterus Albus Zwiew, 1793) in Soc Trang

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**ABSTRACT**
The study "Application of IoT Technology combined with cold plasma techniques in larvae production and commercial farming of swamp Eel in Soc Trang" was conducted from 2023 to 2025, aiming to stabilize water quality and improve the survival and growth rates of swamp eel in Soc Trang. The results showed that although water quality parameters in the nursing and grow-out systems fluctuated from the larvae stage to commercial size, these variations did not adversely affect the growth and development of the swamp eel.

Analysis of Coliform levels (CFU/mL) in the nursing system indicated values ranging from $2.2 \times 10^2$ to $3.3 \times 10^3$, and notably, E. coli was not detected (CFU/mL). In the nursing experiment from Larvae eel to 30-day-fingerlings, body weight and survival rates in Treatment 1 (NT1) (brood stock fed trash fish) were higher than those in Treatment 2 (NT2) (brood stock fed a 42% protein commercial feed). After 90 days of nursing, the survival rate in NT1 reached 92.6% with a yield of 3.586 kg/m², higher than NT2 (81.2% and 2.699 kg/m², respectively) ($p < 0.05$). In the grow-out phase, the stocking density of 800 fish/m² (NT2) resulted in higher total yield and production than NT1. However, the stocking density of 600 fish/m² (NT1) produced better results in terms of body weight, survival rate, and profit margin (%). The feed conversion ratio (FCR) in both commercial farming treatments was low (1.13–1.16), indicating high feed utilization efficiency.

Application of IoT technology, combined with sensor networks and plasma techniques, provided an effective solution for stabilizing and managing water quality in swamp eel nursing and grow-out systems. This approach offers significant scientific and practical value by improving survival rates, growth performance, and the overall efficiency of larvae production and commercial farming systems for swamp eel.

**Keywords:** IoT Technology, Plasma technique, Eel Nursing, Commercial Swamp Eel Farming

## Introduction

The swamp eel (Monopterus albus Zwiew, 1793) is a species commonly found in muddy ponds, canals, garden ditches, rice fields, and wetlands throughout Southeast Asia [1]. Currently, the swamp eel is one of the widely cultured species in the Mekong Delta region. Farming methods are diverse, including semi-intensive and intensive systems in cement and composite tanks, and home - made tank with or without substrates. Stocking densities are typically high.

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In practical production activities have shown that the efficiency of seed production and commercial grow-out of swamp eel has supported the development of a new aquaculture model, created additional income opportunities and contributed to improving the livelihoods of many households in the region.

**Figure 1:** Swamp eels (Monopterus albus Zuiew, 1793)

According to the economic office of Nga Nam village, the swamp eel is considered an easy species to culture, and eel farming activities have expanded rapidly in the locality [2]. Surveys indicate that in 2020, only a few farming systems existed in the area, but the number has now increased to 72 farming households. In practical production, it has also been observed that the operation and management of eel farming systems still face numerous challenges. Farmers often lack technical knowledge, and farming practices mainly rely on experience shared among local households or information obtained from social media. Many farmers do not fully understand technical procedures and have not identified appropriate stocking densities; as a result, cultured eels are frequently infected with diseases and experience high mortality rates. In addition, the quality of seed supplied by hatcheries is often unreliable, leading to slow growth, increased feed conversion ratios, and reduced survival rates, which range from only 15–25%. In some cases, seed survival has dropped to just 8–10%, resulting in insufficient seed supply for farmers and negatively affecting the performance and quality of farming systems [3].

From these practical challenges, it is essential to research technical solutions that improve management practices and enhance the survival and growth of swamp eel in both hatchery and grow-out systems. Therefore, the application of the technical solution "Using IoT technology combined with cold plasma techniques in seed production and commercial farming of swamp eel in Soc Trang" has been discussed and implemented in practical production. This approach holds significant value in improving seed survival rates as well as enhancing the quality and efficiency of commercial eel farming systems in Soc Trang.

## Research Methods

### Research Duration and Location

The study was conducted from August 2023 to July 2025. Experimental activities were carried out at the Nga Nam Agricultural hatchery and at selected commercial swamp eel farms in Nga Nam village, Can Tho City.

### Research Methods

Brood Stock Conditioning and Induced Spawning

### Brood Stock Conditioning

Brood stock swamp eels were selected from commercial farming facilities, with individual weights ranging from 60–200 g. The brood stock was reared in two cement composite tanks, each with an area of 30 m² (5 m × 6 m × 0.8 m). After composite tank preparation, brood stock was stocked at 20 individuals/m².

Two types of Feed were used during the Conditioning Period

1. Trash fish (low value fresh water fish)
2. Commercial feed with 40–42% crude protein

Feed was supplied at 2–3% of body weight per day, offered in the late afternoon (18:00–19:00). Water levels were maintained at 0.5 m and renewed every three days by replacing 50–60% of the composite tank volume. After three months of conditioning, brood stock was examined, and sexually mature individuals were selected for induced spawning.

### Sex Identification of Swamp Eel Brood Stock

- **Female:** 60–100 g, 35–40 cm long, large abdomen, thin abdominal skin, reddish genital opening, and rounded tail.
- **Male:** 200–250 g, 50–60 cm long (larger than females), slender body, slightly sunken genital opening, and a longer, more pointed tail.

### Induced Spawning Experiment

Spawning trials were conducted in six tarpaulin-lined composite tanks (12 m² each). Each composite tank was prepared with a substrate consisting of clay mixed with aquatic plants (water hyacinth or water spinach). Water depth was maintained at 40 – 45 cm, with a male-to-female ratio of 1:1. After 10–20 days of conditioning in the spawning composite tanks, water spraying (rain simulation) was applied to stimulate nest building and spawning behavior. Collected and treated eggs were incubated in plastic trays (60 cm × 60 cm × 15 cm), with a water depth of 4–5 cm. Water quality was maintained stable, and temperature was kept at 28 – 31°C. After 5 – 7 days, the eggs hatched larvae.

### Nursing of Swamp Eel Seed

**Experiment 1: Nursing from Eel larvae to 30-day Fingerlings**

*** Experimental Design**

The nursing experiment from eel larvae eel to 30-day fingerlings was conducted with two treatments based on the type of feed used for the brood stock during the conditioning period (trash fish or commercial feed). Each treatment was replicated three times. Stocking density was 5,000 larvae/m².

- **Treatment 1:** Eel larvae produced from brood stock conditioned with trash fish.
- **Treatment 2:** Eel larvae produced from brood stock conditioned with commercial feed.

### Plasma technique


**Figure 2:** Nursing experiment with IoT technology, sensor networks, and plasma techniques

Management of the experiment: In Experiment 1, from day 3 to day 6, eel larvae were fed mainly natural feed Moina. From day 7 to day 30, they were fed a fine-powdered commercial feed with 45% crude protein. Feeding frequency was twice daily, with a feeding rate of 60–70% of biomass per day. Water used for the nursing experiment was sourced from the Nga Nam River and treated through sedimentation, filtration, and a plasma system via a continuous-flow setup.

**Experiment 2: Nursing from 30 Day Fingerlings to 90 Day Fingerlings**

*** Experimental Design**

Experiment 2 involved two treatments using fingerlings 30 day reared to 90 days of age, with a stocking density of 1,000 fingerlings/m². The experiment followed a completely randomized design with three replicates per treatment.

- **Treatment 1:** 30-day fingerlings from brood stock conditioned with trash fish.
- **Treatment 2:** 30-day fingerlings from brood stock conditioned with commercial feed.

*** Nursing System Management**

In Experiment 2, fingerlings (after 30 days of age) continued to be fed fine powdered high-protein feed until 60 days of age. They were then switched to small-sized commercial pellets (0.4–0.8 mm) at a feeding rate of 6–8% BW/day, supplemented with vitamin C at 2–5 g/kg feed and Mita glucan at 5–6 g/kg feed, administered every two weeks. The nursing system was completely renewed twice daily, with 100% water replacement each time. Fingerlings were harvested at 90 days of age.

**Commercial Grow-Out of Swamp Eel**

*** Preparation of the Experimental Grow-Out System**

The grow-out experiment was implemented at six farming households. Each household operated at least three culture composite tanks, each with an area of 6 m². The culture composite tanks were rectangular cement composite tanks (2 m × 3 m × 0.5 m), with the inner walls and bottom lined with ceramic tiles to facilitate cleaning. Water supply and discharge for culture system used clean, filtered water, and water exchange was controlled automatically using IoT technology and sensor networks. One day prior to stocking, composite tanks were filled with water to a depth of 15–20 cm. The fingerling eels were stocked at a size of 3 – 4 g per individual.

*** Experimental Design**

The commercial grow-out experiment consisted of two density treatments, each replicated three times, arranged in a completely randomized design:

- **Treatment 1:** densities of 600 individuals/m²
- **Treatment 2:** densities of 800 individuals/m².

*** Management System**

The commercial pellet feed (1.5 - 4 mm; 40 - 42% protein) were used for feeding, supplemented with vitamin C (1–2 g/kg feed) twice weekly. The feeding rate was 3 – 7% BW/day, supplied twice daily. Water was exchanged twice daily (07:00 – 08:00 and 16:00 – 17:00). Water exchange was controlled automatically through IoT technology and sensor networks to ensure stable water quality. After ten months of culture, all eels were harvested.

**Data Collection Methods**

- Water Quality Parameters: Environmental parameters in the nursing experiments were analyzed every 15 days, while in the grow-out experiment analyses were conducted monthly. Parameters measured included water temperature, pH, DO, N - $NH_4^+$, and N - $NO_2^-$, using HANNA instruments and Sera test kits.
- **Technical Parameters:** Spawning rate, fertilization rate, and hatching rate (%) were calculated based on methods used in the College of Aquaculture, Can Tho University (Long et al., 2014). Growth sampling was conducted every 10 days (Eel larvae to 30 days), every 15 days (30–90 days), and every 30 days during the grow-out phase. The survival rate and yield were recorded at harvest for each experiment. Feed conversion ratio (FCR) was determined at 90 days of nursing and at the end of the commercial grow-out period.

**Data Analysis**

All data collected during the experiments were processed and statistically analyzed using Excel 2016 and SPSS 20.0, with significance determined at $p < 0.05$.

**Results and Discussions**

**Results of Brood Stock Culture Conditions and Induced Reproduction of Swamp Eels**

A survey and assessment of the brood stock conditioning process, along with the application of reproductive induction techniques for Monopterus albus, were conducted. The results are presented in table 1 below:

**Table 1: Reproductive performance of Monopterus albus under two different brood stock culture conditions**

| Treatments | T1 (Trash fish) | T2 (Commercial feed) |
|---|---|---|
| Spawning rate (%) | $22.8 \pm 0.3^a$ | $17.3 \pm 0.9^b$ |
| Fertilization rate (%) | $94.6 \pm 1.0^a$ | $73.7 \pm 6.5^b$ |
| Hatching rate (%) | $90.8 \pm 2.8^a$ | $81.3 \pm 3.1^b$ |

Values are presented as mean ± standard deviation. Values in the same row with different superscript letters differ significantly ($p < 0.05$)

Analysis showed that in treatment 1, swamp eels conditioned with trash fish (low value freshwater trash fish) reached sexual maturity and participated in spawning at an average rate of 22.8%, which was higher than the rate observed in eels conditioned with commercial pelleted feed (17.3%) ($p < 0.05$). The fertilization rate averaged 94.6% in treatment 1 compared to 73.7% in treatment 2 ($p < 0.05$), and the hatching rate averaged 90.8% in treatment 1, higher than 81.3% in treatment 2 ($p < 0.05$). Compared with the findings of Đỗ Thị Thanh Hương et al., who reported an average fertilization rate of 97.5% for Monopterus albus, the results of this study were lower [4]. According to Phuong et al., brood stock swamp eels fed trash fish showed higher maturation rates (females 88.9% and males 66.7%) compared to those fed commercial pellets (females 66.1% and males 53.3%) [5].

Based on these findings, it could be inferred that due to their carnivorous nature often containing various natural food items in their digestive system such as crabs, snails, crustaceans, decaying animal matter, decomposed plant material, insects, and oligochaeta worms, which are rich in macro and micro-nutrients as well as essential amino acids swamp eels exhibit better growth and gonadal development throughout their life cycle when fed trash fish. Consequently, the brood stock Monopterus albus adapt more readily to fresh feeds such as trash fish compared to commercial feeds, leading to higher maturation and spawning participation rates in those fed fresh feed.

**Results of Nursing the Swamp Eel Fingerlings**

**Nursing Swamp Eel from Larval Stage to 30-day Fingerlings**

**Water Quality Parameters in Composite Tank Nursing**

During the experiment, water-quality analyses conducted in the nursing tanks indicated that there were no substantial differences in water quality between the two nursing treatments. The environmental parameters remained stable, with water temperature ranging from 29.6 to 30 °C, pH from 7.7 to 7.8, and dissolved oxygen levels between 5.5 and 5.6 mg/L ($p > 0.05$). Ammonium concentrations ranged from 0.33 to 0.39 mg/L, while nitrite concentrations varied from 0.06 to 0.09 mg/L ($p < 0.05$). The analytical results further demonstrated that effective management of water quality in the nursing tanks particularly through the proper application of cold plasma technology in water-treatment processes helped maintain low concentrations of Coliforms (CFU/mL), ranging from $2.2 \times 10^2$ to $3.3 \times 10^3$. This contributed to limiting pathogen proliferation within the nursing system, thereby reducing potential risks to the survival and development of the swamp eels.

These findings are consistent with previous experimental results reported by Boyd, Nguyen Chung, and Nghia [6-8]. Moreover, the observed increase in nitrite ($N\text{-}NO_2$) concentration toward the end of the 30-day nursing cycle indicates an accumulation of residual organic matter in the system. Consequently, regular monitoring, management, and treatment of water quality are essential technical measures to stabilize environmental conditions, improve survival rates, and enhance the overall performance of eel nursing during the larval to 30-day fingerlings.

**Table 2: Water quality parameters during nursing from larval stage to 30 days fingerlings**

| Treatments | T (°C) | Oxy (mg/L) | pH | $N\text{-}NH_4^+$ (mg/L) | $N\text{-}NO_2^-$(mg/L) |
|---|---|---|---|---|---|
| Treatment 1 (Trash fish) | 30,0±0,9$^{a}$ | 5,5±0,1$^{a}$ | 7,7±0,3$^{a}$ | 0,39±0,25$^{b}$ | 0,09±0,10$^{b}$ |
| Treatment 2 (Commercial feed) | 29,6 ±0,9$^{a}$ | 5,6±0,2$^{a}$ | 7,8±0,2$^{a}$ | 0,33±0,22$^{a}$ | 0,06±0,08$^{a}$ |

**Note:** Values are presented as means ± standard deviations.

**Mean Weight of Swamp Eels During the Nursing Period (Larvae – 30 Days Fingerlings)**

Analysis of the growth performance of swamp eels after 30 days of nursing in two treatments (table 3) showed that:

**Table 3: Mean growth of swamp Eels in nursing period (larval stage to 30 days fingerling)**

| Nursing Period | Parameters | Treatment 1 | Treatment 2 |
|---|---|---|---|
| Initial Weight | W Ini (g/ind) | 0,019±0,002$^{a}$ | 0,017±0,001$^{a}$ |
| After 10 days | $W_{10}$ (g/ind)<br>DWG (g/day) | 0,048±0,003$^{a}$<br>0,003±0,0004$^{a}$ | 0,042±0,002$^{a}$<br>0,002±0,0003$^{a}$ |
| After 20 days | $W_{20}$ (g/ind)<br>DWG (g/day) | 0,088±0,003$^{a}$<br>0,004±0,0003$^{a}$ | 0,083±0,001$^{a}$<br>0,004±0,0002$^{a}$ |
| After 30 days | $W_{30}$ (g/ind)<br>DWG (g/day) | 0,133±0,004$^{a}$<br>0,005±0,0002` | 0,125±0,004$^{a}$<br>0,004±0,0005$^{a}$ |

**Note:** Values are presented as mean ± standard deviation; values within the same row followed by different letters are significantly different ($p < 0.05$).

After 30 days of nursing, the mean weight of swamp eels in treatment 1 reached 0.133 ± 0.004 g/individual, which was higher than that of treatment 2 at 0.125 ± 0.004 g/individual ($p > 0.05$). Compared with the results reported by Nguyen Thanh Hieu et al., in which eel larvae were nursed for 28 days using finely chopped Tubifex worms combined with low value fish (trash fish) as feed, the mean body weight after 28 days ranged from 0.268 to 0.596 g/ind. Thus, the growth performance observed was considerably lower [9]. These results indicates that differences in feed type and nutritional quality between the two nursing treatments played a crucial role. In particularly, Tubifex worms a preferred, high-nutrient feed for swamp eels are known to stimulate feeding activity and enhance growth, resulting in higher body weight compared to eels fed commercial diets. These findings are consistent with the observations of Nguyễn Thị Hồng Vân et al, who reported that brood stock eels fed low-value fish rich in amino acids, protein, and lipid - exhibited better reproductive performance, producing high-quality eggs and larvae with superior development compared to those fed exclusively high-protein commercial diets [10]. In practice, feed type can therefore be considered a key technical factor influencing growth performance and the overall quality of swamp eels.

**Survival Rate (%) and Yield ($G/M^2$) of 30-Day Fingerlings**

**Table 4: Survival rate and yield of swamp eels in nursing period from larvae to 30 days old**

| Treatments | Survival rate (%) | Yield ($g/m^2$) |
|---|---|---|
| Treatment 1 | 93,3±2,4$^{a}$ | 639±89,3$^{a}$ |
| Treatment 2 | 82,4±1,2$^{b}$ | 515±19,0$^{b}$ |

**Note:** Values are presented as mean ± standard deviation; values within the same column followed by different letters are significantly different ($p < 0.05$).

The experimental data showed that the survival rate (%) and the average yield (g/m²) of fingerling eels during the nursing period from larval stage to 30 days old in treatment 1 were 93.3% and 639 g/m², respectively significantly higher ($p < 0.05$) than those in treatment 2, which averaged 82.4% and 515 g/m². Compared with grow out and survival rate results from practical farming conditions in Can Thơ City, Đồng Tháp and An Giang province, the outcomes of this experiment were notably higher. The results indicated that, in addition to the stable quality of swamp eels during the nursing period, the following factors contributed substantially to performance: (1) improved water quality through the application of plasma technology, and (2) the use of natural feed with diverse and high nutritional value, which effectively met the dietary requirements of swamp eels. Swamp eel survival rates ranged from 82.4% to 93.3%, with the treatment using low value fish as feed achieving significantly higher survival than the treatment using commercial feed ($p < 0.05$). These findings are comparable to those reported by Nguyen Thanh Hieu et al, in which survival rates of 30-day fingerling across different stocking densities ranged from 87.91% to 91.46% [9]. Yield of swamp eels after 30 days of nursing differed significantly between the two treatments, ranging from 515 to 639 g/m² ($p < 0.05$). The experimental results considered that 30-day swamp eels fingerling produced from brood stock fed fresh natural feed perform better than those derived from brood stock fed commercial diets.

**Results of Nursing Swamp Eel from 30 Days to 90 Days of Age**

**Water Quality Parameters in the Nursing Composite Tanks**

The analytical results presented in table 5 show that there were no major differences in water quality conditions between the two experimental treatments. Water temperature ranged from 29.4 to 30.1 °C, dissolved oxygen from 4.8 to 5.2 mg/L, and pH from 7.7 to 7.9. Concentrations of $N\text{–}NH_4^+$ and $N\text{–}NO_2^-$ were recorded at 0.43 – 0.50 mg/L and 0.07 – 0.09 mg/L, respectively. Swamp eels possess accessory respiratory organs; therefore, the recorded water quality parameters fluctuate within a range suitable for their growth and do not impose adverse effects on development within the culture system.

**Table 5: Water quality parameters in nursing period from 30 to 90 days of age**

| Treatments | T (°C) | Oxy (mg/L) | pH | $N\text{-}NH_4^+$ (mg/L) | $N\text{-}NO_2^-$ (mg/L) |
|---|---|---|---|---|---|
| Treatment 1 | 29,4±0,2 | 4,8±0,4 | 7,9±0,2 | 0,5±0,26 | 0,09±0,08 |
| Treatment 2 | 30,1 ±0,2 | 5,2±0,5 | 7,7±0,3 | 0,43±0,15 | 0,07±0,09 |

**Note:** Values are presented as means ± standard deviations.

**Growth of Swamp Eel During the 30 – 90 days Nursing Period**

**Table 6: Mean weight of swamp eel in nursing period from 30 - 90 days of age**

| Nursing period | Parameters | Treatment 1 | Treatment 2 |
|---|---|---|---|
| 30 days | $W_{30}$ (g/ind.) | 0,134±0,005[a] | 0,124±0,004[a] |
| After 45 days | $W_{45}$ (g/ind.)<br>DWG (g/day) | 0,519±0,025[a]<br>0,026±0,0014[b] | 0,464±0,028[a]<br>0,023±0,0016[b] |
| After 60 days | $W_{60}$ (g/ind.)<br>DWG (g/day) | 0,994±0,040[a]<br>0,032±0,0015[a] | 0,865±0,053[b]<br>0,027±0,0022[b] |
| After 75 days | $W_{75}$ (g/ind.)<br>DWG (g/day) | 2,046±0,097[a]<br>0,070±0,0054[b] | 1,815±0,040[b]<br>0,063±0,0015[b] |
| After 90 days | $W_{90}$ (g/ind.)<br>DWG (g/day) | 3,871±0,112[a]<br>0,122±0,0011[a] | 3,322±0,134[b]<br>0,100±0,0063[b] |

**Note:** Values are presented as mean ± standard deviation; values within the same row followed by different letters are significantly different ($p < 0.05$).

Analysis of the results presented in table 6 shows that, at the initial stage (after 30 days), the body weight of swamp eels in the two treatments ranged from 0.124 to 0.134 g/individual ($p > 0.05$). By day 60, eel body weight increased to 0.865 - 0.994 g/individual, with daily weight gain ranging from 0.027 to 0.032 g/day ($p < 0,05$). The growth performance was influenced by the transition from powdered commercial feed to pelleted commercial feed. Fingerling eels did not immediately adapt to this change, resulting in reduced feeding activity or temporary feed refusal. In the nursing phase from 30 to 90 days of age, it is needing an additional time for training are necessary to familiarize the fingerlings with the new feed form, after which feeding behavior stabilizes and growth improves.

During the 30 - 90-day culture period, mean weight ranged from 3.322 to 3.871 g/individual, with daily weight gain varying between 0.100 and 0.122 g/day ($p < 0.05$). Compared with the findings of Hiệu (2015), where the mean weight of eel fingerlings ranged from 3.84 to 4.13 g/individual, the growth performance in the present study was lower value. This difference can be attributed primarily to variations in feed type and nutritional composition used in the experiments. In the present study, eels were fed commercial feed (powdered form) during the initial stages and were gradually transitioned to pelleted commercial feed after 60 days. In contrast, in the study by Nguyen Thanh Hieu, eels were fed natural feed (Tubifex worms) from 15 to 60 days of age, followed by minced fish combined with commercial pellets from 60 to 90 days [9]. These differences in feed type, palatability, nutrient quality for the higher growth performance observed in that earlier study.

**Weight Distribution of Eel Fingerling During the 30–90 days Nursing Period**

Analysis of results from treatment 1 showed that the body weight distribution of fingerling eels during the 30 – 90-day nursing period ranged from 2.789 to 4.903 g/individual. Among these, eels weighing 3.200 – 4.600 g/individual accounted for the highest proportion at 90%, followed by the group weighing 2.789 – 3.200 g/individual at 6.7%, while individuals exceeding 4.600 g/individual represented 3.3%. For treatment 2, the body weight of swamp eels ranged from 2.087 to 4.822 g/individual.

Of these, individuals weighing 3.000 – 4.600 g/individual accounted for 64.44%, followed by those weighing less than 3.000 g/individual at 33.33%, while the group exceeding 4.600 g/individual represented 2.22%.

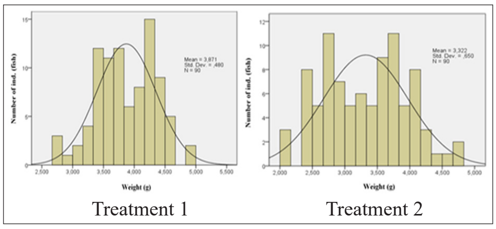


**Figure 3:** Weight distribution of swamp eels under different nursing treatments

The collected data indicate a clear weight differentiation between the two nursing treatments. Notably, the proportion of fingerling eels within the desirable weight range of 3.000–4.600 g/individual was higher and more favorable in Treatment 1 compared to Treatment 2.

**Survival Rate, Yield, and FCR During the 30–90 Day Nursing Period**

After 90 days of nursing, the survival rate (%) ranged from 81.2% to 92.6%, with treatment 1 showing a significantly higher survival rate than treatment 2 ($p < 0.05$). According to the findings of Nguyen Thanh Hieu et al. (2015), the survival rate of fingerling eels after 90 days ranged from 24.25% to 36.25%, which is considerably lower than the results obtained in the present study. The improved performance observed here can be attributed to the well-equipped experimental system, particularly the incorporation of a cold plasma water-treatment unit. This technology, combined with consistently stable water quality parameters, played a key role in enhancing survival during the 30–90-day nursing phase. Yield in treatment 1 averaged 3.586 kg/$m^2$, while treatment 2 yielded 2.699 kg/$m^2$ ($p < 0.05$). Analysis from table 7 also indicates that the feed conversion ratio (FCR) in the two treatments ranged from 0.88 to 0.92 ($p > 0.05$).

**Table 7: Survival rate, productivity, and FCR of eels from 30 day to 90 days fingerlings**

| Treatments | Survival rate (%) | Yield (Kg/$m^2$) | FCR |
|---|---|---|---|
| Treatment 1 | 92,6±0,7$^a$ | 3,586±86,4$^a$ | 0,88±0,025$^a$ |
| Treatment 2 | 81,2±1,1$^b$ | 2,699±127,1$^b$ | 0,92±0,030$^a$ |

**Note:** Values are presented as mean ± standard deviation; values within the same column followed by different letters are significantly different ($p < 0.05$).

These findings demonstrate that fingerling eels produced from brood stock fed low value fish with their higher nutritional content exhibited increased feeding activity, improved nutrient absorption, enhanced growth, and more rapid progression toward gonadal maturation and reproductive readiness. Consequently, such fingerlings achieved higher survival rates and yield compared to those originating from brood stock fed commercial diets.

**Grow-out Culture of Swamp Eel (Monopterus Albus)**

**Water Quality Parameters in Grow-Out Composite Tanks**

The analytical results presented in table 8 show that the water quality parameters (temperature, transparency, pH, and dissolved oxygen) during the culture period in both stocking density treatments (600 and 800 individuals/$m^2$) were generally stable, and these values remained within the suitable ranges for eel growth and development.

**Table 8: Fluctuations of water quality parameters during the grow-out culture of swamp eel**

| Treatments | T ($^o$C) | Transparency (cm) | pH | Oxy (mg/L) | N-$NH_4^+$ (mg/L) |
|---|---|---|---|---|---|
| T 1 (600 ind./$m^2$) | 29,4±0,2 | 31,9±1,0 | 7,4±0,1 | 4,8±0,1 | 2,1±0,4 |
| T 2 (800 ind./$m^2$) | 29,5±0,1 | 30,8±0,5 | 7,6±0,1 | 4,6±0,2 | 2,9±0,2 |

The survey also indicated that the ammonium concentration (N–$NH_4^+$) in the treatment with a density of 800 individuals/$m^2$ (2.9 ± 0.2 mg/L) was higher than in the 600 individuals/$m^2$ treatment (2.1 ± 0.4 mg/L), exceeding the recommended threshold of < 1.0 mg/L (Boyd, 1990). This suggests that higher stocking density increases the accumulation of waste materials, thereby raising the risk of adverse effects on the health, metabolic activity, and growth performance of the swamp eel. However, due to the functionality of the accessory respiratory organs in swamp eel, the observed N–$NH_4^+$ levels in the experiment did not cause significant negative impacts on their development. In addition, the application of IoT technologies and sensor networks in the automated water-quality regulation system enabled timely water exchange when N–$NH_4^+$ concentrations (mg/L) increased within the culture system.

**Growth Performance of Grow Out Swamp eels in Culture Systems**

The analytical results show at figure 4 that, the growth of swamp eel in both stocking density treatments (600 and 800 individuals/$m^2$) tended to increase over the culture period; however, the growth rate of eels cultured at the density of 600 individuals/$m^2$ was consistently higher than that of the 800 individuals/$m^2$ treatment. After 300 days (10 months) of culture, the average body weight reached 236.23 ± 4.30 g/individual in the 600 individuals/$m^2$ treatment and 226.53 ± 7.20 g/individual in the 800 individuals/$m^2$ treatment ($p < 0.05$). The absolute growth rate (DWG) also exhibited a similar trend, with the highest values of 1.33 ± 0.05 g/day in the lower-density group and 1.17 ± 0.18 g/day in the higher density group. Competition for feed and living conditions are two major factors contributing to differences in weight and growth, resulting in greater growth performance in the lower density treatment (600 individuals/$m^2$) compared to the higher-density treatment (800 individuals/$m^2$).

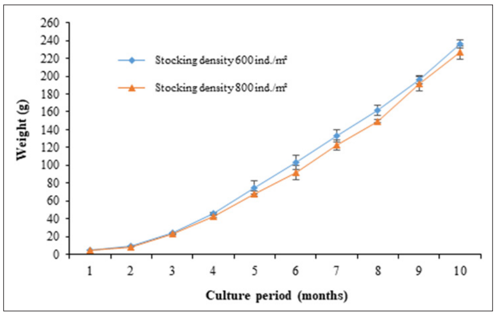


**Figure 4:** Mean weight of swamp eel cultured at two different stocking densities

The analytical results were fully consistent with the findings of Lương Công Trung and Nguyễn Trung, who reported that stocking density directly influences growth rate and feed utilization efficiency in swamp eel [11]. The highly stocking density leads to competition for space, reduced prey capture ability, and increased stress. Similarly, Tăng Hoàng Vinh noted that eels cultured at lower densities exhibit faster growth and higher survival rates due to more stable environmental conditions and higher dissolved oxygen levels in the culture system [12]. These findings provide important scientific and practical evidence for production recommendations, contributing to improved productivity and economic efficiency in swamp eel farming in Soc Trang.

**Weight Distributions of Grow-Out Swamp eel in Culture Systems**

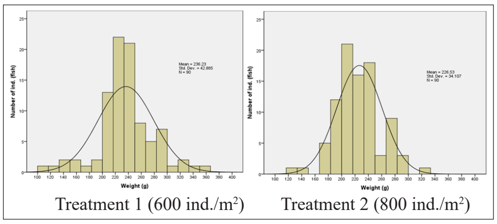


**Figure 5:** Weight distribution of swamp eel cultured at two different stocking densities

The analysis of eel body weight from the two treatments showed that, in Treatment 1 (600 individuals/m²), eel weight ranged from 104.3 to 363.4 g/individual, with the 201–250 g group accounting for the highest proportion (63.3%), followed by the 251–300 g group (21.1%), while the <150 g and >300 g groups accounted for the lowest proportions (4.4% and 5.6%, respectively). In Treatment 2 (800 individuals/m²), eel weight ranged from 126.5 to 334.4 g/individual, with the 201–250 g group again dominating (61.1%), followed by the 251–300 g and 150–200 g groups (both 17.8%), whereas the <150 g and >300 g groups accounted for the smallest proportions (2.2% and 1.1%, respectively). The analysis indicated that size variation in both treatments was relatively uniform; however, in Treatment 1 (600 individuals/m²), the lower stocking density enabled a higher proportion of individuals to reach larger sizes. In grow-out culture of swamp eel, in addition to the profitability of the production model, eel size at harvest is an important factor for determining the stocking density that yields the most practical and effective outcomes.

Survival Rate and Yield of Swamp Eel in the Culture Model

Analysis of the experimental results in Table 9 shows that stocking density had a significant influence on the survival rate, yield, and total production of grow-out swamp eel. The average survival rate was 80.2 ± 1.2% in the 600 individuals/m² treatment and 75.9 ± 4.2% in the 800 individuals/m² treatment, with a statistically significant difference between the two treatments.

**Table 9: Survival Rate, Yield, Total Production, And Fcr of Grow-Out Swamp Eel**

| Treatments | Survival rate (%) | Yield (kg/m²) | Production (kg/household/year) | FCR |
|---|---|---|---|---|
| T 1 (600 ind/m²) | 80,2±1,2$^{b}$ | 113,6±2,7$^{b}$ | 2.045±49$^{b}$ | 1,16±0,03$^{a}$ |
| T 2 (800 ind/m²) | 75,9±4,2$^{a}$ | 137,5±6,5$^{a}$ | 2.474±116$^{a}$ | 1,13±0,02$^{a}$ |

These results indicate that increasing stocking density intensifies competition for living space, reduces dissolved oxygen levels in the system, and increases stress in swamp eel. However, eel yield in the model tended to increase with higher stocking density. Yield reached 137.5 ± 6.5 kg/m² and 2,474 ± 116 kg/household in the 800 individuals/m² treatment, significantly higher ($p < 0.05$) compared to the 600 individuals/m² treatment (113.6 ± 2.7 kg/m² and 2,045 ± 49 kg/household).

The feed conversion ratio (FCR) recorded in both treatments was relatively low (1.13 – 1.16), indicating efficient feed utilization in the culture model and stable conditions in husbandry and environmental management. These experimental results are consistent with the findings of Nguyễn Thị Hồng Vân and Huỳnh Thanh Tới (2017), who reported FCR values ranging from 1.1 to 1.3 in intensive swamp eel culture systems. Additionally, according to Lương Công Trung and Nguyễn Trung, selecting an appropriate stocking density requires careful analysis and balancing of yield and survival rate to achieve optimal profitability [11].

In this study, treatment 2 (800 individuals/m²) produced higher yield but exhibited lower survival rates, whereas treatment 1 (600 individuals/m²) resulted in better growth performance and a more stable culture system. Therefore, depending on infrastructure conditions, farmers can select a suitable stocking density while applying appropriate IoT technologies and sensor networks to effectively control environmental parameters and operate automated water-exchange systems. This approach helps maintain stable water quality, improve feeding and growth performance, enhance survival rate and yield, and thereby contribute to increased effectiveness of grow-out swamp eel farming systems in Soc Trang.

**Financial Efficiency of the Culture Model**

**Table 10: Financial performance of the experimental culture system (units: 1,000 VND)**

| Contents | T 1 (600 ind./m²) | T 2 (800 ind./m²) |
|---|---|---|
| Total investment cost | 120.573±6.143[b] | 141.954±3.993[a] |
| Tanks (3 units): 5 years depreciation | 2.720±35 | 2.820±72 |
| Machinery & equipment: 3 years depreciation | 627±25 | 647±45 |
| Substrate materials | 960±104 | 930±52 |
| Eel larvae | 34.560±0 | 46.080±0 |
| Commercial Feed | 76.032±6.754 | 85.419±3.878 |
| Drugs and chemicals | 1.750±350 | 1.925±175 |
| Electricity cost | 2.425±189 | 2.400±75 |
| Other costs (basins, nets, scales, etc.) | 1.500±265 | 1.733±153 |
| Total revenue | 237.275±5.673[a] | 260.095±23.114[a] |
| Revenue from eel market | 237.275±5.673 | 260.095±23.114 |
| Profit | 116.701±3.254[a] | 118.141±19.570[a] |
| Profit cost ratio (%) | 97,0±6,6[a] | 83,0±11,6[a] |

Analysis of the financial performance of the grow-out swamp eel culture systems across the two treatments presented in table 10 shows that both stocking densities, 600 and 800 individuals/m², and generated high profits. The average total investment cost in the 600 individuals/m² treatment was 120.57 ± 6.14 million VND, while in the 800 individuals/m² treatment it was 141.95 ± 3.99 million VND. Among these expenses, the cost of seed and feed accounted for the largest proportion (over 90% of total costs). Although the investment cost in the 800 individuals/m² treatment was significantly higher ($p < 0.05$) than that of the 600 individuals/m² treatment, and total harvest output increased correspondingly, the financial efficiency and profit margin (%) did not differ significantly between the two treatments ($p > 0.05$).

These analytical results indicate that culturing eel at a stocking density of 800 individuals/m² helps producers increase harvest output; however, the increased costs of seed and feed lead to a reduction in profit margin. This finding is fully consistent with the observations of Nguyễn Thị Hồng Vân and Huỳnh Thanh Tới (2017), who reported that increasing stocking density can improve total production but may negatively affect growth rate and financial efficiency due to higher environmental pressure and increased feed costs. When compared with the results of Lương Công Trung and Nguyễn Trung in the Mekong Delta, the profit levels obtained in this study were higher [11]. Among the factors influencing economic outcomes, water quality management, the use of high-quality seed, the integration of IoT technology and sensor networks, and the effective application of automated water-exchange techniques all contributed to stabilizing water quality, improving growth performance and survival rates, and enhancing the overall effectiveness of the culture model. According to FAO, aquaculture production models that achieve a profit margin greater than 50% are considered economically sustainable [13]. This provides important scientific grounds for local authorities in the Mekong Delta to guide the application of science and technology, thereby promoting production efficiency and improving livelihoods for local communities in the Mekong Delta.

**Conclusions**

- The water quality parameters in the swamp eel nursing system exhibited certain fluctuations; however, these variations did not negatively affect growth and development within the system. Across all nursing experiments, the Coliform concentration (CFU/mL) remained low, ranging from $2.2 \times 10^2$ to $3.3 \times 10^3$, thereby reducing potential risks and improving the survival rate (%) of swamp eel fingerlings.
- In the nursing phase from newly hatched larvae to 30-day fingerlings, both mean weight and survival rate (%) of eels in treatment 1 (trash fish) were higher than those in treatment 2 (commercial feed 42% protein). During the 30 – 90-day stage, the survival rate in treatment 1 reached 92.6%, and production reached 3.586 kg/m², which were higher than those of treatment 2, with survival rate of 81.2% and a production of 2.699 kg/m². In the grow-out phase, culturing eels at a density of 800 individuals/m² resulted in higher yield and total production compared with 600 individuals/m². Conversely, the total body weight, survival rate, and profit were higher in the 600 individuals/m² treatment. The FCR in both treatments remained low (1.13–1.16).
- The application of IoT technology, sensor networks, and cold plasma techniques in experimental systems improved the survival rate of 30-day fingerling eels. Combined with the implementation of automated water exchange technology in the grow out system, these innovations resulted in high production efficiency, significant scientific and practical values, and contributed to improving farmers' income and promoting local economic development.

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