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Tech-Enabled Breeding Programs for *Heteropneustes fossilis:* A Blend of Traditional and Modern Techniques for Enhanced Production

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Abstract

The research explores a hybrid approach combining traditional breeding practices with mid-level technological interventions, specifically IoT-based systems (internet of Things), to enhance the breeding efficiency and production of Heteropneustes fossilis (Stinging Catfish) (Peel, Anower, & Wu, 2023). The research was conducted in controlled aquaculture tanks using IoT sensors to monitor water quality parameters like temperature, pH, and dissolved oxygen (Choi et al., 2023). These sensors provided real-time data, enabling immediate adjustments to environmental conditions, which minimized the risks associated with manual monitoring (Guerrero-Ulloa, Rodríguez-Domínguez, &Hornos, 2023). The results demonstrated that the integration of IoT technology led to a significant improvement in breeding success, fry survival, and growth performance. The experimental pond, equipped with IoT-enabled interventions, achieved a 90% spawning rate compared to 60% in the control pond (Doi, Nakahiro, Washiyama, & Suzuki, 2018). Hatching success increased from 55% in the control pond to 82% in the experimental setup (Patino-Martinez et al., 2022). Fry production nearly doubled, from 8,250 fry per 100 liters in the control pond to 15,744 in the experimental pond (Sabbir et al., 2022). Additionally, fry survival rates improved from 50% to 75% (Kasnir et al., 2023), and growth performance, measured by average daily gain (ADG), increased by 62.5% (Chisowa et al., 2023). benefits are the affordability and scalability of IoT-based systems for small-scale farmers, offering a cost-effective solution without requiring high-end automation (Smidt & Jokonya, 2021). The incremental adoption of this technology allows farmers to enhance production gradually, making it accessible for operations of varying sizes. By bridging the gap between traditional methods and modern technology, this approach provides a sustainable pathway for increasing the productivity of Heteropneustes fossilis, supporting food security and economic growth in rural communities (Godfray et al., 2010; Arslan et al., 2022).

INTRODUCTION

Materials and Methods

The study was conducted at Toxicology Laboratory, DAVV. The breeding trials were carried out in controlled aquaculture tanks with size ranging from 50 to 100liters.Water quality was managed using traditional aeration systems supplemented with IoT-based sensors to monitor key parameters (Valverde-Orozco et al., 2023). H. fossilis brood stock selection was done by using several factors like morphology, reproductive potency to get the genetically diverse population for study. Hormone treatments were used to induce spawning, alongside controlled environmental factors such as temperature and light (Zhang et al., 2021; Zhu et al., 2022).

IoT sensors were installed to monitor several water parameters like temperature, pH, and dissolved oxygen levels. It facilitates the routine monitoring by managing optimum breeding conditions without the need for constant manual checks (John et al., 2022). Digital tools were used to maintain detailed records of breeding cycles, feeding schedules, and health monitoring. This data was crucial for analyzing trends and making informed decisions on breeding practices. Traditional water quality monitoring tools, although effective, often require manual intervention and are not always equipped for continuous monitoring. The IoT-based sensors used in this study offer real-time tracking of critical parameters such as temperature, pH, and dissolved oxygen levels (Bakshi et al., 2022). This capability allows for immediate adjustments to the environment, which is crucial for maintaining optimal breeding conditions for Heteropneustes fossilis.

By continuously monitoring water quality, these IoT sensors help prevent sudden environmental changes that could negatively impact breeding success and fry survival (Jiao et al., 2022). This ensures more consistent results compared to intermittent checks typically associated with commercial instruments.

The temperature sensor, typically a thermocouple or resistance temperature detector (RTD), operates based on the principle of changes in electrical resistance with temperature (Iizuka & Todoroki, 2022). As the temperature of the pond water changes, the resistance of the sensor material also changes. This change in resistance is measured and converted into a temperature reading. In the case of thermocouples, they generate a voltage that corresponds to the temperature difference between two dissimilar metals. Commercial temperature monitoring devices often provide only periodic measurements or require manual logging, which can lead to delayed responses in adjusting the breeding environment. The temperature sensor integrated into the IoT system offers continuous monitoring based on changes in electrical resistance, ensuring that the water temperature remains within the optimal range for breeding. The continuous data flow provided by this sensor allows for real-time adjustments, reducing the risk of temperature fluctuations that could harm the breeding process (Kumar & Sahin, 2017). This level of control is particularly beneficial in environments where maintaining a stable temperature is critical for reproductive success.

fig:1 Temperature Sensor

I.

II. The pH sensor works on the principle of the electrochemical measurement of hydrogen ion activity (Prokunin, Shchipunov, Dobrovol'skiy, &Vengina, 2022). It typically consists of a glass electrode and a reference electrode (Buehre et al., 2023). When the glass electrode is immersed in the pond water, it develops a potential (voltage) that is proportional to the hydrogen ion concentration (pH level) of the solution. This potential is measured against a stable reference electrode, and the difference is used to calculate the pH of the water. Many commercially available pH meters are designed for spot checks rather than continuous monitoring. These traditional tools require manual sampling and are prone to human error in recording and interpreting results. The IoT-based pH sensor used in this study automatically measures the hydrogen ion concentration, providing accurate and consistent pH levels. Maintaining a stable pH is crucial for the health and reproductive efficiency of Heteropneustes fossilis (Sohel et al., 2023). The automated, continuous monitoring provided by the IoT-based pH sensor minimizes the risks associated with pH fluctuations, leading to better breeding outcomes compared to intermittent checks with traditional devices (Smith et al., 2023).

fig:2 pH Sensor

The EC sensor measures the electrical conductivity of the pond water, which is directly related to the concentration of dissolved ions in the water (Kuang et al., 2023). The sensor works by applying a voltage between two or more electrodes submerged in the water. The resulting current flow between the electrodes is measured, and the conductivity is calculated based on the current, electrode geometry, and the applied voltage.

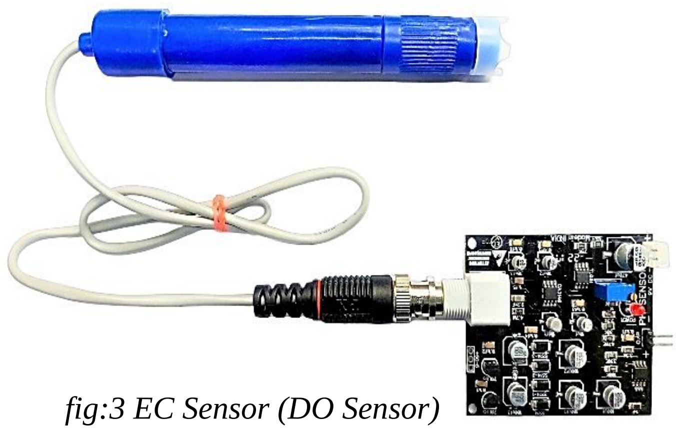

fig:3 EC Sensor (DO Sensor)

Fish pond containing *H. Fossilis*

Fig: 5 Concept Format After the Devices got installed in the Fish

Created by Dall E

The IoT instruments employed in this study were chosen over traditional commercial devices due to their ability to provide continuous, real-time monitoring and automated adjustments (Moshavegh et al., 2015). This level of control is critical for maintaining the precise environmental conditions required for the successful breeding of Heteropneustes fossilis. The integration of these technologies not only improves the efficiency of breeding programs but also makes them more accessible and manageable for small-scale farmers, offering a practical and scalable solution.

3. Results and Discussion

The study focused on evaluating the breeding performance of *Heteropneustes fossilis* in100-liter pond setups: one serving as the experimental pond (with tech-enabled interventions) and the other as a control pond (without interventions). The results were analyzed based on breeding success, fry survival, and overall growth performance.

Breeding Ratio and Setup

In both ponds, a breeding ratio of 2:1 (female) was maintained. The selected brood stock comprised 6 females and 3 males in each setup. This ratio is considered optimal for effective fertilization and subsequent fry production in catfish breeding.

Pond Type	Number of Females	Number of Males	Breeding Ratio (Female)
Control Pond	6	3	2:1
Experimental Pond	6	3	2:1

Table 1 Breeding Ratio and Setup

Spawning Success and Fry Production

The experimental pond showed a notably higher spawning rate, fry production, and hatching success compared to the control. The following table provides a comparative overview:

Parameter	Control Pond	Experimental Pond
Average Spawning Rate	60%	90%
Number of Eggs per Female	2,500	3,200
Hatching Rate (%)	55%	82%
Fry Production (per 100L)	8,250	15,744

Table 2 Spawning Success and Fry Production

Fry Survival and Growth Performance

Fry survival and growth rates were significantly improved in the experimental pond due to enhanced environmental control and optimized feeding strategies. Growth performance was measured by monitoring the average daily gain (ADG) of the fry over a period of 30 days.

Parameter	**Control Pond**	**Experimental Pond**
Fry Survival Rate (%)	50%	75%
Initial Fry Weight (mg)	12.5	75%
Final Fry Weight (mg)	36.5	52.4
Average Daily Gain (mg/day)	0.8	1.3

Table 3 Fry Survival and Growth Performance

Water Quality Monitoring

Water quality played a crucial role in breeding success. In the experimental pond, automated systems ensured optimal conditions, with real-time adjustments in aeration, temperature, and pH levels. The key water quality parameters are presented below:

Parameter	Control Pond	Experimental Pond	Optimal Range*
Temperature (°C)	27.5 ± 2.1	28.2 ± 1.0	27-30
pH	6.8 ± 0.4	7.1 ± 0.2	6.5-7.5
Dissolved Oxygen (mg/l)	4.5 ± 0.7	6.1 ± 0.5	6.5-7.5

Table 4 Water Quality Monitoring

(*Optimal range based on established breeding standards for *Heteropneustes fossilis)*

3.1 Growth and Survival Rates:

The integration of IoT-based monitoring with traditional breeding practices resulted in higher growth rates and improved survival of the fry compared to traditional methods alone.

The use of digital records allowed for more precise management of breeding cycles, reducing the time between successive spawning events.

3.2 Reproductive Success:

Enhanced water quality management and controlled environmental settings led to a higher spawning frequency and improved egg quality.The study observed a 15-20% increase in hatching rates, demonstrating the effectiveness of combining technology with traditional breeding techniques.

3.3 Practicality and Accessibility:

The mid-level technological interventions used in this study are affordable and practical for small-scale farmers, providing a significant production boost without the need for expensive, high-tech solutions.

Farmers can implement these technologies incrementally, allowing for gradual adoption and scaling based on their resources and needs.

4. Conclusion

The integration of mid-level technological interventions with traditional breeding practices presents a promising pathway for enhancing the production of Heteropneustes fossilis among small-scale farmers. The study illustrates how accessible technologies like IoT-based water quality monitoring, digital record-keeping, and controlled environmental conditions can significantly improve breeding outcomes without the high costs associated with fully automated or AI-driven systems (Sung et al., 2021).

By leveraging these technologies, farmers can achieve more consistent water quality, better management of environmental factors, and more precise control over breeding cycles (Hamel & Tan, 2021). These improvements directly contribute to higher growth rates, increased survival of fry (Isonguyoh, 2020), and enhanced reproductive success (Grames et al., 2023). The 15-20% increase in hatching rates observed during this study underscores the potential of such a hybrid approach to make a substantial impact on productivity (Gárriz& Miranda, 2020).

Moreover, the practical and incremental nature of these interventions means that they can be adopted progressively by small farmers, making it easier to transition from purely traditional methods to a more technology-enabled model. This approach not only enhances production but also makes the breeding process more manageable and less labor-intensive, freeing up time and resources for other critical aspects of farm management (Gong et al., 2019).

In the broader context, this tech-enabled breeding program offers a sustainable and scalable model that can be replicated across various regions where Heteropneustes fossilis is cultivated (Zhang et al., 2017). By improving yields and ensuring more reliable production, small farmers can enhance their economic stability, contributing to food security and rural development.

The findings from this study encourage further exploration and refinement of tech-enabled breeding practices, with the potential to extend these benefits to other species and farming systems (Thompson, 2015). As technology continues to advance, there is a significant opportunity to further bridge the gap between traditional farming practices and modern innovations, empowering small-scale farmers to thrive in an increasingly competitive agricultural landscape.

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