

## Effect of Nanobubble Air Pressure on the Hatching Success of Giant Gourami (*Osphronemus gouramy*) Eggs

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### ABSTRACT

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nanobubble;

Giant gourami (*Osphronemus gouramy*) is an important freshwater commodity in Indonesia, but seed production is often constrained by low egg hatching rates and poor larval survival. Optimizing dissolved oxygen during egg incubation is critical, particularly because embryos and early larvae have not yet developed functional accessory breathing organs. This study evaluated the effect of different nanobubble air pressures on the hatching performance of giant gourami eggs. A completely randomized design with four treatments and three replications was applied: A) incubation without nanobubble (control); B) nanobubble air pressure of 0.3 psi; C) 0.6 psi; and D) 0.9 psi. A total of 1,000 eggs per incubation basin were stocked in 12 basins, and nanobubble aeration was supplied using a high-blower pump, fine-bubble diffusers, and digital manometers. Observed parameters included fertilization rate, hatching rate, hatching time, survival rate until day 3, and basic water quality (dissolved oxygen, temperature, and pH). Nanobubble air pressure significantly affected hatching time and larval survival ( $p < 0.05$ ), but had no significant effect on hatching rate ( $p > 0.05$ ). The 0.6 psi treatment yielded the best biological performance, with fertilization rate of 91.57%, hatching rate of 83.53%, and survival rate of 94.58%, and along with the fastest hatching time (36 h 43 min at 80% hatch). Dissolved oxygen ranged from 4.36–5.75 mg L<sup>-1</sup>, temperature 31.7–32.2°C, and pH 7.2–7.7 across treatments, all within acceptable ranges for gourami incubation, with the most stable conditions observed at 0.6 psi. These findings indicate that nanobubble aeration at 0.6 psi is an effective and practical strategy to improve egg hatching performance and early larval survival of giant gourami, and can be readily applied in small- to medium-scale hatchery systems with relatively low operational costs.

### INTRODUCTION

Giant gourami (*Osphronemus gouramy*) is a leading freshwater fish commodity in Indonesia, favored by consumers for its firm texture and desirable taste. Demand for this species continues to increase and is supported by stable market prices, making gourami hatchery and grow-out activities economically attractive from backyard scale up to more intensive systems (Subhan and Hartono, 2022; Pertiwi et al, 2024). According to production data from the Ministry of Marine Affairs and Fisheries (KKP, 2024), gourami production increased by 1.82% per year during 2020–2024.

Despite its economic importance, seed production of giant gourami still faces a major bottleneck at the early life stage, namely low egg hatching rate and low larval survival. These

constraints are closely related to broodstock quality and environmental conditions during spawning and incubation. While broodstock factors can be managed through proper selection, nutrition, and health management, environmental factors—particularly water quality—are more difficult to stabilize under tropical conditions. Temperature, dissolved oxygen (DO), and pH are among the key water quality parameters determining the success of egg incubation and early larval rearing in freshwater fish.

In giant gourami, optimal temperatures for egg incubation and early nursery are reported around 30–32°C, but at such elevated temperatures, oxygen solubility in water decreases, making DO a potential limiting factor for embryos and early larvae. Although adult gourami possess a labyrinth organ that allows facultative air breathing, this organ is absent or not fully functional during egg and early larval stages, making them highly dependent on dissolved oxygen in the water column. Consequently, strategies to maintain or increase DO during incubation are crucial to improve hatching performance (Muslim and Yonarta, 2017; Pratama et al, 2018; Violita et al, 2019; Subhan and Hartono, 2022).

Conventional aeration and recirculating aquaculture systems (RAS) are widely applied to improve water quality and oxygenation (Boyd et al, 2020; Chen et al, 2021). However, RAS may not be suitable for delicate eggs due to mechanical stress and shear forces generated by water flow, which can damage eggs and newly hatched larvae (Usman et al, 2022). Similarly, conventional aeration with coarse bubbles can create strong turbulence and direct bubble impact on eggs, leading to physical damage and reduced hatching success.

Nanobubble or fine-bubble (FBs) technology is a recent advancement in aquaculture aeration (Hata et al, 2019). Nanobubbles are characterized by extremely small bubble size (micro- to nano-scale), long residence time in water, and high interfacial area, providing more efficient oxygen transfer and more stable DO compared with standard aeration. Previous studies have demonstrated the benefits of nanobubble systems in improving growth performance, feed efficiency, and water quality in different cultured species, as well as reducing harmful metabolites and pathogen loads (Fadhillah, 2016; Mahasri et al, 2019; Andriani et al, 2021).

However, most applications of nanobubble technology in aquaculture have focused on grow-out or advanced nursery stages, typically using relatively high air pressures that are unsuitable for egg incubation (Yaparathne et al, 2024; Sravani et al, 2024). High air pressure may generate excessive turbulence and microcavitation, potentially damaging the egg chorion and disrupting embryonic development. To date, information on the appropriate nanobubble air pressure for the incubation of giant gourami eggs in intensive hatchery systems remains limited (Zaidy et al, 2021).

Therefore, the present study was designed to evaluate different levels of nanobubble air pressure during egg incubation of giant gourami. Specifically, this work aimed to: (1) determine the effect of nanobubble air pressure on fertilization rate, hatching rate, hatching time, and early survival of giant gourami; and (2) identify the optimum nanobubble air pressure that maximizes hatching success while maintaining acceptable water quality. The novelty of this research lies in the application and optimization of nanobubble technology for gourami egg incubation, a stage where published information is still scarce compared with grow-out applications.

## METHOD

### Study site and experimental period

The experiment was conducted from July to October 2025 at the Fisheries Laboratory, Department of Fisheries and Marine, Politeknik Negeri Lampung, Bandar Lampung, Indonesia.

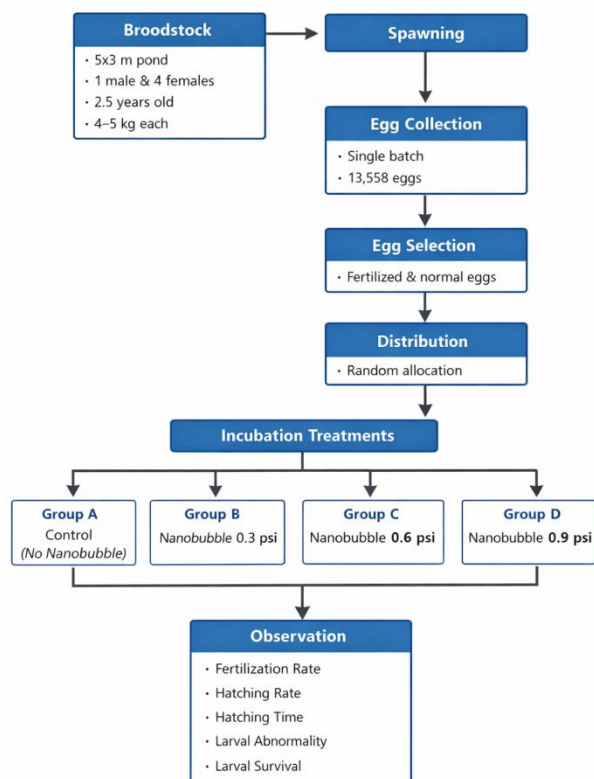


Figure 1. Flowchart of the experimental design for giant gourami egg incubation under different nanobubble air pressure treatments.

### Broodstock management and egg collection

Broodstock of giant gourami (strain Bastar) were reared in  $5 \times 3$  m<sup>2</sup> earthen ponds with a water depth of approximately 1 m. Spawning was carried out naturally by pairing one male with four females per pond. Broodstock were at least 2.5 years old with body weights of 4–5 kg fish<sup>-1</sup>. Nests made of plant fibers (ijuk) were provided as spawning substrates. Broodstock were fed a commercial pellet (PF-128, 38% crude protein) and supplemented with taro leaves 2–3 times per week.

Following spawning, nests containing eggs were collected, and the eggs were gently separated and counted. To minimize variability in egg quality, eggs collected from multiple broodstock were pooled, gently mixed, and randomly distributed across all experimental units. Only fertilized and morphologically normal eggs were selected for the experiment. A total of 1,000 eggs were stocked into each incubation basin that had been prepared according to the respective treatments. The total number of eggs collected (13,558) was sufficient to supply all experimental units and additional operational needs.

### Experimental design and nanobubble system

A completely randomized design (CRD) was used, consisting of four treatments with three replications each:

A (Control): incubation and larval rearing without nanobubble aeration

B: nanobubble air pressure of 0.3 psi per aeration line

C: nanobubble air pressure of 0.6 psi per aeration line

D: nanobubble air pressure of 0.9 psi per aeration line

In total, 12 incubation basins (plastic bowls, diameter 25–30 cm, water depth 15 cm) were used. For nanobubble treatments (B–D), fine-bubble diffusers (nanobubble stones, diameter 35 mm, special pore size) were installed in each basin. Air was supplied by a high-blower unit (Resun Highblow LP-40; power 40 W; maximum pressure 0.040 MPa  $\approx$  5.801 psi), connected to aeration lines via a 12-way manifold. Air pressure in each line was regulated using aeration valves equipped with digital manometers, adjusted to the target pressures (0.3, 0.6, and 0.9 psi per line). The manometers were checked and calibrated prior to the experiment to ensure consistent and accurate pressure measurements.

Each basin was equipped with a 30 W heater, set to maintain water temperature at approximately 32°C. To minimize external disturbance and temperature fluctuation, basins were covered with black plastic sheets, leaving a small opening for air exchange and observation.

### Incubation and larval rearing

Eggs were incubated in the respective treatments for approximately two days, until hatching. During incubation, no feed was provided. After hatching, larvae remained in the same basins and were reared for three days (D0–D3) without feeding, as giant gourami larvae can rely on yolk sac reserves until about 10 days post-hatch. Dead eggs and larvae were removed daily and recorded.

### Observed variables

The following biological parameters were observed:

Fertilization rate (FR, %)

$$FR (\%) = \left( \frac{\text{number of fertilized eggs}}{\text{total eggs}} \right) \times 100$$

Hatching rate (HR, %)

$$HR (\%) = \left( \frac{\text{number of hatched larvae}}{\text{total eggs fertilized}} \right) \times 100$$

Hatching time (hours)

Hatching time was recorded as the elapsed time from stocking eggs into the incubation basin until at least 80% of eggs were observed to have hatched in each replicate.

Survival rate (SR, %) of larvae from day 0 (hatching) to day 3:

$$SR (\%) = \left( \frac{\text{number larvae survived}}{\text{total larvae}} \right) \times 100$$

Water quality

Water quality parameters measured included dissolved oxygen (DO), temperature, and pH. Measurements were conducted daily throughout the incubation and larval rearing period following APHA (2012) procedures.

### Data analysis

Data were tabulated in Microsoft Excel and analyzed using SPSS 21.0. Prior to analysis, data normality was assessed using the Shapiro–Wilk test, and homogeneity of variance was evaluated using Levene’s test. One-way analysis of variance (ANOVA) at a 95% confidence level ( $\alpha = 0.05$ ) was performed to test the effect of nanobubble air pressure on each biological parameter. When significant differences were detected ( $p < 0.05$ ), Duncan’s multiple range test was applied to compare mean values among treatments, due to its sensitivity in detecting differences among treatment groups. Water-quality data were analyzed descriptively.

## RESULT AND DISCUSSION

### Fertilization rate

Nanobubble air pressure showed a significant difference in fertilization rate among treatments ( $p < 0.05$ ). The 0.6 psi treatment (C) resulted in the highest mean fertilization rate (91.57%), while the highest pressure (0.9 psi) tended to show lower values. However, as fertilization occurred prior to the application of treatments, these differences were likely associated with initial egg quality rather than the direct effect of nanobubble air pressure.

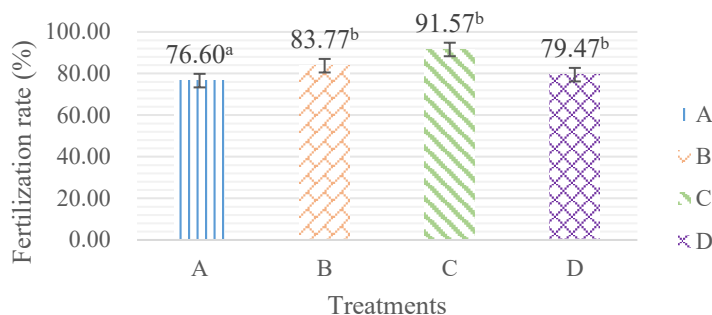


Figure 2 Fertilization rate of giant gourami eggs under different air pressures in the application of fine-bubble (FBs) technology

Although fertilization occurred prior to the application of treatments, nanobubble aeration may play an important role in maintaining dissolved oxygen saturation during early embryonic development, thereby supporting hatching success, particularly at the optimal pressure of 0.6 psi. Biologically, the observed improvement in fertilization rate under moderate nanobubble pressure may be linked to enhanced oxygen availability in the immediate microenvironment of the eggs. Nanobubbles are known to improve gas-liquid mass transfer efficiency due to their nanoscale size, large interfacial area, and prolonged stability in aqueous systems, resulting in higher oxygen transfer efficiency and retention (Yaparathne et al., 2024). Consequently, oxygen diffusion into the egg boundary layer is enhanced, minimizing localized hypoxia during early embryogenesis and supporting normal cell division and development (Junior et al., 2024).

However, excessive air pressure, as reflected in the reduced fertilization rate observed at 0.9 psi compared to the peak value at 0.6 psi, may generate stronger turbulence and microvibrations that physically disturb the eggs or compromise chorion integrity. Although fertilization occurred prior to treatment application, these differences among treatments were statistically significant ( $p < 0.05$ ), suggesting that subsequent environmental conditions may influence the apparent fertilization outcome. Under such conditions, mechanical stress may outweigh the benefits of increased dissolved oxygen (DO). This pattern highlights that optimizing—rather than maximizing—air pressure is critical when applying nanobubble technology during early embryonic development.

From a hatchery-management perspective, the data indicate that nanobubble application around 0.6 psi provides a favorable balance between improved oxygenation and acceptable hydrodynamic conditions in gourami egg incubation.

### Hatching rate

The hatching rate (HR) of giant gourami eggs ranged from  $71.96 \pm 8.78\%$  to  $83.53 \pm 3.88\%$  among treatments, with the highest value observed in treatment C (0.6 psi) and the lowest in the control (A, without nanobubble). However, ANOVA indicated no statistically significant differences among treatments ( $p > 0.05$ ). Although a tendency for higher HR was observed at moderate pressure (0.6 psi), this pattern should be interpreted with caution due to the lack of statistical significance.

The improvement in HR under nanobubble treatments can be attributed to more stable and elevated DO levels during incubation. Nanobubbles maintain DO at higher levels compared with conventional aeration while minimizing bubble coalescence and rapid escape to the surface. Adequate oxygen supply is vital for sustaining embryonic metabolism and preventing developmental arrest or mortality, especially in species with relatively large and oil-rich eggs like gourami.

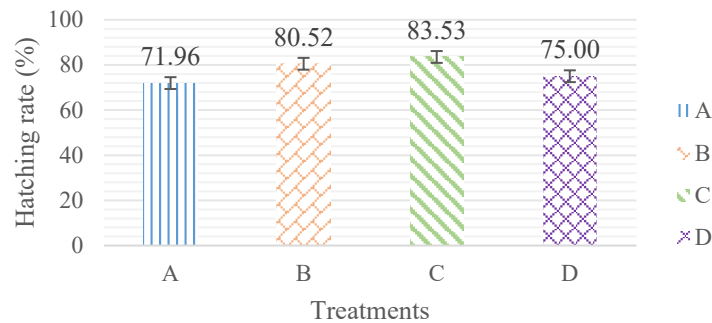


Figure 3. Hatching rate of giant gourami eggs under different air pressures in the application of fine-bubble (FBs) technology

Comparisons of the number of hatched gourami eggs across several studies have shown variable results. An important point highlighted in the present study is the maximum egg density within the incubation medium. Therefore, although the hatching percentage in this study was not higher, the absolute number of hatched eggs produced per incubation medium, particularly with the application of FBs, was greater than that reported in studies employing conventional systems.

The absence of statistical significance in HR, despite clear biological trends, may be related to inherent variability in egg quality among spawns and replicates. In tropical broodfish, differences in maternal condition, hormonal status, and seasonal factors often produce substantial variation in egg viability, which can mask treatment effects unless sample sizes are very large. Nonetheless, the combination of higher mean HR, lower variability, and better performance in other endpoints (hatching time and survival) supports the conclusion that 0.6 psi nanobubble pressure is biologically superior.

### Hatching time

Hatching time, defined at 80% hatch, ranged from 36 h 43 min to 38 h 21 min across treatments. The shortest and significantly faster hatching time was observed at 0.6 psi (C), while the control (A) hatched the slowest. Treatments B (0.3 psi) and D (0.9 psi) showed intermediate values.

Table 1. Hatching time of giant gourami eggs at different nanobubble air pressures (time to 80% hatch).

Treatment	Hatching time (h)	Hatching time (min)
A (control, 0 psi)	38	21
B (0.3 psi)	37	48
C (0.6 psi)	36	43
D (0.9 psi)	37	43

A moderate reduction in hatching time under optimal nanobubble pressure suggests more efficient embryonic development supported by better oxygenation and stable microenvironment around the eggs. Faster hatching under adequate DO is generally a positive sign, indicating that embryos are not subjected to chronic stress or sublethal hypoxia. Importantly, in this study, faster hatching at 0.6 psi was accompanied by high HR, indicating

that it did not reflect premature or forced hatching but rather physiologically optimal development.

Sari et al (2004) reported that the hatching of gourami eggs under a conventional system without FBs at a temperature of 28–29 °C required up to 44 hours. Therefore, the application of FBs in the present study resulted in significantly better outcomes; however, its potential effects on embryonic development and larval developmental completeness remain important aspects that require further attention. Consistent oxygen supply enables embryos to develop properly, even though the hatching period becomes shorter (Huang et al, 2016; Huang et al, 2020).

From a practical standpoint, shorter and more synchronized hatching provides management advantages: it allows hatchery operators to optimize labor, reduce exposure time to fluctuating environmental conditions, and plan subsequent nursery steps more efficiently.

### Larval survival

Survival rate (SR) of larvae from hatching (D0) to D3 ranged from 86.69% to 94.58%. The highest survival was obtained at 0.6 psi (C, 94.58%), followed by 0.3 psi (B, 91.72%), control (A, 88.52%), and the lowest at 0.9 psi (D, 86.69%). Statistical analysis confirmed a significant effect of nanobubble air pressure on SR, with treatment C differing from A and D, but not from B.

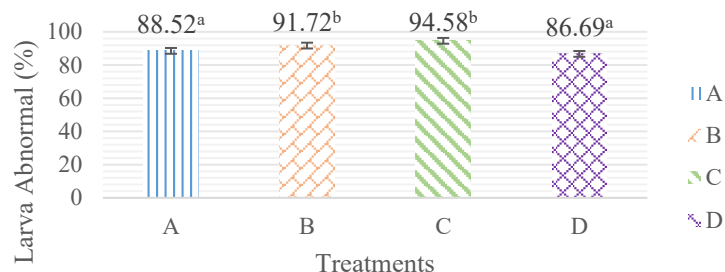


Figure 4. Survival rate of giant gourami larvae reared under different air pressures in the application of fine-bubble (FBs) technology up to day 3

Although larvae were not fed during the three-day observation period and relied solely on yolk reserves, environmental conditions—particularly DO, temperature, and pH—remain decisive for survival. Moderate nanobubble pressure appears to enhance larval resilience by maintaining DO levels within a comfortable range while avoiding the stress of strong turbulence. The relatively low survival at 0.9 psi suggests that hydrodynamic stress can substantially affect fragile newly hatched larvae, increasing energy expenditure to maintain position and potentially damaging developing tissues. Taken together with HR data, the SR results reinforce the conclusion that 0.6 psi represents an optimum nanobubble air pressure for early-life-stage performance in giant gourami.

### Water quality

Water quality parameters during the study were within suitable ranges for incubation and larval rearing of giant gourami in all treatments. Dissolved oxygen ranged from 4.36–4.68 mg L<sup>-1</sup> in the control (A) and increased progressively with nanobubble pressure, reaching 5.23–5.75 mg L<sup>-1</sup> in the highest-pressure treatment (D). Treatment C (0.6 psi) maintained DO between 5.24–5.44 mg L<sup>-1</sup>. Temperature remained stable across treatments, between 31.7–32.2°C, while pH varied from 7.2–7.7, slightly higher in nanobubble treatments than in the control.

These ranges are compatible with previously reported optimal conditions for gourami egg incubation and larval rearing, which recommend DO above 4 mg L<sup>-1</sup>, temperature around 28–32°C, and near-neutral to slightly alkaline pH. The improvement in DO and stabilization of pH under nanobubble treatments reflect enhanced oxygen transfer and potential oxidative

transformation of organic matter, indirectly reducing accumulation of acidic compounds. Adequate and stable dissolved oxygen is essential for embryonic metabolism, as oxygen is required for aerobic respiration, ATP production, and normal cell division during early development. Insufficient or fluctuating DO can lead to metabolic stress, impaired embryogenesis, and reduced hatching success.

Interestingly, the treatment with the highest DO (0.9 psi) did not yield the best biological performance, highlighting that oxygen concentration alone cannot be used as the sole criterion for system optimization. For delicate life stages, physical stability of the water column and avoidance of excessive turbulence are equally important. Under practical hatchery conditions, treatment C appears to offer the best compromise, providing adequate DO without causing hydrodynamic stress.

#### Implications for gourami hatchery technology

The present findings demonstrate that a relatively simple nanobubble system—using a high-blower pump, fine-bubble diffusers, and pressure control via aeration valves and manometers—can substantially improve key performance indicators of gourami seed production when optimally calibrated. Compared with more complex and costly nanobubble generators, the system tested here is technically and economically accessible for small to medium-scale hatcheries.

However, the clear performance peak at 0.6 psi and deterioration at 0.9 psi emphasize that “more is not always better” when it comes to nanobubble pressure. Hatchery operators must treat air pressure as a critical control parameter, not merely as an on–off function. Further work should refine operational guidelines by evaluating different combinations of pressure, nanobubble exposure duration, and stocking density, as well as by integrating more advanced water-quality indicators such as ammonia and nitrite.

#### CONCLUSION

Application of nanobubble aeration with different air pressures during egg incubation and early larval rearing of giant gourami significantly affected hatching time and larval survival, while no significant effect was observed on hatching rate. A nanobubble air pressure of 0.6 psi produced the best overall biological performance, with a hatching rate of 83.53%, the fastest hatching time (36 h 43 min at 80% hatch), and the highest survival rate (94.58%) up to day three. Water-quality parameters remained within suitable ranges across treatments, with dissolved oxygen ranging from 4.36–5.75 mg L<sup>-1</sup>, temperature 31.7–32.2°C, and pH 7.2–7.7. Among these, dissolved oxygen appeared to be the most influential factor, with the most stable conditions observed at 0.6 psi. These findings indicate that nanobubble aeration at 0.6 psi is an effective and practical approach to improve egg hatching performance and early larval survival of giant gourami in hatchery systems.

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#### REFERENCES

- American Public Health Association (APHA). (2012). *Standard methods for the examination of water and wastewater* (22nd ed., pp. 34–62). Washington, DC: APHA Press.
- Andriani, Y., Zahidah, Z., Rosidah, R., & Iskandar, I. (2021). Pengaruh perbedaan tekanan dalam fine bubbles (FBs) terhadap pertumbuhan, konversi pakan ikan patin siam

- Pangasianodon hypophthalmus dan kualitas air pada sistem akuaponik. *Jurnal Iktiologi Indonesia*, 21(3), 277–290.
- Boyd, C. E., Tucker, C. S., & Somridhivej, B. (2020). Aquaculture pond fertilization and water quality management. *Aquaculture Research*, 51(8), 3211–3222.
- Chen, L., Gao, X., & Li, H. (2021). Enhancement of oxygen transfer efficiency using micro–nano bubble aeration system in aquaculture ponds. *Aquacultural Engineering*, 92, 102137.
- Sari, D. W. K., Hardanngsih, I., & Rustadi, R. (2004). Embryonic and Larval Development of Bastar, Bluesafir, and Bule of Giant Gouramy (*Osphronemus goramy* Lac.). *Jurnal Perikanan (J. Fish. Sci.)*, 4(2), 56–61.
- Hata, T., Nishiuchi, Y., & Minagawa, H. (2019). Development of new agriculture and aquaculture technology using fine bubbles. *Journal of Plasma Environmental Science & Technology*, 12(2), 39–43.
- Huang, C. Y., & Lin, H. C. (2016). Different oxygen stresses on the responses of branchial morphology and protein expression in the gills and labyrinth organ in the aquatic air-breathing fish *Trichogaster microlepis*. *Zoological Studies*, 55, 27.
- Huang, X., Li, W., & Zhao, Y. (2020). Effects of nanobubble aeration on dissolved oxygen stability and larval fish survival. *Aquaculture Research*, 51(7), 2752–2761.
- Junior, T. I., Hardningsih, I., Bimasuci, H., & Sari, D. W. K. (2024). Reproductive behavior and parental role of giant gourami (*Osphronemus goramy* Lacepède, 1801). *Journal of Tropical Biodiversity and Biotechnology*, 9(3), 1–21.
- Kementerian Kelautan dan Perikanan (KKP). (2024). Laporan Kinerja 2024: Direktorat Jenderal Perikanan Budi Daya (p. 40). Jakarta: Kementerian Kelautan dan Perikanan.
- Pertiwi, Y. U. P., rahayu, N. D., & Hartono, F. R. (2024). Identification of the Use of Noni Leaf Extract (*Morinda citrifolia*) in Blood Observations in Gouramy Fish (*Osphronemus gouramy*) Infected with *Aeromonas hydrophila*. *Grouper: Jurnal Ilmiah Perikanan*, 15(2), 305–312.
- Pratama, B. A., Susilowati, T., & Yuniarti, T. (2018). Pengaruh perbedaan suhu terhadap lama penetasan telur, daya tetas telur, kelulushidupan dan pertumbuhan benih ikan gurame (*Osphronemus gouramy*) strain Bastar. *Jurnal Sains Akuakultur Tropis*, 2(1), 59–65.
- Subhan, R. Y., & Hartono, D. P. (2022). Growth performance of giant gouramy (*Osphronemus gouramy*) in pre-enlargement phase with different temperature. *Asian Journal of Aquatic Sciences*, 5(1), 96–104.
- Sravani, G., Akamad, D. K., Chanu, T. I., Kumar, P., Rathlavath, S., & Sarma, D. (2024). Nanobubble technology: An ultrafine solution to emerging challenges in aquaculture. *Periodicum Biologorum*, 126, 105–120.
- Usman, Z., Kurnaiji, A., Saridu, S. A., Anton, A., & Riskayanti, R. (2022). Produksi juvenil ikan gurame (*Osphronemus gouramy*) menggunakan teknologi recirculating aquaculture system. *Jurnal Budidaya Perairan*, 10(2), 262–271.
- Violita, V., Muslim, M., & Fitriani, M. (2019). Derajat penetasan dan lama waktu menetas embrio ikan betok (*Anabas testudineus*) yang diinkubasi pada media dengan pH berbeda. *Jurnal Ilmiah Perikanan dan Kelautan*, 11(1), 21–27.
- Yaparathne, S., Morón-López, J., Bouchard, D., Garcia-Segura, S., & Apul, O. G. (2024). Nanobubble applications in aquaculture industry for improving harvest yield, wastewater treatment, and disease control. *Science of the Total Environment*, 931, 172687. <https://doi.org/10.1016/j.scitotenv.2024.172687>
- Zaidy, A. B., Anggoro, A. D., & Kasmawijaya, A. (2021). Pengaruh penggunaan nanobubble dalam transportasi udang vaname (*Litopenaeus vannamei*). *Jurnal Akuatika Indonesia*, 6(2), 50–56.

Zhang, X., Liu, Y., & Wang, H. (2021). Role of nanobubbles in improving aquatic environment and fish survival under intensive culture conditions. *Environmental Technology & Innovation*, 23, 101718.