

Research Article

DIYM O₂^{Rs} Microbubble Aeration as an Alternative to Conventional Root Blower Systems in Super-Intensive Vannamei Shrimp Farming

Imam Taukhid ^{1,*} , Dody Dharmawan Trijuno ² , Muhammad Yusri Karim ² , Rachman Syah ¹ ,
Makmur Makmur ³ , Alimuddin Alimuddin ⁴ , Bunga Rante Tampangallo ^{5,*} 

¹ Research Center for Marine Aquaculture, Research Organization for Agriculture and Food, National Research and Innovation Agency, Bogor, 16911, Indonesia

² Department of Aquaculture, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, 90245, Indonesia

³ Research Institute for Coastal Aquaculture and Fisheries Extension, Ministry of Marine Affairs and Fisheries, Maros, 90512, Indonesia

⁴ Department of Aquaculture, Fisheries Aquaculture Technology Study Program, Pangkep State Polytechnic of Agriculture, Pangkep, 90655, Indonesia

⁵ Research Center for Veterinary Science, Research Organization for Health, National Research and Innovation Agency, Bogor 16911, Indonesia

* Corresponding Authors: Imam Taukhid, Email: imam027@brin.go.id

Bunga Rante Tampangallo, Email: bung004@brin.go.id

Article Info	Abstract
Article History	The advancement of aeration systems is crucial in enhancing the productivity and sustainability of super-intensive whiteleg shrimp (<i>Litopenaeus vannamei</i>) farming. Therefore, this study aims to introduce and evaluate the performance of a novel aeration technology, namely Do-It-Yourself Microbubble (DIYM O ₂ ^{Rs}), designed to optimize dissolved oxygen levels in shrimp ponds. The experiment was conducted using three treatments, including (1) DIYM O ₂ ^{Rs} , (2) conventional Root Blower aerators, and (3) a combination of both systems. Post-larval shrimp with an initial average weight of 0.15 ± 0.07 g were stocked at a high density of 500 ind/m ³ . Parameters analyzed were dissolved oxygen (DO) concentration, growth rate, feed conversion ratio (FCR), survival rate, and water quality indicators. The results showed that DIYM O ₂ ^{Rs} significantly improved shrimp growth rate and size to 0.20 ± 0.005 g/day and 64.18 ± 7.24 (ind/kg), respectively. These observations suggest that DIYM O ₂ ^{Rs} is an alternative aeration solution, and the adoption can enhance water quality, shrimp health, and production efficiency, contributing to more sustainable super-intensive farming practices.
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1. Introduction

The innovation in whiteleg shrimp (*Litopenaeus vannamei*) farming technology is advancing significantly, transitioning from traditional methods to super-intensive cultivation systems. This evolution

is driven by the need to increase production efficiency and meet the growing market demand [1-3]. Various shrimp farming models have been developed, ranging from extensive pond systems to intensive household-scale setups [4, 5]. Super-intensive farming, characterized by high stocking densities ranging from 282 to 450 individuals per square meter [6] and up to 2,450 individuals per square meter [7], represents the future of shrimp aquaculture, utilizing the low-volume, high-density method [6].

Super-intensive farming, characterized by high-density and low-water-volume systems, presents significant challenges in maintaining water quality. The accumulation of organic waste from uneaten feed and feces often leads to deteriorating water conditions, resulting in reduced dissolved oxygen (DO) levels that directly impact shrimp health, growth, and survival [7, 8]. Maintaining optimal DO levels is essential for successful cultivation, necessitating the implementation of effective aeration systems. Traditional technologies, such as paddle-wheel aerators and fine-bubble diffusers, have been widely adopted to address these challenges [9-16]. However, these systems are unsuitable for household-scale farming due to the high operational costs, mechanical complexity, and potential adverse effects on shrimp [17, 18]. To overcome the described limitations, innovative aeration strategies that balance efficiency, affordability, and shrimp welfare are needed to support sustainable aquaculture practices.

Several aeration systems are currently employed in intensive shrimp farming, including paddle-wheel aerators [18-30], microbubble generators [7, 31] and nanobubble generators [17, 32-34]. However, the systems are not constantly suitable for household-scale farming due to equipment complexity, high operational costs, and potential harm to shrimp from mechanical components. In response to the challenges, this study proposes using Do-It-Yourself Microbubble (DIYM O₂^{Rs}), a novel microbubble generator technology [35], for the production of micro-sized bubbles in accordance with ISO 20480-1:2017 standards [36]. DIYM O₂^{Rs} system features a robust piping design with large cross-section nozzles as well as air tubes to prevent blockages and effectively circulates water while increasing oxygen levels using ambient air.

High DO levels are beneficial, but excessive oxygen saturation can lead to gas bubble disease (GBD), a condition detrimental to fish health and survival [37]. GBD occurs when the total dissolved gas (TDG) in water exceeds ambient pressure, causing bubbles to form in tissues and blood vessels, which can lead to significant mortality [38-40]. This suggests the importance of balancing aeration efficiency with the biological tolerance of aquatic organisms in super-intensive systems.

Based on the context described, this study aims to evaluate the performance of DIYM O₂^{Rs} aeration system in super-intensive whiteleg shrimp farming, focusing on water quality, shrimp growth, feed conversion ratio, survival rate, productivity, histology, and glucose content in the hemolymph. The results are expected to provide valuable insights into using a microbubble generator as an alternative aeration system for household-scale super-intensive shrimp farming and to serve as a reference for future investigations.

2. Literature Review

Microbubble generators (MBGs) represent an advanced aeration technology capable of producing micron-sized bubbles ranging from 0.1 to 100 μm in diameter [36, 41, 42], characterized by high stability and long residence time in fluids [34, 43, 44]. Due to their unique physicochemical properties, such as a large gas–liquid interfacial area, enhanced mass transfer efficiency, and self-pressurization effects, MBGs have attracted growing attention across various disciplines, including aquaculture, wastewater treatment, and biomedical applications. In aquaculture, MBGs significantly enhance DO transfer efficiency, improve water quality, and create optimal growth environments for aquatic organisms such as shrimp.

Previous studies have explored various MBG configurations, such as swirl-type [45-49], Venturi [11, 50-52], and orifice-type generators, each offering distinct advantages in controlling bubble size and enhancing oxygen transfer efficiency. Swirl-type MBGs are widely recognized for their structural simplicity and ability to generate uniform microbubbles through optimized flow conditions. Venturi-based systems, on the other hand, have demonstrated high efficiency in gas–liquid mixing by optimizing the air–water flow ratio, which significantly enhances oxygen dissolution rates. Orifice-type generators, despite their simpler construction, have been effectively applied in aquaculture, markedly improving DO levels in pond environments [42, 53-55]. In super-intensive aquaculture systems, MBG aeration has been proven to maintain optimal water quality and DO stability essential for shrimp growth and survival [32-34, 37]. Additionally, studies that modify the nozzle diameter and pump power have demonstrated improvements in microbubble production and oxygen diffusion, thereby minimizing clogging issues under high-density culture conditions.

Although MBG's aeration technology has shown tremendous potential in a wide range of applications, some research gaps continue to limit its full optimization and widespread adoption in the industry. One critical gap lies in the inadequate understanding of the gas-liquid mass transfer mechanism in microbubble systems, which is crucial for enhancing aeration efficiency and performance [35, 42, 56]. Another challenge involves the high energy consumption required to sustain microbubble generation, necessitating design and operational upgrades to reduce power demand without compromising oxygen transfer performance [56]. Additionally, the scalability of MBG systems from laboratory settings to real-world aquaculture operations poses additional challenges due to the complexity and durability of the system. Addressing these research gaps through experimental-based and simulation-based approaches is critical to advancing MBG aeration technology and expanding its application in the environmental, industrial, and aquaculture sectors.

Super-intensive shrimp farming, maintaining optimal DO levels, is an important determinant of water quality, growth performance, and survival. Conventional aeration systems, such as paddle wheels and root blowers, often face limitations in oxygen transfer efficiency, energy consumption, and uneven oxygen distribution, especially under high stocking densities. MBG aeration has emerged as a promising alternative,

capable of producing high-density microbubbles that remain suspended for extended periods, thereby enhancing the solubility and stability of oxygen in cultured water. Nevertheless, empirical studies evaluating these integrated systems under real pool conditions are still scarce. The study addressed this gap by developing a DIYM O₂^{RS} microbubble generator, which aims to improve DO dynamics and support the growth and health of whiteleg shrimp in a super-intensive aquaculture system. This research provides new insights into the optimization of microbubble aeration design and its biological applications, offering a scientific foundation for sustainable aquaculture practices and high productivity.

3. Materials and Methods

This study was conducted at the Experimental Pond Installation (ITP) of the Research Institute for Brackishwater Aquaculture and Fisheries Extension (RIBAFE), Punaga Village, Mangarabombang District, Takalar Regency, specifically as a shrimp rearing location. The rearing container included a fiber bath with a capacity of 24 m³ and was filled with 20 m³ of media water, which had a salinity of 30-34 ppt. A total of six container pieces were supplied with aeration equipment for each treatment medium, which utilized a microbubble generator in addition to a Root Blower.

Two treatments with three repetitions were carried out in this study, where the tested treatments included Microbubble generator (DIYM O₂^{RS}) producing [56] bubble sizes of 0 – 100 µm [36], and Root blower. The test animals used were 30 Post-Larval (PL) whiteleg shrimp with an average body weight of 0.15 ± 0.07 g/ind, obtained from a total of 10000 juveniles from a nursery system in Pond Installation sourced from a Hatchery trip to ITP Takalar. Shrimp were stocked at a density of 500 ind/m³ and had a rearing period of 91 days.

Protein 36-38% was present in the commercial feed supplied at a dose of 10-3% of biomass with a frequency of six times daily at 07:00 AM, 10:00 AM, 1:00 PM, 4:00 PM, 7:00 PM, and 10:00 PM [57]. Disposal of sludge (shrimp manure and feed residue) that settles to the bottom of the pond was carried out in the morning, afternoon, and evening before feeding, with a total water volume shrinkage of about 10 cm per day or 10% of the water volume in the fiber tank.

During rearing, measurements of water quality parameters, including temperature, salinity, pH, and DO, were carried out in situ using a YSI ProfPro Quatro Series (606933) DO meter. Measurements were conducted twice daily at 07:00 AM and 4:00 PM. Ammonia, Nitrite, and Phosphate parameters were estimated using a spectrophotometer (Shimadzu UV-2401 PC). Meanwhile, Total suspended solids (TSS) were calculated using a TSS meter (Hach TSS Portable), and Alkalinity was determined with the titrimetric method, once a week at the ITP Takalar water quality laboratory.

Blood glucose levels were analyzed using a GlucoDr Auto A glucometer, where five shrimps were selected from each experimental unit as representative samples to reflect the population in the container.

Hemolymph (0.1 mL) was collected from the base of the last pereopod of each individual. Subsequently, the hemolymph sample was applied to a glucose test strip, which was then inserted into the glucometer. The detected glucose level was read and recorded as the blood glucose concentration at the time of measurement.

Gill tissues were collected from one shrimp per aquarium, resulting in $n = 3$ for each aeration treatment. The tissue samples were fixed in Davidson solution for 24 h and then preserved in 70% ethanol at 4°C for histological analysis. Following standard histological procedures, the tissues were embedded in paraffin, sectioned at a thickness of 8 μm on a microtome (Microm, HM330, Heidelberg, Germany), and stained with hematoxylin and eosin (H&E). Histological examination was performed using a light microscope (Olympus, Tokyo, Japan) at 400 $\times$ magnification. Tissue abnormalities and histological alterations were documented and compared across different aeration treatments. The data obtained were analyzed using software-assisted T-Tests (SPSS version 25.0) with a significance level of 95% ($P < 0.05$), and Graphs were plotted using OriginPro 2024.

4. Results and Discussion

4.1. Water quality, Shrimp farming performance, Blood Glucose, and Gill Histology

The values of water quality parameters of whiteleg shrimp rearing media during cultivation are presented in Table 1.

Table 1. Values of water quality parameters of shrimp cultivation media

Parameter	DIYM O ₂ Rs	Root Blower
Temperature (°C)	28.4 $\pm$ 1.38 ^a	28.3 $\pm$ 1.41 ^a
Salinity (ppt)	29 $\pm$ 1.99 ^a	28.9 $\pm$ 1.98 ^a
pH	7.36 $\pm$ 0.19 ^a	7.33 $\pm$ 0.17 ^a
DO (mg L ⁻¹)	4.7 $\pm$ 0.32 ^a	4.5 $\pm$ 0.37 ^a
TSS (mg L ⁻¹)	57.38 $\pm$ 13.31 ^a	53.92 $\pm$ 12.75 ^a
Phosphate (PO ₄) (mg L ⁻¹)	0.13 $\pm$ 0.03 ^a	0.14 $\pm$ 0.03 ^a
Nitrite (NO ₂ -N) (mg L ⁻¹)	0.11 $\pm$ 0.05 ^a	0.12 $\pm$ 0.05 ^a
Nitrate (NO ₃ -N) (mg L ⁻¹)	0.29 $\pm$ 0.16 ^a	0.28 $\pm$ 0.09 ^a
Ammonia (NH ₃ -N) (mg L ⁻¹)	0.18 $\pm$ 0.06 ^a	0.17 $\pm$ 0.05 ^a
Alkalinity (mg L ⁻¹)	100.7 $\pm$ 2.59 ^a	102.3 $\pm$ 4.75 ^a

Temperature plays a crucial role in improving survival and inducing morphological changes in shrimp [58]. Additionally, higher temperatures can increase the weight gain and life recovery of shrimp [59]. Temperature is related to the level of oxygen consumption, which increases appetite [60]. However, extremely low air temperature tends to harm shrimp farming [61]. The results showed water temperature values of 28.4 $\pm$ 1.38 °C and 28.3 $\pm$ 1.41 °C for DIYM O₂Rs and Root Blower, respectively. These values are included in conditions considered optimal for shrimp growth and development. According to previous

studies [62, 63], the optimum temperature for shrimp farming ranges from 28 °C to 34 °C.

Salinity is among the factors affecting the growth of whiteleg shrimp [64], which can be cultured at various salinities ranging from 0.5 to 78 ppt [26, 65, 66]. Excessively high or low salinity reduces the growth rate because the osmoregulation system in whiteleg shrimp will respond to changes in salinity [67-69]. High salinity concentrations lead to stress, which decreases growth and productivity. The optimum salinity for shrimp farming ranges from 28 to 35 ppt [26]. The results showed a salinity value of 29 ± 1.99 ppt DIYM O₂^{Rs} and 28.9 ± 1.98 ppt Root Blower. Salinity value of water in both treatments is still in the optimal range, corresponding with a previous investigation on whiteleg shrimp farming that reported a salinity of 30-33 ppt [7], 29-30 ppt [70], and 31-34 ppt [71, 72] suitable for optimal growth and development.

The pH parameters can significantly impact water quality in shrimp farming [56], and maintaining proper pH control in aquaculture media is crucial for optimal growth [6, 58]. Shrimp is very sensitive to pH changes; hence, extreme fluctuations in pH need to be prevented [58, 73]. The optimal pH parameters in shrimp farming range from 6.8 to 7.6 [58, 73-75]. The results showed pH values of 7.36 ± 0.19 and 7.33 ± 0.17 for DIYM O₂^{Rs} and Root Blower treatments, respectively. These two values indicate that the pH of the water is relatively stable and remains within a suitable range for shrimp growth. According to a study [26], the recommended pH concentration values for shrimp farming range from 6 to 9. The pH values in the two treatments remain within a decent range for growth and development.

DO parameters in aquaculture water influence respiration and metabolism, while maintaining sufficient oxygen concentrations is essential for survival and growth in semi-intensive and super-intensive aquaculture [18, 76, 77]. When the concentration of DO in aquaculture is maintained, shrimp immunity and biomass can increase [76, 78, 79]. Extremely low DO concentration in aquaculture water causes hypoxia in shrimp [80]. Some investigations report that the ideal DO concentrations for shrimp farming were 5 mg/L [9, 21]. DO values obtained in this study were 4.7 ± 0.3 mg L⁻¹ and 4.5 ± 0.37 mg L⁻¹ for DIYM O₂^{Rs} and Root Blower treatments, respectively. Both values are suitable for shrimp growth and development, although they are less than optimal [9, 26].

TSS is defined as the number of solids dispersed in the cultivation water, and is often considered an essential factor that affects water quality in shrimp farming because of the capability to reduce DO concentration and increase ammonia concentration (NH₃-N) [81, 82]. TSS in super-intensive shrimp farming originates from feed residues and feces that are not appropriately degraded. The measurements in super-intensive shrimp farming yielded TSS values of 57.38 ± 13.31 mg/L and 53.92 ± 12.75 mg/L for the treatments DIYM O₂^{Rs} and Root Blower, respectively. These values remain within the range considered feasible for growth and development. According to a previous study [83], TSS values recommended for super-intensive shrimp farming range from 50 to 100 mg/L. However, TSS concentration exceeding 120

mg L⁻¹ will harm shrimp farming [81, 82], suggesting the need to manage and control feed residues [8].

Phosphate concentration is a factor that should be considered in whiteleg shrimp farming. The dissolved form of phosphate in intensive shrimp farming comes from shrimp excretion, and the decomposition of feed residue ranges from 40–90% [84, 85]. Super-intensive cultivation with artificial feeding increases phosphate concentration in aquaculture water [6, 86]. Phosphate concentration is required as a nutrient for cultivation and growth [87]. The results showed phosphate concentrations of 0.13 ± 0.03 mg/L and 0.14 ± 0.03 mg/L for whiteleg shrimp farming using DIYM O₂^{Rs} and a Root Blower, respectively. These are lower than the value of 0.13–1.67 mg L⁻¹ reported in a previous study [85, 87]. The concentrations in both treatments remain within safe limits for growth and development.

Nitrite (NO₂-N) is a chemical compound formed through the processes of nitrification and denitrification by Ammonia and Nitrate bacteria, respectively [6]. Nitrite accumulation in intensive shrimp aquaculture can decrease water quality and affect the growth rate [6, 88]. Deterioration in water quality and impaired growth lead to high mortality [88]. The results showed that the concentration of Nitrite in whiteleg shrimp farming was 0.11 ± 0.05 mg L⁻¹ for DIYM O₂^{Rs} and 0.12 ± 0.05 mg L⁻¹ for Root Blower treatment. The nitrite concentration value remains within the range considered suitable for shrimp growth and development. Two studies, by Romano and Zeng [89] and Furtado, et al. [90], reported that a Nitrite concentration of 1–5 mg L⁻¹ in shrimp farming could cause damage to shrimp gills and lead to death.

Nitrate is among the nitrogen compounds in water needed as a source of nutrition for the growth of whiteleg shrimp. It is achieved through the aerobic nitrification process, which is facilitated by nitrifying bacteria [89–92]. However, extremely high Nitrate concentrations cause stress in shrimp and reduce growth [93]. The results showed that the concentration of Nitrate in whiteleg shrimp farming using DIYM O₂^{Rs} and Root Blower was 0.29 ± 0.16 mg L⁻¹ and 0.28 ± 0.09 mg L⁻¹, respectively. According to Tierney and Ray [94], a clear water system signifies nitrate concentration of 4.6 ± 0.7 mg L⁻¹, which is viable for whiteleg shrimp farming. A Nitrate concentration of 177 mg L⁻¹ is acceptable, but needs to be followed by a concentration of DO of 6 mg L⁻¹ [90]. Considering the results obtained, the Nitrate parameter is still suitable for developing shrimp.

High ammonia concentrations in aquaculture media interfere with shrimp health due to their toxicity and increased susceptibility to disease [91, 95–97]. Increased Ammonia concentration during the cultivation process interferes with growth, and the extremely high level shows that the nitrification process is not optimal [98]. The nitrification process is the oxidation of ammonia to nitrate by nitrifying bacteria [92]. In whiteleg shrimp farming, the value of Ammonia concentration should not be more than 0.4 mg L⁻¹ [26]. The results showed ammonia concentration of 0.18 ± 0.06 mg L⁻¹ and 0.17 ± 0.05 mg L⁻¹ for DIYM O₂^{Rs} and Root Blower, respectively. Ammonia concentration is still expected to promote the growth of whiteleg shrimp.

Alkalinity and salinity in shrimp farming water are two major factors that cannot be discounted [99]. Alkalinity is the number of carbonates, bicarbonates, and hydroxides contained in water that serve as buffers for pH [18, 100, 101]. The results showed alkalinity concentration of $100.7 \pm 2.59 \text{ mg L}^{-1}$ and $102.3 \pm 4.75 \text{ mg L}^{-1}$ in whiteleg shrimp farming using DIYM O₂^{Rs} and Root Blower, respectively. This value is consistent with the study showing that [102] alkalinity of aquaculture water ranges from 109.40 ± 10.57 to $108.36 \pm 10.63 \text{ mg L}^{-1}$. The super-intensive whiteleg shrimp farming requires an alkalinity concentration of at least 100 mg L^{-1} [20]. An investigation previously reported Alkalinity ranging from 80-150 mg L^{-1} in concentrated shrimp farming [103, 104]. The Alkalinity measured in this study remains within the limits suitable for the decent growth of whiteleg shrimp.

4.2. Shrimp Farming Performance

The performance of whiteleg shrimp farming results was increased using DIYM O₂^{Rs} and Root Blower, as presented in Table 2.

Table 2. Performance of whiteleg shrimp increased using a microbubble generator and a root blower

Parameter	DIYM O ₂ ^{Rs}	Root Blower
Volume of water (m ³)	20 ± 0.00	20 ± 0.00
Initial size (g)	0.15 ± 0.07	0.15 ± 0.07
Final weight (g)	18.9 ± 8.21	15.6 ± 7.34
Absolute weight (kg)	15.279 ± 1.195	12.100 ± 0.051
Daily growth rate (g)	0.18 ± 0.08	0.15 ± 0.07
Stocking Density (ind/m ³)	500 ± 0.00	500 ± 0.00
Survival Rate (%)	67.78 ± 13.59^a	85.96 ± 6.44^a
Feed Conversion Ratio	1.59 ± 0.05^a	1.77 ± 0.12^a
Shrimp size (ind/kg)	64.18 ± 7.24^a	79.33 ± 4.56^b
Production (kg)	107.53 ± 12.74^a	108.30 ± 2.82^a
Productivity (kg/m ³)	5.38 ± 0.68^a	5.41 ± 0.41^a

Whiteleg shrimp subjected to aeration treatments using DIYM O₂^{Rs} and a Root Blower had survival rates (SR) of $67.78 \pm 13.59\%$ and $85.96 \pm 6.44\%$, respectively. The results showed no differences in the survival of whiteleg shrimp in the two treatments, and a significant effect was not observed. A previous study reported [7] that there was no significant difference in the treatment of air disc diffusers with microbubble injectors on the survival of whiteleg shrimp. In the second week of maintenance, low SR levels on treatment DIYM O₂^{Rs} were caused by pump damage, leading to a decrease in DO. However, SR was higher, with whiteleg shrimp cultivation at a stocking density of 500 ind/m² and aeration microbubble injectors producing SR of 52.36 ± 2.70 [7]. An investigation used microbubble aeration with a stocking density of 113 ind/m³ to obtain SR ranges between 30-70% [105]. In high-density shrimp farming, 26-45 ind/m² produced a minimum SR of $58.0 \pm 8.7\%$ and a maximum of $65.1 \pm 11.19\%$ [106].

Feed conversion Ratio (FCR) of whiteleg shrimp on aeration treatments using DIYM O₂^{Rs} and Root Blower was 1.59 ± 0.05 and 1.77 ± 0.12 , respectively. The results in Table 2 showed no difference in FCR between the two treatments, leading to no significant effect. A similar report Novriadi, et al. [7] and Sookying, et al. [106] showed that there was no real difference between the FCR values of whiteleg shrimp. The FCR obtained in this study is better than the previous results, which showed 2.11 [107] and values ranging from 1.64 to 3.01 [108].

Whiteleg shrimp harvest in aeration treatment using DIYM O₂^{Rs} and Root Blower was 64.18 ± 7.24 ind/kg and 79.33 ± 4.56 ind/kg, respectively. The results showed a significant difference in the size of whiteleg shrimp in the two treatments, suggesting a significant effect. Stocking density in shrimp farming can reduce the growth rate of shrimp [109], which aligns with a report stating that the lowest-density treatment yields larger shrimp sizes in high-density farming [7]. This occurs because the amount of feed given is the same, but the number of individual shrimps in the treatment DIYM O₂^{Rs} is fewer in volume than the total number in the straight SR treatment.

Whiteleg shrimp growth performance under two different aeration systems, namely DIYM O₂^{Rs} and Root Blower, is presented in Figure 1. Both treatments showed a strong linear relationship between farming duration and shrimp body weight, as signified by high Pearson's correlation coefficients ($r = 0.98969$ for DIYM O₂^{Rs} and $r = 0.98588$ for Root Blower). The coefficient of determination (R^2) values exceeded 0.97 in both systems, indicating that more than 97% of the variation in shrimp weight could be attributed to farming duration.

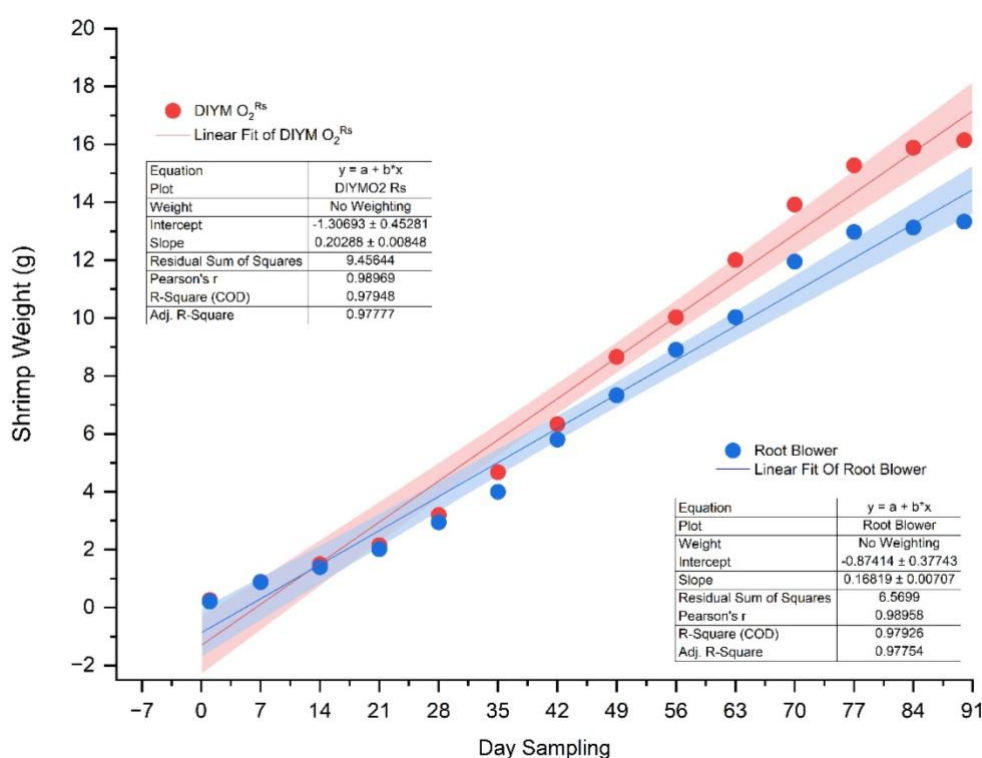


Figure 1. The relationship between farming duration and the weight of whiteleg shrimp

The linear regression model showed that shrimp reared under the DIYM O₂^{Rs} system had a significantly higher growth rate (slope = 0.20283 ± 0.00488 g/day) compared to those reared with the Root Blower system (slope = 0.16819 ± 0.00707 g/day). This difference in slope suggests that DIYM O₂^{Rs} provides superior conditions for shrimp growth. The higher growth rate may be associated with enhanced DO distribution and water mixing efficiency, which can positively affect shrimp metabolism, feed utilization, and immune function [110-114].

The Root Blower system showed a slightly lower residual sum of squares (6.5699) compared to the DIYM O₂^{Rs} (9.45644), indicating a marginally tighter data distribution around the regression line. However, the higher slope observed in the DIYM O₂^{Rs} system has greater implications for production performance. Improved aeration has been widely reported to stimulate shrimp feeding activity, enhance nutrient assimilation, and reduce stress, resulting in improved growth performance and survival [110, 115-117].

The intercept values in both models were negative (-1.30693 for DIYM O₂^{Rs} and -0.87414 for Root Blower), a common occurrence in linear growth modelling as the regression line extends beyond the initial measurement period. This does not imply actual negative shrimp weight but reflects the extrapolation of the fitted line before stocking or measurable biomass [118-120].

The average weight of whiteleg shrimp each week during rearing is shown in Figure 1. There is an increase in the average weight of whiteleg shrimp in correspondence with the length of maintenance. The distinction in average weight is due to differences in the number of individuals at the end of the maintenance period. This is consistent with the results, which show that the number of individuals influences shrimp growth [113, 114, 121]. According to Suwoyo and Hendrajat [109], a lower density of 100/m³ led to a high final weight of 13.70 ± 1.32 g/ind in shrimp cultivated for 70 days.

Whiteleg shrimp produced on aeration using DIYM O₂^{Rs} and Root Blower weighed 107.53 ± 12.74 kg and 108.30 ± 2.82 kg, respectively. The results showed no significant differences in production between the two treatments. These offer a good value, as the 20 m³ container volume has the capacity to produce large shrimp weighing 107-108 kg. Production is the primary goal of aquaculture, which can raise shrimp in large quantities and weights [122].

The productivity of whiteleg shrimp in aeration treatment using DIYM O₂^{Rs} and Root Blower was 5.38 ± 0.68 kg/m³ and 5.41 ± 0.41 kg/m³, respectively. The results showed no difference in productivity between the two treatments, leading to no significant effect. However, the values are good compared to a previous investigation that produced shrimp measuring 5.38 and 5.41 kg/m³. Another investigation [6] obtained a productivity of 3.64 kg/m³ and 5.2 kg/m³ with a density of 500 ind/m², and [123] stock density of 500 ind/m³, respectively.

The results suggest that the DIYM O₂^{Rs} aeration system provides a more favorable rearing environment than the Root Blower system. The superior growth rate observed under DIYM O₂^{Rs} could lead

to shorter production cycles or higher harvest weights in the same farming period, potentially improving economic returns for farmers. This finding is consistent with a previous study demonstrating the role of microbubble-based aeration systems in enhancing shrimp aquaculture performance through improved oxygen transfer efficiency and stable water quality [31, 56, 124].

Analysis of blood glucose concentration found differences between the two aeration systems, as shown in Figure 2. Shrimp reared under the DIYM O₂^{Rs} aeration system had higher mean blood glucose concentrations (38.1 ± 15.7 mg dL⁻¹) compared to those reared under the conventional Root Blower system (30.8 ± 8.6 mg dL⁻¹). The different trends suggest a physiological response related to the aeration regime and its effect on DO stability.

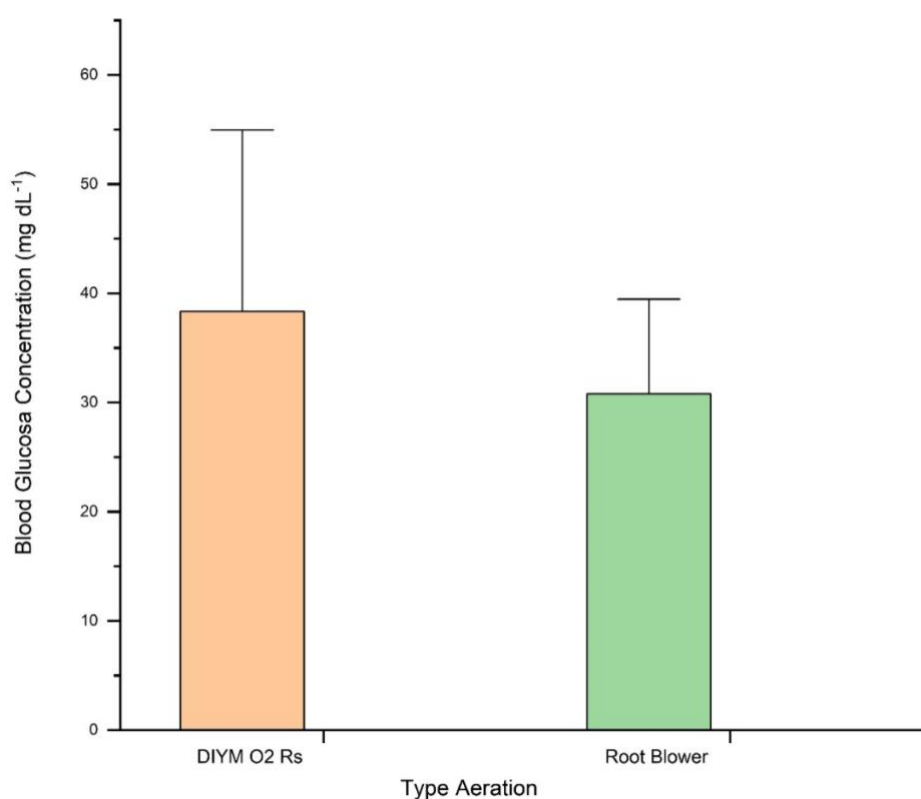


Figure 2. Graph of the relationship between treatment and glucose concentration

Blood glucose is a sensitive indicator of shrimp stress response, primarily regulated through the release of shrimp hyperglycemic hormone (CHH) during environmental changes, such as fluctuations in DO [125-127]. In this study, the slightly higher glucose levels observed in shrimp under the DIYM O₂^{Rs} system could be attributed to elevated metabolic activity associated with faster growth rates, as previously found in the growth performance analysis [128-131]. Increased oxygen availability plays a crucial role in enhancing aerobic metabolism in shrimp, thereby supporting key physiological processes such as protein synthesis and muscle accretion. Under hypoxic conditions, shrimp have elevated oxygen consumption rates, which are closely connected to increased activity of enzymes in the tricarboxylic acid cycle and electron transport chain central pathways for efficient ATP production through aerobic metabolism [132, 133]. This metabolic upregulation facilitates the mobilization and utilization of glucose (a primary energy substrate)

to meet the increased energy demands of protein biosynthesis. Moreover, the upregulation of glucose transporter expression (e.g., GLUT1 and GLUT2) under stress conditions ensures sufficient intracellular glucose availability to sustain energy production and cellular homeostasis [131, 134]. Adequate oxygen and glucose levels collectively promote an optimal environment for protein synthesis, which is essential for muscle growth and tissue repair [135-137]. The interplay between oxygen availability, glucose metabolism, and protein synthesis shows the importance of oxygen-rich environments in supporting growth performance and metabolic resilience in shrimp aquaculture systems [131-142].

Shrimp reared under the Root Blower system had lower mean hemolymph glucose levels with reduced variability, potentially reflecting a more stable yet subdued metabolic state, compared to other treatment groups. The described condition may represent a lower acute stress response or a reduction in metabolic turnover, possibly due to suboptimal oxygen distribution, which limits aerobic energy production [133, 142]. The metabolic moderation corresponds with the observation of relatively lower growth rates in the group raised under the Root Blower system, suggesting that energy allocation may have been directed more toward maintenance than growth. This is consistent with the broader physiological concept that energy distribution in aquatic organisms is tightly regulated by both environmental conditions and internal metabolic demands [143]. Acute stress in shrimp is mainly associated with transient hyperglycemia, driven by neuroendocrine-mediated glycogenolysis and gluconeogenesis to fulfill immediate energy requirements [144, 145]. However, shrimp with enhanced environmental adaptability often maintain lower hemolymph glucose levels, signifying reduced stress and more efficient energy utilization [145]. Under chronic stress or prolonged suboptimal oxygen conditions, metabolic adjustments occur, often leading to a shift toward anaerobic metabolism and the diversion of glycolytic intermediates such as glucose-6-phosphate to alternative pathways [138, 146]. The shifts can lead to depleted glucose and glycogen reserves, compromising growth potential. Therefore, the observed glucose dynamics in the Root Blower group tend to reflect a multifaceted interaction between environmental oxygen availability, stress physiology, and growth-related energy demands. This observation highlights the importance of optimizing aeration strategies to enhance metabolic efficiency and improve growth performance in shrimp aquaculture systems.

Glucose concentration after maintenance is shown in Figure 2. Shrimp samples reared under DIYM O₂^{Rs} were larger than those exposed to Root Blower treatment, primarily due to the lower number of individuals in the DIYM O₂^{Rs} SR group at the final stage of the study. Therefore, the growth and body composition of shrimp are excellent and substantially influenced by the concentration of glucose. Glucose serves as the primary energy provider in the organisms [147], with potential effects on growth performance and body composition [147-150]. When the blood glucose concentration reaches a level of 150 mg/dL, whiteleg shrimp require significantly more energy [151]. The increase in energy needs and glucose concentration shows that stress is experienced [152-154]. Stress in shrimp can affect physiological

processes and the body's resistance to disease, thereby serving as a health indicator [122]. The results show that the blood glucose concentration in both treatments remains at normal levels, allowing shrimp to grow and develop. These emphasize that aeration systems influence growth performance and physiological energy management. Through enhanced oxygen distribution, the DIYM O₂Rs system may promote both higher growth rates and a metabolic profile indicating increased but controlled energy turnover. The combination of growth and physiological data supports the perception that engineering improvements in aeration design simultaneously optimize production and maintain shrimp health in intensive aquaculture systems. Normal blood glucose levels in shrimp vary widely, depending on factors such as light cycles, diet, and temperature. Generally, hemolymph glucose levels range from approximately 10.97 mg dL⁻¹ to 33.40 mg dL⁻¹ under different conditions [152, 155-157]. Maintaining appropriate dietary and environmental conditions is crucial for shrimp health to avoid hyperglycemia and ensure homeostasis. The treatments using DIYM O₂Rs and Root Blower did not cause bubble disease in shrimp gills, as shown in Figure 3.

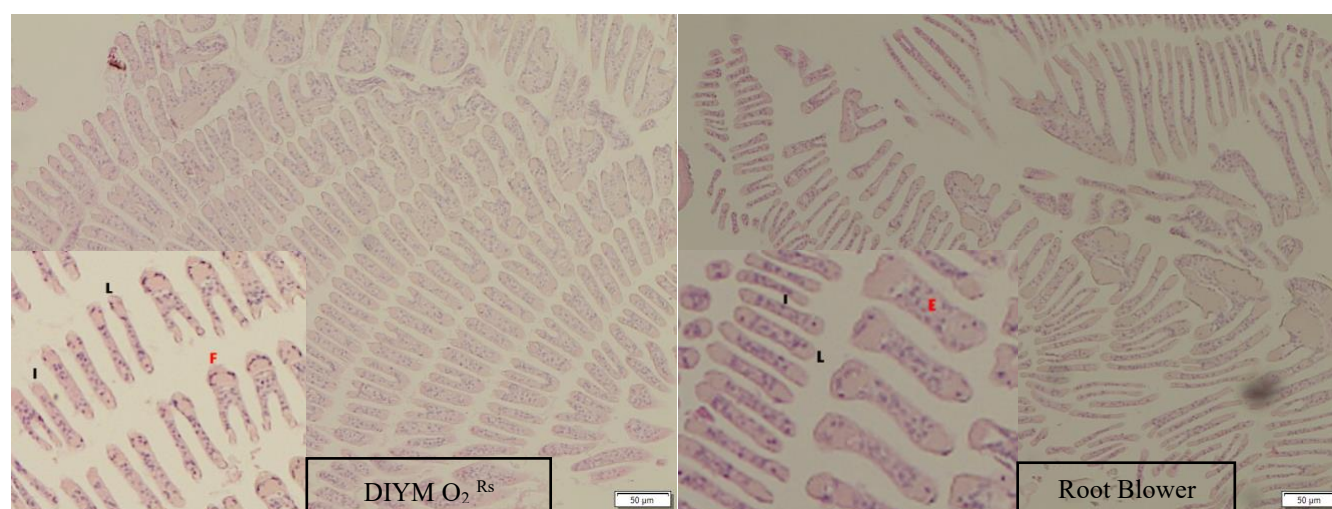


Figure 3. Histology of shrimp gill organs with microbubble treatment (left) and root blower (right).

Note. L: lamella, I: cell nucleus. Damage criteria: Edema (e), fusion (f). SCORING : 0: no change; 1: damage less than 25% (minimal); 2: damage 25-50% (moderate); 3: damage over 50% (High) [158-163].

Gill histology of shrimp under microbubble (left) and Root Blower (right) aeration showed that the lamellae structure in both treatments appeared normal, with no signs of tissue damage or symptoms of bubble disease. The lamellae were neatly arranged, without swelling, necrosis, or significant morphological alterations, indicating that both aeration systems maintained gill physiological conditions within normal limits. This result was consistent with the blood glucose data in the normal range, suggesting that aeration treatments did not induce physiological stress in shrimp. In correspondence with previous literature, microbubble aeration is generally beneficial for aquaculture due to the slow rising velocity and large interfacial area, which enhances dissolved oxygen levels [111, 164-166], as well as the ability to improve water quality and shrimp growth [12, 56, 111]. Root blower aeration, which operates by delivering

compressed air through fine-porous aeration pipes, has been shown to effectively increase oxygen concentrations [110] without direct evidence of causing gill damage. Gill injuries in shrimp tend to originate from factors such as microplastics or excessive water pressure [167-170].

This study can still be carried out, even though high-density shrimp farming increases the prevalence of the disease and leads to decreased production [110]. Other damages found on the gills are minimal, and tissue damage from the gill organs in both treatments tends to be similar, namely, edema (e), hemorrhage (h), vacuolization (v), and fusion (f). Shrimp gills are essential in respiration, osmoregulation, and ionic balance [90, 171-173]. Tissue damage in the form of oedema is characterized by the swelling of cells that occurs due to changes in the membrane permeability system at the cellular or tissue level. In edematous abnormalities, the lamella contains fluid that causes swelling. Lamella fusion occurs due to hyperplasia that spreads to basal cells, making the lamella look fused. This event causes inhibition of the respiration process and the expiration of breathing. According to a previous study [174], damage to gill tissue can cause various diseases. This tissue damage remains at a minimum level, ensuring that the cultivated shrimp does not experience interference and can grow and develop normally. The present observations show that both microbubble and Root Blower aeration systems do not cause gill damage, provided that operational settings are adequately managed.

5. Conclusion

In conclusion, the microbubble aeration system of DIYM O₂^{Rs} generator can serve as an effective alternative aeration technology for super-intensive whiteleg farming, capable of maintaining optimal water circulation in round culture tanks. General water quality parameters and overall shrimp performance showed no substantial differences between treatments; however, shrimp reared with the DIYM O₂^{Rs} system had significantly greater final size without any signs of bubble disease. Histological analysis confirmed intact gill lamellae with no swelling, necrosis, or morphological abnormalities. Blood glucose concentrations in both treatments remained within the normal physiological range, indicating minimal stress. Compared to the Root Blower system, microbubble aeration consistently delivered superior growth performance. The results provide integrated evidence combining growth, physiological, and histological parameters that advanced aeration technologies, particularly microbubble systems, are capable of improving production outcomes and safeguarding shrimp welfare. This study demonstrates the operational reliability of DIYM O₂^{Rs}; however, further optimization is recommended, including the selection of pumps to prevent equipment failure during prolonged farming cycles. The adoption of microbubble aeration in commercial operations offers the potential to increase production efficiency, ensure sustainability, and enhance climate resilience in high-density shrimp aquaculture. Future investigations should evaluate the long-term effects on pond microbial ecology, energy efficiency, and performance under diverse environmental conditions.

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