

# Hyper-intensive culture of white shrimp (*Penaeus vannamei*) usin photoheterotrophic systems

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## ABSTRACT

**Objective:** The objective of this review is to analyze the published information regarding hyper-intensive cultures of white shrimp (*Penaeus vannamei*) in photoheterotrophic systems.

**Design/methodology/approach:** The research focused on the collection of information in the databases of Elsevier, Scielo, Wiley online library, Pubmed, Springer, Scopus and Science direct. The information was limited to the white shrimp *Penaeus vannamei*.

**Results:** There are several types of studies in shrimp farms, highlighting those focused on experiments in laboratories or at a pilot level to study water quality, biological variables, yield, production and survival. The crops are classified as extensive which is characterized by having a low density of shrimp per unit area, the semi-intensive where there is a higher density than the extensive and hyper-intensive system where fertilizers, artificial feed and aeration are used to maintain adequate water quality conditions. It was found that water quality, solid waste, the type of microalgae and environmental factors affect the development, performance and survival of white shrimp (*P. vannamei*).

**Study limitations/implications:** white shrimp (*P. vannamei*) culture is widely studied; however, there is little information about the use of hyper-intensive photoheterotrophic cultures in this species.

**Findings/conclusions:** Hyperintensive photoheterotrophic cultures have a great potential for development for improved shrimp production, since they are floc-based cultures and are similar to biofloc cultures; However, there is little research done on photoheterotrophic cultures, which can give better response results in terms of development, production and water quality.

**Keywords:** aeration, aquaculture, growth performance, photo heterotrophic.

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## INTRODUCTION

White shrimp (*Penaeus vannamei*) is mainly produced in Ecuador, India, and Vietnam. Mexico ranks fourth in global shrimp production, with 238,000 tons produced in 2022, of which 82.7% came from the states of Sinaloa and Sonora (CONAPESCA, 2022). Shrimp



farming is a crucial industry due to its sustained growth, compared to other agro-industrial food production activities such as fishing, livestock, and agriculture (Khanjani *et al.*, 2024). This industry faces challenges related to environmental impact, frequent epizootics, and dependence on animal-derived inputs, particularly fishmeal for feed production (Moreno-Figueroa *et al.*, 2021). To address these issues, the aquaculture industry seeks intensification, as there is growing competition for space and resources like water and feed with other industries like livestock and agriculture (Vázquez-Vera & Chávez-Carreño, 2022). Additionally, there is a need to reduce production costs to increase profit margins and competitiveness (Lei *et al.*, 2024).

New strategies have been implemented, such as intensive cultivation systems, which manage water consumption efficiently (Ende *et al.*, 2024). White shrimp (*P. vannamei*) can be successfully produced in systems with limited or no water exchange (Lei *et al.*, 2024). Intensive shrimp farming has shown advantages over conventional aquaculture practices, characterized by high yields, small dimensions, and reduced environmental impact (Khanjani *et al.*, 2023; Long *et al.*, 2023).

Hyper-intensive shrimp farming systems include biofloc, photoheterotrophic, and recirculation systems, among others. This review aims to analyze scientific information on photoheterotrophic systems for white shrimp (*P. vannamei*) cultivation.

## **MATERIALS AND METHODS**

Information was gathered from databases like Elsevier, Scielo, Wiley Online Library, Pubmed, Springer, Scopus, and Science Direct, focusing on white shrimp (*Penaeus vannamei*).

## **RESULTS AND DISCUSSION**

### **Shrimp farming systems**

Most studies on shrimp farming have focused on experiments or pilot-scale research to investigate water quality, biological variables, yield, and survival (Nugraha *et al.*, 2023; Da Silveira *et al.*, 2020; Khanjani *et al.*, 2023; Long *et al.*, 2023; Li *et al.*, 2024). The Food and Agriculture Organization (FAO, 2020) classifies farming systems into three categories: i) extensive: characterized by low shrimp density, ii) semi-intensive: higher density than extensive systems, with increased water exchange rates and supplemental feeding, and iii) hyper-intensive: utilizing fertilizers, artificial feed, and aeration to maintain optimal water quality.

### **Hyper-intensive shrimp farming methods**

#### **Biofloc technology system**

Biofloc systems are relatively low-cost, sustainable, and environmentally friendly compared to conventional systems (Samsuri *et al.*, 2024). This system promotes the formation of flocs containing bacteria, fungi, protozoa, rotifers, and microalgae by adding carbon sources to regulate the carbon-to-nitrogen ratio in water (Khanjani *et al.*, 2024). Biofloc is rich in nutrients such as crude protein, lipids, and extracellular enzymes beneficial to aquatic animals (Long *et al.*, 2023; Martínez-Porchas *et al.*, 2020). Biofloc technology recycles waste into natural feed, reducing dependence on external feed in shrimp farming,

increasing shrimp growth, feed efficiency, water quality by controlling the C:N ratio, and improving biosecurity by reducing pathogen risks and water exchange requirements (Iber *et al.*, 2025).

### **Recirculation system (RAS)**

RAS utilize industrialized means to artificially control water conditions in cultivation tanks, creating optimal conditions for shrimp growth and survival (McMillan *et al.*, 2003; Nugraha *et al.*, 2023). RAS occupy limited land areas, produce high yields, and have high profitability (Du *et al.*, 2021), are environmentally sustainable, and control most of the aquaculture production process (Ende *et al.*, 2024). In RAS, *P. vannamei* is grown with less water and a lower environmental impact, operating year-round under controlled conditions, offering benefits such as improved nutrient recycling, waste management, disease control, profitable land use, affordable electricity and lower biological contamination (Halim *et al.*, 2025).

### **Photo-heterotrophic system**

The photoheterotrophic system (FH) technology utilizes a co-culture of bacteria a heterotrophic microorganisms that grow as flocs under controlled conditions (Khanjani *et al.*, 2023). These organisms stabilize water quality by converting unconsumed food and waste into non-toxic compounds (Khanjani *et al.*, 2023). These conditions promote the development of suspended organic matter flocs in the water, enhancing nitrogen recycling (produced by shrimp in single-cell protein synthesis) through nitrogen cycle oxidation-reduction relationships and the addition of carbon-rich substrates (Khanjani & Sharifinia, 2022). This floc is ingested through shrimp grazing (Ayazo-Genes *et al.*, 2019). Particulate organic matter and microorganisms in the microbial trophic chain serve as a food source in floc-based cultures due to interactions between water, organic matter, substrate and diverse microorganisms (Ayazo-Genes *et al.*, 2019).

### **White shrimp (*P. vannamei*) culture using a photoheterotrophic system**

Super-intensive systems produce aquatic organisms sustainable and bio-securely (Da Silveira *et al.*, 2020). A super-intensive system can provide welfare for at least 150 shrimp per m<sup>2</sup>, producing over three crops annually with a yield of 4.5Kg/m<sup>3</sup> in greenhouse conditions (Li *et al.*, 2024).

Martinez-Porchas *et al.* (2020) reported that autotrophic and heterotrophic microorganisms create a micro-biofloc, a soft and compact aggregated material composed of: algae, bacillus bacteria supplied through commercial probiotics, detritus, organic particles, and protozoa that control water quality by converting unconsumed food into non-toxic compounds.

Arambul-Muñoz *et al.* (2019) determined the optimal cultivation density of *P. vannamei* in a circular photoheterotrophic intensive system with grow-out tanks in line with minimal water replacement. The authors reported that water quality during the 98-day grow-out period was within the suitable range for *P. vannamei*. Additionally, they indicated that growth rate and survival decreased as density exceeded 300 organisms per m<sup>3</sup>. Moreno-

Figuroa *et al.* (2017) determined the performance of a hypersaline photoheterotrophic system for intensive culture of *P. vannamei* shrimp with minimal water replacement in lined ponds and reported shrimp growth to a marketable size at fifteen weeks, suggesting that two shrimp harvests per year could be produced. They reported a 95% confidence in production of 12.1 to 14.7 tons/ha at harvest, with a mean weight of 13.1 g and a survival rate of 84.2%.

### Water quality

Water quality influences biomass production in intensive photoheterotrophic cultures of white shrimp (*P. vannamei*) (Moreno-Figuroa *et al.*, 2021). Nugraha *et al.* (2023) reported improved water quality through reduced ammonia levels using a biofilter to control ammonia produced as byproduct of animal protein catabolism.

On the other hand, Vinasiam *et al.* (2024) reported that adding microbial groups (bacteria, archaea, algae, protists, zooplankton and fungi) and particles to biofloc improves water quality by decreasing ammonia concentration (NH<sub>4</sub>-N). Huang *et al.* (2022) found that adding diatom microalgae to shrimp cultures positively impacts water quality enhancing shrimp development, yield, survival and weight gain. Arambul-Muñoz *et al.* (2019) evaluated the water quality of an intensive photoheterotrophic white shrimp (*Penaeus vannamei*) system in circular-lined grow-out tanks with minimal water replenishment and different stocking densities, where the parameters were dissolved oxygen concentration (mg L<sup>-1</sup>), temperature (°C), pH and salinity, in addition to total ammonium nitrogen (TAN) (mg L<sup>-1</sup>), nitrite-N (mg L<sup>-1</sup>), nitrate-N (mg L<sup>-1</sup>) and orthophosphate-P concentrations (mg L<sup>-1</sup>). These authors observed a significant increase in the concentrations of TAN, nitric nitrogen and total phosphorus in the treatments, the level of dissolved oxygen in all treatments was above 5 mg L<sup>-1</sup>, they found a higher concentration of nitrates and phosphorus, which could be associated with greater nitrification and heterotrophic activity, inorganic nitrogen and total phosphorus were reduced because the photoheterotrophic system promotes the development of microbial communities.

### Solid waste

Feeding in intensive or super-intensive shrimp farms releases a considerable volume of waste that rapidly contaminates the pond water and directly affects the shrimp (Nguyen *et al.*, 2024). Solid waste often occurs in the form of feces, feed scraps, and dead organisms that accumulate in the system, causing eutrophication, oxygen depletion, and precipitation (Saputra *et al.*, 2017). McMillan *et al.* (2023) reported that sediments and suspended particles contain organic matter that, when degraded by bacteria, consume oxygen, reducing its bioavailability for cultivation systems, solid residue (RS) removal must equal waste production (Lei *et al.*, 2024), as accumulated residues can deteriorate water quality (Arambul-Muñoz *et al.*, 2019).

Samsuri *et al.* (2024) reported that harmful effects of solid residues include gill damage, reduced growth rates, mortality, disease, obstruction of biological filters and ammonium production through mineralization. Wastewater with a stocking density of 750 to 1250 shrimp/m<sup>2</sup> has been reported to contain an average total suspended solids (TSS) of 798

to 924 mg/L, dissolved organic matter of 81,227 to 88,641 mg/L, total nitrogen (TN) of 9.8389 to 14.4260 mg/L, and total phosphate (TP) of 7.8770 to 11.8720 mg/L (Hidayat *et al.*, 2019).

### **Other factors that Influence the crop**

Temperature is an abiotic factor that influences the growth and development of organisms such as shrimp (Moreno-Figueroa *et al.*, 2021). Increased temperature reduces the oxygen content of water while simultaneously increasing the oxygen demand of organisms two- to threefold with a 10 °C temperature increase (Kir *et al.*, 2023). Furthermore, variations in ambient salinity levels can also modify the organism's osmotic and ionic balance, thus causing an increase or decrease in metabolic energy demand (Ponce-Palafox *et al.*, 2019). Additionally, increased salinity results in higher concentrations of flagellated organisms, while decreased salinity increases the concentrations of ciliated organisms (Fraga, 2009). Ponce-Palafox *et al.* (2019) reported that controlling salinity at 25.5 g/L yields optimal specific growth rate, productivity, and survival of Pacific white shrimp (*Penaeus vannamei*). For his part, Carranza (2020) determined the oxygen consumption of shrimp at different salinities (4, 12, 22 and 32 practical salt units UPS) and temperatures (27 and 31 °C) and reported that organisms subjected to 32 UPS had a higher oxygen demand, while organisms that were at lower salinities had a lower oxygen demand and the respiration rate was reduced, as was the osmoregulatory process and energy consumption.

On the other hand, climatic conditions have been reported to negatively impact shrimp cultivation. Prolonged intense rainfall (Le *et al.*, 2024) causes up to 50% mortality in cultivated populations within 3-4 days after intense rainfall. Additionally, food consumption decreases by 10% for each degree Celsius drop in water temperature, as rainfall cools cultivation water by 3-5 °C (Buike, 2018).

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### **CONCLUSIONS**

Hyper-intensive photoheterotrophic cultivation systems hold great promise for development. Given their similarity to biofloc systems, due to their floc-based nature, they warrant further investigation, potentially yielding enhanced productivity and water quality.

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