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Cultivo superintensivo do camarão-branco do Pacífico *Penaeus vannamei* na fase de pré-berçário (PL_{15} – PL_{35}) em sistema de recirculação de água (SRA) utilizando diferentes vazões de água e densidades de estocagem

Florianópolis
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Orientador: Prof. Luis Alejandro Vinatea Arana, Dr.

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O presente trabalho em nível de Mestrado foi avaliado e aprovado, em 14 de fevereiro de 2025, pela banca examinadora composta pelos seguintes membros:

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Florianópolis
2025

Quanto mais aumenta nosso conhecimento, mais evidente fica nossa ignorância. (John F. Kennedy)

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RESUMO

A densidade de estocagem e as vazões de água em sistemas de recirculação são fatores importantes no cultivo de *Penaeus vannamei*. O presente estudo teve como objetivo avaliar um sistema superintensivo para o cultivo de pós-larvas (PL) de *P. vannamei* na fase de pré-berçário, analisando os efeitos da densidade de estocagem e das vazões de água sobre o desempenho zootécnico dos camarões e da qualidade de água. Um total de 12.960 PL_{15} (peso e comprimento médios de 0,00055 ± 0,0001g e 9,0 ± 1,0mm) foram distribuídas em 27 unidades experimentais (8L úteis), submetidas a diferentes vazões de de água (100%, 200% ou 300% por hora) e densidades de estocagem (30, 60 ou 90 PL L^{-1}), em um delineamento bifatorial (30_{100}, 30_{200}, 30_{300}, 60_{100}, 60_{200}, 60_{300}, 90_{100}, 90_{200}, 90_{300}). O experimento teve duração de 20 dias, abrangendo a fase de pré-berçário (PL_{15} – PL_{35}). Durante o período, foram monitorados parâmetros de qualidade de água, incluindo oxigênio dissolvido (OD), temperatura, pH, nitrogênio amoniacal total (NAT), nitrito ($N{-}NO_2^-$), nitrato ($N{-}NO_3^-$), alcalinidade ($CaCO_3$), salinidade e sólidos suspensos totais (SST), além do desempenho zootécnico do *P. vannamei*. Houve diferenças significativas entre os tratamentos para temperatura ($p < 0,0001$), OD ($p = 0,0031$), NAT ($p = 0,0076$) e $N{-}NO_2^-$ ($p < 0,0001$). Observou-se interação significativa ($p = 0,0459$) entre os fatores especificamente para os níveis de $N{-}NO_2^-$. Isoladamente, a vazão de água influenciou significativamente os valores de temperatura, OD, NAT, $N{-}NO_2^-$ e $CaCO_3$ ($p = 0,0216$), enquanto a densidade afetou significativamente $N{-}NO_2^-$, salinidade e pH. Diferenças significativas ($p < 0,05$) também foram observadas entre os tratamentos para biomassa final (g), peso final das PL (g) e coeficiente de crescimento diário (CCD % dia^{-1}). O tratamento 90_{100} apresentou biomassa significativamente maior (19,46 ± 2,64 g; $p < 0,0001$) em relação aos demais. O peso final das PLs e o CCD não diferiram entre os tratamentos 90_{100} (0,0321 ± 0,003 g; 1,18 ± 0,0% dia^{-1}), 30_{100} (0,0324 ± 0,005 g; 1,17 ± 0,08% dia^{-1}), 30_{200} (0,0395 ± 0,002 g; 1,29 ± 0,03% dia^{-1}), 30_{300} (0,0425 ± 0,001 g; 1,33 ± 0,02% dia^{-1}), 60_{100} (0,0305 ± 0,002 g; 1,15 ± 0,03% dia^{-1}) e 60_{200} (0,0333 ± 0,003 g; 1,19 ± 0,05% dia^{-1}). Não foi observado interação ($p > 0,05$) entre os fatores para o desempenho zootécnico das PLs. A biomassa final foi significativamente maior ($p < 0,0001$) no tratamento com densidade 90 PL L^{-1}. Conclui-se que pós-larvas (PL_{15} a PL_{35}) do camarão-branco do Pacífico *P. vannamei* podem ser cultivadas com sucesso em densidades de até 90 PL L^{-1} na fase de pré-berçário, em sistema de recirculação de água (SRA), com vazões de água de 100% h^{-1}.

Palavras-chave: Aquicultura; Alta densidade de estocagem;, Larvicultura; Carcinicultura; Sobrevivência.

ABSTRACT

Stocking density and water flow rates are important considerations in *P. vannamei* farming. The study aimed to explore a system for superintensive rearing of *P. vannamei* postlarvae (PL) in the pre-nursery phase by examining the effects of stocking density and water flow rates on shrimp performance and water quality. A total of 12,960 PL_{15} (average weight and length of 0.00055 ± 0.0001g and 9.0 ± 1.0mm) were randomly distributed into 27 experimental units (8L useful) and subjected to varying water flow rates (100%, 200%, or 300% per hour) and stocking densities (30, 60, or 90 PL L^{-1}) in a bi-factorial treatment design (30_{100}, 30_{200}, 30_{300}, 60_{100}, 60_{200}, 60_{300}, 90_{100}, 90_{200}, 90_{300}). The trial spanned 20 days and encompassed the pre-nursery stage (PL_{15} – PL_{35}). During this period, water quality parameters including dissolved oxygen (DO), temperature, pH, total ammonia nitrogen (TAN), nitrite ($N\text{-}NO_2^-$), nitrate ($N\text{-}NO_3^-$), alkalinity ($CaCO_3$), salinity, and total suspended solids were monitored, as well as the growth performance of *P. vannamei*. Temperature ($p < 0.0001$), DO ($p = 0.0031$), TAN ($p = 0.0076$), and N-NO2 (p = < 0.0001) differed significantly between treatments. There was a notable interaction ($p = 0.0459$) between the factors specifically for the $N\text{-}NO2^-$ levels. Individually, the flow rate factor significantly affected the levels of temperature, DO, TAN, $N\text{-}NO2^-$, and CaCO3 ($p = 0.0216$). On the other hand, individually, density significantly affected $N\text{-}NO2^-$, Salinity, and pH levels. There were significant differences ($p < 0.05$) between treatments in final biomass (g), PL final weight (g), and daily growth coefficient (DGC %day^{-1}). Treatment 90_{100} exhibited a significantly higher ($p < 0.0001$) biomass (19.46 ± 2.64) compared to the other treatments. PL final weight and DGC were the same among treatments 90_{100} (0.0321 ± 0.003 g, 1.18 ± 0.0% day^{-1}), 30_{100} (0.0324 ± 0.005g, 1.17 ± 0.08% day^{-1}), 30_{200} (0.0395 ± 0.002 g, 1.29 ± 0.03% day^{-1}), 30_{300} (0.0425 ± 0.001g, 1.33 ± 0.02% day-1), 60_{100} (0.0305 ± 0.002 g, 1.15 ± 0.03% day^{-1}), 60_{200} (0.0333 ± 0.003g, 1.19 ± 0.05% day^{-1}).There was no interaction ($p > 0.05$) of factors for PL growth performance. Final biomass was significantly higher ($p < 0.0001$) in the 90-density treatment. Postlarvae (from PL_{15} to PL_{35}) of Pacific white shrimp *P. vannamei* can be successfully raised in high densities of up to 90 PL L^{-1} during the pre-nursery phase in a clear-water RAS system at a water flow rate of 100% h^{-1}.

Keywords: Aquaculture; High stocking density; Larviculture; Shrimp farming; Survival.

LISTA DE FIGURAS

LISTA DE TABELAS

LISTA DE ABREVIATURAS E SIGLAS

ABCC	Associação Brasileira de Criadores de Camarão
ANOVA	Análise de variância unifatorial
$CaCO_3$	Carbonato de Cálcio
DGC	Daily Growth Coefficient (Coeficiente de Crescimento Diário)
DO	Dissolved Oxygen (Oxigênio dissolvido)
FAO	Food and Agriculture Organization
L	Litro
LCM	Laboratório de Camarão Marinho
NH_4^+	Íon amônio
NO_2^-	Nitrito
NO_3^-	Nitrato
OH^-	Íon hidróxido
PH	Potencial hidrogeniônico
PL	Postlarvae (Pós-larva)
RAS	Recirculating aquaculture system
SRA	Sistema de recirculação de água
TAN	Total Ammonia Nitrogen (Amônia)
TSS	Total suspended solids (sólido suspenso total)
UV	Ultravioleta

LISTA DE APÊNDICES

SUMÁRIO

1 INTRODUÇÃO GERAL

1.1 PANORAMA GLOBAL DA AQUICULTURA

A aquicultura é uma das atividades que mais cresce no setor do agronegócio mundial, desempenhando papel fundamental na segurança alimentar e na produção de proteína animal (FAO, 2022). Este avanço tem sido impulsionado por diversos fatores, como a estagnação da pesca extrativa desde o final da década de 1980, a crescente demanda por alimentos e a necessidade de práticas sustentáveis de produção (FAO, 2024). Além disso, a aquicultura oferece vantagens como a previsibilidade de produção, o melhor aproveitamento dos recursos hídricos e a possibilidade de cultivo em ambientes controlados (MARTINS, C. et al., 2010).

Segundo FAO (2024), a produção aquícola mundial atingiu 130 milhões de toneladas em 2022, superando, pela primeira vez, os volumes oriundos da pesca extrativa. Esse marco representa um crescimento expressivo de 8,1 milhões de toneladas em relação ao ano de 2020, evidenciando a importância crescente da aquicultura como fornecedora de pescado para o consumo humano.

1.2 EXPANSÃO DA CARCINICULTURA NO CENÁRIO INTERNACIONAL

Dentro do setor aquícola, a produção de crustáceos tem se destacado nos últimos anos, especialmente com o avanço tecnológico aplicado à carcinicultura. Em 2022, a produção mundial de crustáceos provenientes da aquicultura alcançou cerca de 16 milhões de toneladas, correspondendo a aproximadamente 24,6% da produção total da aquicultura (FAO, 2024). As principais espécies cultivadas são o camarão-branco do Pacífico *penaeus vannamei* e o camarão-tigre *penaeus monodon*, com destaque para o primeiro, que representou 51,7% da produção global de crustáceos em 2020 (YANG et al., 2024).

O continente asiático é responsável por cerca de 90% dessa produção, sendo países como China, Índia, Vietnã, Indonésia e Tailândia líderes mundiais em cultivo de camarões marinhos (WOOD et al, 2022). Esse cenário reforça a importância da adoção de tecnologias avançadas para garantir competitividade e sustentabilidade nos sistemas produtivos.

1.3 SITUAÇÃO ATUAL DA PRODUÇÃO DE CAMARÃO NO BRASIL

No Brasil, a carcinicultura tem apresentado crescimento consistente, consolidando-se como uma importante atividade do setor aquícola nacional. De acordo com a Associação Brasileira de Criadores de Camarão (ABCC, 2025), a produção brasileira de camarão atingiu

210 mil toneladas em 2024, colocando o país como o sétimo maior produtor mundial, atrás apenas de Equador, China, Índia, Vietnã, Indonésia e Tailândia.

A atividade é predominantemente desenvolvida na região Nordeste, onde fatores climáticos e disponibilidade de área favorece o cultivo. Em 2023, o Nordeste foi responsável por cerca de 99,6 % da produção nacional de camarão marinho, com destaque para os estados do Ceará (48,9 %), Rio Grande do Norte (16,7 %) e Paraíba (12,8 %) (ROCHA et al., 2024). No Sul do Brasil, apesar da menor participação, Santa Catarina apresenta produção considerável no setor, tendo certo destaque na carcinicultura marinha com cerca de 1 % a 2 % da produção nacional, resultado de iniciativas locais e expansão recente em viveiros costeiros e de baixa salinidade (ABCC; MPA, 2025). Apesar dos avanços, desafios como doenças, custos operacionais e pressão ambiental exigem a adoção de modelos de cultivo mais eficientes e sustentáveis.

1.4 RELEVÂNCIA DA LARVICULTURA NA CADEIA PRODUTIVA DO CAMARÃO

Dentre as várias etapas no processo da cadeia produtiva do camarão marinho, a larvicultura representa uma parte crítica e determinante para o sucesso nas fases subsequentes. A produção de pós-larvas (PLs) com alta qualidade sanitária e nutricional exige controle rigoroso de parâmetros como temperatura, salinidade, pH e compostos nitrogenados (MIRZAEI et al., 2021).

Contudo, mesmo com boas práticas realizadas em laboratório, a fase inicial ainda apresenta desafios consideráveis, especialmente em relação à sobrevivência e à estabilidade dos parâmetros físico-químicos da água, uma vez que os camarões chegam para os produtores darem início aos cultivos com média de PL10 a PL15, ainda muito susceptíveis às variações de qualidade de água (HU et al., 2023; APRESIA et al., 2024). Altas concentrações de amônia e nitrito, comuns em sistemas intensivos, podem comprometer o desenvolvimento e aumentar a mortalidade das PLs (ESPARZA-LEAL et al., 2020; MOHAMMADI et al., 2023).

1.5 APLICAÇÕES DOS SISTEMAS DE RECIRCULAÇÃO DE ÁGUA (SRA)

Sabendo que o controle de qualidade água é fundamental para o sucesso de um cultivo, os sistemas de recirculação de água têm ganhado espaço como alternativa tecnológica promissora. Esses sistemas possibilitam o cultivo em altas densidades, com maior controle da qualidade da água e menor consumo hídrico, aspectos fundamentais para a sustentabilidade da produção (EMERENCIANO et al., 2022; DHANDE et al., 2024). O SRA permite o monitoramento rigoroso e contínuo de parâmetros como pH, oxigênio, temperatura e compostos nitrogenados, além de desinfecção por luz UV, reduzindo substancialmente a transferência de patógenos, contribuindo para maior biossegurança do sistema (TANGL et al., 2024).

Os sistemas de recirculação de água permitem a expansão da carcinicultura para regiões continentais, ou com restrições hídricas, utilizando águas oligohalinas ou salinizadas artificialmente, contribuindo para a descentralização da atividade (PHAM et al., 2021; PIMENTEL et al., 2025). Para seu funcionamento ideal, é essencial ajustar variáveis como a vazão da água e a densidade de estocagem, que influenciam diretamente o desempenho zootécnico dos camarões (LIU et al., 2024; SHARAWY et al., 2022).

Segundo PINTO et al (2020), no Brasil, há evidências de viabilidade zootécnica e econômica do cultivo de *P. vannamei* em água doce salinizada em sistemas fechados, especialmente bioflocos, com desempenho comparável ao obtido em água marinha quando a adequação iônica e o manejo de sólidos e compostos nitrogenados são implementados. Esses modelos reforçam a possibilidade de descentralização da atividade para áreas interiores, mantendo biossegurança e previsibilidade produtiva.

Em sistemas de recirculação de água para *P. vannamei*, o aumento da recirculação de água reduz amônia e nitrito e melhora o desempenho zootécnico, entretanto, alguns estudos observaram maiores taxas de sobrevivência e rendimento em recirculações mais baixas, sugerindo que faixas intermediárias podem maximizar o desempenho global (crescimento × sobrevivência) para uma dada biomassa (CHEN et al., 2019; ESPARZA-LEAL et al., 2020).

Em termos práticos de manejo, isso implica ajustar densidade e vazão ao longo do ciclo (PL15 - PL35), com monitoramento contínuo de OD, TAN, $N–NO_2^-$, $N–NO_3^-$, TSS e alcalinidade (RAY et al., 2017; RAMIRO et al., 2024).

Diante disso, torna-se fundamental testar estratégias de manejo que maximizem a eficiência produtiva na fase de pré-berçário do camarão-branco do Pacífico, utilizando tecnologias como sistema de recirculação de água. A avaliação do desempenho zootécnico das PLs em diferentes densidades de estocagem e taxas de vazões de água podem fornecer subsídios importantes para a melhoria dos sistemas produtivos.

2 OBJETIVOS

2.1 OBJETIVO GERAL

Testar um modelo de sistema de recirculação de água para o cultivo de pós-larvas de *P. vannamei* em fase de pré-berçário capaz de aumentar a produção quando comparada às tecnologias atualmente utilizada no Brasil e no mundo.

2.2 OBJETIVOS ESPECÍFICOS

Determinar a sobrevivência e o ganho de peso das pós-larvas do camarão marinho na fase de pré-berçário em sistema de recirculação de água em densidades de 30, 60 e 90 cam/L, utilizando taxas de vazões de água de 100%, 200% e 300% por hora.

3 ESTRUTURA DA DISSERTAÇÃO

Essa dissertação conta com um artigo científico, publicado no periódico “Aquaculture International”, com percentil de 78% em Ciências Agrárias e Biológicas, correspondendo a um Qualis A3 (plataforma Scopus).

4 ARTIGO CIENTÍFICO

Superintensive pre-nursery for *penaeus vannamei* (PL15–35) varying stocking densities and water flow rates in clear-water recirculating aquaculture system

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ABSTRACT

Stocking density and water flow rates are important considerations in *P. vannamei* farming. The study aimed to explore a system for superintensive rearing of *P. vannamei* postlarvae (PL) in the pre-nursery phase by examining the effects of stocking density and water flow rates on shrimp performance and water quality. A total of 12,960 PL_{15} (average weight and length of 0.00055 ± 0.0001g and 9.0 ± 1.0mm) were randomly distributed into 27 experimental units (8L useful) and subjected to varying water flow rates (100%, 200%, or 300% per hour) and stocking densities (30, 60, or 90 PL L^{-1}) in a bi-factorial treatment design (30_{100}, 30_{200}, 30_{300}, 60_{100}, 60_{200}, 60_{300}, 90_{100}, 90_{200}, 90_{300}). The trial spanned 20 days and encompassed the pre-nursery stage (PL_{15} – PL_{35}). During this period, water quality parameters including dissolved oxygen (DO), temperature, pH, total ammonia nitrogen (TAN), nitrite ($N\text{-}NO_2^-$), nitrate ($N\text{-}NO_3^-$), alkalinity ($CaCO_3$), salinity, and total suspended solids were monitored, as well as the growth performance of *P. vannamei*. Temperature ($p < 0.0001$), DO ($p = 0.0031$), TAN ($p = 0.0076$), and N-NO2 ($p = < 0.0001$) differed significantly between treatments. There was a notable interaction ($p = 0.0459$) between the factors specifically for the N-NO2- levels. Individually, the flow rate factor significantly affected the levels of temperature, DO, TAN, N-NO2-, and CaCO3 ($p = 0.0216$). On the other hand, individually, density significantly affected N-NO2-, Salinity, and pH levels. There were significant differences ($p < 0.05$) between treatments in final biomass (g), PL final weight (g), and daily growth coefficient (DGC %day^{-1}). Treatment 90_{100} exhibited a significantly higher ($p < 0.0001$) biomass (19.46 ± 2.64) compared to the other treatments. PL final weight and DGC were the same among treatments 90_{100} (0.0321 ± 0.003 g, 1.18 ± 0.0% day^{-1}), 30_{100} (0.0324 ± 0.005g, 1.17 ± 0.08% day^{-1}), 30_{200} (0.0395 ± 0.002 g, 1.29 ± 0.03% day^{-1}), 30_{300} (0.0425 ± 0.001g, 1.33 ± 0.02% day-1), 60_{100} (0.0305 ± 0.002 g, 1.15 ± 0.03% day^{-1}), 60_{200} (0.0333 ± 0.003g, 1.19 ± 0.05% day^{-1}).There was no interaction ($p > 0.05$) of factors for PL growth performance. Final biomass was significantly higher ($p < 0.0001$) in the 90-density treatment. Postlarvae (from PL_{15} to PL_{35}) of Pacific white shrimp *P. vannamei* can be successfully raised in high densities of up to 90 PL L^{-1} during the pre-nursery phase in a clear-water RAS system at a water flow rate of 100% h^{-1}.

Keywords: Aquaculture, high stocking density, harviculture, shrimp farming, survival.

4.1 INTRODUCTION

The Pacific white shrimp (*Penaeus vannamei*) is a leading species in the aquaculture industry worldwide. In 2022, it was the most produced species, totaling 6.8 million tons (FAO, 2024). In Brazil, the production of *P. vannamei* exceeded 120,000 tons (ABCC, 2022). Despite this achievement, the Brazilian shrimp farming industry is still impacted by the presence of the white spot virus, limiting its full potential (XIMENES; VIDAL, 2023; JUNIOR et al., 2024).

The farming of *P. vannamei* offers numerous benefits compared to other shrimp species. These advantages include well-developed technological methods, higher disease resistance, faster growth, and increased stress tolerance (FELIX et al., 2020; EMERENCIANO et al., 2022; NUGRAHA et al., 2023). Nevertheless, attaining high survival rates during the initial stages of *P. vannamei* life remains a hurdle for laboratories and shrimp farmers due to factors like fluctuations in water physical-chemical parameters and elevated levels of ammoniacal nitrogen, which contribute to higher mortality rates in early cultivation stages (ESPARZA-LEAL et al., 2020; MOHAMMADI et al., 2023; COUTINHO et al., 2024; SOUZA et al. 2025).

Postlarvae (PLs) are a key component in marine shrimp farming, and effective hatchery management is crucial for ensuring the production of top-quality PLs (MIRZAEI et al., 2021). Hence, employing closed and controlled systems with limited water exchange in the pre-nursery phase is a crucial strategy.

In recent years, marine shrimp farming has been expanding to inland areas in various regions around the world, such as Brazil (FRANÇA et al., 2024). This includes farming in oligohaline waters and artificially salinized waters, moving away from traditional coastal locations (ROY et al., 2010; PHAM et al., 2021; PIMENTEL et al., 2025). Thus, it is crucial to manage water usage in these crops and reduce effluent discharges into the environment to encourage environmentally friendly practices in these continental regions. Implementing technological solutions like recirculating aquaculture systems (RAS) to recycle water is vital for the sustainability of the industry (LORENZO et al., 2016; PHAM et al. 2021; EMERENCIANO et al., 2022; DHANDE et al., 2024).

RAS, when integrated with other approaches, showed potential as innovative technologies for ensuring the sustainability of inland shrimp farming (PHAM et al., 2021). Nevertheless, further studies on RAS are essential for enhancing and advancing intensification in aquaculture (WIDIASA et al., 2024). Nevertheless, intensive and superintensive systems, which involve high stocking density in a reduced water volume, necessitate precise adjustments for the economic viability of the operation (EMERENCIANO et al., 2022). For instance, a small-scale *P. vannamei* (PL$_{10}$) nursery achieved higher profits with a stocking density of 20,000 PLs m^{-3} and survival rates exceeding 90% per production cycle (ASAAD, 2021).

Indeed, stocking density does impact shrimp behavior, and at appropriate densities, shrimp show increased growth potential and well-being (COSTA et al., 2016; HAMILTON et al., 2023). COUTINHO et al. (2024) found that stocking density in a symbiotic pond had a significant effect on the growth and productivity of *P. vannamei* (PL$_{10}$) stocked at a density of 2000 PLs m-3. Likewise, raised in a mixotrophic biofloc system until reaching 0.5 g, *P. vannamei* (PL$_{7–9}$) could be stocked at a density of 5,000 PLs m^{-3}. Despite a survival rate of around 72%, it showed a productivity of approximately 1.72 kg m-3, with no notable negative effects on water quality, growth, and survival (MOHAMMADI et al., 2023). In addition to stocking density, water renewal can affect the growth and survival of *P. vannamei* PLs in superintensive systems (ESPARZA-LEAL et al., 2020; SILVA et al., 2022; SHARAWY et al., 2022). However, unlike coastal regions, water exchanges in super-intensive shrimp farming are limited in inland locations and rely solely on water reuse (EMERENCIANO et al., 2022), which could be facilitated by the RAS.

Water flow rates are essential in RAS as they have a direct impact on water quality, the health of aquatic organisms, and the overall efficiency of the system (EBELING; TIMMONS, 2012). Proper water flow rates are necessary for effective removal of solid waste and adequate oxygenation of the water. It is important to carefully adjust flow rates to ensure optimal performance of mechanical and biological filters while also maintaining the health and well-being of the animals (LIU et al., 2024, NATIVIDADE et al., 2024).

In Brazil and globally, juvenile forms (PLs) of the marine shrimp *P. vannamei* are primarily produced by specialized commercial laboratories. Despite being a high-performance species, there is room for improvement in the initial stages of *P. vannamei* production. The RAS system, a technology that provides better control over water quality variables, has the potential to significantly increase stocking densities of PLs per liter of water. The objective of the current study was to examine how varying stocking densities (30, 60, and 90 postlarvae (PL) L^{-1}) and water flow rates (100%, 200%, and 300% h^{-1}) impact the cultivation of Pacific white shrimp *P. vannamei* during the pre-nursery phase using clear-water RAS technology.

4.2 MATERIAL AND METHODS

The study was conducted at the Laboratory of Marine Shrimps (LCM), Aquaculture Department, Federal University of Santa Catarina, Florianópolis, SC. Twenty thousand 9-day-old *P. vannamei* (PL9) were acquired from the Aquatec® laboratory (Rio Grande do Norte, Brazil), and raised at the LCM until they reached the PL_{15} stage for the experiment.

4.2.1 Experimental design

Twelve thousand nine hundred and sixty PL_{15} (average weight and length of 0.00055 ± 0.0001 g and 9.0 ± 1.0 mm) were distributed randomly into 27 experimental units (8L useful) and exposed to three different water flow rates (100%, 200%, or 300% per hour) in conjunction with three stocking densities of 30, 60, or 90 *P. vannamei* PL per liter. This resulted in a total of nine treatments in a two-factor design (30_{100}, 30_{200}, 30_{300}, 60_{100}, 60_{200}, 60_{300}, 90_{100}, 90_{200}, 90_{300}) with three replicates for each treatment.

The experimental units were housed in a 20m2 room and filled with seawater (35‰, 21.11 ± 0.11°C, dissolved oxygen 7.13 ± 0.02 mg L^{-1}, pH 8.14 ± 0.01, and ≥150 mg $CaCO_3$ L^{-1}) from Barra da Lagoa beach in Florianópolis, SC. The photoperiod regime followed daylight conditions in July (winter in Brazil), with approximately 10h of daily light. A headlamp was used for routine management. The 27 experimental units were organized into three separate lines. Each line was connected to a RAS system that was designed and constructed with identical dimensions and materials, varying only in the water flow rates used.

The RAS was designed according to Timmons and Ebeling (2010), and included a decanter (10 L), mechanical filter (10 L), skimmer (30L), biological reactor (30L), thermostatic heaters (200W), and ultraviolet disinfection system. The biological support material used was polypropylene (Kaldnes type) with a diameter of 30 mm, nine cavities, and an average surface area of 500 m^2/m^3 (Nanoplastic®). The biological filter maturation started two months prior to the experiment. Urea (45%) was utilized as a substrate for establishing the microbial community. Each experimental unit had individual aeration provided by a central system.

The trial spanned 20 days and encompassed the pre-nursery stage (PL_{15} – PL_{35}). Shrimp were fed a commercial feed (Camanutri 40, Neovia, with 40% crude protein, 11% ether extract) ad libitum six times daily (7 am, 11 am, 2 pm, 5 pm, 8 pm, and 11 pm).

4.2.2 Routine management and water quality

Water quality parameters including dissolved oxygen (DO), temperature (measured with a YSI Pro20), and pH (measured with a Tecnal® pH-meter) were monitored twice daily at 8:00 a.m. and 5:00 p.m. Total ammonia nitrogen (TAN), nitrite ($N\text{-}NO_2^-$) levels were analyzed daily using commercial colorimetric kits (Alfakit®). Every three days, water samples were collected for analysis of TAN, $N\text{-}NO_2^-$, nitrate ($N\text{-}NO_3^-$), and alkalinity ($CaCO_3$) at the LCM water quality laboratory, following the method described by Silva et al. (2023). If alkalinity dropped below 100 mg $CaCO_3$ L^{-1}, 5.0g of sodium bicarbonate was added to the system.

Salinity levels were monitored daily using an Eco-Sense YSI EC3 digital salinometer, and total suspended solids (TSS) were measured on days 0, 10, and 20 according to APHA (2017) guidelines. The experimental units were cleaned daily by siphoning to remove leftover feed and waste. The flow rates in each unit were also monitored daily to ensure the treatments were maintained. To account for evaporation, approximately 5% of the system volume was replenished with fresh water from the Florianópolis public water works company.

4.2.3 *Penaeus vannamei* growth performance

Shrimp growth performance was evaluated based on the variables outlined by Silva et al. (2023):

$$\textit{Final weight (FW g)} = \textit{(biomass)} / \textit{(number of animals)}$$

$$\textit{Daily growth coefficient (DGC\% day}^{-1}\textit{)} = [(\textit{final weight}^{1/3} - \textit{initial weight}^{1/3}) \div \textit{days of rearing}] \times 100$$

$$\textit{Survival (S \%)} = [(\textit{final number of animals}) / (\textit{initial number of animals})] \times 100$$

4.3 STATISTICAL ANALYSIS

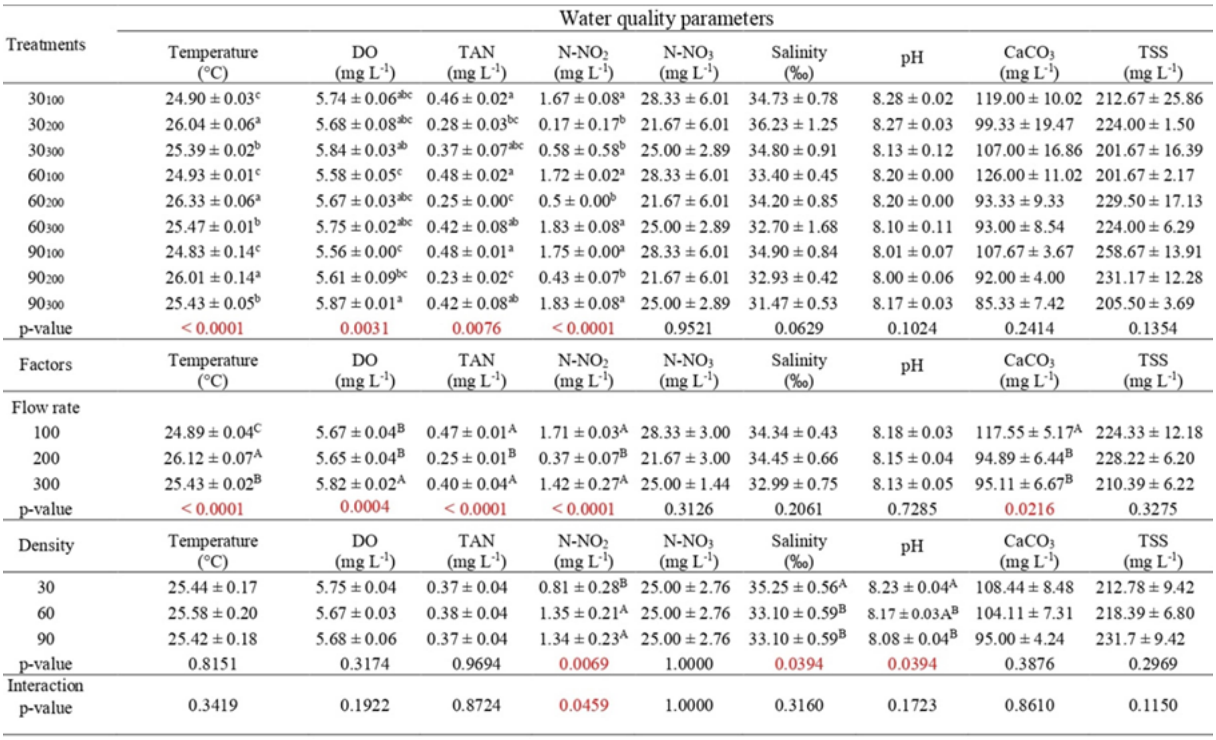
The data underwent Bartlett and Shapiro-Wilk tests to assess homoscedasticity and normality, respectively. Data showing variance heterogeneity were transformed using Log2 (x + 1). After confirming that the assumptions were satisfied, a two-factor analysis of variance (ANOVA) was performed to compare treatments with different densities and flow rates as factors, along with their interaction. If any of the factors showed statistical significance, post-hoc pairwise comparisons were carried out. The analysis was performed using Statistica 10.0 software. Results are presented as mean ± standard deviation, and statistical significance was considered at $p < 0.05$.

4.4 RESULTS

4.4.1 Water quality

Statistically significant differences ($p < 0.05$) were noted among treatments for water quality parameters. Temperature (< 0.0001), DO ($p = 0.0031$), TAN ($p = 0.0076$), and N-NO2^{-} (p = < 0.0001) differed significantly between treatments. The other water quality parameters did not differ among treatments (Table 1).

Table 1 - Water quality parameters (mean ± standard deviation) during the pre-nursery phase of juvenile *P. vannamei* at different stocking densities (30,000; 60,000; and 90,000 PL m^{-3}) and flow rates (100%, 200%, and 300% h^{-1}) using clear water RAS. Different lowercase letters $^{(a,\ b,\ c)}$ in the columns indicate significant differences among treatments by Tukey's test ($p < 0.05$). Different uppercase $^{(A,\ B,\ C)}$ letters indicate significant differences within factors by Tukey's test ($p < 0.05$). DO, dissolved oxygen; TAN, total ammonia nitrogen; NO2^{-}-N, nitrite nitrogen; NO3^{-}-N, nitrate nitrogen; CaCO3,alkalinity; TSS, total suspended solids.



Treatments	Water quality parameters								
	Temperature (°C)	DO (mg L^{-1})	TAN (mg L^{-1})	N-NO$_2$ (mg L^{-1})	N-NO$_3$ (mg L^{-1})	Salinity (‰)	pH	CaCO$_3$ (mg L^{-1})	TSS (mg L^{-1})
30_{100}	24.90 ± 0.03^{c}	5.74 ± 0.06^{abc}	0.46 ± 0.02^{a}	1.67 ± 0.08^{a}	28.33 ± 6.01	34.73 ± 0.78	8.28 ± 0.02	119.00 ± 10.02	212.67 ± 25.86
30_{200}	26.04 ± 0.06^{a}	5.68 ± 0.08^{abc}	0.28 ± 0.03^{bc}	0.17 ± 0.17^{b}	21.67 ± 6.01	36.23 ± 1.25	8.27 ± 0.03	99.33 ± 19.47	224.00 ± 1.50
30_{300}	25.39 ± 0.02^{b}	5.84 ± 0.03^{ab}	0.37 ± 0.07^{abc}	0.58 ± 0.58^{b}	25.00 ± 2.89	34.80 ± 0.91	8.13 ± 0.12	107.00 ± 16.86	201.67 ± 16.39
60_{100}	24.93 ± 0.01^{c}	5.58 ± 0.05^{c}	0.48 ± 0.02^{a}	1.72 ± 0.02^{a}	28.33 ± 6.01	33.40 ± 0.45	8.20 ± 0.00	126.00 ± 11.02	201.67 ± 2.17
60_{200}	26.33 ± 0.06^{a}	5.67 ± 0.03^{abc}	0.25 ± 0.00^{c}	0.5 ± 0.00^{b}	21.67 ± 6.01	34.20 ± 0.85	8.20 ± 0.00	93.33 ± 9.33	229.50 ± 17.13
60_{300}	25.47 ± 0.01^{b}	5.75 ± 0.02^{abc}	0.42 ± 0.08^{ab}	1.83 ± 0.08^{a}	25.00 ± 2.89	32.70 ± 1.68	8.10 ± 0.11	93.00 ± 8.54	224.00 ± 6.29
90_{100}	24.83 ± 0.14^{c}	5.56 ± 0.00^{c}	0.48 ± 0.01^{a}	1.75 ± 0.00^{a}	28.33 ± 6.01	34.90 ± 0.84	8.01 ± 0.07	107.67 ± 3.67	258.67 ± 13.91
90_{200}	26.01 ± 0.14^{a}	5.61 ± 0.09^{bc}	0.23 ± 0.02^{c}	0.43 ± 0.07^{b}	21.67 ± 6.01	32.93 ± 0.42	8.00 ± 0.06	92.00 ± 4.00	231.17 ± 12.28
90_{300}	25.43 ± 0.05^{b}	5.87 ± 0.01^{a}	0.42 ± 0.08^{ab}	1.83 ± 0.08^{a}	25.00 ± 2.89	31.47 ± 0.53	8.17 ± 0.03	85.33 ± 7.42	205.50 ± 3.69
p-value	< 0.0001	0.0031	0.0076	< 0.0001	0.9521	0.0629	0.1024	0.2414	0.1354
Factors	Temperature (°C)	DO (mg L^{-1})	TAN (mg L^{-1})	N-NO$_2$ (mg L^{-1})	N-NO$_3$ (mg L^{-1})	Salinity (‰)	pH	CaCO$_3$ (mg L^{-1})	TSS (mg L^{-1})
Flow rate									
100	24.89 ± 0.04^{C}	5.67 ± 0.04^{B}	0.47 ± 0.01^{A}	1.71 ± 0.03^{A}	28.33 ± 3.00	34.34 ± 0.43	8.18 ± 0.03	117.55 ± 5.17^{A}	224.33 ± 12.18
200	26.12 ± 0.07^{A}	5.65 ± 0.04^{B}	0.25 ± 0.01^{B}	0.37 ± 0.07^{B}	21.67 ± 3.00	34.45 ± 0.66	8.15 ± 0.04	94.89 ± 6.44^{B}	228.22 ± 6.20
300	25.43 ± 0.02^{B}	5.82 ± 0.02^{A}	0.40 ± 0.04^{A}	1.42 ± 0.27^{A}	25.00 ± 1.44	32.99 ± 0.75	8.13 ± 0.05	95.11 ± 6.67^{B}	210.39 ± 6.22
p-value	< 0.0001	0.0004	< 0.0001	< 0.0001	0.3126	0.2061	0.7285	0.0216	0.3275
Density	Temperature (°C)	DO (mg L^{-1})	TAN (mg L^{-1})	N-NO$_2$ (mg L^{-1})	N-NO$_3$ (mg L^{-1})	Salinity (‰)	pH	CaCO$_3$ (mg L^{-1})	TSS (mg L^{-1})
30	25.44 ± 0.17	5.75 ± 0.04	0.37 ± 0.04	0.81 ± 0.28^{B}	25.00 ± 2.76	35.25 ± 0.56^{A}	8.23 ± 0.04^{A}	108.44 ± 8.48	212.78 ± 9.42
60	25.58 ± 0.20	5.67 ± 0.03	0.38 ± 0.04	1.35 ± 0.21^{A}	25.00 ± 2.76	33.10 ± 0.59^{B}	8.17 ± 0.03A^{B}	104.11 ± 7.31	218.39 ± 6.80
90	25.42 ± 0.18	5.68 ± 0.06	0.37 ± 0.04	1.34 ± 0.23^{A}	25.00 ± 2.76	33.10 ± 0.59^{B}	8.08 ± 0.04^{B}	95.00 ± 4.24	231.7 ± 9.42
p-value	0.8151	0.3174	0.9694	0.0069	1.0000	0.0394	0.0394	0.3876	0.2969
Interaction p-value	0.3419	0.1922	0.8724	0.0459	1.0000	0.3160	0.1723	0.8610	0.1150

There was a notable interaction ($p = 0.0459$) between the factors specifically for the N-NO2 levels. The flow rate of 200 and density of 30 consistently showed the lowest nitrite levels over the entire experimental period.

Individually, the flow rate factor significantly affected the levels of temperature, DO, TAN, N-NO2^{-}, and CaCO3 ($p = 0.0216$). 200-flow rate treatment presented a significantly higher (< 0.0001) temperature than those observed in 100- and 300-flow rate treatments. DO was significantly higher ($p = 0.0004$) at the 300-flow rate treatment. 200-flow rate exhibited the lowest levels ($p < 0.0001$) of TAN and N-NO2. Alkalinity was notably elevated ($p = 0.0216$) in the 100-flow rate treatment.

On the other hand, individually, density significantly affected N-$NO2^-$, Salinity, and pH levels. N-$NO2^-$ remained significantly lower, while salinity ($p = 0.0394$) and pH ($p = 0.0394$) remained significantly higher in the 30-density treatment (Table 1).

4.4.2 Growth performance

Significant differences ($p < 0.05$) were found between treatments for *P. vannamei* growth parameters (Table 2). There were significant differences ($p < 0,05$) between treatments in final biomass, PL final weight, and DGC. Survival did not differ between treatments.

Treatment 90100 exhibited a significantly higher ($p < 0.0001$) biomass compared to the other treatments. PL final weight was significantly higher ($p = 0.0018$) in treatment 30300 when compared to treatments 60300, 90200 and 90300, while DGC (%day -1) was significantly higher ($p = 0.0075$) in treatment 30300 when compared to treatments 90200 and 90300. However, PL final weight (g) and DGC ($\%day^{-1}$) were the same among treatments 90100, 30100, 30200, 30300, 60100, 60200 (Table 2).

There was no interaction ($p > 0.05$) of factors for PL growth performance. There was no significant effect ($p > 0.05$) of the flow rate on PL growth performance. However, when considered on its own, density had a significant ($p < 0.05$) impact on final biomass, final weight of PL, and DGC. A density of 30 led to significantly higher final PL weight ($p = 0.0010$) and DGC ($p = 0.0027$) compared to densities of 60 and 90, which were not significantly different from each other. Final biomass was significantly higher ($p < 0.0001$) in the 90-density treatment.

4.5 DISCUSSION

The current study examined the impact of different stocking densities of PL *P. vannamei* along with varying water flow rates. Despite the changes in densities and flow rates, all monitored water quality parameters remained within the ideal range for the species (EMERENCIANO ET AL., 2022). Li et al. (2021) found that stocking densities had a negative correlation with temperature and dissolved oxygen levels, potentially affecting the growth of aquacultured animals. The researchers also noted that lower stocking densities were associated with reduced feeding rates and improved water quality, whereas higher stocking densities had the opposite effect, leading to deteriorating water quality and higher mortality rates. In the current study, when considered on its own, the stocking density factor did not have a significant effect on temperature and dissolved oxygen levels. Instead, it affected N-NO2, salinity, and pH levels.

Closed systems like RAS, as utilized in this research, can maintain stable water quality parameters when appropriately sized and with an established microbial community (OWATARI et al., 2018). Nitrification is the conversion of ammonium ($NH4^+$) into nitrite ($N\text{-}NO2^-$) and then into nitrate ($N\text{-}NO3^-$) by nitrifying bacteria. This process consumes hydroxyls (OH-) and reduces alkalinity, leading to the acidification of the medium and a decrease in pH. Therefore, nitrification typically results in a lower pH, making the water more acidic. This could account for the lower pH levels observed in treatments with densities of 60 and 90 Pls L^{-1}, which are associated with higher levels of N-NO2.

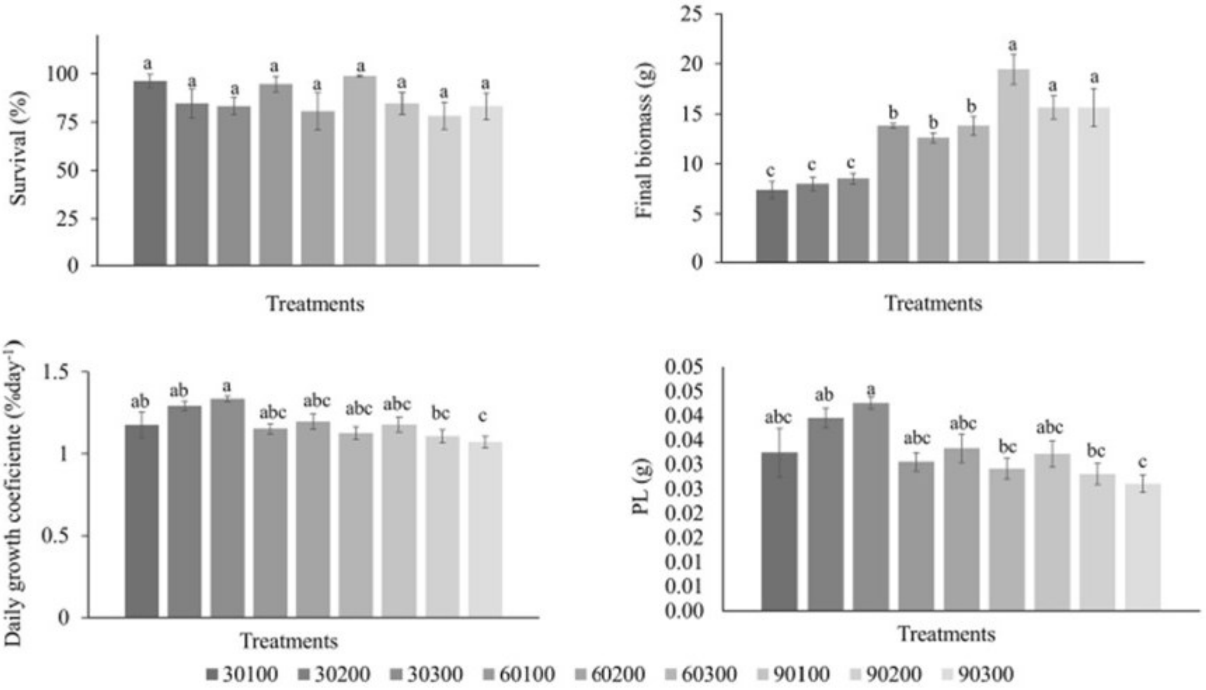
On the other hand, the ecdysis process may deplete salts present in the water, particularly calcium and other vital minerals (JAFFER et al., 2020). Following the shedding of the exoskeleton, crustaceans must re-harden it through a process known as calcification. This involves the absorption of ions like calcium directly from the surrounding water. Furthermore, prior to molting, crustaceans can increase calcium and magnesium levels in their hemolymph by absorbing water, creating a crucial relationship between mineral levels and salinity (LEMOS; WEISSMAN, 2021). This salt intake can be significant in closed systems such as RAS, potentially accounting for the lower salinities observed at densities of 60 and 90 PLs L^{-1}. Thus, in line with the current research, it is important to consider other water quality parameters such as total ammonia nitrogen, temperature, $N\text{-}NO2^-$, $N\text{-}NO3^-$, TSS, and pH when determining the optimal stocking density for a species.

In the present study, water flow rate was a significant factor that, on its own, led to greater fluctuations in water quality parameters. CHEN et al. (2019) noted that as the water recirculation rate increased in a RAS system, water quality parameters such as ammonia and nitrite decreased. The researchers highlighted the significant influence of water recirculation rate on microbial communities, water quality, and shrimp growth. Therefore, enhancing the water recirculation rate could enhance water quality and facilitate shrimp growth. Nonetheless, *P. vannamei* exhibited higher survival rates and yields under a low water recirculation rate (CHEN et al., 2019). This was refuted in the current study. The survival of PL *P. vannamei* was not impacted by the water flow rate factor, with consistent survival rates observed at 100%, 200%, or 300% h^{-1}. Similarly, the growth parameters of PL final weight (g) and daily growth coefficient ($\%day^{-1}$) remained unaffected by the water flow rate factor.

Table 2 - Growth performance (mean±standard deviation) of juvenile P. vannamei reared at different stocking densities (30, 60 and 90 PL L-1) and flow rates (100%, 200% and 300% h-1) during the pre-nursery phase using clean water RAS technology. Different lowercase letters (a, b, c) in the columns indicate significant differences between treatments by Tukey's test ($p < 0.05$). Different uppercase (A, B, C) letters indicate significant differences within factors by Tukey's test ($p < 0.05$). DGC = Daily growth coefficient.

Treatments	Growth parameters			
	Survival (%)	Final biomass (g)	PL final weight (g)	DGC (%day^{-1})
30100	96.25 ± 6.14	7.39 ± 1.49^{c}	0.0324 ± 0.005^{abc}	1.17 ± 0.08^{abc}
30200	84.58 ± 13.00	7.99 ± 1.15^{c}	0.0395 ± 0.002^{ab}	1.29 ± 0.03^{ab}
30300	83.33 ± 7.78	8.51 ± 0.96^{c}	0.0425 ± 0.001^{a}	1.33 ± 0.02^{a}
60100	94.72 ± 6.39	13.81 ± 0.41^{b}	0.0305 ± 0.002^{abc}	1.15 ± 0.03^{abc}
60200	80.62 ± 16.68	12.61 ± 0.83^{b}	0.0333 ± 0.003^{abc}	1.19 ± 0.05^{abc}
60300	98.82 ± 1.03	13.79 ± 1.62^{b}	0.0291 ± 0.002^{bc}	1.13 ± 0.04^{abc}
90100	84.58 ± 9.93	19.46 ± 2.64^{a}	0.0321 ± 0.003^{abc}	1.18 ± 0.04^{abc}
90200	78.28 ±12.00	15.65 ± 2.00^{b}	0.0280 ± 0.002^{bc}	1.11 ± 0.03^{bc}
90300	83.18 ± 11.90	15.65 ± 3.29^{b}	0.0260 ± 0.002^{c}	1.07 ± 0.03^{c}
p-value	0.2186	< 0.0001	0.0018	0.0075
Factors				
Flow rate	Survival (%)	Final biomass (g)	PL final weight (g)	DGC (%day^{-1})
100	91.85 ± 8.73	13.55 ± 5.45	0.0317 ± 0.005	1.17 ± 0.02
200	81.16 ± 12.46	12.08 ± 3.56	0.0335 ± 0.006	1.20 ± 0.03
300	88.45 ± 10.55	12.65 ± 3.72	0.0325 ± 0.008	1.18 ± 0.04
p-value	0.1130	0.2500	0.6737	0.8308
Density	Survival (%)	Final biomass (g)	PL final weight (g)	DGC (%day^{-1})
30	88.05 ± 10.24	7.96 ± 1.16^{C}	0.0381 ± 0.007^{A}	1.27 ± 0.03^{A}
60	91.39 ± 12.25	13.40 ± 1.11^{B}	0.0310 ± 0.004^{B}	1.16 ± 0.02^{B}
90	79.19 ± 10.21	16.22 ± 3.01^{A}	0.0290 ± 0.004^{B}	1.12 ± 0.02^{B}
p-value	0.1835	< 0.0001	0.0010	0.0027
Interaction p-value	0.4986	0.1705	0.0588	0.0607

Figure 1 - Growth performance (mean ± standard deviation) of *juvenile L. vannamei* reared at differente stocking densities (30,000; 60,000; and 90,000 PL m^{-3}) and flow rates (100%, 200% and 300% h^{-1}) during the pre-nursery phase using clear water RAS. Different lowercase letters. $^{(a,b,c)}$ indicate significant diferences between treatments by Tukey's test (p-value < 0.05).



It is crucial to emphasize that varying water flow rates can impact the growth performance of aquacultured aquatic organisms. This was illustrated by LIU et al (2023) in their study on Micropterus salmoides in a RAS system. The higher water flow rates were found to have a negative effect on the specific growth rate of the animals, likely due to the increased metabolic expenditure caused by the greater volume of water. Factors like water velocity at the tank bottom can cause physical stress, induce molting, and decrease shrimp performance (LEMOS; WEISSMAN, 2021). This may be attributed to the fact that shrimp expend more energy during various forms of movement such as walking, swimming, and tail flicking (LI et al., 2018). The movement of pleopods or uropods is a highly energy-intensive activity for shrimp, requiring significantly more energy than when they are at rest (YU et al., 2009). LI et al. (2018) also noted that glycogen breakdown in the pleopod muscle of *P. vannamei* rises with the pleopod stroke rate to meet the heightened energy demands of rapid swimming, while glycogen breakdown in the abdominal muscles increases during tail flicking. Furthermore, *P. vannamei* displays positive rheotaxis in water currents, indicating increased energy consumption to maintain its position by swimming against the flow. Nevertheless, in the present study, growth performance was not affected by water flow rates.

On the other hand, the current research showed that a superintensive pre-nursery for *P. vannamei* (PL$_{15–35}$) can be successfully set up with a high stocking density (90 PLs L^{-1}) and minimal water flow rate (100% h^{-1}) in a clear-water RAS. While *P. vannamei* can tolerate high stocking densities in grow-out ponds, deviating from the recommended optimum levels can have adverse effects on the physiology and growth performance of the animals (MUGWANYA et al., 2022). In biofloc systems, SAID et al. (2024) conducted a study comparing the growth performance of *P. vannamei* at low density (50 shrimp m^{-2}) and high density (200 shrimp m^{-2}) and found that exposing shrimp to high densities led to negative physiological effects, resulting in decreased growth performance compared to shrimp raised at lower densities. In contrast, the current study found that the growth performance of *P. vannamei* was statistically similar at high stocking densities (90 PLs L^{-1}) compared to lower densities (30 and 60 PLs L^{-1}) when a water flow rate of 100% h^{-1} was maintained. This suggests that the pre-nursery phase of this species could be enhanced in clear-water RAS systems.

SILVA et al. (2021) studied how different stocking densities (2000, 4000, and 6000 shrimp m^{-3}) affected *P. vannamei* during the nursery phase in a low salinity biofloc system. They found that shrimp production was significantly higher (0.133 ± 0.028 kg m^{-3}) at a density of 6000 shrimp m^{-3}. However, shrimp survival was significantly higher at the lowest stocking density (71.66 ± 10.36%). In contrast to the findings of the current study, where survival rates were similar across treatments.

SUWOYO AND HENDRAJAT (2021) also found that, with 70 days of cultivation in fiber tank and varying stocking densities (100, 200, and 300 PL m^{-3}), *P. vannamei* PL_{42} (initial weight 0.14g) experienced decreased final weight and absolute weight as the density reached 300 shrimp m^{-3}. In our study, the final weight and daily growth coefficient of *P. vannamei* (from PL_{15} to PL_{35}) were not adversely affected when raised at high densities (90 PL L^{-1}) and reduced water flow rates (100% h^{-1}). This suggests a potential new approach for pre-nursery rearing in clear water using RAS technology.

Indeed, inland marine shrimp culture systems utilizing RAS technology are becoming increasingly popular for *P. vannamei* production, as they offer improved control over environmental factors and waste management (FRANÇA et al., 2024; DHANDE et al., 2024). A study conducted by RODRIGUEZ-OLAGUE et al. (2021) compared the growth performance of *P. vannamei* in clean-water RAS, photoheterotrophic, and biofloc systems with stocking densities of 500, 1000, and 1500 shrimp m^{-3} over a 35-day nursery phase. The researchers observed that growth parameters were significantly higher in the photoheterotrophic and biofloc systems at the lowest density (500 shrimp m^{-3}), while the clean water RAS system exhibited the lowest survival rate.

Stocking density and water flow rates are important considerations in *P. vannamei* farming, as they directly impact shrimp performance and water quality. High stocking densities can lead to competition for resources like oxygen and nutrients, as well as increased stress on shrimp, potentially resulting in lower growth and survival rates. However, this study found that these effects were only significant when high densities were paired with high flow rates. Conversely, high water flow rates (300 % h^{-1}) maintained higher dissolved oxygen levels in the water, a critical factor for the well-being of aquatic organisms.

4.6 CONCLUSION

Postlarvae (from PL_{15} to PL_{35}) of Pacific white shrimp *P. vannamei* can be successfully raised in high densities of up to 90 PL L^{-1} during the pre-nursery phase in a clear-water RAS system. A water flow rate of up to 100% h^{-1} can be used without affecting animal growth, while still maintaining water quality parameters suitable for the species.

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APÊNDICES

Apêndice A - Hydraulic recirculating aquaculture system (RAS).
Photo by Marcelo Santana

Apêndice B - Experimental room with 27 units.

Photo by Marcelo Santana

Apêndice C - Decanter used to separate solids from the recirculating water in the RAS system.
Photo by Marcelo Santana

Apêndice D - Mechanical filter filled with polyester fiber to retain suspended solids.
Photo by Marcelo Santana

Apêndice E - Skimmer and biological reactor used for foam fractionation and nitrification.
Photo by Marcelo Santana

Apêndice F - Ultraviolet (UV) disinfection system.
Photo by Marcelo Santana

Apêndice G - Media maturation system.
Photo by Marcelo Santana

Apêndice H - Polypropylene biological support media.
Photo by Marcelo Santana

Apêndice I - Water recirculation pump.
Photo by Marcelo Santana