



**UNIVERSIDADE FEDERAL RURAL DE PERNAMBUCO**

**PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO**

**PROGRAMA DE PÓS-GRADUAÇÃO EM RECURSOS PESQUEIROS E AQUICULTURA**

**EFEITO DO AJUSTE IÔNICO EM ÁGUA DE BAIXA SALINIDADE NO DESEMPENHO  
ZOOTÉCNICO E COMPOSIÇÃO CENTESIMAL DO *Litopenaeus vannamei* CULTIVADO EM  
SISTEMA SIMBIÓTICO**

**CAIO RUBENS DO RÊGO OLIVEIRA**

Dissertação apresentada ao Programa de Pós-Graduação em Recursos Pesqueiros e Aquicultura da Universidade Federal Rural de Pernambuco como exigência para obtenção do título de Mestre.

**Prof. Dr. Luis Otavio Brito da Silva**

Orientador

**Profº. Dr. Paulo Roberto Campagnoli de Oliveira Filho**

Co-orientador

**RECIFE,**

**Fevereiro/2022**

**UNIVERSIDADE FEDERAL RURAL DE PERNAMBUCO**

**PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO**

**PROGRAMA DE PÓS-GRADUAÇÃO EM RECURSOS PESQUEIROS E AQUICULTURA**

**EFEITO DO AJUSTE IÔNICO EM ÁGUA DE BAIXA SALINIDADE NO DESEMPENHO ZOOTÉCNICO E COMPOSIÇÃO CENTESIMAL DO *Litopenaeus vannamei* CULTIVADO EM SISTEMA SIMBIÓTICO**

**CAIO RUBENS DO RÊGO OLIVEIRA**

Dissertação julgada adequada para obtenção do título de mestre em Recursos Pesqueiros e Aquicultura. Defendida e aprovada em 18/02/2022 pela seguinte Banca Examinadora.

---

**Prof. Dr. Luis Otavio Brito da Silva**

Orientador

Departamento de Pesca e Aquicultura/Universidade Federal Rural de Pernambuco

---

**Prof. Dr. Alfredo Olivera Gálvez**

Membro interno

Departamento de Pesca e Aquicultura / Universidade Federal de Alagoas

---

**Profa. Dra. Gelcirene de Albuquerque Costa**

(Membro Externo)

Departamento de Pesca e Aquicultura/Universidade Federal Rural de Pernambuco

---

**Profa. Dr. Suzianny Maria Bezerra Cabral da Silva**

(Membro Suplente Interno)

Departamento de Pesca e Aquicultura/Universidade Federal Rural de Pernambuco

---

**Profa. Dra. Jéssika Lima de Abreu**

(Membro Suplente Externo)

Campus Serra Talhada/Universidade Federal Rural de Pernambuco

## Dedicatória

Dedico este trabalho a todos que confiam em mim, principalmente a minha mãe, Regina Célia e minha tia, Roseneide Augusta.

Dados Internacionais de Catalogação na Publicação  
Universidade Federal Rural de Pernambuco  
Sistema Integrado de Bibliotecas  
Gerada automaticamente, mediante os dados fornecidos pelo(a) autor(a)

---

- O48ee Oliveira, Caio  
EFEITO DO AJUSTE IÔNICO EM ÁGUA DE BAIXA SALINIDADE NO DESEMPENHO ZOOTÉCNICO E  
COMPOSIÇÃO CENTESIMAL DO *Litopenaeus vannamei* CULTIVADO EM SISTEMA SIMBIÓTICO / Caio Oliveira. -  
2022.  
49 f.
- Orientador: Luis Otavio Brito da Silva.  
Coorientador: Paulo Roberto Campagnoli de Oliveira Filho.  
Inclui referências.
- Dissertação (Mestrado) - Universidade Federal Rural de Pernambuco, Programa de Pós-Graduação em Recursos  
Pesqueiros e Aquicultura, Recife, 2022.
1. Baixa Salinidade. 2. Perfil Iônico. 3. Composição bioquímica. 4. Flocos microbianos. 5. Sistema Intensivo. I. Silva,  
Luis Otavio Brito da, orient. II. Filho, Paulo Roberto Campagnoli de Oliveira, coorient. III. Título

## **Agradecimentos**

Primeiramente, gostaria de agradecer a Deus, por estar presente em todos os momentos e escolhas da minha vida;

Agradeço a minha mãe, Regina Célia e minha tia Roseneide Augusta, por durante toda minha vida, terem perseverança, cuidado e amor para comigo, amo vocês;

Agradeço a minha irmã, Carolina Rêgo, por ser a irmã mais chata e legal ao mesmo tempo;

Agradeço a minha companheira, Nathália Maria, pelo apoio, companhia, pela força que me dá em todos os momentos, te amo, Amor;

A Universidade Federal Rural de Pernambuco (UFRPE), em especial ao Programa de Pós-Graduação em Recursos Pesqueiros e Aquicultura (PRPPG) e aos professores que fizeram parte da minha graduação e pós-graduação;

A Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) pela concessão da bolsa de mestrado;

Aos meus amigos de laboratório: Rildo Andrade, Otávio Augusto e Valdemir Queiroz pela companhia e auxílio durante todo o período em que passamos juntos e aos demais colegas do Laboratório de Carcinicultura – LACAR/DEPAq/UFRPE que sempre apoiaram no decorrer da pesquisa;

A Elizabeth dos Santos por aguentar o aperreio em me auxiliar na realização da estatística do trabalho;

A Reginaldo Florêncio pelas oportunidades que mostrou e auxiliou nos momentos de necessidade;

Ao meu orientador Prof<sup>o</sup> Dr. Luis Otavio Brito da Silva, por ser além de um orientador, um grande amigo para todos os momentos, pela paciência e ensinamentos que me passou durante todo esse período;

Ao Prof<sup>o</sup> Dr. Paulo Roberto Campagnoli de Oliveira Filho, pela co-orientação e apoio;

A todos os membros da banca pelas valiosas considerações;

E a todas pessoas que sempre me apoiaram e acompanharam minha jornada.

## Resumo

O cultivo de camarão marinho em águas interiores ocorre em diferentes salinidades e perfis iônicos em todo o mundo. Apesar da contribuição desta modalidade na aquicultura, diversos obstáculos são observados para a realização de um ciclo de cultivo completo. Este estudo teve como objetivo a avaliação de diferentes composições iônicas em água oligohalina sobre o desempenho zootécnico e composição centesimal do *Litopenaeus vannamei*, cultivado em sistema simbiótico. O experimento foi realizado durante 56 dias (densidade: 300 camarões/m<sup>3</sup>) em unidades experimentais de 60 L, em um delineamento experimental inteiramente casualizado, sob três tratamentos: PI – água na salinidade ~ 2,7 g/L com sua relação Ca:Mg:K ajustada para 1:3:1, C1 (controle) – água na salinidade ~ 2,7 g/L e C2: água na salinidade ~ 2,7 g/L com correção de magnésio (Mg<sup>2+</sup>) equivalente a proporção a água do mar, todos em triplicata. Os indivíduos atingiram um peso final (g) de 3,79 ± 0,07 – 4,72 ± 0,09 e uma produtividade (Kg/m<sup>3</sup>) de 0,61 ± 0,14 - 1,22 ± 0,06, apresentando diferenças significativas entre os tratamentos. O melhor resultado em peso médio final e produtividade foram observados nos tratamentos C1 e C2, por outro lado, o tratamento PI apresentou os menores resultados, isso pode ser influenciado pela adição de cloreto de potássio (KCl) para aumentar a concentração de potássio (K<sup>+</sup>), resultando em uma redução da razão Na:K. Em relação à qualidade da água, foi observado um aumento da alcalinidade total (mg CaCO<sub>3</sub>/L) em todos os tratamentos durante o experimento, também foram observadas baixas concentrações de compostos nitrogenados, o que pode ter sido acarretado pelo sistema simbiótico e o uso de substratos artificiais compostos por conchas de *Anomalocardia brasiliiana*, que funcionaram como substrato para bactérias e uma fonte de carbonato de cálcio. A composição centesimal dos camarões não apresentou diferença significativa entre os tratamentos, porém, a composição dos flocos microbianos apresentou diferenças significativas nas cinzas (%). A relação Na:K mostrou uma relação positiva com o desempenho zootécnico dos camarões neste estudo. Nossos resultados indicam que juvenis de camarão apresentam desempenho satisfatório em água oligohalina em sistema simbiótico.

**Palavras-chave: Baixa salinidade; Perfil iônico; Composição bioquímica; Flocos microbianos; Sistema intensivo.**

## **Abstract**

Shrimp farming in inland waters is carried out under different salinity and ionic water profiles worldwide. Despite the contribution of this culture modality, several obstacles are observed to accomplish a complete farming cycle. This study aimed the evaluation of different ionic compositions in oligohaline water on the zootechnical performance and proximal composition of *Litopenaeus vannamei* reared in synbiotic system. A 56-day trial (300 shrimp/m<sup>3</sup>) was performed in 60 L experimental units in a completely randomized experimental design, under three treatments: IP – water at a salinity ~2,7 g/L with its Ca:Mg:K ratio adjusted to 1:3:1, C1 (control) - water at a salinity ~2,7 g/L, and C2 - water at a salinity ~2,7 g/L with a magnesium (Mg<sup>2+</sup>) adjusted seawater equivalent concentration, all in triplicates. The individuals reached a final weight (g) of  $3.79 \pm 0.07$  –  $4.72 \pm 0.09$  and an average yield (kg/m<sup>3</sup>) of  $0.61 \pm 0.14$  -  $1.22 \pm 0.06$ , showing significant differences among treatments, the best overall growth and average yield were observed at C1 and C2, in the other hand PI treatment presented the worst results, this may be influenced due to potassium chloride (KCl) addition to increase potassium (K<sup>+</sup>) concentration, resulting in a Na:K ratio reduction. Regarding the water quality, an increase of total alkalinity (mg CaCO<sub>3</sub>/L) was observed in all low salinity treatments during the experiment, also, low concentrations of nitrogenous compounds were observed, this may be accomplished due to the presence of artificial substrates composed by *Anomalocardia brasiliiana* shells, that worked as a substrate for bacteria and a calcium carbonate source. Shrimps' proximal compositions did not show significant differences among treatments, however, microbial floc composition presented significant differences in ashes (%). Na/K ratio showed a positive relationship to shrimps zootechnical performance in this study. Our results indicate that shrimp juveniles present satisfactory performance in oligohaline water in synbiotic system.

**Key Words: Low salinity; Ionic profile; Proximal composition; Microbial flocs; Intensive system**

## Lista de Tabelas

<b>Tabela 1.</b> Perfil iônico inicial da água do cultivo de <i>Litopenaeus vannamei</i> em sistema simbiótico utilizando água com baixa salinidade	16
<b>Tabela 2.</b> Aumento em porcentagem da concentração iônica (após 72 horas de aplicação de 100 g/m <sup>3</sup> ) para os fertilizantes químicos utilizados no ajuste iônico.	18
<b>Tabela 3.</b> Variáveis de qualidade de água durante o cultivo do <i>Litopenaeus vannamei</i> em sistema simbiótico em água oligohalina com diferentes composições iônicas.	23
<b>Tabela 4.</b> Concentração dos principais íons, razão Ca:Mg:K, e erro de análise (%) na água do cultivo do <i>Litopenaeus vannamei</i> em água oligohalina utilizando sistema simbiótico.	24
<b>Tabela 5.</b> Composição centesimal do <i>Litopenaeus vannamei</i> (base úmida) e floco microbiano (base seca), cultivado em diferentes composições iônicas com água oligohalina em sistema simbiótico.	27
<b>Tabela 6.</b> Desempenho zootécnico de juvenis <i>Litopenaeus vannamei</i> cultivados em diferentes composições iônicas com água oligohalina em sistema simbiótico durante 56 dias*.	28



## Lista de Figuras

**Figura 1.** Variação dos cátions, ânions, proporções iônicas, dureza total e alcalinidade total durante o cultivo do *L.vannamei* em sistema simbiótico, em baixa salinidade com diferentes composições iônicas. 25

## **Sumário**

1. Introdução	5
1.1. Objetivos	9
1.1.1. Objetivo Geral	9
2. Hipóteses	10
3. Referências	10
4. Artigo Científico	15
1. Introdução	18
2. Material e Métodos	20
3. Resultados	28
4. Discussão	33
5. Conclusão	39
6. Agradecimentos	39
7. Referências Bibliográficas	40
5. Considerações Finais	49

## 1. Introdução

O camarão branco do pacífico *Litopenaeus vannamei* (Boone, 1931) é a espécie de camarão marinho mais produzida no mundo. No ano de 2018 a produção da espécie representou 52,9% da produção total de crustáceos, atingindo 4,9 milhões de toneladas, com um incremento de 22,8% em relação à produção do ano de 2016 (FAO, 2020). Esse incremento na produção de crustáceos também se deve pela produção do camarão marinho em zonas interiores, em água oligohalina e mesohalina, visto que a produção em zonas litorâneas tem bastante conflitos relacionados ao uso de terras e de água com agências ambientais. Dessa forma o cultivo em zonas interiores vem sendo considerado como alternativa para uma contínua expansão da carcinicultura (FAO, 2020). Segundo Jaime-Ceballos et al. (2012), outro fator que auxilia na expansão desta atividade para zonas interiores é o aspecto sanitário, visto que nelas não ocorrem a presença de outros crustáceos marinhos, que são vetores de doenças virais como a mancha branca (WSSV), síndrome de Taura (TS) e a doença da cabeça amarela (YHV). Entretanto, nos últimos anos observa-se o aumento nos casos de surtos de doenças em águas interiores.

O *Litopenaeus vannamei* é nativo da costa norte do Peru ao noroeste do México e por ser uma espécie eurialina, pode tolerar altas variações de salinidade, desde 0,5 até 60 g/L (DAVIS et al., 2004; ESPARZA-LEAL et al., 2010; ROY et al., 2010; CHONG-ROBLES et al., 2013, JAFFER et al., 2019). Aliado à adaptação do cultivo em diferentes salinidades, o sucesso do *L. vannamei* está atrelado a sua alta taxa de crescimento, grande aceitação no mercado consumidor, tolerância a altas densidades de estocagem e a variações ambientais (LIN e CHEN, 2003; RACOTTA et al., 2003; BRIGGS et al., 2004; XU e PAN., 2014). Essas qualidades, conferem ao *L. vannamei* como espécie preferida nos cultivos de camarões marinhos em águas de baixa salinidade, seja esta advinda de rios, lagos, poços e afloramentos subterrâneos. A implementação deste cultivo auxiliou no desenvolvimento da carcinicultura em diversos países como Brasil, China, Equador, Estados Unidos, México e Venezuela (SAMOCHA et al., 2001; BOYD e THUNJAI, 2003; MIRANDA et al., 2010; NUNES e LÓPEZ, 2001; ROY et al., 2010; GODÍNEZ-SIORDIA et al., 2011; ARUNA e FELIX, 2017).

No Brasil, especialmente no Nordeste, o cultivo do *L. vannamei* é uma importante fonte de renda, principalmente para os produtores rurais (MARQUES et al., 2016). Principalmente quando a atividade ocorre em zonas interiores, auxiliando a retenção de mão de obra local, além de fortalecer e modificar a economia regional. Esta contribuição das zonas interioranas é desenvolvida pela abundância de aquíferos subterrâneos, com mais de 330 mil poços registrados no Serviço Geológico do Brasil e 83 mil destes poços apresentam salinidade próxima a 0,5 g/L (CPRM, 2020), apresentando dessa forma condições para o cultivo do *L. vannamei*.

Embora o interesse no cultivo do *L. vannamei* em água de baixa salinidade esteja em pleno crescimento nos últimos anos, pesquisas relatando o desempenho zootécnico do *L. vannamei* em cultivos utilizando água oligohalina ocorrem desde os anos 90, tendo em vista que nessa década já havia uma preocupação com o custo de terras em zonas costeiras e questões ambientais (BRAY et al., 1994; LARAMORE et al., 2001; SAMOCHA et al., 2004). Os primeiros resultados referem-se ao efeito da idade das pós-larvas, tempo de aclimação e taxa de redução da salinidade na sobrevivência e desempenho dos camarões (MCGRAW et al., 2002; MCGRAW e SCARPA, 2004; ROY et al., 2009; ESPARZA-LEAL et al., 2010). A partir dos resultados obtidos, diversos estudos apresentaram dados satisfatórios sobre o desempenho do camarão marinho cultivado em ambientes oligohalinos (SANTOS et al., 2009; MAICÁ et al., 2014; ESPARZA et al., 2016; VALENZUELA-MADRIGAL et al., 2017). Em contrapartida, Ray e Lotz (2017), afirmam que ainda há uma falta de informação a respeito do desempenho do *L. vannamei* em sistemas intensivos com diferentes perfis iônicos, demonstrando dessa forma um desafio para novas pesquisas a respeito do cultivo intensivo e superintensivo do camarão marinho em baixa salinidade.

Um dos principais desafios no cultivo do camarão marinho nessas condições diferenciadas, é a determinação dos requisitos iônicos ideais da água, visto que a composição iônica e a salinidade podem variar amplamente entre os locais de cultivo. Além disso, para potencializar o desenvolvimento de espécies marinhas em águas de baixa salinidade, as proporções iônicas devem-se manter semelhantes à água marinha (BOYD e THUNJAI, 2003). A preocupação com a composição iônica na água advém da sua importância no desenvolvimento do camarão, visto que as concentrações dos cátions e ânions, atuam na osmorregulação, sobrevivência, metabolismo e crescimento do *L.*

*vannamei* (BOYD e THUNJAI, 2003; SAOUD et al., 2003; DAVIS et al., 2005). Por outro lado, o desequilíbrio ou deficiência na relação entre esses íons, proporcionam limitações no desenvolvimento ou até na mortalidade do animal (VALENZUELA-MADRIGAL et al., 2017; NEHRU et al., 2018). Por isso, a partir destes fundamentos científicos, independente da salinidade em que o cultivo é realizado, é imprescindível a observação das concentrações individuais e relativas destes íons, principalmente os íons majoritários que são responsáveis por grande parte dos sólidos totais dissolvidos nas águas naturais (BOYD e THUNJAI, 2003), sendo os cátions: cálcio ( $\text{Ca}^{2+}$ ), magnésio ( $\text{Mg}^{2+}$ ), sódio ( $\text{Na}^+$ ) e potássio ( $\text{K}^+$ ) e os ânions: cloreto ( $\text{Cl}^-$ ), sulfato ( $\text{SO}_4^{2-}$ ), bicarbonato ( $\text{HCO}_3^-$ ) e carbonatos ( $\text{CO}_3^{2-}$ ).

Assim, visando à correção da concentração dos íons na água, fertilizantes minerais estão sendo utilizados com o intuito de manter proporções iônicas ideais para o cultivo do *L. vannamei* em sistemas semi intensivos utilizando água de baixa salinidade (ROY e DAVIS, 2010; SUGUNA, 2020). Neste sentido, Aruna e Felix (2017) adicionaram fertilizantes a base de cálcio ( $\text{Ca}^{2+}$ ) e magnésio ( $\text{Mg}^{2+}$ ) em tanques de cultivo a fim de compensar a deficiência desses íons e avaliar o efeito desta adição no crescimento e sobrevivência do *L. vannamei*. Enquanto Liu et al. (2016) utilizaram fertilizantes minerais em águas de poço com baixa salinidade para testar diversas razões de sódio ( $\text{Na}^+$ ) e potássio ( $\text{K}^+$ ) no crescimento e composição centesimal do *L. vannamei*.

A adição de fertilizantes minerais na água, pode modificar a composição centesimal de camarões peneídeos, pois esta varia de acordo com a salinidade do cultivo (HUANG et al., 2014). Estudos apontam que quanto mais baixa a salinidade maior será a umidade do *L. vannamei* (LIANG et al., 2008; PEREZ-VELAZQUEZ et al., 2007). No entanto, resultados controversos em relação ao conteúdo de proteínas, lipídios e cinzas foram obtidos por Liu et al. (2016) que obtiveram maiores valores destas três características em salinidades mais altas, enquanto Li et al. (2007), Perez-Velazquez et al. (2007) e Liang et al. (2008) observaram um comportamento inverso. Além disso, há também uma falta de conhecimento em como a adição de fertilizantes minerais pode influenciar na composição centesimal do *L. vannamei* em sistemas intensivos.

A utilização dos fertilizantes minerais exige alto investimento financeiro. Segundo Boyd (2018), são necessárias 2 ou 3 aplicações de fertilizantes minerais para manutenção das concentrações iônicas em um cultivo de camarões com duração entre 100 a 160 dias, sendo esta frequência influenciada tanto pelo perfil iônico da água quanto o tamanho do tanque e/ou viveiro de cultivo e as renovações de água. Dessa forma, para otimizar o uso dos fertilizantes minerais e a compensação iônica, é prudente utilizar sistemas com mínima troca de água, visto que estes sistemas reduzem o descarte de água, sendo também um método que oferece maior biossegurança ao cultivo (WASIELESKY et al., 2006; SAMOCHA et al., 2017).

O sistema de mínima troca de água consiste na reciclagem de parte dos resíduos e/ou nutrientes dos ambientes de cultivo para produção de biomassa microbiana, que ocorre devido à adição de uma fonte de carbono orgânico e inorgânico (EMERENCIANO et al., 2013). A redução na troca de água e a adição do carbono (orgânico e inorgânico) proporciona o surgimento de agregados microbianos que são responsáveis pelo controle da qualidade da água, influenciando diretamente no controle dos compostos nitrogenados (EKASARI et al., 2014; KRUMMENAUER et al., 2014; XU et al., 2016; CARDONA et al., 2016; ESPARZA-LEAL et al., 2016). Desta forma, o sistema simbiótico vem sendo utilizado na aquicultura, provendo a redução na concentração de amônia e o aumento abrupto nos sólidos suspensos na água. Este sistema se baseia na fermentação ou respiração microbiana de carboidratos como, farelos de arroz, soja e trigo, proporcionando a formação de agregados microbianos em sistemas com mínima troca de água, que além de melhorar a qualidade da água, também servem como alimento aos organismos cultivados, auxiliando no crescimento. (ROMANO et al., 2018; LIMA et al., 2021; SILVA et al., 2021, PIMENTEL et al., 2022; SANTOS et al., 2022). Apesar de vários estudos em sistemas semi intensivos e mais informações adquiridas a respeito do cultivo do *L. vannamei* em água oligohalina nos últimos anos, ainda existe uma necessidade de novos estudos em sistemas intensivos, dessa forma, essa pesquisa demonstra-se importante na compreensão de como diferentes composições iônicas podem influenciar no desempenho zootécnico e composição centesimal do camarão marinho em água oligohalina em sistema simbiótico.

## **1.1. Objetivos**

### **1.1.1. Objetivo Geral**

Avaliar o ajuste iônico no desempenho zootécnico e a composição centesimal do *L. vannamei* em água oligohalina no sistema simbiótico.

### **1.1.2. Objetivos Específicos**

- Avaliar o efeito do ajuste iônico nas variáveis físico-químicas da água durante o cultivo em águas oligohalinas;
- Avaliar o índice zootécnico dos camarões cultivados com ajustes iônicos em águas oligohalinas;
- Analisar a composição centesimal do floco microbiano e do *L. vannamei* em cultivo utilizando ajustes iônicos em águas oligohalinas;

## **2. Hipóteses**

- Os ajustes iônicos na água melhoram o desempenho zootécnico do *L. vannamei* em águas oligohalinas.
- Os ajustes iônicos na água alteram a composição centesimal do *L. vannamei*.

### 3. Referências

- ARUNA, S.; FELIX, S., 2017 The effect of ionic concentration of low saline waters on growth characteristics of *Penaeus vannamei*. International Journal of Fisheries and Aquatic Studies, 3: 73-76.
- BOYD, C.E.; THUNJAI, T., 2003. Concentrations of major ions in waters of inland shrimp farms in China, Ecuador, Thailand, and the United States. Journal of the World Aquaculture Society, 34: 524-532.
- BOYD, C. E., 2018. Revisitando o desequilíbrio iônico na carcinicultura de baixa salinidade: quantidades determinantes dos principais cátions necessários para combater o desafio do desequilíbrio iônico. Revista da Associação Brasileira de Criadores de Camarões. 20: 36-37.
- BRAY, WA; LAWRENCE, AL; LEUNG-TRUJILLO, JR., 1994. The effect of salinity on growth and survival of *Penaeus vannamei*, with observations on the interaction of IHHN virus and salinity. Aquaculture, USA, 122: 133–146.
- BRIGGS, M.; FUNGE-SMITH, S.; SUBASINGHE, R.; PHILLIPS, M., 2004. Introductions and movement of *Penaeus vannamei* and *Penaeus stylirostris* in Asia and the Pacific. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific. RAP Publication, p. 1-12.
- CARDONA, E., GUEGUEN, Y., MAGRÉ, K., LORGEUX, B., PIQUEMAL, D., PIERRAT, F., SAULNIER, D., 2016. Bacterial community characterization of water and intestine of the shrimp *Litopenaeus stylirostris* in a biofloc system. BMC microbiology, EUA, 16: 157p.
- CHONG-ROBLES, J., CHARMANTIER, G., BOULO, V., LIZÁRRAGA-VALDÉZ, J., ENRÍQUEZ-PAREDES, L.M., GIFFARD-MENA, I., 2013. Osmoregulation pattern and salinity tolerance of the white shrimp *Litopenaeus vannamei* (Boone, 1931) during post-embryonic development. Aquaculture, 422–423, 261–267.
- CPRM (SERVIÇO GEOLÓGICO DO BRASIL). SIAGAS – Sistema de Informações de Águas Subterrâneas. Acesso em <http://siagasweb.cprm.gov.br/layout/index.php>
- DAVIS, D. A.; SAMOCHA, T. M.; BOYD, C. E., 2004. Acclimating Pacific White Shrimp, *Litopenaeus vannamei* to inland low salinity waters. Southern Regional Aquaculture Center. n. 260.
- DOS SANTOS, R. B., COELHO FILHO, P. A., GONÇALVES, A. P., DOS SANTOS, R. A., LINS RODRIGUES, M., DE SOUZA CORREIA, E., DE OLIVEIRA, V. Q., BRITO, L. O., 2022. Effects of organic carbon sources on water quality, microbial flocs protein and performance of *Macrobrachium rosenbergii* post-larvae reared in biofloc and synbiotic systems. Aquaculture Research, 388–397.



- DAVIS, D. A.; BOYD, C. E.; ROUSE, D. B., 2005. Effects of Potassium, Magnesium and Age on Growth and Survival of *Litopenaeus vannamei* Post-Larvae Reared in Inland Low Salinity Well Waters in West Alabama. *Journal of the World Aquaculture Society*, 36: 416–419.
- EMERENCIANO, M.; GAXIOLA, G.; CUZO, G., 2013. Biofloc Technology (BFT): A Review for Aquaculture Application and Animal Food Industry. *Biomass Now - Cultivation and Utilization*.
- EKASARI, J.; AZHAR, M. H.; SURAWIDJAJA, E. H.; NURYATI, S.; DE SCHRYVER, P.; BOSSIER, P., 2014. Immune response and disease resistance of shrimp fed biofloc grown on different carbon sources. *Fish e shellfish immunology*. 41: 332-339.
- ESPARZA-LEAL, H.M.; PONCE-PALAFIX, J.T.; ARAGÓN-NORIEGA, E.A.; ARREDONDO-FIGUEROA, J.L.; GARCÍA-ULLOA GÓMEZ, M.; VALENZUELA-QUIÑONEZ, W. 2010. Growth and performance of the whiteleg shrimp *Penaeus vannamei* (Boone) cultured in low-salinity water with different stocking densities and acclimation times. *Aquaculture Research*, 41: 878-883.
- ESPARZA-LEAL, H. M.; AMARAL XAVIER, J. A.; WASIELESKY, W., 2016. Performance of *Litopenaeus vannamei* postlarvae reared in indoor nursery tanks under biofloc conditions at different salinities and zero-water exchange. *Aquaculture International*, 24: 1435–1447.
- GODÍNEZ-SIORDIA, D.E., CHÁVEZ-MEDINA, M.C., GÓMEZ-JIMÉNEZ, S., 2011. Acuicultura epicontinental del camarón blanco del Pacífico, *Litopenaeus vannamei* (Boone, 1931). *Trop. Subtrop. Agroecol.* 14: 55–62.
- HUANG, K.; WANG, W.; LU, J.; DAI, X. W. AND ZHOU, J. N. 2004. Salinity effects on growth and biochemical composition of *Litopenaeus vannamei*. *Marine Science*. 28: 20-25.
- JAFFER, Y. D., SARASWATHY, R., ISHFAQ, M., ANTONY, J., BUNDELA, D. S., e SHARMA, P. C., 2019. Effect of low salinity on the growth and survival of juvenile pacific white shrimp, *Penaeus vannamei*: A revival. *Aquaculture*, 515: 734561.
- JAIME-CEBALLOS, B.J., CABRERA-MACHADO, J.E., VEJA-VILLASANTE, F., 2012. Cultivo tierra adentro de camarón marino *Litopenaeus vannamei*: Evaluación del agua de dos granjas acuícolas em Cuba. *Revista electrónica de veterinaria*, 13: 1-17.
- KRUMMENAUER, D., SAMOCHA, T., POERSCH, L., LARA, G., WASIELESKY, W., 2014; The reuse of water on the culture of Pacific white shrimp, *Litopenaeus vannamei*, in BFT system. *Journal of the World Aquaculture Society*, 45: 3-14.
- LARAMORE, S.; LARAMORE, C.R.; SCARPA, J., 2001. Effect of low salinity on growth and survival of postlarvae and juvenile *Litopenaeus vannamei*. *Journal of the World Aquaculture Society*, 32: 385-392.

- LI, E.; CHEN, L.; ZENG, C.; CHEN, X.; YU, N.; LAI, Q. AND QIN, J. G. 2007. Growth, body composition, respiration and ambient ammonia nitrogen tolerance of the juvenile white shrimp *Litopenaeus vannamei* at different salinities. *Aquaculture*, 265: 385-390.
- LIANG, M.; WANG, S.; WANG, J.; CHANG, Q. AND MAI, K. 2008. Comparison of flavor components in shrimp *Litopenaeus vannamei* cultured in sea water and low salinity water. *Fisheries Science*, 74: 1173-1179.
- LIMA, P. C. M., SILVA, A. E. M., SILVA, D. A., SILVA, S. M. B. C., BRITO, L. O., e GÁLVEZ, A. O. 2021. Effect of stocking density of *Crassostrea* sp. in a multitrophic biofloc system with *Litopenaeus vannamei* in nursery. *Aquaculture*, 530, 735913.
- LIN, Y. C.; CHEN, J. C., 2003. Acute toxicity of nitrite on *Litopenaeus vannamei* (Boone) juveniles at different salinity levels. *Aquaculture*, 224: 193-201.
- LIU, H., TAN, B., YANG, J., CHI, S., DONG, X., YANG, Q., 2016. Effects of aqueous Na/K and dietary K on growth and physiological characters of the Pacific white shrimp, *Litopenaeus vannamei*, reared in low-salt well water. *Aquaculture Research*, 47: 540-553.
- MAICÁ, P. F.; BORBA, M. D.; MARTINS, T. G.; JUNIOR, W. W., 2014. Effect of salinity on performance and body composition of Pacific white shrimp juveniles reared in a super-intensive system. *Revista Brasileira de Zootecnia*, 43: 343–350.
- MARQUES, A.R., FERREIRA NETO, J.S., FERREIRA, F., 2016. Hierarchical clustering and partitioning to characterize shrimp grow-out farms in Northeast Brazil. *Aquaculture*, 463: 106–112.
- MCGRAW, W. J; DAVIS, D. A; TEICHERT-CODDINGTON, D; ROUSE, D. B., 2002. Acclimation of *Litopenaeus vannamei* Postlarvae to Low Salinity: Influence of Age, Salinity Endpoint, and Rate of Salinity Reduction. *Journal of the World Aquaculture Society*, 33: 78–84.
- MCGRAW, JW.; SCARPA, J., 2004. Mortality of freshwater acclimated *Litopenaeus vannamei* associated with acclimation rate, habituation period, and ionic challenge. *Aquaculture*, EUA, 236: 285–296.
- MIRANDA, I., VALLES, J.L., SÁNCHEZ, R., ÁLVAREZ, Z., 2010. Cultivo del camarón marino *Litopenaeus vannamei* (Boone, 1931) en agua dulce. *Rev. Científ.* 20: 339–346.
- NEHRU, E.; CHANDRASEKHARA RAO, A.; PAMANNA, D.; PRIYADARSHINI, N.; ANIL KUMAR, P.; RAVEENDRA, M., 2018. Effect of Dietary Minerals Supplementation on Growth and Survival of *Litopenaeus vannamei* in Low Salinity Water. *International Journal of Current Microbiology and Applied Sciences*, 7: 3040-3049.

PEREZ-VELAZQUEZ, M.; GONZÁLEZ-FÉLIX, M. L.; JAIMES-BUSTAMENTE, F.; MARTÍNEZ-CÓRDOVA, L. R.; TRUJILLO-VILLALBA, D. A. AND DAVIS, D. A. 2007. Investigation of the effects of salinity and dietary protein level on growth and survival of pacific white shrimp *Litopenaeus vannamei*. Journal of the World Aquaculture Society, 38: 475-485.

PIMENTEL, O. A. L. F., DE OLIVEIRA, V. Q., OLIVEIRA, C. R. DO R., SEVERI, W., OLIVERA GÁLVEZ, A., AMADO, A. M., e BRITO, L. O., 2022. Assessment of different ionic adjustment strategies in low-salinity water on the growth of *Litopenaeus vannamei* and microbial community stoichiometry in a synbiotic nursery system. Aquaculture Research, 53: 50–62.

RACOTTA, I. S.; PALACIOS, E.; IBARRA, A. M., 2003. Shrimp larval quality in relation to broodstock condition. Aquaculture, 227: 107–130.

RAY, A.J., LOTZ, J.M., 2017. Comparing salinities of 10, 20, and 30‰ in intensive, commercial-scale biofloc shrimp (*Litopenaeus vannamei*) production systems. Aquaculture, 476: 29-36.

ROMANO, N.; DAUDA, A. B.; IKHSAN, N.; KARIM, M.; KAMARUDIN, M. S., 2018. Fermenting rice bran as a carbon source for biofloc technology improved the water quality, growth, feeding efficiencies, and biochemical composition of African catfish *Clarias gariepinus* juveniles. Aquaculture research, 49: 1-11.

ROY, L.A.; DAVIS, D.A.; WHITIS, G.N., 2009. Pond-to-pond variability in post-larval shrimp, *Litopenaeus vannamei*, survival and growth in inland low salinity waters of west Alabama. Aquaculture Research, EUA, 40: 1823-1829.

ROY, L. A., DAVIS, D. A., SAOUD, I. P., BOYD, C. A., PINE, H. J., e BOYD, C. E., 2010. Shrimp culture in inland low salinity waters. Reviews in Aquaculture, 2: 191–208.

SAMOCHA, T. M., LAWRENCE, A. L., COLLINS, C. R., EMBERSON, C. R., HARVIN, J. L., e VAN WYK, P. M., 2001. Development of integrated, environmentally sound, inland shrimp production technologies for *Litopenaeus vannamei*. In C. L. Browdy, e D. Jory (Eds.), The new wave: Proceedings of the special session on sustainable shrimp farming. (pp. 64-75). Baton Rouge, LA: World Aquaculture Society

SAMOCHA, T.M.; LAWRENCE, A.L.; COLLINS, C.A.; CASTILLE, F.L.; BRAY, W.A.; DAVIES, C.J.; LEE, P.J.; WOOD, G.F., 2004. Production of the Pacific White Shrimp, *Litopenaeus vannamei*, in High-Density Greenhouse-Enclosed Raceways Using Low Salinity Groundwater, Journal of Applied Aquaculture, 15: 1-19.

SAMOCHA, T. M.; PRANGNELL, D. I.; HANSON, T. R.; TREECE, G. D.; MORRIS, T. C.; CASTRO, L. F.; STARESINIC, N., 2017. Design and Operation of Super Intensive, Biofloc-Dominated Systems for Indoor Production of the Pacific White Shrimp, *Litopenaeus vannamei* The

- Texas AeM AgriLife Research Experience. The World Aquaculture Society, Baton Rouge, Louisiana, USA, 368p.
- SANTOS, C. H. A.; LOURENÇO, J. A.; BAPTISTA, B. R.; IGARASHI, M. A., 2009. Crescimento e sobrevivência do camarão-branco do pacífico *Litopenaeus vannamei* (Boone, 1931) em diferentes salinidades. *Ciencia Animal Brasileira*, 10: 783–789.
- SAOUD, I. P.; DAVIS, D. A.; ROUSE, D. B., 2003. Suitability studies of inland well waters for *Litopenaeus vannamei* culture. *Aquaculture*, EUA, 217: 373-383.
- SILVA, D. A, DA SILVA, P.C.M; FILHO, A.E.M, DA SILVA, P.R.C, GÁLVEZ, S.M.B.C; BRITO, L.O., 2021. Effects of adding rotifers on the water quality, plankton composition and growth of Pacific white shrimp, *Litopenaeus vannamei* juvenile, when cultured with biofloc technology. *Aquaculture Research*, 53: 4380–4393.
- SUGUNA, T; 2020. Application of minerals in low saline water cultures systems of *L. vannamei*. *International Journal of Current Microbiology and Applied Sciences*. 9: 516:521
- VALENZUELA-MADRIGAL, I. E.; VALENZUELA-QUÍÑÓNEZ, W.; LEAL, H. M. E., QUIROZ, G. R., NORIEGA, E. A. A., 2017; Effects of ionic composition on growth and survival of white shrimp *Litopenaeus vannamei* culture at low-salinity well water. *Revista de biología marina y oceanografía*, Chile, 52: 103-112.
- VENICE SYSTEM, 1958. The Venice System for the classification of marine waters according to salinity. *Limnol. Oceanogr.* 3: 346–347.
- WASIELESKY, W.; ATWOOD, H.; STOKES, A. AND BROWDY, C. L., 2006. Effect of natural production in a zero-exchange suspended microbial floc based super-intensive culture system for white shrimp *Litopenaeus vannamei*. *Aquaculture* 258: 396-403.
- XU, W. J.; PAN, L. Q., 2014. Dietary protein level and C/N ratio manipulation in zero-exchange culture of *Litopenaeus vannamei*: Evaluation of inorganic nitrogen control, biofloc composition and shrimp performance, *Aquaculture Research*, 45: 1842-1851.
- XU, WU-JIE; MORRIS, T.C.; SAMOCHA, T.M., 2016. Effects of C/N ratio on biofloc development, water quality, and performance of *Litopenaeus vannamei* juveniles in a biofloc-based, high-density, zero-exchange, outdoor tank system. *Aquaculture*. 453: 169-175.

#### 4. Artigo Científico

Os resultados obtidos durante o trabalho experimental desta dissertação estão apresentados no artigo intitulado “**Growth performance and proximal composition of *Litopenaeus vannamei* reared in low salinity water with different ionic composition in a synbiotic nursery system**” (manuscrito), que se encontra anexado.

Artigo científico a ser submetido à Revista: Aquaculture  
International  
<https://www.springer.com/journal/10499>

**Growth performance and proximal composition of *Litopenaeus vannamei* reared in low salinity water with different ionic composition in a synbiotic nursery system**

**ABSTRACT**

This study aimed the evaluation of different ionic compositions in oligohaline water on the growth and proximal composition of *Litopenaeus vannamei* reared in the synbiotic system. A 56-day trial (300 shrimp/m<sup>3</sup>) was performed in 60 L units in a completely randomized experimental design, with three treatments (each with three repetitions): C1 – seawater diluted to a salinity ~2.7 g/L (control); IP – seawater diluted to a salinity ~2.7 g/L with Ca:Mg:K ratio adjusted to 1:3:1 and C2 - seawater diluted to a salinity ~2.7 g/L with Mg<sup>2+</sup> adjusted to approximate seawater equivalent concentration. The shrimps reached a final weight of 3.70 ± 0.07 – 4.72 ± 0.01 g and an average yield of 0.61 ± 0.14 - 1.22 ± 0.06 Kg/m<sup>3</sup>, showing significant differences among treatments. The best overall growth was observed at C2 treatment. Ionic profile IP treatment presented the worst results, this may be influenced due to Na:K ratio reduction after K<sup>+</sup> corrections. Low concentrations of nitrogenous compounds were observed, accomplished due to the synbiotic system and substrate composed by *Anomalocardia brasiliensis* shells, functioning as a substrate for bacteria and a calcium carbonate source. Shrimp's proximal compositions did not show significant differences among treatments. Microbial flocs showed differences in ash, where the PI treatment had a higher percentage of ash than treatments C1 and C2. Na/K ratio showed a positive relationship to shrimp zootechnical performance in this study. Our results indicate that shrimp juveniles present satisfactory performance in oligohaline water in a synbiotic system.

**Key words:** Oligohaline water; Ionic profile; Biochemical composition; Microbial flocs; Intensive system.

## 1. Introduction

Shrimp farming production is expanding worldwide, showing an increase of 22.8% in its production between 2016 and 2018. Among the most cultivated crustacean species, the Pacific white shrimp *Litopenaeus vannamei* stands out with a production of approximately 4.9 million tons, equivalent to 52.9% of world production in 2018 (FAO, 2020). Part of this crustacean production (38.9%, equivalent to 3.7 million tons) comes from inland water, data that demonstrate a trend towards the growth of shrimp farming in areas further away from the coast (FAO, 2020). This increase is closely linked to the *L. vannamei* farming, since this species is able to tolerate a wide saline gradient (0.5 to 60 g/L), allowing it to be cultivated in oligohaline and hypersaline waters (Davis et al. 2004; Esparza-Leal et al. 2010; Roy et al. 2010; Chong-Robles et al. 2013; Jaffer et al. 2019).

However, there are obstacles such as the wide variation of water ionic profiles among the culture sites (Boyd and Thunjai 2003; Valenzuela-Madrigo et al. 2017), lack of information about *L. vannamei* performance in intensive and super intensive systems using oligohaline waters with different ionic profiles (Ray and Lotz 2017) and how the water ionic condition can limit the shrimp productive potential in different regions (Valenzuela-Madrigo et al. 2017). Thus, culture using oligohaline water in intensive systems becomes challenging.

The importance of the water ionic composition in the culture of *L. vannamei* comes from the role that cations concentration [Calcium ( $\text{Ca}^{2+}$ ), Magnesium ( $\text{Mg}^{2+}$ ), Potassium ( $\text{K}^+$ ) and Sodium ( $\text{Na}^+$ )] play in the *L. vannamei* ecdysis, osmoregulation and metabolism. On the other hand, are the anions [bicarbonate ( $\text{HCO}_3^-$ ), carbonate ( $\text{CO}_3^{2-}$ ), sulfate ( $\text{SO}_4^{2-}$ ) and chloride ( $\text{Cl}^-$ )], where  $\text{HCO}_3^-$  and  $\text{CO}_3^{2-}$  are closely connected to alkalinity which helps phytoplankton and bacterial communities' maintenance in the culture environment, while  $\text{SO}_4^{2-}$  and  $\text{Cl}^-$  contribute to osmotic pressure and salinity. However, they play a limited role in physiological

processes when compared to the main cations (Boyd and Thunjai 2003; Saoud et al. 2003; Davis et al. 2005; Antony et al. 2015). In addition,  $\text{Cl}^-$  presents itself as a fundamental anion in water quality, being responsible for reducing nitrite toxicity, due to its greater affinity for this ion absorption by the gill cells in relation to nitrite (Tomasso 2012).

In this context, mineral fertilizers have been used to maintain the ideal ionic proportions for *L. vannamei* culture in oligohaline waters in semi-intensive systems (Roy and Davis 2010; Suguna 2020). Liu et al. (2016) used mineral fertilizers in well water in order to test different ratios of  $\text{Na}^+$  and  $\text{K}^+$  on the growth and proximate composition of *L. vannamei* grown in low salinity. While Aruna and Felix (2017), added mineral fertilizers containing  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  to the water in order to compensate the deficiency of these cations and evaluate its effect on the growth and survival of *L. vannamei*. In addition, it is necessary to understand the possible changes in the proximal composition of these animals while culture in low salinity, due to variations according to mineral concentrations in the water (Maicá et al. 2014) and possible modifications through the addition of minerals using chemical fertilizers.

However, the addition of mineral fertilizers in the water to increase these ions concentrations requires a high financial investment, requiring two or three applications to maintain ionic concentrations in a *L. vannamei* culture, being application frequency and concentration influenced by cycle duration, pond size, and water ionic profile (Boyd 2018). Therefore, in order to optimize fertilizer application in the water, it is advisable to use systems with minimal water exchange, which provide a reduction in water discharge, in addition to offering greater biosecurity to the crop (Samocho et al. 2017; Abdel-Tawwab et al. 2020; Xu et al. 2021).

Minimal water exchange systems are characterized by their contribution to sediment and/or nutrients cycling, from the production of microbial biomass, which occurs according to



the addition of an organic carbon source (Emerenciano et al. 2013). The reduction in water exchange and carbon addition provides the growth of microbial aggregates that are responsible for maintaining water quality and directly influencing the control of nitrogen compounds (Ekasari et al. 2014; Krummenauer et al. 2014; Xu et al. 2016; Cardona et al. 2016; Esparza-Leal et al. 2016; El-Sayed 2021).

On the other hand, in oligohaline waters, the control of these nitrogen compounds must be performed regularly, due to the greater toxicity of nitrogen compounds [Total ammoniacal nitrogen (TAN) and Nitrite ( $\text{NO}_2^-$ )] in low salinity (Tomasso, 2012). From this, aiming at greater control of these nitrogenous compounds, the synbiotic system can be used, being characterized by the use of polysaccharide carbohydrates such as rice, soybean and wheat bran, submitted to fermentation processes and/or microbial respiration with *Bacillus*, *Lactobacillus* and yeasts in water fertilization (Lima et al. 2021; Silva et al. 2021; Pimentel et al. 2022; Santos et al. 2022). Thus, the present study aimed to evaluate the zootechnical performance and proximal composition of marine shrimp *L. vannamei* cultured in a synbiotic system, using oligohaline water with different ionic compositions.

## **2. Material and Methods**

### *2.1. Experimental structures and facilities*

This study was conducted for 56 days at the Shrimp Culture Laboratory (LACAR) of the Fisheries and Aquaculture Department of the Rural Federal University of Pernambuco (UFRPE), Brazil. The experimental design was completely randomized with three treatments (all in triplicate): C1 (control) – *L. vannamei* reared in seawater diluted to salinity of  $2.7 \text{ gL}^{-1}$ ; IP – (ionic profile adjustment) *L. vannamei* reared in seawater diluted to salinity of  $2.7 \text{ gL}^{-1}$  with ionic adjustment to obtain a Ca:Mg:K ratio of 1:3:1; C2 – *L. vannamei* reared in seawater

diluted to salinity of 2.7 gL<sup>-1</sup> with Mg<sup>2+</sup> adjusted to a concentration approximately equivalent to that of seawater.

The water used in this study was obtained by diluting seawater (ionic profile: n= 3: Ca<sup>2+</sup> = 437.33 ± 36.95 mgL<sup>-1</sup>; Mg<sup>2+</sup> = 1,380.24 ± 25.72 mgL<sup>-1</sup>; K<sup>+</sup> = 364.80 ± 4.33 gL<sup>-1</sup>; Na<sup>+</sup> = 13,843.37 ± 299.24 gL<sup>-1</sup>; Cl<sup>-</sup> = 25,051.33 ± 250.67 gL<sup>-1</sup>; SO<sub>4</sub><sup>2-</sup> = 977.87 ± 10.25 gL<sup>-1</sup>; total alkalinity = 173.33 ± 2.89 mg CaCO<sub>3</sub>L<sup>-1</sup>; and total hardness = 6,773.33 ± 180.37 mg CaCO<sub>3</sub>L<sup>-1</sup>) in freshwater to a salinity of 2.7 g L<sup>-1</sup> (Table 1).

**Table 1.** Initial water ionic compositions of *L. vannamei* reared in a synbiotic system in low-salinity water.

Variables	Treatments		
	IP	C1	C2
Ca <sup>2+</sup> (mg L <sup>-1</sup> )	43.20 ± 5.76	46.40 ± 11.53	45.33 ± 6.66
Mg <sup>2+</sup> (mg L <sup>-1</sup> )	132.52 ± 16.39	98.82 ± 11.34	109.70 ± 13.23
K <sup>+</sup> (mg L <sup>-1</sup> )	37.07 ± 4.28	35.37 ± 4.87	35.16 ± 3.28
Na <sup>+</sup> (mg L <sup>-1</sup> )	881.50 ± 129.57	799.91 ± 130.43	852.10 ± 110.38
SO <sub>4</sub> <sup>2-</sup> (mg L <sup>-1</sup> )	46.20 ± 3.38	34.19 ± 10.42	113.00 ± 6.71
Cl <sup>-</sup> (mg L <sup>-1</sup> )	1,595.20 ± 234.47	1,447.00 ± 236.03	1,542.00 ± 199.75
HCO <sub>3</sub> <sup>-</sup> (mg L <sup>-1</sup> )	111.83 ± 12.20	115.90 ± 12.20	95.56 ± 18.63
Total alkalinity (mg L <sup>-1</sup> )	63.30 ± 2.88	56.60 ± 2.88	60.00 ± 5.00
Total hardness (mg L <sup>-1</sup> )	653.00 ± 67.21	522.60 ± 38.85	532.00 ± 69.74
Salinity (g/L)	2.66 ± 0.16	2.61 ± 0.13	2.75 ± 0.23
Mg:Ca	3.11	2.26	2.43
Mg:K	3.58	2.81	3.12
Ca:K	1.17	1.32	1.29
Na:K	23.73	22.56	24.28
TH: TA	10.34	9.22	8.86
Error (%)	10.28	7.96	4.25

Data correspond to the mean (n=3) ± standard deviation. C1 (control) – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup>; IP – (ionic profile adjustment) *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with ionic adjustment to obtain a Ca:Mg:K ratio of 1:3:1;

C2 – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with Mg<sup>2+</sup> adjusted to a concentration approximately equivalent to that of seawater.. Ca<sup>2+</sup> : calcium; Mg<sup>2+</sup>: magnesium; K<sup>+</sup> : potassium; Na<sup>+</sup>: sodium; SO<sub>4</sub><sup>2-</sup>: sulfate ; Cl<sup>-</sup>: chloride; HCO<sub>3</sub><sup>-</sup>:bicarbonate; TH:TA: total hardness:total alkalinity.

The water in the experimental units was prepared 15 days prior to animal stocking. This procedure was carried out by filling the tanks with 20% (12 L) microbial synbiotic (Total ammonia nitrogen -TAN = 0.39 mgL<sup>-1</sup>, nitrite nitrogen -N-NO<sub>2</sub><sup>-</sup>= 0.41 mgL<sup>-1</sup>, nitrite nitrogen -N-NO<sub>3</sub><sup>-</sup>= 12.1 mgL<sup>-1</sup>) and 80% (48 L) water treated with sodium hypochlorite at a concentration of 15 gm<sup>-3</sup> of activated chloride. The synbiotic was then added at two-day intervals for a total of seven fertilizations. The fertilizer was submitted to an anaerobic phase (24 h) and an aerobic phase (24 h). The synbiotic was composed of 10 gm<sup>-3</sup>of rice bran (< 200 µm), 1 gm<sup>-3</sup>of sugar, gm<sup>-3</sup>of sodium bicarbonate and 0.05 gm<sup>-3</sup>of a commercial bacterial mix [6.5×10<sup>7</sup> colony-forming units (CFUs)g<sup>-1</sup>] containing *Bacillus subtilis*, *B. licheniformis*, *Bacillus* sp., sodium chloride (NaCl) and magnesium hydroxide (Mg(OH)<sub>2</sub>) (Kayros Agrícola and Ambiental, São Paulo, Brazil) and chlorinated water [20 mg L<sup>-1</sup> of active chlorine (60%), then unchlorinated through aeration] at a proportion of 10 × the amount of rice bran. During experimental time, the synbiotic was added to the experimental treatments every three days until settleable solids reached 5 mL L<sup>-1</sup>.

The experimental units (60 L) were constantly aerated (dissolved oxygen > 5.0 mg L<sup>-1</sup> with the temperature maintained at ~31°C (Hopar Sh-608 heater 100 W), a 12:12-h photoperiod and mean luminance of 8.65 µmol photons m<sup>-2</sup> s (Equitherm Lux-204). No water exchange was performed during the experimental time. Dechlorinated freshwater was added four times a week to compensate for evaporation loss. The artificial substrate added to the experimental units was composed of mollusk shells (*Anomalocardia brasiliiana*), which

covered  $\approx 28.12\%$  of the bottom area ( $25 \times 24 \times 5$  cm, width  $\times$  height  $\times$  depth) and corresponded to  $\approx 3.36\%$  of the useful volume of the experimental unit.

## 2.2. Shrimp stocking, feeding and monitoring

Post-larvae (PL10:  $3.0 \pm 0.12$  mg) were acquired from a commercial hatchery (Aguasul, Nísia Floresta, Rio Grande do Norte, Brazil). Shrimps had been produced in water with salinity of  $35 \text{ gL}^{-1}$ . Prior to the experiment, the PL10 were acclimated to salinity of  $2.7 \text{ gL}^{-1}$  for 14 days. At the end of the acclimatization period, PL24 ( $9.24 \pm 1.38$  mg) were randomly selected and stocked at a density of  $2000 \text{ PLm}^{-3}$  in nursery tanks (800 L) for 35 days. No water exchange was performed during the entire experimental period and de-chlorinated freshwater was added to compensate for evaporation.

For the nursery phase, post-larvae were fed a commercial feed with 40% crude protein, 11% lipids, 4% crude fiber and 14% mineral matter (Guabitech Inicial, Guabi, Brazil) four times a day (8:00 am, 11:00 am, 2:00 pm and 5:00 pm). A daily feeding rate of 33.75% of body weight was initially adopted, which was gradually reduced to 10.5% over 35 days (Van Wyk et al. 1999). The feeding rate was adjusted daily in accordance with the estimated feed consumption and mortality rate.

The experimental units (60 L) were stocked with *L. vannamei* juveniles (initial weight:  $0.42 \pm 0.01$  g) at a density of  $300 \text{ shrimps m}^{-3}$ . The animals were fed three times a day (8:00 am, 12:00 pm and 4:00 pm) using a commercial shrimp feed with 35% crude protein, 10% lipids, 4% crude fiber and 14% mineral matter (Guabitech Active, Guabi, Brazil). The amount of feed offered to the animals was calculated based on Garza de Yta et al. (2004), considering a weekly growth rate of 0.5 g, weekly mortality of 2% and FCR 1.1.

Shrimp weight was monitored every 10 days to determine growth and adjust the amount of feed offered. At the end of the experimental period, biomass gain, mean final

weight, specific growth rate (SGR), feed conversion ratio (FCR), survival and yield were determined using the following equations:

Biomass gain (g) = final biomass (g) – initial biomass (g);

Final weight (g) = final biomass (g)/number of individuals at the end of evaluation period;

SGR (%/day<sup>-1</sup>) = 100 × [ln final weight (g) – ln initial weight (g)]/time (days);

FCR = feed supplied/biomass gain;

Survival (%) = (number of individuals at the end of evaluation period/initial number of individuals) × 100;

Yield (Kg m<sup>-3</sup>) = final biomass (Kg)/volume of experimental unit (m<sup>3</sup>).

### 2.3. Ionic adjustment

Commercial products were used for the ionic adjustment of the water: potassium chloride (KCl), calcium carbonate (CaCO<sub>3</sub>) and magnesium sulfate (MgSO<sub>4</sub>). The addition of ions was performed based on previous tests of the efficiency of the chemical compounds at increasing the concentration of ions in the water. The test was performed in experimental units containing 14 L of water with salinity of 2.5 gL<sup>-1</sup> (seawater diluted with freshwater) under constant aeration. The pH and ion concentrations were analyzed before and 72 h after application of the chemicals at a concentration of 100 gm<sup>-3</sup> (Table 2).

**Table 2.** Percentage % increment of the target ion (after 72 h of the application of 100 gm<sup>-3</sup>) by chemical compounds used for ionic adjustment in intensive nursery symbiotic system.

Commercial product		MgSO <sub>4</sub>	CaCO <sub>3</sub>	KCl
% increment of the target ion	pH <sup>a</sup>	0.4 ± 0.07	0.32 ± 0.06	0.41 ± 0.05
	Ca <sup>2+</sup>	-	30.4 ± 0.73	-
	K <sup>+</sup>	-	-	51.1 ± 11.38
	Mg <sup>2+</sup>	9.4 ± 0.51	-	-

*Note:* The data correspond to the mean of 2 replicates ± standard deviation. MgSO<sub>4</sub>: magnesium sulfate; KCl: potassium chloride; CaCO<sub>3</sub>: calcium carbonate; <sup>a</sup>pH in absolute value; Ca<sup>2+</sup>: calcium; K<sup>+</sup>: potassium; Mg<sup>2+</sup>: magnesium

The application of chemical compounds to the experimental units to adjust the ion concentration was performed according to the following equation (Samocho 2019):

$$\text{Amount of product} = \frac{Fc - Ic}{TI} \times V$$

in which:

- Fc: Final concentration;
- Ic: Initial concentration;
- TI: % increment of the target ion (decimal value);
- V: tank volume (m<sup>3</sup>).

After analyzing the water in all treatments, ion concentrations in milliequivalent L<sup>-1</sup> (mEq L<sup>-1</sup>) were calculated to check the cation and anion equilibrium. The calculation was performed by determining the difference between the sum of the cation mEq L<sup>-1</sup> (Na<sup>+</sup> = 23 mg mEq<sup>-1</sup>; K<sup>+</sup> = 39.1 mg mEq<sup>-1</sup>; Ca<sup>2+</sup> = 20 mg mEq<sup>-1</sup> and Mg<sup>2+</sup> = 12.15 mg mEq<sup>-1</sup>) and sum of the anion mg mEq<sup>-1</sup> (HCO<sub>3</sub><sup>-</sup> = 61 mg mEq<sup>-1</sup>; Cl<sup>-</sup> = 35.45 mg mEq<sup>-1</sup> and SO<sub>4</sub><sup>2-</sup> = 48.03 mg mEq<sup>-1</sup>) (Boyd 2020). A balance error lower than 10% between cations and anions was adopted as a standard for certifying the accuracy of the analysis of these major ions (Custodio and Llamas 1983). This error was calculated using the following equation:

$$\text{Error (\%)} = \frac{|\Sigma \text{ cations} - \Sigma \text{ anions}|}{\Sigma \text{ cations} + \Sigma \text{ anions}} \times 200$$

in which:

- $\Sigma$  cations: sum of cations;
- $\Sigma$  anions: sum of anions.

In the C1 treatment, seawater was diluted with freshwater to reach salinity of 2.7 g L<sup>-1</sup>. This treatment was used as a control treatment and no ionic adjustment was performed during the experimental period. In the C2 treatment, Mg<sup>2+</sup> supplementation was performed at the

beginning of the experiment to achieve a concentration equivalent to that of seawater. Optimal ion concentrations in farming ponds are determined by multiplying the salinity of the water in the tank by the ratio of the ion concentration in seawater and mean seawater salinity (Boyd and Thunjai, 2003). The  $Mg^{2+}$  concentration was adjusted from  $98 \text{ mg L}^{-1}$  to  $109 \text{ mg L}^{-1}$  by adding magnesium sulfate ( $MgSO_4$ ).

In the IP treatment, adjustments were made to the Ca:Mg:K ratio on Days 0, 14, 28 and 42, maintaining the ratio at 1:3:1 to simulate Ca:Mg:K ratios found in seawater (Boyd, 2020). At the beginning of the experiment (Day 0), the  $Mg^{2+}$  concentration was increased from  $98.8$  to  $132.5 \text{ mg L}^{-1}$ . On Day 14,  $Mg^{2+}$  was increased from  $130.2 \text{ mg L}^{-1}$  to  $148.8 \text{ mg L}^{-1}$  and  $K^+$  was increased from  $31.9 \text{ mg L}^{-1}$  to  $49.6 \text{ mg L}^{-1}$ . On Day 28,  $Mg^{2+}$  was increased from  $142.5 \text{ mg L}^{-1}$  to  $203.2 \text{ mg L}^{-1}$  and  $K^+$  was increased from  $53.5 \text{ mg L}^{-1}$  to  $67.7 \text{ mg L}^{-1}$ . On Day 42,  $Ca^{2+}$  was increased from  $62.4 \text{ mg L}^{-1}$  to  $72.9 \text{ mg L}^{-1}$  and  $K^+$  was increased from  $58.8 \text{ mg L}^{-1}$  to  $72.9 \text{ mg L}^{-1}$ . Magnesium sulfate ( $MgSO_4$ ), potassium chloride (KCl) and calcium carbonate ( $CaCO_3$ ) were used to achieve the desired Ca:Mg:K ratio of 1:3:1.

#### *2.4. Water Quality*

Dissolved oxygen (DO;  $\text{mg L}^{-1}$ ) and temperature ( $^{\circ}\text{C}$ ; YSI model 100, Yellow Springs, Ohio, USA) were monitored twice a day (8:00 am and 4:00 pm). Salinity (salinity meter AZ, model 8371), pH (pH meter Akso, model A90) and settleable solids ( $\text{mL L}^{-1}$ ; Imhoff cone) (Avnimelech 2012) were monitored three times a week. Total ammonia nitrogen (TAN; APHA 2012), nitrite nitrogen ( $\text{NO}_2^-$ -N; Fries 1971) and total alkalinity (TA; APHA 2012) were monitored every seven days. Nitrate nitrogen ( $\text{NO}_3^-$ -N; APHA 2012), orthophosphate ( $\text{PO}_4^{3-}$ ; APHA 2012), total hardness (TH; APHA 2012),  $Ca^{2+}$  (APHA, 2012),  $Mg^{2+}$  (APHA 2012),  $Na^+$  (APHA 2012),  $Cl^-$  (APHA, 2012),  $SO_4^{2-}$  (APHA 2012) and  $K^+$  (Fries and Getrost 1977) were monitored every 14 days.

## 2.5. Proximate composition

At the end of experimental time, floc samples were collected with a cylindrical mesh net (50 µm) for the retention of solids and whole body of the shrimps for the proximate composition analysis (crude protein, lipids, moisture, ash and fiber contents) using standard methods (AOAC 2012) (all in triplicate). The animals were washed in the laboratory with filtered freshwater and carefully inspected to eliminate encrusted organisms. The samples were oven-dried at 60°C. For moisture content, samples were oven-dried at 105°C for 24 h until reaching a constant weight (315 SE model, Fanem). The difference in weight before and after drying was recorded and expressed as percentage. Protein content was determined by measuring nitrogen (N x 6.25) using the Kjeldahl method (TE 0363 model; Tecnal, São Paulo, Brazil). Total lipid content was determined using the Soxhlet extraction method with pure hexane (98%) as the solvent (Ma 044/8/50 model, Marconi, São Paulo, Brazil). Crude fiber content was determined using the enzymatic-gravimetric method by measuring the residue after acid and alkaline digestions (Vasconcelos et al. 2010). Ash was determined by oven incineration at 550°C (Q318 D24 model; Quimis, São Paulo, Brazil).

## 2.6. Statistical analyses

The data were performed using the Statistica software version 13.0 (StatSoft). The data were checked for homogeneity of variance using the Cochran test ( $p < 0.05$ ) and normality was determined using the Shapiro-Wilk test ( $p < 0.05$ ). One-way analysis of variance (ANOVA) was performed to evaluate the growth performance variables and proximate composition. Repeated-measures ANOVA was used to compare water quality data, followed by Duncan's test ( $p < 0.05$ ) for the comparison of means. Nonparametric data were analyzed using the Kruskal–Wallis test ( $p < 0.05$ ) followed by Dunn's test (for SGR data) and Friedman's test with



Conover's multiple comparison test with Holm–Bonferroni correction (for DO, TAN, NO<sub>2</sub><sup>-</sup>-N, NO<sub>3</sub><sup>-</sup>-N, PO<sub>4</sub><sup>3-</sup>, salinity, SS, Cl<sup>-</sup>, TA and TH).

### 3. Results

#### 3.1. Water Quality

No significant differences were found among the treatments with regards to water quality variables (Table 3). Dissolved oxygen and temperature were approximately 6.0 mgL<sup>-1</sup> and 30 °C, respectively, throughout the experimental time in all treatments. TAN ranged from 0.19 to 0.25 mgL<sup>-1</sup> and N-NO<sub>2</sub><sup>-</sup> ranged from 0.20 to 0.27 mgL<sup>-1</sup> throughout the experiment ( $p > 0.05$ ; Table 3). pH was similar among the treatments, with no substantial changes between morning and afternoon (Table 3).

**Table 3.** Water quality variables measured during *Litopenaeus vannamei* grow out in a synbiotic system with different ionic composition in low-salinity water.

Variáveis	Tratamentos		
	PI	C1	C2
OD manhã (mg/L)	6.26 (7.31 – 4.91)	6.22 (7.16 – 4.90)	6.25 (7.37 – 5.37)
OD tarde (mg/L)	6.19 (7.35 – 4.52)	6.11 (7.38 – 4.05)	6.17 (7.55 – 4.20)
Temperatura (°C)	30.60 (34.00 – 28.20)	30.66 (33.10 – 28.30)	30.85 (32.90 – 28.80)
Salinidade (g/L) *	2.67 (3.30 – 2.51)	2.85 (3.80 – 2.23)	2.76 (3.50 – 2.35)
pH manhã *	7.31 (8.34 – 7.01)	7.32 (8.45 – 6.98)	7.32 (8.38 – 6.98)
pH tarde *	7.29 (8.10 – 6.97)	7.29 (8.13 – 6.87)	7.33 (8.12 – 6.92)
NAT (mg/L)	0.23 (0.71 – 0.04)	0.25 (0.93 – 0.04)	0.19 (0.57 – 0.05)
N-NO <sub>2</sub> <sup>-</sup> (mg/L)	0.20 (0.85 – 0.04)	0.27 (1.39 – 0.04)	0.23 (0.93 – 0.02)
N-NO <sub>3</sub> <sup>-</sup> (mg/L)	0.41 (1.12 – 0.30)	0.67 (2.27 – 0.10)	0.56 (2.08 – 0.11)
PO <sub>4</sub> <sup>3-</sup> (mg/L)	15.37 (21.21 – 8.71)	15.52 (23.52 – 9.02)	13.66 (23.53 – 8.99)
SS (ml/L)	5.75 (14.00 – 0.50)	6.88 (23.00 – 0.90)	6.28 (20.00 – 0.70)

Data correspond to the mean over the experimental time (maximum - minimum). Repeated measures ANOVA for parametric statistical data and Friedman's test for non-parametric statistical data. C1 (control) – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup>; IP

– (ionic profile adjustment) *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with ionic adjustment to obtain a Ca:Mg:K ratio of 1:3:1; C2 – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with Mg<sup>2+</sup> adjusted to a concentration approximately equivalent to that of seawater.. DO: dissolved oxygen; pH: hydrogen potential; TAN: total ammonia nitrogen; NO<sub>2</sub><sup>-</sup>-N: nitrite nitrogen; NO<sub>3</sub><sup>-</sup>-N: nitrate nitrogen; PO<sub>4</sub><sup>3-</sup>: phosphate; SS: settleable solids.

### 3.2. Major ion and cation ratios

The major ion and cations ratios are summarized in Table 4. Cation concentrations (Ca<sup>2+</sup>, Mg<sup>2+</sup> and K<sup>+</sup>) varied throughout the experimental period (Figure 1). Significant differences in Mg<sup>2+</sup> ( $p < 0.05$ ) were found among the treatments on Days 0 and 56, with higher concentrations in the IP treatment compared to the C1 treatment ( $p < 0.05$ ; Figure 1). On Day 42, the concentration of Mg<sup>2+</sup> was significantly higher in the IP treatment ( $p < 0.05$ ) compared to the C1 and C2 treatments. A significant difference in K<sup>+</sup> was also found among treatments ( $p < 0.05$ ), with higher concentrations in the IP treatment on Days 28, 42 and 56 compared to the C1 and C2 treatments (Figure 1). Significant differences among the treatments were found in SO<sub>4</sub><sup>2-</sup> ( $p < 0.05$ ) on Day 56 as well as TH on Days 42 and 56, with higher concentrations in the IP treatment compared to the C1 and C2 treatments (Figure 1). Ca:K and Na:K<sup>+</sup> differed significantly among treatments ( $p < 0.05$ ), with lower ratios in the IP treatment (Table 4).

**Table 4.** Ion concentration (mg L<sup>-1</sup>) and ratios among cations on *Litopenaeus vannamei* in a synbiotic system with different ionic composition in low-salinity water.

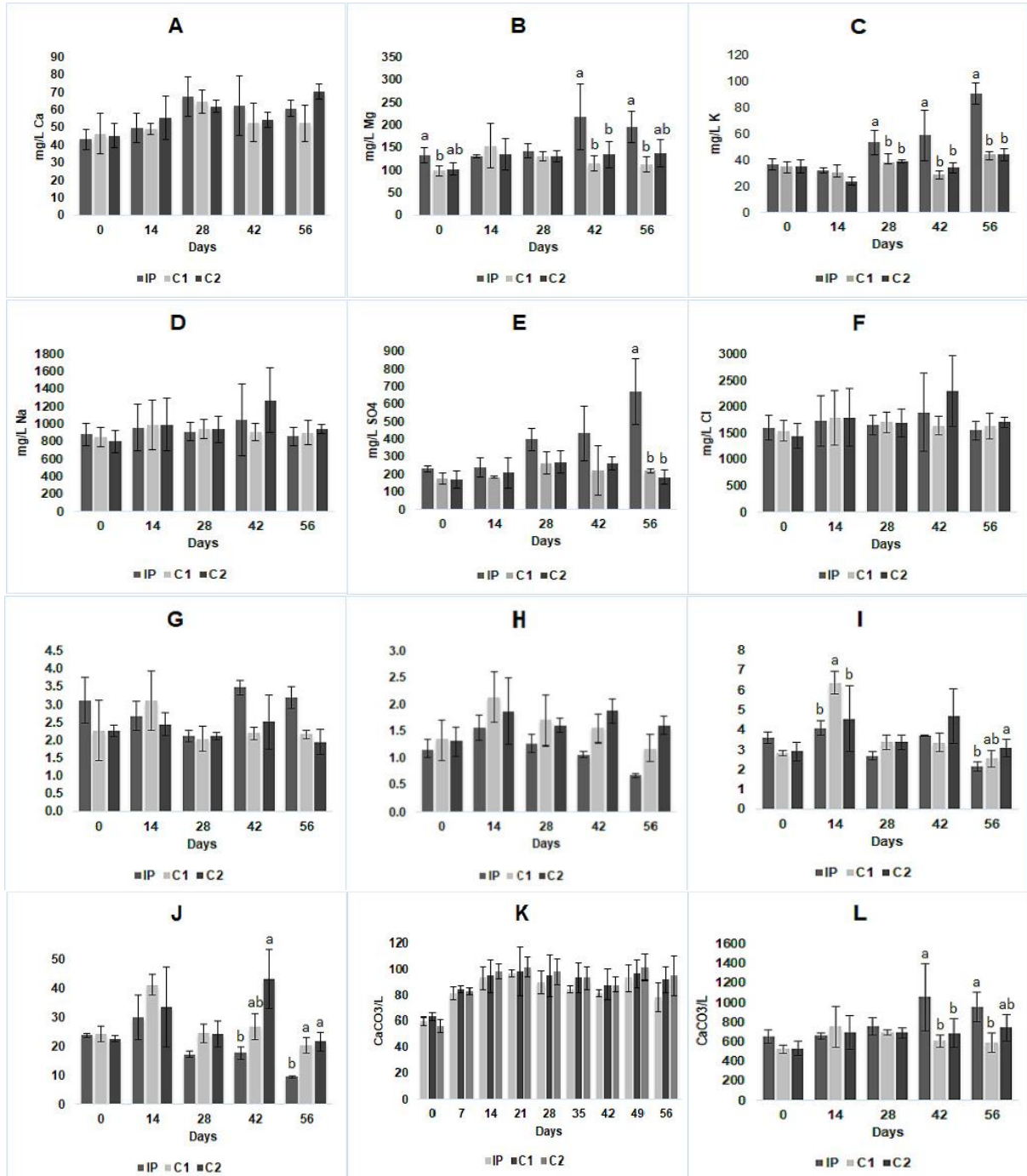
Variables	Treatments		
	PI	C1	C2
Ca <sup>2+</sup> (mg L <sup>-1</sup> )	56.74 ± 9.44	53.01 ± 8.60	57.49 ± 6.13
Mg <sup>2+</sup> (mg L <sup>-1</sup> )	163.81 ± 28.63	121.82 ± 20.72	127.85 ± 23.78
K <sup>+</sup> (mg L <sup>-1</sup> )	54.42 ± 8.52 <sup>a</sup>	35.27 ± 3.96 <sup>b</sup>	35.57 ± 3.51 <sup>b</sup>

Na <sup>+</sup> (mg L <sup>-1</sup> )	929.86 ± 200.70	917.45 ± 148.01	988.63 ± 201.98
SO <sub>4</sub> <sup>2-</sup> (mg L <sup>-1</sup> )	394.35 ± 95.30 <sup>a</sup>	212.96 ± 49.96 <sup>b</sup>	219.13 ± 55.20 <sup>b</sup>
Cl <sup>-</sup> (mg L <sup>-1</sup> )	1,682.69 ± 363.30	1,660.24 ± 267.84	1,789.04 ± 365.52
TA (mg CaCO <sub>3</sub> L <sup>-1</sup> )	89.62 ± 6.20	90.74 ± 10.76	84.44 ± 7.93
TH (mg CaCO <sub>3</sub> L <sup>-1</sup> )	816.00 ± 136.61	634.66 ± 85.32	669.06 ± 114.72
Mg:Ca	2.91 ± 0.34 <sup>a</sup>	2.35 ± 0.46 <sup>b</sup>	2.25 ± 0.33 <sup>b</sup>
Mg:K	3.24 ± 0.22	3.68 ± 0.34	3.72 ± 0.85
Ca:K	1.14 ± 0.13 <sup>b</sup>	1.58 ± 0.37 <sup>a</sup>	1.65 ± 0.28 <sup>a</sup>
Na:K	19.55 ± 2.34 <sup>b</sup>	27.39 ± 3.39 <sup>a</sup>	29.03 ± 6.48 <sup>a</sup>
Error (%)	5.06 ± 0.01	5.07 ± 0.01	3.31 ± 0.01

---

Data correspond to the mean (n=15) ± standard deviation. Different capital letters represent significant differences ( $p < 0.05$ ) among the treatments. Repeated measures ANOVA results followed by Duncan's test ( $p < 0.05$ ) for the comparison of means. C1 (control) – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup>; IP – (ionic profile adjustment) *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with ionic adjustment to obtain a Ca:Mg:K ratio of 1:3:1; C2 – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with Mg<sup>2+</sup> adjusted to a concentration approximately equivalent to that of seawater. TA = total alkalinity; TH = total hardness.

**Figure 1.** Variation of cations, anions, ionic ratios, total hardness and total alkalinity during a *Litopenaeus vannamei* grow out using a synbiotic system with different ionic composition in low-salinity water.



### 3.3. Proximate composition

The proximate composition of the shrimps and microbial floc at the end of the experimental time are summarized in Table 5. No significant differences among treatments were found for crude protein, lipids, moisture or ash in the shrimps ( $p > 0.05$ ). No significant

differences in the proximate composition of the microbial floc were among treatments ( $p > 0.05$ ) for crude protein, lipids or moisture. However, ash content was higher ( $p < 0.05$ ) in the IP treatment (Table 5).

**Table 5.** *Litopenaeus vannamei* (wet base) and microbial floc (dry base) proximal composition in a synbiotic system with different ionic composition in low-salinity water.

	Proximal composition	Treatments		
		IP	C1	C2
Shrimp	Moisture (%)	77.68 ± 0.92	77.92 ± 2.55	77.65 ± 1.26
	Crude protein (%)	17.80 ± 0.34	17.25 ± 0.30	18.04 ± 1.16
	Lipids (%)	5.60 ± 0.04	5.41 ± 1.25	5.69 ± 0.09
	Ash (%)	4.06 ± 0.88	3.96 ± 0.31	3.94 ± 0.23
Microbial floc	Moisture (%)	92.57 ± 0.69	93.43 ± 1.63	93.77 ± 1.24
	Crude protein (%)	25.61 ± 9.20	26.02 ± 5.33	30.9 ± 7.43
	Lipids (%)	4.55 ± 0.09	5.40 ± 0.44	5.52 ± 0.12
	Ash (%)	28.23 ± 2.14 <sup>a</sup>	20.31 ± 3.10 <sup>b</sup>	22.13 ± 2.40 <sup>b</sup>

Data correspond to the mean ± standard deviation. Different capital letters represent significant differences ( $p < 0.05$ ) among the treatments by One-way variance analysis (ANOVA) followed by Duncan's test. C1 (control) – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup>; IP – (ionic profile adjustment) *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with ionic adjustment to obtain a Ca:Mg:K ratio of 1:3:1; C2 – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with Mg<sup>2+</sup> adjusted to a concentration approximately equivalent to that of seawater.

### 3.4. Shrimp growth performance

Growth performance data at the end of the 56 days of experimental time are summarized in Table 6. No significant differences ( $p > 0.05$ ) were found among treatments with regards to survival or FCR. Performance was greater in C2 treatment (final weight: 4.72 g; weekly growth: 0.59 g; SGR: 4.10 %day<sup>-1</sup>; yield; 1.22 Kg/m<sup>-3</sup>) compared to the IP treatment.

**Table 6.** Shrimp zootechnical performance in a synbiotic system with different ionic composition in low-salinity water during 56 days.

Zootechnical Performance	Treatments		
	IP	C1	C2
Survival (%)	53.70 ± 11.56	70.37 ± 19.51	81.48 ± 8.49
Final weight (g)	3.79 ± 0.07 <sup>b</sup>	4.55 ± 0.37 <sup>a</sup>	4.72 ± 0.09 <sup>a</sup>
Yield (Kg m <sup>-3</sup> )	0.61 ± 0.14 <sup>b</sup>	0.96 ± 0.28 <sup>ab</sup>	1.22 ± 0.06 <sup>a</sup>
Wg (g)	0.47 ± 0.01 <sup>b</sup>	0.57 ± 0.06 <sup>a</sup>	0.59 ± 0.10 <sup>a</sup>
SGR (% day <sup>-1</sup> )	4.08 ± 0.03 <sup>b</sup>	4.27 ± 0.18 <sup>a</sup>	4.33 ± 0.10 <sup>a</sup>
FCR	1.32 ± 0.07	1.26 ± 0.16	1.20 ± 0.05

\* Shrimp Initial weight (0.42 ± 0.01g). Data correspond to the mean ± standard deviation. Different capital letters represent significant differences ( $p < 0.05$ ) among the treatments by One-way variance analysis (ANOVA) followed by Duncan's test. C1 (control) – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup>; IP – (ionic profile adjustment) *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with ionic adjustment to obtain a Ca:Mg:K ratio of 1:3:1; C2 – *L. vannamei* reared in seawater diluted to salinity of 2.7 gL<sup>-1</sup> with Mg<sup>2+</sup> adjusted to a concentration approximately equivalent to that of seawater.. Wg: weekly growth; SGR: specific growth rate; FCR: feed conversion ratio.

#### 4. Discussion

Water quality variables (temperature, DO and pH) remained within the recommended ranges for the reared of *L. vannamei* (Van Wyk and Scarpa 1999). In low-salinity systems with minimal water exchange, high concentrations of nitrogen compounds, especially TAN and NO<sub>2</sub><sup>-</sup>-N, are considered the main cause of mortality due to their high toxicity in low-salinity environments (Laramore et al. 2001; Maicá et al. 2012; Esparza-Leal et al. 2016). In this study, the concentration of nitrogen compounds remained lower than 0.3 mgL<sup>-1</sup>, which is below the upper limit of the safe range for this species in water with salinity of 2.7 gL<sup>-1</sup> (Sowers et al. 2004; Gross et al. 2004; Ramirez-Rochin et al. 2016; Valencia-Castaneda et al. 2018). The present results differ from those reported in other studies involving the farming of *L. vannamei*

in low-salinity water with minimal water exchange (Esparza-Leal et al. 2010; Maicá et al. 2012 and 2014; Khanjani et al. 2020).

The control of these nitrogen compounds may be related to the strategy implemented to lower the stress of the shrimps reared in a low-salinity environment with minimal water exchange, which was the use of the fermentation and microbial respiration of polysaccharide carbohydrates by a mix of probiotic bacteria, stimulating the growth of heterotrophic and chemoautotrophic bacteria, enhancing the oxidation of nitrogen compounds (Lima et al. 2021; Dos Santos et al. 2022; Silva et al. 2021; Pimentel et al. 2022) and increasing the availability of nutrients in the rice bran through the breakdown of organic molecules, such as polysaccharides, into simpler molecules, such as sucrose, resulting in the formation of organic acids, such as lactic acid (Wainwright 1995; Feddern et al. 2007). In contrast, the addition of polysaccharide carbohydrates with no fermentation or microbial respiration leads to a greater biomass production of heterotrophic bacteria rather than chemoautotrophic bacteria, causing an initial reduction in the nitrification process (Serra et al. 2015; Khanjani et al. 2017).

The use of inoculum from water of a previous culture is a strategy used in several studies to accelerate the stabilization of heterotrophic and autotrophic bacterial communities in tanks and/or ponds. Hostins et al. (2017) and Santos et al. (2019) also obtained TAN and  $\text{NO}_2^-$ -N concentrations below  $0.3 \text{ mgL}^{-1}$  with water inoculum from previous crops. Another efficient strategy for the control of nitrogen compounds is the use of artificial substrates composed of the shells of the mollusk *Anomalocardia brasiliiana*. According to Navada et al. (2019), chemoautotrophic bacteria need substrates for their fixation and are more efficient in the oxidation of nitrogen compounds compared to heterotrophic bacteria. Studies on the grow out of *L. vannamei* with salinity between 25 and  $32 \text{ gL}^{-1}$  have reported the effectiveness of artificial substrates at controlling nitrogen compounds in intensive systems (Schweitzer et al. 2013; Santos et al. 2019; Satanwat et al. 2019).

In addition to being used as a substrate for nitrifying bacteria, the substrate in the present study was composed of calcium carbonate ( $\text{CaCO}_3$ ), which contributes to the increase of total alkalinity in the water, enabling a lower fluctuation of pH, the variation of which was less than 0.1 between morning and afternoon throughout the experimental period (Boyd 2020; Furtado et al. 2015). The addition of this substrate also assisted in the increase of the total alkalinity of the water in the IP, C1 and C2 treatments, which was 63.3, 56.6 and 60 mg  $\text{CaCO}_3 \text{ L}^{-1}$  for 90, 95 and 85 mg  $\text{CaCO}_3 \text{ L}^{-1}$ , respectively, at the end of the experimental period, even though the compound was consumed through nitrification processes (Chen et al. 2006; Ebeling et al. 2006) and ecdysis of the shrimps (Boyd and Tucker 1998), which require bioavailable calcium carbonate in the water. According to Van Wyk and Scarpa (1999), the recommended total alkalinity concentration for *L. vannamei* farming is  $\geq 100 \text{ mg CaCO}_3 \text{ L}^{-1}$ , which was not reached in the treatments, although total alkalinity increased gradually.

Regarding the cation ratios, despite having a Ca:Mg:K ratio close to 1:3:1, the IP treatment led to a poorer growth performance compared to the other treatments. This result may be related to the combination of the lower Na:K ratio and total alkalinity concentrations below 100 mg  $\text{CaCO}_3 \text{ L}^{-1}$ . According to Roy et al. (2007), it is extremely important to maintain the Na:K ratio close to 28:1 to promote better shrimp development and growth, as the proper ratio of these elements is involved in processes such as osmoregulation and ionic transport (Valenzuela-Madrigo et al. 2017). Zhu et al. (2004) found that Na:K ratios lower than 25.6:1 and higher than 119.1:1 negatively affected the performance of *L. vannamei* in salinity of 30 gL<sup>-1</sup> at 25 °C. Likewise, Liu et al. (2014) reported that Na:K ratios between 23:1 and 33:1 resulted in the better growth and survival of *L. vannamei* in salinity of 4 gL<sup>-1</sup>. However, Pimentel et al. (2022) found no loss of production efficiency in *L. vannamei* nurseries with a Na:K ratio below 20:1 and mean alkalinity above 100 mg  $\text{CaCO}_3 \text{ L}^{-1}$ . Esparza-Leal et al. (2009) also found no loss of production with the Na:K ratio between 8.6:1 to 185:1 and total alkalinity



values above 200 mg CaCO<sub>3</sub> L<sup>-1</sup> during the grow-out phase of *L. vannamei*. Thus, the combination of the Na:K ratio and alkalinity concentration below 100 mg CaCO<sub>3</sub> gL<sup>-1</sup> may have negatively influenced shrimp performance.

During the experimental period, the ionic adjustments of the Ca:Mg:K ratio did not influence the performance of *L. vannamei* in low-salinity using a symbiotic system and artificial substrate. *L. vannamei* growth was similar when the initial concentrations of the main ions were Ca<sup>2+</sup> = 45 mgL<sup>-1</sup>, Mg<sup>2+</sup> = 98 mgL<sup>-1</sup>, K<sup>+</sup> = 35 mgL<sup>-1</sup> and total hardness was close to 522 mg CaCO<sub>3</sub>L<sup>-1</sup>. During grow out, however, the combination of a lower Na:K (< 22:1) and lower total alkalinity (< 100 mg CaCO<sub>3</sub> L<sup>-1</sup> ) limited shrimp growth and survival. However, the final weight (4.55 to 4.72 g) in the C1 and C2 treatments was close to that reported by Roy et al. (2007) in systems with 100 shrimp m<sup>-3</sup> and 4 gL<sup>-1</sup> of salinity (49 days) and Furtado et al. (2014) in a BFT system with 425 shrimp m<sup>-3</sup> and 25 gL<sup>-1</sup> of salinity (56 days). The survival rate (> 70%) and yield (0.96 and 1.22 kg m<sup>-3</sup>) in the C1 and C2 treatments can be considered high when compared to other studies with low-salinity water (0.25 to 4 gL<sup>-1</sup>), which obtained a survival rate of less than 25% for *L. vannamei* reared in intensive system (300 shrimp m<sup>-3</sup>) with minimal water exchange (Maicá et al. 2012) and average yield up to 0.5 kg m<sup>-3</sup> (Roy et al. 2007; Maicá et al. 2012).

The FCR was similar to that found by Furtado et al. (2014), who tested the effect of different levels of Ca(OH)<sub>2</sub> on the growth of *L. vannamei* juveniles (425 shrimp m<sup>-3</sup>) in water with salinity of 25 gL<sup>-1</sup> for 56 days, reporting an FCR ranging from 1.2 to 1.7. Likewise, Esparza-Leal et al. (2009) evaluated the effect of different ionic compositions in low-salinity water (~1 gL<sup>-1</sup>) on the growth of *L. vannamei* juveniles (200 shrimp m<sup>-3</sup>) for 84 days and found an FCR between 1.3 and 1.5.

Satisfactory results observed with the salinity used in the present study are similar to Moura et al. (2021) that found that the addition of an inoculum of 6% natural marine water

reaching salinity of  $2.9 \text{ gL}^{-1}$  positively affected the growth performance of *L. vannamei* post-larvae reared in a biofloc system for 27 days.

According to Huang et al. (2014), the shrimp proximate composition can vary according to salinity. In this study, no differences were found in the proximate composition of *L. vannamei* reared in low-salinity water ( $\sim 2.7 \text{ gL}^{-1}$ ) with different ionic concentrations. Moisture, proteins and ash in this study were similar to those found in several studies involving using low-salinity water (Li et al. 2007; Maicá et al. 2014; Wang et al. 2014). However, the concentration of lipids was higher than that reported in studies involving shrimp reared in seawater (Huang et al. 2004; Ashild et al. 2004; Li et al. 2007). According to Chen and Nan (1994), the high concentration of lipids in *L. vannamei* at low-salinity water may be related to the use of this nutrient by the shrimp for processes such as osmoregulation and enzyme activation. In *L. vannamei* reared in salinity of  $3 \text{ gL}^{-1}$ , Huang et al. (2019) found a reduction in the concentration of the lipid metabolite phosphatidylcholine, which is related to the elevation of the hormone choline under hyposmotic stress, the regulation of gill permeability and the functioning of gill cells. However, the reasons behind the shrimp's need to store lipids when living in low salinity conditions remain unclear.

According to Ekasari et al. (2009), microbial flocs larger than  $100 \mu\text{m}$  have higher concentrations of crude protein (27.8%) and lipids (7.5%). The present findings are in agreement with this statement, as flocs collected with a  $50\text{-}\mu\text{m}$  mesh had lower concentrations than those reported by Maicá et al. (2014) and Khanjani et al. (2014). The literature reports different results regarding the lipid content of microbial flocs. In the present study, the concentration of lipids ranged from 4.55 to 5.52%, which is higher than the concentration found by Khanjani et al. (2020) and similar to values reported by Tacon (2000) and Wasielesky et al. (2006), who found lipid concentrations in microbial flocs ranging from 5 to 6%. This may be linked to the source of organic carbon and the microbial composition found in the floc as well

as the size of the mesh in which the flocs were collected. Regarding the ash content, the IP treatment had a higher concentration than the other treatments, which may be related to the addition of mineral fertilizers to the water to achieve the Ca:Mg:K ratio of 1:3:1.

## 5. Conclusion

The ionic adjustment performed in this study demonstrated that the addition of mineral fertilizers ( $\text{CaCO}_3$ ,  $\text{MgSO}_4$  and  $\text{KCl}$ ) to maintain the Ca:Mg:K ratio close to 1:3:1 caused a reduction in the Na:K ratio, culminating in a poorer growth performance and survival. The study also demonstrated that the combination of an artificial substrate composed of *Anomalocardia brasiliiana*, a synbiotic system (anaerobic and aerobic processing of rice bran) and an inoculum of 20% of the nursery water were sufficient to promote the control of nitrogen compounds during the shrimp *L. vannamei* reared in low-salinity water. In the C1 and C2 treatments, the initial ionic concentration, total alkalinity close to  $90 \text{ mg CaCO}_3 \text{ L}^{-1}$  and the Na:K ratio close to 28:1 produced conditions that did not limit the growth of *L. vannamei* in low-salinity water with a synbiotic system. Moreover, the ionic adjustments did not alter the proximate composition of the shrimp. On the other hand, the addition of mineral fertilizers ( $\text{CaCO}_3$ ,  $\text{MgSO}_4$  and  $\text{KCl}$ ) altered the ash concentration in the microbial floc. Further studies addressing the ionic concentration and cation ratios in low-salinity water using a synbiotic system could help clarify the results of the present investigation.

## 6. Acknowledgements

The authors are grateful for the financial support provided by the Rural Federal University of Pernambuco (Pró-Reitoria de Pesquisa e Pós-Graduação - PRPPG 015/2018); Brazil's National Council for Scientific and Technological Development and the Coordination for the Improvement of Higher Education Personnel (CAPES) for the scholarships granted (process numbers: 88882.436207/2019-01 ; 88882.436206/2019-01; 88882.436231/2019-01).

CNPq also provided a grants to Alfredo Olivera Gálvez (PQ 308063/2019-8) and Luis Otavio Brito (PQ309669/2021-9 ).

## 7. References

- Abdel-Tawwab, M.; Khalil, R. H.; Nour, A. M.; Elkhayat, B. K.; Khalifa, E.; Abdel-Latif, H. M. R. (2020) Effects of *Bacillus subtilis* fermented rice bran on water quality, performance, antioxidants / oxidants, and immunity biomarkers of White leg shrimp (*Litopenaeus vannamei*) reared at different salinities with zero water exchange. *Journal of Applied Aquaculture*, 1-26. <https://doi.org/10.1080/10454438.2020.1844110>
- AOAC, Official Methods of Analysis. 20th Ed. (2016) Association of Official Analytical Chemistry, Washington, DCA, USA, 3172p.
- APHA, Standard Methods for the Examination of Water and Wastewater. 22th Ed. (2012) American Public Health Association, Washington, DC, USA, 541p.
- Aruna, S.; Felix, S. (2017) The effect of ionic concentration of low saline waters on growth characteristics of *Penaeus vannamei*. *International Journal of Fisheries and Aquatic Studies*, 5(3): 73-76.
- Avnimelech, Y. (2009) *Biofloc Technology A Practical Guide Book*. The World Aquaculture Society, 182p.
- Boyd, C. E. (2020) *Water quality: an introduction*. 3th Ed. Springer Science, Switzerland.
- Boyd, C. E. (2018) Revisitando o desequilíbrio iônico na carcinicultura de baixa salinidade: quantidades determinantes dos principais cátions necessários para combater o desafio do desequilíbrio iônico. *Revista da Associação Brasileira de Criadores de Camarões*, 20: 36-37.
- Boyd, C. E.; Thunjai, T. (2003) Concentrations of major ions in waters of inland shrimp farms in China, Ecuador, Thailand, and the United States. *Journal of the World Aquaculture Society*, 34: 524-532. <https://doi.org/10.1111/j.1749-7345.2003.tb00092.x>
- Boyd, C.E.; Tucker, C.S. (1998). *Pond aquaculture water quality management*. Boston: Kluwer Academic Publishers, 700p.
- Cardona, E., Gueguen, Y., Magré, K., Lorgeoux, B., Piquemal, D., Pierrat, F., Saulnier, D. (2016) Bacterial community characterization of water and intestine of the shrimp *Litopenaeus stylirostris* in a biofloc system. *BMC microbiology*, 16: 157p. <https://doi.org/10.1186/s12866-016-0770-z>

- Chen S., Ling J. E., Blancheton J.P. (2006) Nitrification kinetics of biofilm as affected by water quality factors. *Aquaculture Engineering*, 34:179–197. <https://doi.org/10.1016/j.aquaeng.2005.09.004>
- Chen, J.C., Nan, F.H. (1994) Comparisons of oxygen consumption and ammonia-N excretion of five penaeids. *Journal of Crustacean Biology*, 14: 289–294. <https://doi.org/10.2307/1548909>
- Chong-Robles, J., Charmantier, G., Boulo, V., Lizárraga-Valdéz, J., Enríquez-Paredes, L.M., Giffard-Mena, I. (2013) Osmoregulation pattern and salinity tolerance of the white shrimp *Litopenaeus vannamei* (Boone, 1931) during post-embryonic development. *Aquaculture*, 422–423, 261–267. <https://doi.org/10.1016/j.aquaculture.2013.11.034>
- Custodio, E., Llamas, M. R. (1983) *Hidrología subterránea*, 2nd ed. Ediciones Omega, Barcelona.
- Davis, D. A.; Boyd, C. E.; Rouse, D. B. (2005) Effects of Potassium, Magnesium and Age on Growth and Survival of *Litopenaeus vannamei* Post-Larvae Reared in Inland Low Salinity Well Waters in West Alabama. *Journal of the World Aquaculture Society*, 36: 416–419. <https://doi.org/10.1111/j.1749-7345.2005.tb00346.x>
- Davis, D. A.; Saoud, I. P.; McGraw, W. J.; Rouse, D. B. (2002) Considerations for *Litopenaeus vannamei* reared in inland low salinity waters. *Avances en Nutrición Acuicola*, 6: 73–90.
- Davis, D. A.; Samocha, T. M.; Boyd, C. E. (2010) Acclimating Pacific White Shrimp, *Litopenaeus vannamei* to inland low salinity waters. Southern Regional Aquaculture Center. n. 260.
- Ebeling, J. M., Timmons, M. B., E Bisogni, J. J. (2006) Engineering analysis of the stoichiometry of photoautotrophic, autotrophic, and heterotrophic removal of ammonia-nitrogen in aquaculture systems. *Aquaculture*, 257:346–358. <https://doi.org/10.1016/j.aquaculture.2006.03.019>
- Ekasari, J.; Azhar, M. H.; Surawidjaja, E. H.; Nuryati, S.; De Schryver, P.; Bossier, P. (2014) Immune response and disease resistance of shrimp fed biofloc grown on different carbon sources. *Fish e shellfish immunology*, 41: 332-339. <https://doi.org/10.1016/j.fsi.2014.09.004>
- Emerenciano, M., Gaxiola, G., & Cuzon, G. (2013). Biofloc Technology (BFT): A Review for Aquaculture Application and Animal Food Industry. In (Ed.), *Biomass Now - Cultivation and Utilization*. IntechOpen. <https://doi.org/10.5772/53902>

Esparza-Leal, H. M.; Amaral Xavier, J. A.; Wasielesky, W. (2016) Performance of *Litopenaeus vannamei* postlarvae reared in indoor nursery tanks under biofloc conditions at different salinities and zero-water exchange. *Aquaculture International*, 24: 1435–1447. <https://doi.org/10.1007/s10499-016-0001-5>

Esparza-Leal, H.M.; Ponce-Palafox, J.T.; Aragón-Noriega, E.A.; Arredondo-Figueroa, J.L.; García-Ulloa Gómez, M.; Valenzuela-Quiñonez, W (2010) Growth and performance of the whiteleg shrimp *Penaeus vannamei* (Boone) cultured in low-salinity water with different stocking densities and acclimation times. *Aquaculture Research*, 41: 878-883. <https://doi.org/10.1007/s10499-016-0001-5>

Esparza-Leal, H.M.; Ponce-Palafox, J.T.; Valenzuela-Quiñonez, W.; Beltrán, H.C.; Figueroa, J.L.A. (2009) The effect of low salinity water with diferente ionic composition on the growth and survival of *Litopenaeus vannamei* (Boone, 1931) inintensive culture, *Journal of Applied Aquaculture*, 21: 215, 227.

El-Sayed, A. F. M. (2021) Use of biofloc technology in shrimp aquaculture: acomprehensive review, with emphasis on the last decade. *Reviews in Aquaculture*. 13: 676–705. <https://doi.org/10.1111/raq.12494>

Feddern, V., Furlong, E. B., Soares, L. A. D. S. (2007) Efeitos da fermentação nas propriedades físico-químicas e nutricionais do farelo de arroz. *Ciência e Tecnologia de Alimentos*, 27: 800–804. <https://doi.org/10.1590/S0101-20612007000400020>

Food and Agriculture Organization of The United Nations – FAO (2020). *The State of World Fisheries and Aquaculture: Meeting the sustainable development goals*. Fisheries an Aquaculture Technical Paper. Rome, 206p.

Fries, J.; Getrost, H. (1977) *Organic Reagents for Trace Analysis*. Darmstadt, Alemanha, E. Merck, 453 p.

Furtado P.S., Poersch L.H. e Wasielesky W. Jr. (2013) The effect of different alkalinity levels on *Litopenaeus vannamei* reared with biofloc technology (BFT). *Aquaculture International*, 23: 345–358. <https://doi.org/10.1007/s10499-014-9819-x>

Furtado P. S., Fugimura M. M. S., Monserrat J. S., Souza D. M. (2015) Acute effects of extreme pH and its influences on the survival and biochemical biomarkers of juvenile White Shrimp,

*Litopenaeus vannamei*. Marine and Freshwater Behaviour and Physiology. 48: 1-13. <https://doi.org/10.1080/10236244.2015.1086539>

Garza De Yta, A., Rouse, D. B., Davis, D. A. (2004). Influence of nursery period on the growth and survival of *Litopenaeus vannamei* under pond production conditions. Journal of the World Aquaculture Society, 35: 357–365. <https://doi.org/10.1111/j.1749-7345.2004.tb00099.x>

Gross, A., Abutbul, S., Zilberg, D. (2004) Acute and chronic effects of nitrite on white shrimp, *Litopenaeus vannamei*, cultured in low-salinity brackish water. Journal of the World Aquaculture Society, 35: 315–321. <https://doi.org/10.1111/j.1749-7345.2004.tb00095.x>

Hostins, B., Lara, G., Decamp, O., Cesar, D. E., Wasielesky, W. (2017) Efficacy and variations in bacterial density in the gut of *Litopenaeus vannamei* reared in a BFT system and in clear water supplemented with a commercial probiotic mixture. Aquaculture, 480: 58-64. <https://doi.org/10.1016/j.aquaculture.2017.07.036>

Jaffer, Y. D., Saraswathy, R., Ishfaq, M., Antony, J., Bundela, D. S., E Sharma, P. C. (2019) Effect of low salinity on the growth and survival of juvenile pacific white shrimp, *Penaeus vannamei*: A revival. Aquaculture, 515: 734561. <https://doi.org/10.1016/j.aquaculture.2019.734561>

Huang, M., Dong, Y., Zhang, Y., Chen, Q., Xie, J., Xu, C., Zhao, Q., Li, E. (2019) Growth and Lipidomic Responses of Juvenile Pacific White Shrimp *Litopenaeus vannamei* to Low Salinity. Frontiers in Physiology, 10: 1–13. <https://doi.org/10.3389/fphys.2019.01087>

Huang, K.; Wang, W.; Lu, J.; Dai, X. W. And Zhou, J. N. (2004) Salinity effects on growth and biochemical composition of *Litopenaeus vannamei*. Marine Science 28: 20-25.

Khanjani, M. H., Alizadeh, M., E Sharifinia, M. (2020) Rearing of the Pacific white shrimp, *Litopenaeus vannamei* in a biofloc system: The effects of different food sources and salinity levels. Aquaculture Nutrition, 26: 328–337. <https://doi.org/10.1111/anu.12994>

Khanjani, M. H., Sajjadi, M. M., Alizadeh, M., Sourinejad, I. (2017). Nursery performance of Pacific white shrimp (*Litopenaeus vannamei* Boone, 1931) cultivated in a biofloc system: the effect of adding different carbon sources Aquaculture Research., 48: 1491-1501.

Krummenauer, D., Samocha, T., Poersch, L., Lara, G., Wasielesky, W. (2014) The reuse of water on the culture of Pacific white shrimp, *Litopenaeus vannamei*, in BFT system. Journal of the World Aquaculture Society, 45: 3-14. <https://doi.org/10.1111/jwas.12093>



- Kumar, S.; Anand, P. S. S.; De, D.; Deo, A. D.; Ghoshal, T. K.; Sundaray, J. K.; Ponniah, A. G.; Jithendran, K. P.; Raja, R. A.; Biswas, G.; Lalitha, N. (2017) Effects of biofloc under different carbon sources and protein levels on water quality, growth performance and immune responses in black tiger shrimp *Penaeus monodon* (Fabricius, 1978). *Aquaculture Research*, 48: 1168–1182. <https://doi.org/10.1111/are.12958>
- Laramore, S.; Laramore, C.R.; Scarpa, J. (2001) Effect of low salinity on growth and survival of postlarvae and juvenile *Litopenaeus vannamei*. *Journal of the World Aquaculture Society*, 32: 385-392. <https://doi.org/10.1111/j.1749-7345.2001.tb00464.x>
- Li, E.; Chen, L.; Zeng, C.; Chen, X.; Yu, N.; Lai, Q. And Qin, J. G. (2007) Growth, body composition, respiration and ambient ammonia nitrogen tolerance of the juvenile white shrimp *Litopenaeus vannamei* at different salinities. *Aquaculture*, 265: 385-390. <https://doi.org/10.1016/j.aquaculture.2007.02.018>Get rights and content
- Lima, P. C. M., Silva, A. E. M., Silva, D. A., Silva, S. M. B. C., Brito, L. O., E Gálvez, A. O. (2021) Effect of stocking density of *Crassostrea* sp. in a multitrophic biofloc system with *Litopenaeus vannamei* in nursery. *Aquaculture*, 530, 735913. <https://doi.org/10.1016/j.aquaculture.2020.735913>
- Liu, H., Tan, B., Yang, J., Chi, S., Dong, X., Yang, Q., 2016. Effects of aqueous Na/K and dietary K on growth and physiological characters of the Pacific white shrimp, *Litopenaeus vannamei*, reared in low-salt well water. *Aquaculture Research*, 47: 540-553. <https://doi.org/10.1111/are.12513>
- Maicá, P.M.; Borba, M.R.; Wasielesky Junior, W. (2012) Effect of low salinity on microbial floc composition and performance of *Litopenaeus vannamei* (Boone) juveniles reared in a zero-water-exchange super-intensive system. *Aquaculture Research*, 43: 361-370. <https://doi.org/10.1111/j.1365-2109.2011.02838.x>
- Maicá, P. M.; Borba, M.R.; Martins, T.G.; Wasielesky Junior, W., 2014. Effect of salinity on performance and body composition of Pacific white shrimp juveniles reared in a super-intensive system. *Revista Brasileira de Zootecnia*, 43: 343–350. <https://doi.org/10.1590/S1516-35982014000700001>
- Moura, P. S., Wasielesky, W., Serra, F. Da P., Braga, A., & Poersch, L. (2021) Partial seawater inclusion to improve *Litopenaeus vannamei* performance in low salinity biofloc systems. *Aquaculture*, 531: 735905. <https://doi.org/10.1016/j.aquaculture.2020.735905>

- Moussa, M.S., Sumanasekera, D.U., Ibrahim, S.H., Lubberding, H.J., Hooijmans, C.M., Gijzen, H.J., Van Loosdrecht, M.C.M. (2006) Long term effects of salt on activity, population structure and floc characteristics in enriched bacterial cultures of nitrifiers. *Water Res.* 40: 1377-1388. <https://doi.org/10.1016/j.watres.2006.01.029>
- Navada, S., Vadstein, O., Tveten, A. K., Verstege, G. C., Terjesen, B. F., Mota, V. C., Venkataraman, V., Gaumet, F., Mikkelsen, Ø., E Kamstra, A. (2019) Influence of rate of salinity increase on nitrifying biofilms. *Journal of Cleaner Production*, 238. <https://doi.org/10.1016/j.jclepro.2019.117835>
- Nunes, A. J. P., Lopez, C. V. (2001) Low-salinity, inland shrimp culture in Brazil and Ecuador: economics, disease issues move farms away from coasts. *Global Aquaculture Advocate*, 4(3), 62-64.
- Parmenter, K.J., Bisesi Jr, J.H., Young, S.P., Klaine, S.J., Atwood, H.L., Browdy, C.L., Tomasso, J.R. (2009) Culture of Pacific White Shrimp *Litopenaeus vannamei* in a mixed-ion solution. *N. Am. J. Aquac.* 71: 134–137. <https://doi.org/10.1577/A08-015.1>
- Pimentel, O. A. L. F., De Oliveira, V.Q., Oliveira, C. R. R., Severi, W., Gálvez, A.O., Amado, A. M., E.; Brito, L.O. (2022) Assessment of different ionic adjustment strategies in low-salinity water on the growth of *Litopenaeus vannamei* and microbial community stoichiometry in a synbiotic nursery system. *Aquaculture Research*, 53: 50–62. <https://doi.org/10.1111/are.15552>
- Ramírez-Rochín, J., Frías-Espericueta, M.G., Fierro-Sañudo, J.F., Alarcón-Silvas, S.G., Fregoso-López, M.G., Páez-Osuna, F. (2016) Acute toxicity of nitrite on white shrimp *Litopenaeus vannamei* (Boone) juveniles in low-salinity water. *Aquaculture Research*, 48: 2337–2343. [10.1111/are.13069](https://doi.org/10.1111/are.13069)
- Ray, A.J., Lotz, J.M., (2017). Comparing salinities of 10, 20, and 30‰ in intensive, commercial-scale biofloc shrimp (*Litopenaeus vannamei*) production systems. *Aquaculture*, 476: 29-36. <https://doi.org/10.1016/j.aquaculture.2017.03.047>
- Romano, N.; Dauda, A. B.; Ikhsan, N.; Karim, M.; Kamarudin, M. S. (2018). Fermenting rice bran as a carbon source for biofloc technology improved the water quality, growth, feeding efficiencies, and biochemical composition of African catfish *Clarias gariepinus* juveniles. *Aquaculture research*, 49: 1-11. <https://doi.org/10.1111/are.13837>

- Roy, L. A., Davis, D. A., Saoud, I. P., Henry, R. P. (2007) Effects of varying levels of aqueous potassium and magnesium on survival, growth, and respiration of the Pacific white shrimp, *Litopenaeus vannamei*, reared in low salinity waters. *Aquaculture*, 262(2–4): 461–469. <https://doi.org/10.1016/j.aquaculture.2006.10.011>
- Roy, La.; Davis, A. A., (2010) Requirements for the culture of the Pacific white shrimp *Litopenaeus vannamei*, reared in low salinity waters: water modification and nutritional strategies for improving production. In: Cruz-Suárez, L.E.; Ricque-Marie, D.; Tapia-Salazar, M.; Nieto-López, M.G.; Villarreal-Cavazos, D. A.; Gamboa- Delgado, J. (Eds) *Avances en Nutrición Acuícola X - Memorias del X Simposio Internacional de Nutrición Acuícola*: 61-78.
- Roy, L. A., Davis, D. A., Saoud, I. P., Boyd, C. A., Pine, H. J., E Boyd, C. E. (2010) Shrimp culture in inland low salinity waters. *Reviews in Aquaculture*, 2: 191–208. <https://doi.org/10.1111/j.1753-5131.2010.01036.x>
- Samocha, T.M.; Patnaik, S.; Speed, M.; Ali, A.; Burger, J.M.; Almeida, R.V.; Ayub, Z.; Harisanto, M.; Horowitz, A.; Brock, D.L. (2007) Use of molasses as carbon source in limited discharge nursery and grow-out systems for *Litopenaeus vannamei*. *Aquacultural Engineering*, 36: 184-191. <https://doi.org/10.1016/j.aquaeng.2006.10.004>
- Santos, R. B., Coelho Filho, P. A., Gonçalves, A. P., Dos Santos, R. A., Lins Rodrigues, M., De Souza Correia, E., De Oliveira, V. Q., E Brito, L. O. (2022) Effects of organic carbon sources on water quality, microbial flocs protein and performance of *Macrobrachium rosenbergii* post-larvae reared in biofloc and synbiotic systems. *Aquaculture Research*, 54: 388–397. <https://doi.org/10.1111/are.15580>
- Saoud, I. P.; Davis, D. A.; Rouse, D. B. (2003). Suitability studies of inland well waters for *Litopenaeus vannamei* culture. *Aquaculture*, 217: 373-383.
- Santos, N.B.V., Furtado, P.S., César, D.E., Junior, W.W. (2019) Assessment of the nitrification process in a culture of pacific white shrimp, using artificial substrate and bacterial inoculum in a biofloc technology system (BFT). *Ciência Rural*, Santa Maria, 49: 06. <https://doi.org/10.1590/0103-8478cr20180306>
- Schweitzer, R., Arantes, R., Francisco, M., Fóes, P. Costódio, S. (2013). Use of artificial substrates in the culture of *Litopenaeus vannamei* (Biofloc System) at different stocking densities: effects on microbial activity, water quality and production rates. *Aquacultural Engineering*, 54: 93–103. <https://doi.org/10.1016/j.aquaeng.2012.12.003>

- Satanwat, P., Tran, T.P., Hirakata, Y., Watari, T., Hatamoto, M., Yamaguchi, T., Powtongsook, S. (2019). Use of an internal fibrous biofilter for intermittent nitrification and denitrification treatments in a zero-discharge shrimp culture tank. *Aquacultural Engineering*. 10: 20-41. <https://doi.org/10.1016/j.aquaeng.2019.102041>
- Serra, F. P.; Gaona, C. A. P.; Furtado, P. S.; Poersch, L. H.; Wasielesky, W. (2015) Use of different carbon sources for the biofloc system adopted during the nursery and grow-out culture of *Litopenaeus vannamei*. *Aquaculture international*, 23: 1325-1339. <https://doi.org/10.1007/s10499-015-9887-6>
- Silva, D. A, Da Silva, P.C.M; Filho, A.E.M, Da Silva, P.R.C, Gálvez, S.M.B.C; Brito, L.O. (2021) Effects of adding rotifers on the water quality, plankton composition and growth of Pacific white shrimp, *Litopenaeus vannamei* juvenile, when cultured with biofloc technology. *Aquaculture Research*, 53: 4380–4393. <https://doi.org/10.1111/are.15276>
- Sowers, A., Young, S.P., Isely, J.J., Browdy, C.L., Tomasso, J.R. (2004) Nitrite toxicity to *Litopenaeus vannamei* in water containing low concentrations of sea salt or mixed salts. *Journal of the World Aquaculture Society*, 35, 445–451. <https://doi.org/10.1111/j.1749-7345.2004.tb00109.x>
- Suguna, T. (2020) Application of minerals in low saline water cultures systems of *L. vannamei*. *International Journal of Current Microbiology and Applied Sciences*. 9: 516-521. <https://doi.org/10.20546/ijcmas.2020.909.065>
- Tacon, A. G. J. (2000) Shrimp feeds and feeding regimes in zero exchange outdoor tanks. *The Advocate*. 15-16.
- Tomasso J.R., (2012) Environmental nitrite and aquaculture: a perspective. *Aquaculture International* 20: 1107–1116. <https://doi.org/10.1007/s10499-012-9532-6>
- Valencia-Castañeda, G., Frías-Espericueta, M.G., Vanegas-Pérez, R.C., Pérez-Ramírez, J.A., Chávez-Sánchez, M.C., Páez-Osuna, F. (2018) Acute toxicity of ammonia, nitrite and nitrate to shrimp *Litopenaeus vannamei* postlarvae in low-salinity water. *Bulletin of Environmental Contamination and Toxicology*, 101: 229–234. <https://doi.org/10.1007/s00128-018-2355-z>
- Valenzuela-Madrigal, I. E.; Valenzuela-Quiñónez, W.; Leal, H. M. E., Quiroz, G. R., Noriega, E. A. A. (2017) Effects of ionic composition on growth and survival of white shrimp

*Litopenaeus vannamei* culture at low-salinity well water. Revista de biología marina y oceanografía. 52: 103-112. <http://dx.doi.org/10.4067/S0718-19572017000100008>

Van Wyk, P. (1999) Nutrition and feeding of *Litopenaeus vannamei* in intensive culture systems. In: Van Wyk, P.; Davis-Hodgkins, M.; Laramore, R, Main, K.L.; Mounta, J.; Scarpa, J. Farming Marine Shrimp in Recirculating Freshwater Systems. Florida Department of Agriculture and Consumer Services – Harbor Branch Oceanic Institute, Tallahassee, Flórida. 125–140.

Wainwright, M. Introducción a la Biotecnología de los Hongos. Zaragoza, España: Acribia, 1995. 228 p.

Wang, X., Li, E., Xu, C., Qin, J. G., Wang, S., Chen, X., Cai, Y., Chen, K., Gan, L., Yu, N., Du, Z. Y., E Chen, L. (2016) Growth, body composition, ammonia tolerance and hepatopancreas histology of white shrimp *Litopenaeus vannamei* fed diets containing different carbohydrate sources at low salinity. Aquaculture Research, 47: 1932–1943. <https://doi.org/10.1111/are.12650>

Wasielesky, W.; Atwood, H.; Stokes, A. And Browdy, C. L. (2006) Effect of natural production in a zero-exchange suspended microbial floc based super-intensive culture system for white shrimp *Litopenaeus vannamei*. Aquaculture, 258: 396-403. <https://doi.org/10.1016/j.aquaculture.2006.04.030>

Xu, Wu-Jie; Morris, T.C; Samocha, T.M., 2016. Effects of C/N ratio on biofloc development, water quality, and performance of *Litopenaeus vannamei* juveniles in a biofloc-based, high-density, zero-exchange, outdoor tank system. Aquaculture, 453: 169-175. <https://doi.org/10.1016/j.aquaculture.2015.11.021>

Xu, W.; Xu, Y.; Su, H.; Hu, X.; Xu, Y.; Li, Z.; Wen, G.; Cao, Y. (2021) Production performance, inorganic nitrogen control and bacterial community characteristics in a controlled biofloc-based system for indoor and outdoor super-intensive culture of *Litopenaeus vannamei*. Aquaculture, 531: 735-749. <https://doi.org/10.1016/j.aquaculture.2020.735749>

Zhang, K., Pan, L., Chen, W., E Wang, C. (2017) Effect of using sodium bicarbonate to adjust the pH to different levels on water quality, the growth and the immune response of shrimp *Litopenaeus vannamei* reared in zero-water exchange biofloc-based culture tanks. Aquaculture Research, 48: 1194–1208. <https://doi.org/10.1111/are.12961>

Zhu, C., Dong, S., Wang, F., E Huang, G. (2004) Effects of Na/K ratio in seawater on growth and energy budget of juvenile *Litopenaeus vannamei*. *Aquaculture*, 234: 485–496. <https://doi.org/10.1016/j.aquaculture.2003.11.027>

## 5. Considerações Finais

No presente estudo foi observado que os diferentes ajustes iônicos não resultaram em um efeito positivo no desempenho zootécnico do camarão marinho, a adição de fertilizantes minerais para o controle da proporção Ca:Mg:K (1:3:1), causou um desequilíbrio na relação Na:K, culminando em resultados inferiores de desempenho zootécnico em relação aos demais tratamentos. O estudo também demonstrou que a concentração iônica dos tratamentos C1 e C2, conjuntamente a utilização de substratos artificiais de *Anomalocardia brasiliiana*, utilização do sistema simbiótico com fertilização anaeróbica e aeróbica do farelo de arroz e um inóculo de 20% da água do berçário, foram suficientes para prover um crescimento adequado ao camarão marinho *L. vannamei* em baixa salinidade, sem necessidade de correções iônicas durante todo o período experimental. Foi observado também que para os tratamentos C1 e C2, as concentrações iônicas iniciais, alcalinidade total próxima a 90 mg/L CaCO<sub>3</sub> e a relação Na:K próxima a 28:1 proferiram condições que não limitaram o crescimento do *L. vannamei* em água oligohalina em sistema simbiótico. No entanto, mais estudos relacionando a concentração iônica e relações catiônicas em água oligohalina, utilizando sistema simbiótico pode auxiliar e agregar aos resultados deste presente estudo.