UNIVERSIDADE FEDERAL DA GRANDE DOURADOS

FACULDADE DE ADMINISTRAÇÃO, CIÊNCIAS CONTÁBEIS E ECONOMIA

PROGRAMA DE PÓS-GRADUAÇÃO EM AGRONEGÓCIOS

MARCOS SOUZA DE ALMEIDA

DESEMPENHO ECONÔMICO E AMBIENTAL DA PRODUÇÃO DO CAMARÃO *Litopenaeus vannamei* EM SISTEMA DE BIOFLOCOS

DOURADOS-MS

2022

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DESEMPENHO ECONÔMICO E AMBIENTAL DA PRODUÇÃO DO CAMARÃO *Litopenaeus vannamei* EM SISTEMA DE BIOFLOCOS

Linha de Pesquisa: Bioeconomia

Tese apresentada ao Programa de Pós-Graduação em Agronegócios da Universidade Federal da Grande Dourados – Faculdade de Administração, Ciências Contábeis e Economia, para a obtenção do Título de Doutor em Agronegócios.

Orientadora:
Profa. Dra. Juliana Rosa Carrijo Mauad
Coorientador:
Prof. Dr. Clandio Favarini Ruviano
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Prof. Dr. Régio Marcio Toesca Gimenes

Dourados-MS
2022

Dados Internacionais de Catalogação na Publicação (CIP).

A447d	Almeida, Marcos Souza de. Desempenho econômico e ambiental da produção do camarão *Litopenaeus vannamei* em sistema de bioflocos. / Marcos Souza de Almeida. – Dourados, MS : UFGD, 2022. Orientadora: Juliana Rosa Carrijo Mauad. Coorientador: Clandio Favarini Ruviano. Coorientador: Régio Marcio Toesca Gimenez. Tese (Doutorado em Agronegócios) – Universidade Federal da Grande Dourados. 1. Educação do campo. 2. Transformação da forma escolar. 3. Movimento dos Trabalhadores Rurais Sem Terra. I. Título.

Ficha catalográfica elaborada pela Biblioteca Central – UFGD.

MINISTÉRIO DA EDUCAÇÃO
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ATA DA DEFESA DE DOUTORADO APRESENTADA POR **MARCOS SOUZA DE ALMEIDA**, ALUNO DO PROGRAMA DE PÓS-GRADUAÇÃO *STRICTO SENSU* EM AGRONEGÓCIOS, ÁREA DE CONCENTRAÇÃO "EM AGRONEGÓCIOS E SUSTENTABILIDADE".

Aos seis dias do mês de maio de dois mil e vinte e dois, às 14h, em sessão pública, realizou-se na Universidade Federal da Grande Dourados, a Defesa de Tese de Doutorado intitulada **"Desempenho Econômico e Ambiental da Produção intensiva e superintensiva do camarão *Litopenaeus vannamei* em sistema de bioflocos"** apresentada pelo doutorando **Marcos Souza de Almeida**, do Programa de Pós-Graduação em AGRONEGÓCIOS, à Banca Examinadora constituída pelos membros: Prof.ª Dr.ª Juliana Rosa Carrijo Mauad/UFGD (presidente), Prof.ª Dr.ª Daniele Menezes Albuquerque/UFGD (membro titular externo), Prof.ª Dr.ª Débora Gomes de Gomes/FURG (membro titular externo), Prof. Dr. João Augusto Rossi Borges/UFGD (membro titular interno) e Profº Drº Manuel Angel Valenzuela Jimenez/UNAM (membro titular externo). Iniciados os trabalhos, a presidência deu a conhecer ao candidato e aos integrantes da Banca as normas a serem observadas na apresentação da Defesa. Após o candidato ter apresentado a sua Defesa, os componentes da Banca Examinadora fizeram suas arguições. Terminada a Defesa, a Banca Examinadora, em sessão secreta, passouaos trabalhos de julgamento, tendo sido o candidato considerado **APROVADO**, fazendo *jus* ao título de **DOUTOR EM AGRONEGÓCIOS. A presidente da banca abaixo-assinada atesta que os membros** Daniele Menezes Albuquerque, Débora Gomes de Gomes, João Augusto Rossi Borges e Manuel Angel Valenzuela Jimenez, **participaram de forma remota desta defesa de Tese, conforme o** § 3º do Art.1º da Portaria RTR/UFGD n. 200, de 16/03/2020 e a Instrução Normativa PROPP/UFGD Nº 1, de 17/03/2020, **considerando o candidato APROVADO, conforme declaração anexa**. Nada mais havendo a tratar, lavrou-se a presente ata, que vai assinada pelos membros da Comissão Examinadora.

Dourados, 06 de maio de 2022.

Prof.ª Dr.ª Juliana Rosa Carrijo Mauad (Presidente)

ATA HOMOLOGADA EM:___/___/_____, PELA PRÓ-REITORIA DE ENSINO DE PÓS-GRADUAÇÃO E PESQUISA / UFGD.

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Assinatura e Carimbo

Prof.ª Dr.ª Daniele Menezes Albuquerque (participação remota)Profª

Drª Débora Gomes de Gomes (participação remota)

Prof. Dr. João Augusto Rossi Borges (participação remota)

Profº Drº Manuel Angel Valenzuela Jimenez (participação remota)

ATA HOMOLOGADA EM:___/___/_____, PELA PRÓ-REITORIA DE ENSINO DE PÓS-GRADUAÇÃO E PESQUISA / UFGD.

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Programa de Pós-Graduação em Agronegócios
Área de Concentração: Agronegócios e Sustentabilidade
Linha de Pesquisa:

DECLARAÇÃO DE PARTICIPAÇÃO À DISTÂNCIA - SÍNCRONA - EM BANCA DE DEFESA DE DOUTORADO / UFGD

Às 14h00 do dia 06/05/2022, participei de forma síncrona com os demais membros que assinam a ata física deste ato público, da banca de Defesa da Tese de Doutorado do candidato Marcos Souza de Almeida, do Programa de Pós-Graduação em Agronegócios.

Considerando o trabalho avaliado, as arguições de todos os membros da banca e as respostas dadas pelo candidato, formalizo para fins de registro, por meio deste, minha decisão de que o candidato pode ser considerado APROVADO.

Atenciosamente,

Manuel Angel Valenzuela Jimenez

Programa de Pós-Graduação em Agronegócios
Área de Concentração: Agronegócios e Sustentabilidade
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Atenciosamente,

Daniele Menezes Albuquerque
Fundação Universidade Federal da Grande Dourados

Programa de Pós-Graduação em Agronegócios

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Atenciosamente,

Debora Gomes de Gomes

Universidade Federal do Rio Grande (furg)

Ministério da Educação
Universidade Federal da Grande Dourados
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Atenciosamente,

Joao Augusto Rossi Borges
Fundação Universidade Federal da Grande Dourados

AGRADECIMENTOS

Agradeço primeiramente à minha iluminada orientadora, Profa. Dra. Juliana Carrijo Mauad, pela atenção, amizade, ensinamentos, paciência, confiança e leveza na condução da minha orientação.

Aos Profs. Drs. Clandio Favarini Ruviano e Régio Marcio Toesca Gimenes pela honra de tê-los como coorientadores e pelos valiosos ensinamentos e contribuições.

Ao Prof. Dr. João Rossi e a Profa. Dra. Daniele Albuquerque pela disponibilidade para compor a banca e por todas valiosas contribuições que vem dando ao longo da construção desta tese.

A Profa. Dra. Débora Gomes de Gomes por aceitar compor a banca e pelas contribuições.

Ao Prof. Dr. Manuel Valenzuela, o mexicano mais Gaúcho do planeta, por sua amizade, incentivo, disposição de participar das bancas de qualificação e defesa e pelas suas valiosas considerações nessas etapas.

Aos Profs. Drs. Plinio Schmidt e Geraldo Fóes pela parceria, ideias e importantes sugestões que contribuíram para o desenvolvimento desta tese.

Ao Prof. Dr. "Mano", também conhecido como Wilson Wasielesky, por todo incentivo que me deu no decorrer dos anos e pelo exemplo de profissional, líder e pesquisador que é.

Aos colegas e amigos Fábio Mascarenhas e Lethícia Dorce, sempre prontos a ajudar nas dificuldades da vida acadêmica e também na minha "aclimatação" e "sobrevivência" em Dourados nos meses iniciais.

Ao Projeto Camarão, minha segunda casa, pelos dados e por todo o suporte.

A Profa. Dra. Madalena Schlindwein, Coordenadora do Programa de Pós-Graduação em Agronegócios da UFGD.

A todos os professores do Programa de Pós-Graduação em Agronegócios da UFGD.

A todos e todas colegas do mestrado e do doutorado do Programa de Pós-Graduação em Agronegócios da UFGD.

Aos demais membros da banca por sua disponibilidade e pelas contribuições que certamente serão muito importantes para a finalização deste trabalho.

Aos secretários do programa Luiz Murari e Márcia Marques pela presteza e dedicação.

A minha família e aos muitos amigos, professores e antigos colegas de trabalho que direta ou indiretamente contribuíram com este momento.

Agradeço ainda à Faculdade de Administração, Ciências Contábeis e Economia e à Universidade Federal da Grande Dourados pelo acolhimento e a CAPES, pelo aporte financeiro.

Namastê!

Se as coisas são inatingíveis... Ora! Não é motivo para não querê-las.

(Mário Quintana)

RESUMO

Em um cenário de excessiva exploração dos recursos pesqueiros e degradação ambiental, a aquicultura moderna vem ganhando importância e tomando formato de uma atividade ambientalmente correta e amiga da natureza. Nesse contexto, a produção intensiva e superintensiva de camarões marinhos em sistema de bioflocos destaca-se, em termos econômicos e ambientais, pela sua produtividade e uso racional dos recursos naturais. Contudo, ainda são poucos os estudos científicos que comparam o seu desempenho ambiental e econômico, que são relevantes para o desenvolvimento de uma aquicultura sustentável. A fim de verificar e comparar a viabilidade bioeconômica da produção intensiva em viveiros e superintensiva em estufas, em sistema com bioflocos, do camarão *Litopenaeus vannamei,* o presente estudo realiza a análise ambiental e econômica dos dois sistemas produtivos. Para tal foram utilizadas técnicas tradicionais de análise de investimento (Valor Presente Líquido – VPL, Valor Anual Equivalente – VAE, *Payback* – PB, *Payback* Descontado – PBD, Índice de Lucratividade – IL, Taxa Interna de Retorno – TIR, Taxa Interna de Retorno Modificada – TIRM), de análise de risco (Simulação de Monte Carlo) e de desempenho ambiental, utilizando a Avaliação do Ciclo de Vida (ACV). Os resultados do estudo fornecem aos tomadores de decisão subsídios ambientais e econômicos que podem auxiliar na tomada de decisão com relação ao investimento na atividade, assim como fornecerá aos consumidores informações do desempenho ambiental do produto e seu impacto ao meio ambiente.

Palavras-chave: Análise de Sensibilidade, *Biofloc Technology System,* Aquicultura, Carcinicultura, Agronegócio.

ABSTRACT

In a scenario of excessive exploitation of fisheries resources and environmental degradation, modern aquaculture has been gaining importance and taking the form of an environmentally correct and nature-friendly activity. In this context, the intensive and superintensive production of marine shrimp in a biofloc system stands out, in economic and environmental terms, for its productivity and rational use of natural resources. However, there are still few scientific studies that compare its environmental and economic performance, which are relevant to the development of a sustainable aquaculture. In order to verify and compare the bioeconomic viability of intensive production in nurseries and superintensive in greenhouses, in a system with bioflocs, of the shrimp *Litopenaeus vannamei*, this study proposes to carry out an environmental and economic analysis of the two production systems. For this, traditional investment analysis techniques will be used (Net Present Value - NPV, Annual Equivalent Value - VAE, Payback - PB, Discounted Payback - PBD, Profitability Index - IL, Internal Rate of Return - TIR, Modified Internal Rate of Return – TIRM), risk analysis (Monte Carlo simulation) and environmental performance, using Life Cycle Assessment (LCA). The results of the study provide decision makers with environmental and economic subsidies that can assist in decision making regarding investment in the activity, as well as provide consumers with information on the environmental performance of the product and its impact on the environment.

Keywords: Bioeconomics, Sensitivity Analysis, Biofloc Technology System, Aquaculture, Shrimp Farming, Agribusiness.

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CAPÍTULO I

INTRODUÇÃO GERAL

1 INTRODUÇÃO

Os produtos alimentares de origem aquática constituem importante fonte de proteína animal de alta qualidade, tanto para o consumo humano quanto para a fabricação de ração animal. Contudo, estatísticas da Organização das Nações Unidas para Agricultura e Alimentação - FAO, alertam que a captura mundial de pescados se mantém estável desde o final da década de 1980, em torno de 90 milhões de toneladas/ano, e sem indícios de aumentar no curto ou médio prazo (FAO, 2018). A sobre-exploração dos recursos pesqueiros é considerada a grande responsável por esse quadro, pois a sobrepesca tem sido uma constante em todo o mundo (NEWTON et al., 2007; FAO, 2010, 2014, 2018; BOHNES; LAURENT, 2019). Além disso, o extrativismo desordenado e a devastação desenfreada dos berçários naturais contribuem significativamente para a queda progressiva dos estoques pesqueiros naturais em todo o planeta (DINCAO, 1991; PAULY et al., 2002; WORM et al., 2006; SRINIVASAN et al., 2010; CAPELLESSO; CAZELLA, 2011; DIAS et al., 2014).

A pesca e a aquicultura[1] possuem papel imprescindível no fornecimento de proteínas de alta qualidade e na segurança alimentar e nutricional mundial. Por outro lado, o crescimento populacional e a busca por uma alimentação mais saudável estão aumentando a demanda por pescado e por proteína de alta qualidade (DELGADO et al., 2003; DE SILVA, 2012; CRIST; MORA; ENGELMAN, 2017; FARIAS; FARIAS, 2018). A Organização das Nações Unidas estima que a população mundial, que em 2019 era de 7,7 bilhões de pessoas (UNITED NATIONS, 2019), deverá alcançar 9,7 bilhões de pessoas até 2050, e 11 bilhões até 2100 (UNITED NATIONS, 2015). Isso corresponde a um aumento de 42,3% na população mundial até o final do século XXI. Para a FAO (2018) a produção mundial de pescado deve acompanhar o crescimento populacional, contudo, o relatório *The State of Food Security and Nutrition in the World 2017* (FAO, 2017a) relata que a fome global, após um período de queda de mais de 10 anos, voltou a aumentar, trazendo assim mais incertezas com relação à segurança alimentar e nutricional de milhões de pessoas ao redor do mundo.

[1]A pesca é toda operação, ação ou ato tendente a extrair, colher, apanhar, apreender ou capturar recursos pesqueiros. Aquicultura consiste na atividade de cultivo de organismos cujo ciclo de vida em condições naturais se dá total ou parcialmente em meio aquático, implicando a propriedade do estoque sob cultivo, equiparada à atividade agropecuária (BRASIL, 2009).

A FAO (2018) reconhece a importância da aquicultura para alcançar seu objetivo, um mundo sem insegurança alimentar. Contudo, a atividade pesqueira vive um momento alarmante, tanto nos aspectos econômicos, de insegurança alimentar, quanto de degradação ambiental e sobre-exploração dos recursos pesqueiros (HALPERN et al., 2008, 2015; FAO, 2018). O crescimento sustentável da produção de pescado, oriundo da aquicultura bem como da pesca, constitui um desafio cuja importância se evidencia em face do contínuo aumento da demanda, tanto no mercado interno quanto em âmbito mundial (BRASIL, 2015). A aquicultura moderna, por sua vez, deve se desenvolver e evoluir de forma sustentável, buscando o equilíbrio entre as perspectivas ambientais, econômicas e sociais (FAO, 2018; SIQUEIRA, 2018).

Sob essa perspectiva, juntamente com as metas do ODS 14[2], o desenvolvimento sustentável da aquicultura poderia contribuir de diversas formas, incluindo acabar com a pobreza (ODS 1), acabar com a fome, alcançar a segurança alimentar e melhorar a nutrição (ODS 2), e também promover o crescimento econômico sustentável (ODS 8) (BOSSIER; EKASARI, 2017; FAO, 2017a; SUBASINGHE, 2017). Outro fator que impulsiona a expansão da atividade aquícola é o sucesso na adaptação de novas espécies ao cultivo comercial, bem como a expectativa de taxas de retorno relativamente altas (GASCA-LEYVA et al., 2002).

A carcinicultura, atividade que consiste na produção de camarões em cativeiro, é um dos segmentos aquícolas com maior destaque e crescimento a nível mundial, sendo o *Litopenaeus vannamei*, também conhecido como camarão branco do Pacífico, a espécie mais produzida (FAO, 2014; NI et al., 2020). De 1999 a 2015 a carcinicultura passou de uma produção global de 1,1 milhão para 4,9 milhões de toneladas de camarões (OECD; FAO, 2019. Isso significa que mais da metade de todo o camarão consumido no mundo é proveniente da produção aquícola (FAO, 2017a).

O sistema de produção de camarões mais utilizado em nível mundial é o sistema convencional, o qual utiliza viveiros de terra e têm como características a necessidade de grandes áreas para sua instalação, proximidade do mar ou estuários

[2]Os Objetivos de Desenvolvimento Sustentável (ODS) consistem em 17 objetivos que compõem a Agenda 2030, adotada no âmbito das Nações Unidas. Esses objetivos se desdobram em 169 metas, acompanhadas por indicadores, que mesclam as três dimensões do desenvolvimento sustentável – econômico, social e ambiental – e que deverão ser alcançados pelos 193 países membros da ONU até 2030 (UNITED NATIONS, 2015).

e grandes volumes de água para renovação dos viveiros e manutenção da sua qualidade dentro dos limites aceitáveis pelos organismos produzidos. Nesse sistema a produção de camarões é desenvolvida de forma extensiva ou semi-intensiva, com baixas densidades de estocagem. Essas variam de 5 a 45 animais/m², alcançando produtividades médias da ordem de 4,5 T/ha/ano (em três ciclos de produção), com conversões alimentares de 1,4 a 1,6 kg de ração para um kg de camarão produzido (OSTRENSKY, A; BORGHETTI, J. R; SOTO, D, 2008). Em sistemas convencionais o cultivo intensivo é realizado em viveiros pequenos, de 0,1 a 1,0 ha, utilizando densidades de estocagem que variam de 30 a 100 camarões/m^2. Ao intensificar o sistema há a necessidade do uso constante de aeradores e na alimentação ser ofertado apenas ração de alta qualidade (ANH et al., 2010).

A produção brasileira do camarão *Litopenaeus vannamei* representa menos de 2% da produção mundial e apenas 5% da produção chinesa, o maior produtor mundial (ANDERSON; VALDERRAMA; JORY, 2019). Contudo, fatores globais que aliados a características intrínsecas do Brasil como grande extensão costeira, ótima disponibilidade de águas continentais, e um mercado doméstico bastante atraente, colocam-no em uma posição estratégica para o sucesso e desenvolvimento do setor aquícola (PEIXOTO et al., 2005; SILVA et al., 2018). Kluyver & Pearce II (2010) corroboram com base na teoria da vantagem econômica comparativa que enfatiza que, como consequência de suas dotações naturais, alguns países ou regiões do mundo são mais eficientes do que outros na produção de um determinado bem.

O cultivo em meio heterotrófico, também conhecidos como BFT – *Biofloc Technology System* (AVNIMELECH, 2009; EMERENCIANO et al., 2009) tem demonstrado excelentes resultados em termos de biossegurança, produtividade e manejo dos recursos hídricos (WASIELESKY et al., 2006; KRUMMENAUER et al., 2011). Apesar das diversas vantagens ambientais, sanitárias e econômicas, o custo de implantação e de operação do sistema de bioflocos requer o uso intensivo de alguns insumos (POERSCH et al., 2012; ALMEIDA et al., 2021). Contudo, ainda são poucos os estudos que examinaram o equilíbrio de custos e benefícios da produção de camarões nesse sistema (SHINJI et al., 2019).

Dentre as estratégias de produção utilizadas em fazendas de camarões que operam no sistema BFT, se destacam as produções intensivas (PI) e superintensivas

(PS). A PI se caracteriza por ser realizada em viveiros escavados, cobertos por geomembrana, com aeração fornecida por aeradores e densidades de estocagem entre 100 e 200 camarões por m³ (TAW et al., 2008; WASIELESKY et al., 2016). Já a PS é realizada em tanques de madeira, alvenaria, ou outro material, cobertos por geomembrana, no interior de estufas cobertas com filme plástico. A aeração é fornecida de forma constante e intensa, através de sopradores. Nesta, as densidades de estocagem são elevadas, podendo partir de 350 camarões por m³ e chegar a 900 animais por m³ (OTOSHI et al., 2009; SAMOCHA et al., 2010; WASIELESKY et al., 2016).

2 OBJETIVOS

2.1 OBJETIVO GERAL

✓ Realizar a análise bioeconômica da produção intensiva em viveiros e superintensiva em estufas, do camarão *Litopenaeus vannamei* em sistema BFT.

2.2 OBJETIVOS ESPECÍFICOS

✓ Verificar o desempenho ambiental da produção intensiva em viveiros e superintensiva em estufas, do camarão *Litopenaeus vannamei* em sistema BFT;

✓ Comparar o desempenho ambiental e o econômico da produção intensiva em viveiros e superintensiva em estufas, do camarão *Litopenaeus vannamei* em sistema BFT;

Dentre os sistemas de produção animal, a aquicultura é um dos mais promissores e complexos. Muitas são as variáveis (químicas, físicas, biológicas, econômicas e ambientais) que a permeiam e que impactam diretamente no sucesso ou no fracasso dos empreendimentos aquícolas. Essas variáveis são desassociáveis, interdependentes e formam um sistema frágil e sensível a suas variações. Desta forma, é imprescindível para o desenvolvimento sustentável da atividade trabalhos científicos que contemplem suas diferentes dimensões no estudo dos seus fenômenos.

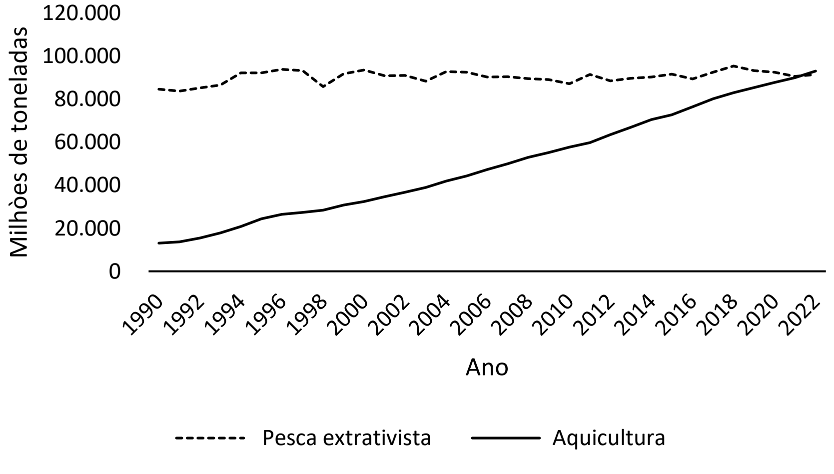
3 REVISÃO BIBLIOGRÁFICA

3.1 AQUICULTURA: DESAFIOS E OPORTUNIDADES

A aquicultura é o segmento do setor de produção animal com uma das maiores taxas de crescimento no mundo (FAO, 2010, 2014, 2018; BOHNES; LAURENT, 2019; ENGLE, 2019; GARLOCK et al., 2020). De 2000 a 2016 apresentou um crescimento médio de 5,8% ao ano (FAO, 2018). Previsões relacionadas à segurança alimentar indicam que a atividade possui um grande potencial para a produção de alimentos no futuro e assim compensar a estagnação da pesca (GASCA-LEYVA et al., 2002; TVETERÅS et al., 2012; NATALE et al., 2013; TROELL et al., 2014; FAO, 2010, 2014, 2018; BOHNES; LAURENT, 2019). Desta forma, a aquicultura pode contribuir para a segurança alimentar e fornecer benefícios sociais e econômicos, como geração de emprego e renda e, consequentemente, redução da pobreza (PAUL; VOGL, 2011; SLATER et al., 2013).

No ano de 2019 a aquicultura foi responsável por suprir 47,8% da demanda mundial de pescado. Nesse ano, a produção aquícola foi de 85.329 milhões de toneladas. Em contrapartida, no mesmo ano, a pesca ofertou 93.207 milhões de toneladas de pescado. Dados da *Organisation for Economic Co-operation and Development* (OECD) revelam que desde a década de 1990 a diferença entre a oferta de pescado oriundo da pesca e da aquicultura está caindo e estima-se que, em 2022, a aquicultura passe a ser responsável por mais da metade da oferta mundial de pescado (Figura 1) (OECD; FAO, 2019).

Figura 1 - Produção mundial da pesca extrativista e da aquicultura - 1990 a 2022.



Fonte: Elaborado a partir de OECD (2019).

https://www.oecd-ilibrary.org/agriculture-and-food/data/oecd-agriculture-statistics/oecd-fao-agricultural-outlook-edition-2019_eed409b4-en.

Na última década a produção aquícola mundial aumentou 43,64%, passando de 57.743 para 85.329 milhões de toneladas. Enquanto isso, no mesmo período, a soma do aumento da produção de todas as principais fontes de proteína animal (carnes bovina, suína, ave, ovina e pescado oriundo da pesca) corresponderam a 56,36% (OECD; FAO, 2019).

A aquicultura moderna é um negócio no qual o gerenciamento possui uma alta complexidade em função dos efeitos das variáveis endógenas e exógenas. A interação de fatores biológicos, técnicos, ambientais, econômicos, financeiros e de mercado gera incerteza sobre a produção e sobre os resultados econômicos a serem estimados (LLORENTE; LUNA, 2013). Neste sentido, Bergfjord (2009) acrescenta que produzir ao menor custo possível, assim como obter e manter altas taxas de sobrevivência e priorizar a solidez e liquidez financeira do negócio, são fatores importantes para o bom desempenho de empreendimentos aquícolas.

Assim como nas demais atividades econômicas, na aquicultura os custos de produção têm uma relação direta com a rentabilidade do negócio (POERSCH et al., 2012; DI TRAPANI et al., 2014; ALMEIDA et al., 2021). A área do empreendimento, a tecnologia empregada e a espécie produzida são fatores preponderantes para o sucesso do empreendimento. Aliado a isso, a densidade de estocagem influencia significativamente na produção (JACKSON; WANG, 1998), e, consequentemente, na lucratividade do empreendimento (ALMEIDA et al., 2021). A intensificação dos sistemas aquícolas, diversificação de espécies e introdução de inovações e tecnologias são fatores que contribuem com o crescimento da atividade (FAO, 2016). Impulsionada por pesquisa e inovação no setor aquícola, a Noruega obteve um significativo aumento da produção. Pesquisas em sanidade, produção e manejo e na cadeia de suprimentos levaram as empresas norueguesas a elevarem seus ganhos de produtividade, redução nos custos de produção e aumento da lucratividade (GARLOCK et al., 2020).

3.2 CARCINICULTURA

Dentre os diversos segmentos da aquicultura, a carcinicultura possui grande importância comercial, representando um grupo de espécies cultivadas de alto valor de mercado (FAO, 2010), sendo uma das atividades mais expressivas do setor no Brasil (IBAMA, 2007) e no mundo (FAO, 2010, 2016).

A produção de camarões no sistema convencional necessita do uso intensivo dos recursos naturais (AHMAD et al., 2017). A característica principal do sistema convencional de produção de camarões é a necessidade de constantes renovações, utilizando grandes volumes de água a fim de manter a qualidade da água dos tanques em níveis aceitáveis (HOPKINS et al., 1993; MCINTOSH, 2001; BURFORD et al., 2003; SAMOCHA; PATNAIK; GANDY, 2004; GÓMEZ-JIMÉNEZ et al., 2005; ANH et al., 2010). Além disso, existe a possibilidade de ocorrência de outros efeitos negativos com a descarga do efluente, rico em nutrientes, a eutrofização das áreas adjacentes, o escape de espécies exóticas para o ambiente natural e a disseminação de doenças (WASIELESKY et al., 2006; SAMOCHA et al., 2007; ABREU et al., 2011; DA SILVA et al., 2016). Abdou et al. (2017) acrescentam que o risco de impactos ambientais negativos oriundos das atividades aquícolas ocorre, principalmente, pela sua relação intima com o meio ambiente.

A espécie de camarão mais produzida no mundo é o *Litopenaeus vannamei* (Figura 2), também conhecido como "camarão branco do pacífico" ou "camarão cinza", tendo sua origem no Pacífico Leste, no trecho que vai do Peru ao México (FAO, 2017b). Cerca de 53% da produção mundial de camarões corresponde a esta espécie. Em 2016 a produção mundial em cativeiro da espécie foi de 4.156 mil toneladas (FAO, 2018).

Figura 2 - Camarão branco do Pacífico, *Litopenaeus vannamei.*

Fonte: arquivo pessoal.

A produção mundial de camarões de cultivo tem seus maiores *players* no continente asiático, sendo a China e a Tailândia os maiores produtores de camarões de cultivo no mundo. Juntos eles respondem por aproximadamente 55% da produção global do camarão *Litopenaeus vannamei* (FAO, 2018; ANDERSON; VALDERRAMA; JORY, 2019). Embora a Ásia seja responsável por quase 90% da produção aquícola mundial, sua eficiência ainda é baixa, sendo necessário a intensificação dos sistemas e a adoção de novas tecnologias a fim de melhorar seu desempenho (FAO, 2017a).

A produção brasileira de camarão cultivado, quase que em sua totalidade, corresponde ao camarão branco do Pacífico, *Litopenaeus vannamei*, e o maior número de fazendas de camarões marinhos está concentrado na região Nordeste do Brasil. No ano de 2003 a região produziu 90.190 toneladas de camarão cultivado (ABCC, 2017), tendo sido responsável por 93,1% da produção brasileira do crustáceo, alcançando produtividade média acima de 6 T/ha/ano, um dos maiores índices de produtividade já obtido a nível mundial em sistema convencional (IBAMA, 2007). Contudo, a partir de 2004, uma sequência de eventos econômicos, políticos, climáticos e sanitários direcionaram a atividade a um desempenho bem inferior aos obtidos em 2003. A partir de 2010 com adoção de medidas sanitárias e novas tecnologias a atividade voltou a obter melhores resultados, embora mais modestos quando comparados com 2003. No ano de 2020 a produção brasileira de camarões cultivados foi de 112.000 toneladas, e a região Nordeste sendo responsável por 99,5% dessa produção, com previsão de produzir aproximadamente 150.000 toneladas em 2021 e 200.000 toneladas em 2022 (ABCCAM, 2021).

A tolerância do *Litopenaeus vannamei* a uma ampla faixa de salinidade, que podem variar de 0,5 a 40 g/L^{-1}, assim como seu excelente desempenho zootécnico, faz com que a espécie se destaque e apresente grande potencial para a produção em baixa salinidade (SAOUD; DAVIS; ROUSE, 2003; CHENG et al., 2006; ALVES NETO et al., 2019). Maicá et al. (2012), avaliando o efeito de baixa salinidade na qualidade da água, composição dos bioflocos e desempenho zootécnico de *Litopenaeus vannamei*, obtiveram melhores resultados em salinidade de 25 g/L^{-1}, embora tenham obtido produtividade satisfatória em salinidade de 4 g/L^{-1}. Nessa linha, Alves Neto et al. (2019), testando a sobrevivência de juvenis de *Litopenaeus vannamei* em água de baixa salinidade (5 e 10 g/L^{-1}) face a toxidade do nitrato, obtiveram sobrevivências superiores a 90%. Tais resultados sugerem ser viável a produção do camarão branco do Pacífico, *Litopenaeus vannamei,* em baixa salinidade, sendo possível produzi-lo, inclusive, em regiões distantes da costa.

Desta forma, a carcinicultura marinha possui potencial de desenvolvimento também em regiões distante da costa, podendo ser uma alternativa em áreas impróprias para a agricultura, a diversificação da produção agrícola e oferta do produto a novos mercados (MIRANDA et al., 2010). Além disso, a possibilidade de produzir camarão marinho no continente é muito interessante, pois os cultivos do interior demonstram maior viabilidade econômica do que na costa, principalmente devido ao alto custo da terra e à rigorosa legislação de proteção ambiental dessas regiões (ATWOOD et al., 2003; MAICÁ; DE BORBA; WASIELESKY JR, 2012).

Outro fator de extrema importância para o desempenho zootécnico do camarão é a temperatura. Vale ressaltar que o *Litopenaeus vannamei* cresce melhor em temperaturas entre 28 e 32°C (VAN WYK; SCARPA, 1999). Ponce-Palafox et al. (1997) testando diferentes salinidades (20, 30, 35, 40 e 50 g/L^{-1}) e temperaturas (20, 25, 20 e $35^{0}C$) nos tanques de engorda, obtiveram melhores resultados de crescimento e sobrevivência com temperaturas de 30 e $35^{0}C$, independente da salinidade. Segundo os autores supracitados, o *Litopenaeus vannamei* apresenta melhor desempenho zootécnico em salinidades acima de 20 g/L^{-1} e em temperatura entre 25 e $35^{0}C$.

Figura 3 - Sistema com alto nível de bioflocos (A); bioflocos em detalhe (B e C).

Fonte: arquivo pessoal (fotos A e B); Dr. Leandro Godoy (foto C).

3.3 BFT – *BIOFLOC TECHNOLOGY SYSTEM*

Os bioflocos (Figura 3) são partículas suspensas formadas a partir do desenvolvimento de uma comunidade microbiana no meio de cultivo (BURFORD et al., 2003). São constituídos por agregados de bactérias autotróficas e heterotróficas, protozoários, metazoários, microalgas, larvas de invertebrados, fezes, restos de animais mortos, exoesqueletos e outras partículas presentes no meio (AVNIMELECH, 2007; EMERECIANO et al., 2007).

A tecnologia de produção de camarões em estufas em sistema BFT foi impulsionada pelo *Waddel Mariculture Center* nos Estados Unidos, e adaptada por pesquisadores brasileiros da Universidade Federal do Rio Grande (FURG) às características locais. O uso de estufas para a produção de camarões no sistema BFT é uma tecnologia que tem, dentre suas vantagens, a possibilidade de aumentar o período de cultivo em latitudes mais altas, onde as temperaturas são mais baixas, reduzindo as trocas de água e minimizando a perda de calor (MCABEE et al., 2003; ARNOLD et al., 2009; CRAB et al., 2009; LI et al., 2009).

O sistema BFT é uma alternativa sustentável para a intensificação da produção na aquicultura, pois oferece vantagens frente ao sistema convencional (AVNIMELECH, 1999, 2012; WASIELESKY et al., 2006; KRUMMENAUER et al., 2014; ZHOU; HANSON, 2017).

Suas principais vantagens são:

- ✓ permite a utilização de altas densidades de estocagem, possibilitando uma maior produção em uma menor área de cultivo, superando o problema da falta de áreas para implantação de empreendimentos aquícolas (KRUMMENAUER et al., 2011);

- ✓ a fertilização orgânica no sistema otimiza o crescimento de bactérias heterotróficas e, consequentemente, dos bioflocos. Essas bactérias convertem nitrogênio inorgânico em proteína bacteriana, melhoram a qualidade da água e permitem que o camarão cresça em altas densidades de estocagem (AVNIMELECH, 1999; BOYD; CLAY, 2002; KUMAR et al., 2017);

✓ o sistema de bioflocos permite a produção intensiva e superintensiva de camarões em pequenas áreas, com densidades de estocagem relativamente seguras, que podem variar de 100 a 450 camarões/m^3. As densidades de estocagem mais utilizadas nos cultivos intensivos em viveiros, no sistema de bioflocos, é de 100 a 200 camarões por m^2 (TAW et al., 2008). O sistema permite o uso de altas densidades de estocagem nos berçários, de 1.000 a 5.000/m², na engorda em viveiros, de 100 a 200/m², em *raceways*, com a possibilidade de realizar o povoamento com 300 a 600 camarões/m² (WASIELESKY et al., 2016). Otoshi et al. (2009) testaram altos níveis de adensamento na engorda, ao utilizarem a densidade de estocagem de 828 camarões por m^2, obtiveram uma produtividade de 10,3 kg/m^2 e uma sobrevivência de 67,9%, em sistema BFT em estufas. Samocha et al. (2010), utilizando densidades de estocagem de 530 camarões/m^2, alcançaram a produtividade de 9,75 kg/m^3 e 95% de sobrevivência. Vale salientar que tais resultados foram alcançados com o uso intensivo de tecnologia;

✓ com altos níveis de proteína, os bioflocos disponibilizam uma fonte extra de alimentos com alto valor nutricional (WASIELESKY et al., 2006; MISHRA et al., 2008; KUMAR et al., 2017), contribuindo assim para uma melhor conversão alimentar (0,8 a 1,4 kg de ração para cada kg de camarões produzidos) e redução nos custos de produção (SMITH et al., 2002; TACON et al., 2002; CUZON et al., 2004; WASIELESKY et al., 2006). Em sistemas tradicionais, a alimentação é responsável por até 60% dos custos totais (BOYD; CLAY, 2002; SMITH et al., 2002; TACON et al., 2002; BURFORD et al., 2003; CUZON et al., 2004; BALLESTER et al., 2010; POERSCH et al., 2012; ROY; DAVIS; WHITIS, 2012). Dessa forma, a alimentação constitui um dos itens de maior relevância na produção de camarões (TEIXEIRA; GUERRELHAS, 2011; POERSCH et al., 2012; REGO et al., 2017; ALMEIDA et al., 2021);

✓ no sistema BFT, com a manipulação da relação carbono/nitrogênio do meio através de fertilizações, é possível controlar os compostos nitrogenados e manter a qualidade da água, reduzindo assim a necessidade de renovações, típicas dos sistemas aquícolas convencionais (SAMOCHA et al., 2012). Uma das vias deste controle baseia-se na formação dos flocos microbianos que absorvem a amônia ou oxidam as frações mais tóxicas (amônia e nitrito) para a menos tóxica (nitrato) pelo processo de nitrificação (FRÓES et al., 2013; LIU et al., 2019; SOUZA et al., 2019).

Outro aspecto de grande relevância ao comparar o sistema convencional de produção de camarões com o sistema de bioflocos é o uso de recursos hídricos e o potencial de eutrofização do meio ambiente. Enquanto no sistema convencional são necessários, aproximadamente, 64 mil litros de água para produzir 1 kg de camarões (HOPKINS et al., 1993), no sistema com bioflocos são necessários entre 98 e 169 litros para produzir a mesma quantidade (OTOSHI et al., 2009; SAMOCHA et al., 2010; GAONA et al., 2011; KRUMMENAUER et al., 2011, 2012). A água utilizada no sistema de bioflocos pode ainda ser usada por sucessivos ciclos produtivos (KRUMMENAUER et al., 2013; MACIEL; FRANCISCO; MIRANDA-FILHO, 2018), enquanto a utilizada no sistema convencional, rica em matéria orgânica, nutrientes e compostos nitrogenados, normalmente é lançada aos corpos d'água e ambientes adjacentes, causando alterações significativas na biota circundante (RIBEIRO et al., 2014; SUÁREZ-ABELENDA et al., 2014; CARDOSO-MOHEDANO et al., 2016).

A produção de camarões no sistema BFT se diferencia por ser uma tecnologia que possibilita oferecer ao mercado um produto ecologicamente correto, produzido com o uso racional dos recursos naturais e com baixo impacto ao meio ambiente. Nesse sentido, outra vantagem do sistema de bioflocos é o maior grau de biossegurança, pois não há troca de água com o ambiente aquático adjacente, reduzindo assim o risco de introdução e disseminação de patógenos nos cultivos (WASIELESKY et al., 2006).

O sistema BFT oferece benefícios na melhoria da produção aquícola, esses podem contribuir para o alcance dos objetivos de desenvolvimento sustentável, juntamente com as demais metas do ODS 14 (BOSSIER; EKASARI, 2017). Além dos resultados extremamente positivos em termos ambientais, a tecnologia apresenta excelentes índices de produtividade, tornando-os também economicamente atraentes (SAMOCHA et al., 2007; CRAB et al., 2009; OTOSHI et al., 2009; KRUMMENAUER et al., 2011; POERSCH et al., 2012; PÉREZ-FUENTES; PÉREZ-ROSTRO; HERNÁNDEZ-VERGARA, 2013; ALMEIDA et al., 2021).

3.4 MÉTODOS E TÉCNICAS DE ANÁLISE DE INVESTIMENTOS

Com a intensificação dos sistemas de produção aquícolas maiores são os custos de implantação, produção e a complexidade gerencial e operacional desse tipo de empreendimento. Assim, faz-se necessário uma análise bioeconômica detalhada dos projetos de investimento dessa natureza, a fim de minimizar riscos ao capital investido. No atual nível de desenvolvimento da carcinicultura informações apresentadas de forma errônea, obtidas com a utilização de metodologias inexistentes na análise de projetos de investimento, interferem de forma negativa para o desenvolvimento do setor, pois decisões com base em informações equivocadas podem trazer grandes perdas e prejuízos financeiros que, certamente, influenciarão negativamente potenciais investidores.

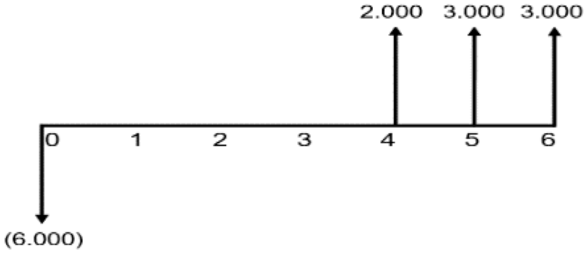
Nesta seção são apresentados os métodos e técnicas que foram utilizados nas análises econômico-financeiras do estudo. Os métodos e técnicas de análise de investimentos consistem em ferramentas que possibilitam a tomada de decisão em condições de incerteza, buscando eliminar ou minimizar o risco na tomada de decisão, onde aceitarmos ou rejeitarmos um investimento com base em critérios pré-definidos e amplamente testados.

3.4.1 Fluxo de caixa (FC)

Segundo Hoji (2017), o fluxo de caixa é um esquema que representa as entradas e saídas de caixa ao longo do tempo. Consiste num facilitador da visualização de uma operação que envolve receitas e despesas em diferentes instantes de tempo (CASAROTTO; KOPITTKE, 2010) (Figura 4).

O fluxo de caixa é um instrumento de planejamento financeiro que tem por objetivo fornecer estimativas da situação do caixa da empresa em determinado período de tempo à frente (SANTOS, 2010).

Figura 4 - Esquematização de fluxo de caixa.



Fonte: Casarotto e Kopittke (2010).

Conforme apresentado na Figura 4 e a partir do exposto por Casarotto & Kopittke (2010) a representação do fluxo de caixa de um projeto pode ser expressa em uma escala horizontal, onde são identificados os períodos de tempo e a representação do fluxo de capital se dá com setas para cima representando as entradas e as setas para baixo as saídas de caixa. A unidade de tempo (mês, semestre ou ano), deve coincidir com o período de capitalização dos juros considerados.

Santos (2010) acrescenta que os dados no fluxo de caixa são dispostos sequencialmente em períodos de tempo, começando no tempo zero, momento em que é registrado o investimento inicial. As entradas e saídas de caixa são consideradas como tendo acontecido no final dos períodos de tempo a que se referem (mês, semestre ou ano).

3.4.2 Valor presente líquido (VPL)

O valor presente líquido é um dos indicadores mais rigorosos e isentos de falhas técnicas. O VPL é a concentração de todos os valores esperados de um fluxo de caixa na data zero, para isso deve ser usada a Taxa Mínima de Atratividade (TMA) do projeto de investimento como taxa de desconto (SOUZA; CLEMENTE, 2008).

Conforme Galesne et al. (1999) o valor presente líquido de um projeto de investimento é igual à diferença entre o valor presente das entradas líquidas de caixa associadas ao projeto e o investimento inicial necessário, com o desconto dos fluxos de caixa feito a uma taxa *k* definida pela empresa, ou seja, sua TMA.

O cálculo do valor presente líquido de um projeto pode ser obtido por meio da seguinte equação:

$$VPL = \sum_{t=1}^{T} \frac{R_t - D_t}{(1+i)^t} + \frac{S_t}{(1+i)^t} - I_0$$

Onde:

R_t = receitas para um período “*t*”;

D_t = despesas para um período “*t*”;

S_T = valor residual do projeto no último período;

I_0 = investimento inicial;

(1 + *i*) = taxa mínima de atratividade.

Os critérios para aceitação ou rejeição do método são simples, pois todo o investimento que apresente um VPL maior ou igual a zero é considerado viável. Os projetos são economicamente inviáveis quando apresentam um VPL negativo, o que indica um retorno abaixo da taxa mínima de atratividade exigida.

3.4.3 Valor Anual Equivalente (VAE)

O método do Valor Anual Equivalente converte todo o fluxo de caixa do projeto numa série de “n” capitais iguais e postecipados, distribuídos entre a data um e a data terminal do fluxo de caixa (LAPPONI, 2007).

O VAE de um projeto pode ser obtido com o uso da seguinte equação:

$$\text{VAE} = \frac{VPL\ .\ i}{\left[1-(1+i)^{(-n)}\right]}$$

Onde:

VPL = valor presente líquido do projeto;

i = taxa mínima de atratividade;

n = tempo de vida do projeto.

O projeto será economicamente viável se apresentar VAE positivo, indicando que os benefícios periódicos são maiores que os custos periódicos. No tocante à seleção de opções, são preferíveis projetos que apresentem maior VAE (NOGUEIRA, 1999; REZENDE; OLIVEIRA, 2013).

3.4.4 *Payback* (PB)

O *Payback*, ou período de retorno, pode ser definido como o período necessário para recuperar o montante do investimento inicial. As empresas desejam um retorno no período mais curto possível para aumentar a rentabilidade e reduzir o risco (LARSON; WILD; CHIAPPETTA, 2004). O método *Payback* é um instrumento de avaliação que permite a visualização do período de recuperação do investimento investido.

Segundo Gitman (2018) o período de retorno pode ser encontrado com a divisão do investimento inicial pela entrada de caixa anual. Contudo, nessa equação, não é levado em conta o valor do dinheiro no tempo.

O *Payback* é obtido a partir da seguinte equação:

$$PB = \frac{I_0}{FC}$$

Onde:

I_0 = investimento inicial;

FC = fluxo de caixa anual líquido;

Segundo Galesne et al. (1999) esse critério corresponde a uma ideia bastante simples: aquela segundo o qual um investimento é tanto mais interessante quanto suas entradas líquidas de caixa anuais permitirem mais rapidamente recuperar o capital inicialmente gasto para realizá-lo.

Assim, na escolha entre dois ou mais projetos, terão preferência aqueles cujos períodos para obter o retorno do capital investido forem menores. Contudo, convém lembrar que este não é um indicador de rentabilidade dos projetos, uma vez que está mais alinhado à medida da liquidez que o projeto apresenta.

O *Payback* Descontado (PD) corresponde a identificação do período necessário ao investidor para recuperar o capital investido levando em consideração o valor do dinheiro no tempo. O fluxo de caixa de cada período é trazido a valor presente, ou seja, calculado o valor de cada fluxo na data zero.

O *Payback* Descontado é obtido a partir da seguinte equação:

$$PD = \frac{I_0}{[(FC/1+i)^n]}$$

Onde:

I_0 = investimento inicial;

FC = fluxo de caixa anual líquido;

i = taxa;

n = período.

O critério de escolha entre projetos no *Payback* Descontado é o mesmo do *Payback,* a preferência é dada a projetos que proporcionem períodos de retorno menores.

3.4.5 Índice de lucratividade (IL)

O Índice de Lucratividade indica quanto o projeto oferece de retorno para cada unidade investida. O Índice de Lucratividade consiste na razão resultante do valor presente das entradas e das saídas de fluxo de caixa (ASSAF NETO, 2019).

O IL pode ser obtido através da seguinte equação:

$$IL = \frac{\sum_{t=1}^{n} \frac{FC_t}{(1+i)^t}}{I_0}$$

Onde:

FC = Fluxos de Caixa;

I_0 = Investimento;

i = taxa mínima de atratividade;

t = número de anos.

O projeto será viável se o resultado desse indicador for maior que 1, ou seja, significa que o capital investido será recuperado. Para que isso ocorra as entradas deverão ser maiores que as saídas, considerando o custo de oportunidade do capital investido (ASSAF NETO, 2019).

3.4.6 Taxa interna de retorno (TIR)

A taxa interna de retorno é uma das mais importantes alternativas para o cálculo de um orçamento de capital além do VPL. A TIR é uma eficiente ferramenta para avaliar a viabilidade de um investimento, ela reflete a taxa de retorno ganha em um projeto (LARSON; WILD; CHIAPPETTA, 2004).

A TIR é definida como a taxa de juros que iguala as inversões ou custos totais aos retornos ou benefícios totais obtidos durante a vida útil de um projeto, sendo atrativo o investimento cuja taxa interna de retorno for maior ou igual à Taxa Mínima de Atratividade (TMA) do investidor.

Tisdell (1993) argumenta que a TIR está intimamente relacionada ao VPL, e consiste em uma taxa de desconto que torna o VPL igual a 0.

$$VPL = \sum_{t=1}^{T} \frac{R_t - D_t}{(1+TIR)^t} + \frac{S_t}{(1+TIR)^t} - I_0 = 0$$

Onde:

R_t = Receita do período t;

D_t = Despesa de um período t;

S_t = Valor residual do projeto no último período;

I_0 = Investimento inicial;

TIR = Taxa interna de retorno.

Um investimento deve ser aceito se a TIR for maior que o retorno exigido (TMA), caso contrário deverá ser rejeitado.

3.4.7 Taxa interna de retorno modificada (TIRM)

A TIRM consiste em uma nova versão da TIR convencional. A TIRM é um misto do método do VPL, que capitaliza os fluxos de caixa intermediário ao custo de capital, e da TIR. Por esse motivo é visto por muitos como um método híbrido (DAMODARAN, 2014).

Para Kassai et al., (2005), a TIRM é uma versão melhorada da TIR e indica a verdadeira taxa interna de retorno de um projeto. Ela busca corrigir seus problemas estruturais relacionados às questões das raízes múltiplas ou inexistentes, das taxas reais de financiamento dos investimentos e de reinvestimentos dos lucros (KASSAI, 1996).

A TIRM pode ser obtida através da seguinte equação:

$$TIRM = \sqrt[n]{\frac{VF}{VP}} - 1$$

Onde:

VF = Valor futuro das entradas líquidas de caixa;

VP = Valor presente das saídas de caixa líquidas, descontadas à taxa de financiamento.

No cálculo da TIRM os fluxos de caixa são trazidos a valor presente, com uma taxa de financiamento compatível. Após a identificação das variáveis de maior relevância, enquanto os fluxos intermediários positivos são levados a valor futuro no último período do fluxo de caixa, a partir de uma taxa de reinvestimento adequada com as praticadas no mercado.

O projeto deverá ser aceito quando a TIRM for maior que o custo de capital da empresa, caso contrário não se considera viável aceitar o projeto.

3.4.8 Taxa mínima de atratividade (TMA)

A TMA consiste em uma taxa com baixo risco que o empreendedor teria como opção para aplicar seu capital e, portanto, é o retorno mínimo que este espera obter (SOUZA; CLEMENTE, 2008). A TMA representa a rentabilidade mínima exigida pelos empreendedores, ela pode coincidir com o custo de oportunidade de capital, caso usem a taxa de mercado em sua política de decisões em investimentos (GALESNE; FENSTERSEIFER; LAMB, 1999).

A TMA será determinada pelo Modelo de Precificação de Ativos Financeiros Ajustado Híbrido (AH-CAPM). Justifica-se a escolha desse modelo, pelo fato de minimizar as limitações da aplicação do *Capital Asset Pricing Model* (CAPM), em suas primeiras aplicações (MARKOWITZ, 1959; SHARPE, 1964; LINTNER, 1965;

MOSSIN, 1966) em países emergentes e por ser o mais utilizado pelos investidores (GRAHAM; HARVEY, 2001; BLANK et al., 2014). Nesse sentido, vários estudos foram realizados e testados empiricamente, para minimizar estas limitações, dentre os quais destacam-se: os modelos de Godfrey-Espinosa (1996); Lessard (1996); Mariscal & Hargis (1999); Damodaran (2014); CAPM por Benchmarking de (ASSAF NETO, 2019); CAPM Local (L-CAPM); CAPM Local Ajustado (AL-CAPM); e CAPM Ajustado Híbrido (AH-CAPM), sendo os últimos três, desenvolvidos por Pereiro (2001).

A expressão de cálculo do AH-CAPM é dada por:

$$TMA = Rf_g + R_c + \beta C_{LG}\left[\beta_{GG}\left(R_{MG} - Rf_g\right)\right](1 - R^2) + Inf\ BR + Inf\ USA$$

Onde:

TMA = Taxa Mínima de Atratividade;

Rf_g = Taxa livre de risco global;

R_c = Risco país;

βC_{LG} = Beta do país;

β_{GG} = Beta desalavancado de investimentos comparáveis no mercado global;

R_{MG} = Retorno do mercado global;

R^2 = Coeficiente de determinação;

$Inf\ BR$ = Taxa de inflação no Brasil;

$Inf\ BR$ = Taxa de inflação nos Estados Unidos.

3.4.9 Análise de sensibilidade e simulação de Monte Carlo (SMC)

O objetivo desses métodos é verificar o grau de sensibilidade do investimento através da variação das principais variáveis econômicas dos empreendimentos, como variações ou oscilações na produção, preços de produtos e insumos, preço de venda, dentre outros.

Após a identificação das variáveis de maior relevância foi utilizado o Método ou Simulação de Monte Carlo (SMC). A SMC introduz a incerteza nas variáveis que mais impactam o resultado do NPV, tendo como objetivo observar seu comportamento em um ambiente de risco (MARTÍNEZ-PAZ; PELLICER-MARTÍNEZ; COLINO, 2014).

A SMC consiste em uma técnica matemática que gera amostras aleatórias de variáveis de saída a partir de várias amostras aleatórias de variáveis de entrada. O processo de simulação envolve repetidas interações aleatórias gerando uma série de distribuição de resultados (MENČÍK, 2016; ALMEIDA et al., 2021).

Ao gerar uma gama de números aleatórios, o investidor não toma como base na tomada de decisão apenas um número reduzido de possibilidades na análise do investimento, mas tem a possibilidade de avaliar os cenários mais prováveis, através das diversas interações realizadas entre as variáveis mais relevantes com o uso do Método de Monte Carlo (ALMEIDA et al., 2021).

3.5 AVALIAÇÃO DO CICLO DE VIDA (ACV)

A aquicultura tem sido constantemente considerada sustentável (TLUSTY; THORSEN, 2017), contudo, ainda está fortemente relacionada a diversos impactos ambientais potenciais, como a eutrofização de ecossistemas aquáticos, uso intensivo de terra e da água, ecotoxicidade nos ecossistemas locais pelo uso de produtos químicos e a introdução de espécies exóticas (DIANA, 2009; OTTINGER; CLAUSS; KUENZER, 2016; BOHNES et al., 2019).

Para Cao et al. (2013), tal contradição faz com que seja totalmente relevante avaliar as atuais práticas aquícolas e identificar os sistemas de produtivos que sejam ambientalmente mais sustentáveis. Além disso, embora a atividade apresente resultados econômicos promissores, para Bohnes e Laurent (2019) é crucial garantir que o rápido desenvolvimento do setor aquícola ocorra da maneira sustentável.

Uma das metodologias mais utilizadas para avaliação de impactos ambientais de produtos e sistemas produtivos na atualidade é a Avaliação do Ciclo de Vida (RUVIARO et al., 2012; FERRARA; DE FEO, 2018). Cao et al. (2013) dizem que a ACV pode ser usada para fazer essa avaliação em termos quantificáveis e que a metodologia possui indicadores claros de sustentabilidade, sendo esse, segundo

Diana (2009), um dos poucos métodos que permitem avaliar a sustentabilidade da aquicultura de forma quantitativa e cientificamente sólida, fato que é confirmado pelo crescimento significativo do número de trabalhos científicos aplicando a ACV na aquicultura (AUBIN, 2013; BOHNES et al., 2019; BOHNES; LAURENT, 2019).

A expansão da aquicultura intensiva está sendo acompanhada de uma maior conscientização e preocupação. Natale et al. (2013) relatam um alto consumo de energia e valores elevados nas emissões de dióxido de carbono nos sistemas aquícolas fechados em relação a gaiolas e tanques, que variam de acordo com o grau de intensificação do sistema. Isso tem direcionado as indústrias a tomarem medidas que as conduzam a uma produção mais sustentável, podendo encontrar na ACV uma metodologia que compare a pressão no ambiente por diferentes sistemas de produção, usando uma metodologia padrão e que aborda preocupações de sustentabilidade (NATALE et al., 2013).

De Feo e Ferrara (2016) argumentam que a ACV permite comparar o desempenho ambiental de diferentes sistemas, considerando o consumo de recursos e a emissão de poluentes que podem ocorrer durante seu ciclo de vida. A ACV se destaca também por mensurar o desempenho ambiental de qualquer cadeia ou sistema produtivo, uma vez que serve como ferramenta de gestão, auxiliado assim na tomada de decisão (BOHNES et al., 2019). A realização da ACV na aquicultura possibilita a obtenção de um panorama mais detalhado dos seus impactos ambientais (ZIEGLER et al., 2016). Além disso, avalia de forma adequada as estratégias de mitigação de Gases de Efeito Estufa (GEE) (RUVIARO et al., 2012), sendo uma ferramenta que permite mensurar os impactos ambientais positivos e negativos de todo o ciclo de vida de um produto, serviço, processo ou atividade (BHATT; BRADFORD; ABBASSI, 2019).

Na aquicultura a ACV pode ser usada para apoiar a tomada de decisões, identificando os pontos críticos do sistema, com o intuito de reduzir seus impactos ambientais, ou então comparar com outros sistemas alternativos para determinar qual deles apresenta os menores impactos ambientais entre as alternativas analisadas (BOHNES et al., 2019).

A Avaliação do Ciclo de Vida, *Life Cycle Assessment* (LCA) em inglês, é normatizada internacionalmente na Europa pela EN 15804 e pelas ISO 14040 e ISO

14044. No Brasil as ISOs foram traduzidas e nomeadas ABNT NBR ISO 14040 e ABNT NBR ISO 14044. A metodologia da Avaliação do Ciclo de Vida é composta por quatro fases que se inter-relacionam (ABNT ISO 14040, 2009; ABNT ISO 14044, 2009):

1. Definição de objetivo e escopo – é a fase em que são determinadas as fronteiras do estudo, que podem ser temporais e geográficas, a quem se destinam os resultados. Convém que o escopo seja suficientemente bem definido para assegurar que a abrangência, profundidade e detalhamento do estudo sejam compatíveis e suficientes para atender ao objetivo declarado. O escopo de uma ACV, incluindo a fronteira do sistema e o nível de detalhamento, depende do objeto e do uso pretendido para o estudo. A profundidade e a abrangência da ACV podem variar consideravelmente, dependendo do objetivo do estudo em particular;

2. Análise de Inventário do Ciclo de Vida (ICV) – a ICV é a segunda fase de uma ACV. Consiste no inventário dos dados de entrada/saída associados ao sistema em estudo. Essa fase envolve a coleta dos dados necessários para o alcance dos objetivos do estudo;

3. Avaliação dos Impactos do Ciclo de Vida (AICV) – a terceira fase da ACV, a AICV, possui o objetivo de prover informações adicionais para ajudar na avaliação dos resultados do ICV de um sistema de produto, com o intuito de proporcionar o melhor entendimento de sua significância ambiental;

4. Interpretação dos resultados – fase final do procedimento de ACV, na qual os resultados de um ICV e/ou de uma AICV, ou de ambos, são sumarizados e discutidos como base para conclusões, recomendações e tomada de decisão de acordo com a definição de objetivo e escopo.

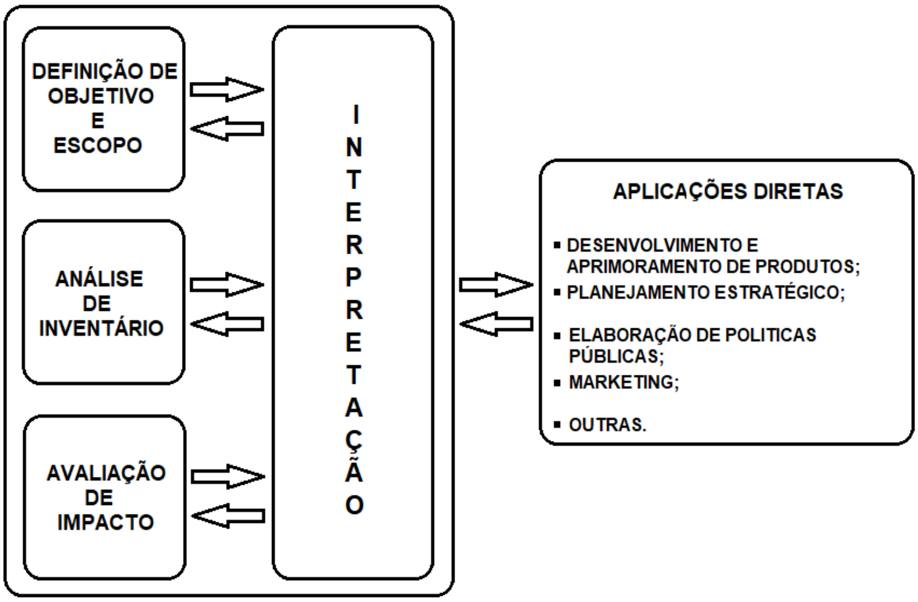
A ISO 14044 (ABNT ISO 14044, 2009) esclarece que ao definir o escopo de uma ACV alguns itens devem ser considerados e descritos claramente. São eles:

- ✓ o sistema do produto que irá ser estudado;
- ✓ as funções do sistema do produto, ou em estudos comparativos, dos sistemas;

- ✓ a unidade funcional;
- ✓ a fronteira do sistema;
- ✓ os procedimentos de alocação, quando utilizados;
- ✓ a metodologia de AICV e os tipos de impacto;
- ✓ a interpretação a ser utilizada;
- ✓ os requisitos de dados;
- ✓ os pressupostos ou hipóteses;
- ✓ a escolha de valores e elementos opcionais;
- ✓ as limitações do estudo;
- ✓ os requisitos de qualidade dos dados;
- ✓ se aplicável, o tipo de revisão crítica;
- ✓ tipo e formato do relatório requerido para o estudo.

Todas as fases da ACV devem ser abordadas de forma integrada, observando suas inter-relações, de forma que possibilitem adequações constantes ao longo da execução do projeto. Suas inter-relações podem ser observadas na Figura 5.

Figura 5 - Esquematização das fases e inter-relações de um estudo de ACV.



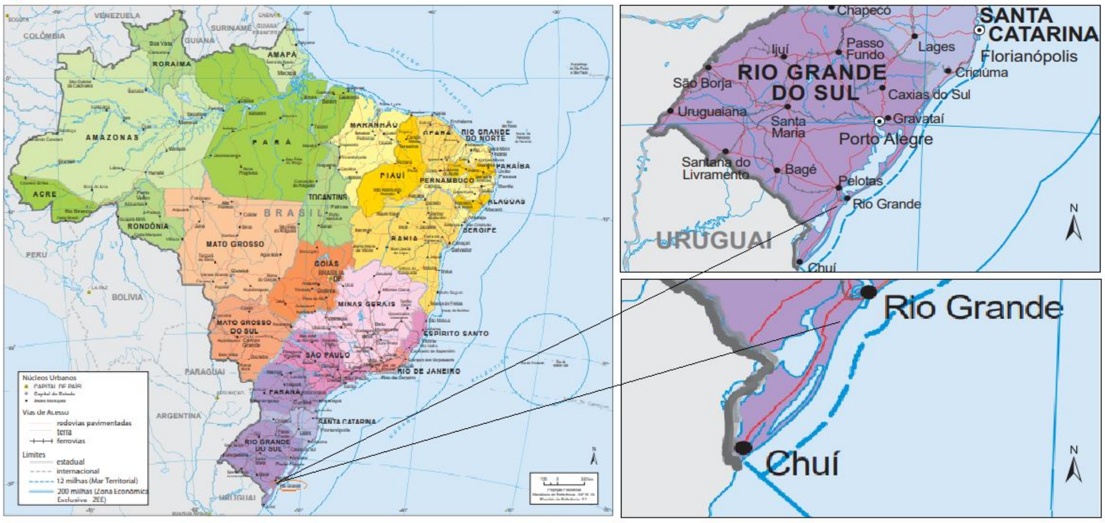
Fonte: NBR ISO 14040 (ABNT ISO 14040, 2009).

A seleção das categorias de impacto consiste em um dos itens principais e obrigatórios de um estudo de ACV. A literatura cientifica com a temática da ACV na aquicultura tem abordado, na sua maioria, as categorias de Potencial de Aquecimento Global (GWP), Potencial de Acidificação (AP), o Potencial de Eutrofização (EP), Ecotoxidade Aquática (EA), a Demanda de Energia Acumulada (CED), Dependência da Água (WD), Uso Líquido da Produção Primária (NPPU) e Competição por Terra (LC) (MUNGKUNG; UDO DE HAES; CLIFT, 2006; AUBIN, 2013; HENRIKSSON et al., 2012; AVADÍ et al., 2015; YACOUT; SOLIMAN; YACOUT, 2016; BOHNES et al., 2019).

4. LOCAL DE ESTUDO

O estudo foi realizado com base em informações e dados de produção do Projeto Camarão, sediado na Estação Marinha de Aquacultura Prof. Marcos Alberto Marchiori (EMA) (Figura 6). O local também é sede do Programa de Pós-graduação em Aquicultura, o qual o Projeto faz parte, e vinculados ao Instituto de Oceanografia da Universidade Federal do Rio Grande - FURG, localizada na praia do Cassino, no município de Rio Grande – RS (Figura 6).

Figura 6 - Localização da EMA - FURG/Projeto Camarão.



Fonte: Adaptado de IBGE (2020).

A EMA (Figura 7) possui uma área construída de 2.800 m² e conta com estruturas reprodução, larvicultura e produção de porte comercial de engorda de camarões marinhos. Além disso, possui instalados laboratórios de Piscicultura Estuarina e Marinha, Nutrição de Organismos Aquáticos e Avaliação de Impactos da Aquicultura.

Dados de desempenho zootécnico, de produção e de comercialização foram obtidos junto a coordenação do Projeto (Prof. Dr. Wilson Wasielesky Jr., Prof. Dr. Geraldo Fóes e Prof. Dr. Luis Henrique Poersch), do período de 2009/2010 a 2019/2020. Estes dados foram utilizados nas análises econômicas/financeiras e na ACV da produção intensiva em viveiros e superintensiva em estufas, do camarão *Litopenaeus vannamei* em sistema BFT.

Figura 7 - Vista aérea da EMA.

Fonte: Google Earth.

No local estão o setor de Maturação, onde ficam os reprodutores e onde ocorrem experimentos e parte do processo de reprodução (Figura 8A), o setor de Desova onde o processo de reprodução é finalizado (Figura 8B), o setor de

Larvicultura, onde as larvas de camarão são mantidas até completarem seu ciclo larval e atingirem o estágio de pós-larvas (Figura 8C), cinco estufas de engorda (nas fotos GH3 e GH5, respectivamente) (Figuras 8D e 8E) e nove viveiros de engorda (Figura 8F).

Figura 7 - Setor de maturação (A), sala de desova (B), tanque de larvicultura (C), tanque berçário e tanques de engorda GH2 (D), tanque de engorda GH5 (E) e viveiros (F) – Projeto Camarão.

Fonte: Arquivo pessoal.

4.1 MATERIAL BIOLÓGICO E SISTEMAS DE PRODUÇÃO

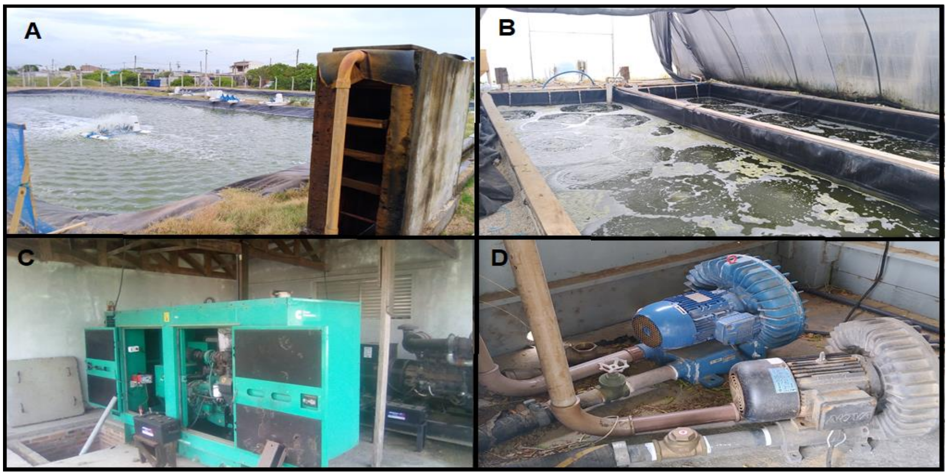
No presente estudo foram utilizados informações e dados da produção intensiva de camarões da espécie *Litopenaeus vannamei* em viveiros e superintensiva em estufas, em sistema BFT. A produção ocorre inicialmente com a aquisição de pós-larvas (PLs) de camarões, provenientes da empresa Aquatec LTDA. (Rio Grande do Norte). Ao chegar na estação, após observados parâmetros de temperatura e salinidade, as PLs são submetidas a um período de aclimatação. Logo após, as pós-larvas são estocadas e mantidas em tanques do setor de larvicultura (Figura 8C) até atingirem o estágio de pós-larva de 15 dias (PL 15). Após esta fase as pós-larvas são transferidas para tanques berçário com área de 35 m^2 na GH3 (Figura 8D), onde permanecem durante 60 dias em sistema de bioflocos, em uma densidade de estocagem de 2.000 PLs por m^2. Ao atingir o estágio de juvenis, com peso médio de 1,0 g, são transferidas para os tanques de engorda na GH3 (Figura 8D) e viveiros (Figura 8F).

A produção intensiva é realizada em nove viveiros (Figura 8F) com área de 600 m^3, cobertos com geomembrana de polietileno de alta densidade (PEAD) e com 0,8 mm de espessura. Nesse sistema os animais com peso médio de 1,0 g são estocados em densidades de 100 a 200 camarões/m^3. Para cada viveiro a aeração é fornecida por aerador elétrico, do tipo *paddle wheel* (Trevisan®) (Figura 9A), com potência de 1,0 HP.

A produção superintensiva é realizada em uma estufa (GH3) (Figura 8D), com nove tanques de 35 m^3, cobertos com geomembrana de polietileno de alta densidade (PEAD) e com 0,8 mm de espessura. Camarões com peso médio de 1,0 g são estocados em densidades de 350 a 600 indivíduos por m^3. No sistema de aeração (Figura 9B) são utilizados em cada unidade mangueiras tipo aerotube acopladas a canos de PVC e ligados a um soprador de 7,5 HP (Figura 9D).

Os camarões foram alimentados três vezes ao dia (8:00 h, 14h e as 19:00 h) com ração comercial extrusada, contendo 40% de proteína bruta. Esta é fornecida por lance, e em bandejas de alimentação a fim de acompanhar o seu consumo, seguindo a metodologia descrita por Wasielesky *et al*. (2006).

Figura 8 - Aerador tipo *paddle wheel* (A), aeração com mangueiras tipo *aerotube* (B), geradores (C), sopradores (D).



Fonte: Arquivo pessoal.

4.1.1 Desempenho zootécnico

Para o acompanhamento do desempenho zootécnico dos camarões e ajuste da quantidade de ração ofertada, são realizadas biometrias quinzenais. Para isto são coletados aleatoriamente 30 camarões de cada unidade experimental. Os animais são pesados individualmente e devolvidos ao seu respectivo tanque. No final do experimento é realizada a pesagem de toda a produção, a fim de estimar a sobrevivência e a biomassa final.

Para avaliar o desempenho zootécnico do camarão *Litopenaeus vannamei* produzido em sistemas com diferentes níveis de bioflocos são utilizados os seguintes parâmetros:

- ✓ sobrevivência (%) = [(biomassa final / peso médio individual) / nº de camarões estocados] x 100;
- ✓ peso médio individual (g);
- ✓ ganho em peso (g) = peso final – peso inicial;
- ✓ taxa de crescimento específico (% dia) = [(peso final – peso inicial) / tempo] x 100;
- ✓ biomassa final (Kg);
- ✓ conversão alimentar aparente (CAA) = quantidade de ração oferecida (g) / (biomassa final (g) – biomassa inicial (g));
- ✓ produtividade = biomassa final x m^3

4.2 QUALIDADE DA ÁGUA

As variáveis físicas e químicas da água, oxigênio dissolvido, pH, temperatura e salinidade dos tanques e viveiros de produção (Tabela 1), são verificadas diariamente com aparelho multiparâmetros.

Tabela 1. Variáveis físicas e químicas registradas durante o período experimental e método de verificação e análise.

Variável	Método de verificação/análise
Temperatura (ºC)	Multiparâmetros*
Oxigênio dissolvido (mg L^{-1})	Multiparâmetros*
Salinidade	Multiparâmetros*
Ph	Multiparâmetros*
Alcalinidade	APHA (1998)
Transparência (cm)	Disco de Secchi
Turbidez	Turbidímetro**
SST*** (mg L^{-1})	Gravimetria
Volume do floco (ml L^{-1})	Cone Imhoff
Amônia (mg L^{-1})	UNESCO (1983)
Nitrito (mg L^{-1})	Bendschneider e Robinson (1952)
Nitrato (mg L^{-1})	Aminot e Chaussepied (1983)
Fosfato (mg L^{-1})	Aminot e Chaussepied (1983)
Alcalinidade (mg $CaCO_3/L^{-1}$)	APHA (1998)

* Aparelho multiparâmetros da marca YSI® modelo 556; **Aparelho Turbidímetro marca Hach® modelo 2100P; *** Sólidos suspensos totais.

A qualidade da água é monitorada com base nas concentrações de amônia, nitrito, nitrato, fósforo total, sólidos suspensos totais e alcalinidade. Também, diariamente, são coletadas amostras para análises de amônia, a cada três dias para nitrito e uma vez por semana para nitrato, fósforo total e alcalinidade. As análises são realizadas no Laboratório de Química da Estação Marinha de Aquacultura (EMA). As análises de amônia total seguem metodologia descrita em UNESCO (1983), nitrito descrita em Bendschneider & Robinson (1952) e ortofosfato e nitrato por Aminot & Chaussepied (1983). A alcalinidade é determinada seguindo a metodologia descrita em APHA (1998).

A fim de manter a qualidade da água dentro do aceitável pela espécie, quando os níveis de amônia total ultrapassarem 1,0 mg L^{-1} são realizadas fertilizações orgânicas baseadas nas metodologias propostas por Avnimelech (1999) e Ebeling et al. (2006), com o intuito de estimular a conversão de nitrogênio em biomassa bacteriana, onde para cada 1,0 g^{-1} de nitrogênio amoniacal total presente no sistema, serão adicionadas 6,0 g^{-1} de carbono.

4.3 ANÁLISES ECONÔMICAS

As análises econômicas foram realizadas com dados obtidos nos últimos 10 anos pelo Projeto Camarão na implantação das estruturas de produção e dos insumos utilizados na produção intensiva em viveiros e superintensiva em estufas, do camarão *Litopenaeus vannamei* em sistema BFT, em estruturas comerciais.

Na Tabela 2 estão expostos o resumo dos dados de investimento inicial, custos fixos e variáveis e capital de giro para a produção intensiva em viveiros do camarão branco, *Litopenaeus vannamei*, em sistema BFT

Tabela 2 - Resumo do investimento inicial, custos fixos e variáveis e capital de giro para a produção intensiva de camarão branco em viveiros, *Litopenaeus vannamei*, em sistema BFT.

	Quantidade	**(US$)***	**Total (US$)**
Investimento			**154.194,86**
Terra (ha)	2	3.125,36	6.250,71
Estrutura de produção[1]	3	24.236,53	72.709,59
Aerador 1 CV	36	741,39	26.690,04
Edificações (80m²)	1	30.588,00	30.588,00
Equipamentos de leitura de parâmetros	-	-	2.519,21
Redes e equipamentos de manutenção	-	-	1.259,60
Gerador (55 KVA)	1	12.996,64	12.996,64
Bomba de água (7.5 HP)	1	1.181,06	1.181,06
Custos Fixos			**61.237,03**
Salário dos funcionários - 2 (/mês)	12	437,54	10.500,96

Salário do gestor (/mês)	12	1.215,40	14.584,80
Encargos (37% sob a folha de pagamento)	12	773,48	9.281,76
Contador (/mês)	12	321,20	3.854,39
Energia elétrica (/mês)	12	1.625,30	19.503,60
Água potável (/mês)	12	94,47	1.133,64
ITR (Imposto Territorial Rural) (/mês)	12	31,49	377,88
Manutenção	-	-	2.000,00
Custos Variáveis			**104.420,55**
Pós-larvas (milheiro)	5.427	2,93	15.901,11
Ração comercial 40% PB (kg)	67.729	1,29	87.370,41
Diversos[3]	-	-	1.149,03
Capital de giro	**-**	**-**	**111.624,99**
TOTAL			**431.477,43**

[1]Estrutura de produção (viveiro): viveiros escavados com revestimento de geomembrana PEAD (1.0mm), malha anti-pássaros, pedilúvio/rodolúvio, rede hidráulica e rede elétrica. [2]Compostos para correção do pH e alcalinidade, probiótico, melaço e farelo para a manutenção do biofloco. *Data da cotação: 10/10/2019, cotação: 4,1139 Reais Brasil = 1 Dólar USA.

Na Tabela 3 pode ser visualizado o resumo dos dados de investimento inicial, custos fixos e variáveis e capital de giro para a produção superintensiva em estufas do camarão branco, *Litopenaeus vannamei*, em sistema BFT.

Tabela 3. - Resumo do investimento inicial, custos fixos e variáveis e capital de giro para a produção superintensiva em estufas do camarão branco, *Litopenaeus vannamei*, em sistema BFT.

	Quantidade	**(US$)***	**Total (US$)**
Investimento			**220.829,83**
Terra (ha)	2	3.125,36	6.250,72
Estrutura de produção[1]	10	16.603,46	166.034,60
Edificações (80m²)	1	30.588,00	30.588,00
Equipamentos de leitura de parâmetros	-	-	2.519,21

Redes e equipamentos de manutenção	-	-	1.259,60
Gerador (55 KVA)	1	12.996,64	12.996,64
Bomba de água (7.5 HP)	1	1.181,06	1.181,06
Custos Fixos			**63.298,46**
Salário dos funcionários (/ano)	2	437,54	10.500,96
Salário do gestor (/ano)	1	1.215,40	14.584,80
Encargos (37% sob a folha de pagamento)	12	773,48	9.281,76
Contador (/mês)	12	321,20	3.854,39
Energia elétrica (/mês)	12	1.797,09	21.565,03
Água potável (/mês)	12	94,47	1.133,64
ITR (Imposto Territorial Rural) (/ano)	1	377,88	377,88
Manutenção	-	-	2.000,00
Custos Variáveis			**138.159,27**
Pós-larvas (milheiro)	7.200	2,93	21.096,00
Ração comercial (kg)	89.856	1,29	115.914,24
Diversos[2]	-	-	1.149,03
Capital de giro	**-**	**-**	**147.373,74**
TOTAL			**569.661,30**

[1]Estrutura de produção (estufa): arcos galvanizados, filme plástico, caixa de madeira com revestimento de geomembrana (1.0mm) e fundo de areia, tubulações de drenagem (150mm), soprador de 4 HP, tubulação de aeração primaria (60mm) e secundaria (20mm) e difusores de ar. [2]Compostos para correção do pH e alcalinidade, probiótico, melaço e farelo para a manutenção do biofloco. *Data da cotação: 10/10/2019, cotação: 4,1139 Reais Brasil = 1 Dólar USA.

A depreciação foi calculada pelo método linear. Para a produção intensiva e superintensiva os valores referentes a depreciação, do primeiro ao quinto ano, foram de US$ 12.959,12 e US$ 18.322,96, e do sexto ao décimo ano US$ 12.833,16 e US$ 18.197,00, respectivamente. Segundo Gitman (2018), além de evitar variação significativa no custo do produto, a depreciação também permite a formação de fundos para renovação dos ativos.

Para a realização das análises econômicas serão seguidas as seguintes etapas: definição da Taxa Mínima de Atratividade (TMA) dos empreendimentos, elaboração dos Fluxos de Caixa (FC) dos empreendimentos, aplicação dos métodos e técnicas de avaliação de investimentos e análise do risco dos empreendimentos por meio da Análise de Sensibilidade e Simulação de Monte Carlo. O tratamento dos dados para as análises econômicas será realizado com o auxílio do software Microsoft Excel®.

4.4 ACV – ESTRUTURA METODOLÓGICA

Seguindo orientações da ABNT NBR ISO 14.044:2009, que detalha os requisitos para a condução de uma ACV, nessa seção são expostas as fases que compõem um estudo de ACV e realizado o detalhamento dos critérios utilizados nesse trabalho.

4.4.1 Definição do objetivo e escopo

A ACV do presente estudo tem por objetivo quantificar e comparar benefícios e os impactos ambientais do ciclo de vida da produção intensiva em viveiros e superintensiva em estufas, do camarão *Litopenaeus vannamei,* em sistema BFT. Bhatt et al. (2019) argumentam que para qualquer estudo comparativo de ACV, uma unidade funcional deve ser designada com o intuito de normalizar o inventário de cada sistema e comparar diretamente os impactos com outros estudos de sistemas similares. Para isso, em ambas estratégias de produção, será adotada como unidade funcional (UF) 1.000 kg de camarões *in natura*. O fluxo de referência é de, aproximadamente, 83.334 camarões com peso médio de 0,012 kg.

A fronteira do sistema foi definida como do berço ao portão da fazenda.

Figura 9 - Definição do Objetivo e Escopo: Função, Unidade Funcional e Fluxo de Referência.

* Camarões com peso médio de 0,012 kg.

4.4.2 Inventário do ciclo de vida (ICV)

Nessa fase é realizado o levantamento e a quantificação das entradas e saídas do sistema. Conforme a ABNT NBR ISO 14.040:2009 o ICV envolve a coleta dos dados para o alcance dos objetivos do estudo. O ICV do presente estudo será elaborado com base em dados de entrada e consumo de insumos, de uso de recursos naturais e energia. Tais dados foram registrados diariamente ao longo dos ciclos de produção pelos pesquisadores do Projeto Camarão, da Universidade Federal do Rio Grande – FURG, no período de 2009/2010 a 2019/2020.

O levantamento dos dados foi realizado com base nas categorias de impacto de maior relevância para a atividade, a partir de estudos anteriores e na opinião de especialistas. Além disso, serão respeitados os limites (fronteiras do sistema) e da unidade funcional definidas para o estudo.

4.4.3 Análise de inventário do ciclo de vida (AICV)

Na fase de AICV é realizada a identificação e a avaliação dos impactos inventariados na fase anterior, no ICV, tendo por objetivo a entender e avaliar a magnitude e a significância dos possíveis impactos ambientais de um sistema ao longo do ciclo de vida de um produto (DEWULF et al., 2015). A NBR ISO 14040 (2009) recomenda a modelagem de caracterização dos dados a partir de categorias específicas para o caso estudado.

As categorias de impacto a serem avaliadas pela presente tese são:

- ✓ Potencial de Aquecimento Global (GWP100a);
- ✓ Potencial de Acidificação;
- ✓ Potencial de Eutrofização;
- ✓ Destruição da camada de ozônio (ODP);
- ✓ Toxicidade Humana;
- ✓ Ecotoxidade Aquática;
- ✓ Ecotoxicidade Marinha;
- ✓ Ecotoxicidade Terrestre;
- ✓ Oxidação fotoquímica;
- ✓ Depleção abiótica;

- ✓ Depleção abiótica combustíveis fósseis.

4.4.4 Interpretação do ciclo de vida

A interpretação do ciclo de vida é a fase final do estudo de ACV. Nessa etapa é realizada a interpretação dos resultados, os quais são sumarizados e discutidos, servindo de base para conclusões, recomendações, proposição de melhorias, minimização e redução dos impactos ambientais, e tomada de decisão, tudo em conformidade com o objetivo e o escopo da ACV.

4.4.5 Software

Na ACV desse estudo foi utilizado o software SimaPro® 9.2.0.1 (*System for Integrated Environmental Assessment of Products*). O SimaPro® consiste em uma ferramenta de coleta de dados e de análise do desempenho ambiental de produtos e serviços.

Dados secundários foram obtidos na base de dados do EcoInvent, disponibilizada no software SimaPro® e por meio de revisão bibliográfica.

5. FORMATAÇÃO DOS CAPÍTULOS

A presente tese foi dividida em quatro capítulos. O primeiro capítulo consiste em uma introdução geral. Os três capítulos seguintes foram redigidos no formato de artigo científico. O Segundo capítulo (primeiro artigo), *Bioeconomic analysis of the production of marine shrimp in greenhouses using the biofloc technology system,* está publicado no periódico *Aquaculture Internacional* (ISSN 0967-6120), no endereço eletrônico DOI: https://doi.org/10.1007/s10499-021-00653-1. O Terceiro capítulo (segundo artigo), *Economic analysis of intensive and super-intensive Litopenaeus vannamei shrimp production in a BFT System*, segue as normas de formatação do periódico Boletim do Instituto de Pesca, ao qual foi submetido. O Quarto capítulo (terceiro artigo), Environmental impacts of *Litopenaeus vannamei* shrimp production in intensive and super-intensive biofloc systems segue as normas de formatação da ABNT e está em fase de ajustes para submissão.

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CAPÍTULO II

BIOECONOMIC ANALYSIS OF THE PRODUCTION OF MARINE SHRIMP IN GREENHOUSES USING THE BIOFLOC TECHNOLOGY SYSTEM[1]

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BIOECONOMIC ANALYSIS OF THE PRODUCTION OF MARINE SHRIMP IN GREENHOUSES USING THE BIOFLOC TECHNOLOGY SYSTEM

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ABSTRACT

This study analyzes the investment in *Penaeus (Litopenaeus) vannamei* shrimp production in greenhouses using the Biofloc Technology System (BFT). Considering bioeconomic variables, a sensitivity analysis was performed with data collected over the course of 10 years to evaluate program efficiency. The parameters considered include a stocking density of 400 shrimp/m², which reached a productivity rate of 3.84

kg/m² (69,120 kg/year - three cycles), a final mean weight of 12 g and a feed conversion rate of 1.3. The results obtained had a net present value (NPV) of US$ 904,947.21, net future value (NFV) of US$ 2,401,094.35, equivalent annual value (EAV) of US$ 148,861.38, payback (PB) of two years and four months, discounted payback period (DPP) of two years and ten months, profitability index (PI) of 2.59, internal rate of return (IRR) of 41.23 % and a modified internal rate of return (MIRR) of 21.25 %. However, shrimp with a final mean weight of 15 g resulted in an NPV of US$ 2,522,150.62, net future value (NFV) of US$ 6,692,016.44, equivalent annual value (EAV) of US$ 414,886.98, a PB of one year and two months, DPP of one year and two months, PI of 5.43, IRR of 89.13 % and a MIRR of 30.57 %. The Monte Carlo simulation (MCS) concluded that the probability of NPV being negative is zero. The analysis confirms that *P. vannamei* production using the BFT system is a financially sustainable activity.

Key words: biofloc technology; investment analysis; *Litopenaeus vannamei*; net present value; payback, Monte Carlo simulation.

INTRODUCTION

FAO data (2018) shows that the farming of *Penaeus (Litopenaeus) vannamei* shrimp has been growing worldwide. In 2010, 2.688 million tons of these crustaceans were produced globally, reaching 4.156 million tons in 2016. This figure represented 53 % of the world production of crustaceans, with *P. vannamei* being the most cultivated in the world. Within the aquaculture sector, shrimp cultivation is commercially significant as it represents a group of reared species with high market value and is one of the most substantial activities of the aquaculture sector in Brazil.

Brazilian production of farmed shrimp is focused on the Pacific white shrimp, *P. vannamei*. Although shrimp farming occurs in the South and Southeast regions of the country, the largest number of marine shrimp farms is concentrated in the Northeast. Global factors, coupled with the inherent characteristics of Brazil, such as a large coastal area, abundant availability of inland waters and an attractive domestic market, place Brazil in a strategic position for development of the aquaculture sector. Conventional shrimp cultivation systems require large areas for installation and proximity to the sea and estuaries. However, most importantly, it requires the availability of investment capital for implementation. In conventional systems, shrimp production is developed in an intensive or semi-intensive way with stocking densities ranging from 5 to 45 animals/m^2, mean productivities of approximately 4.5 tons/ha/year (in three production cycles) and feed conversion rates from 1.4 to 1.6 kg of feed for 1.0 kg of shrimp produced (Ostrensky et al. 2008). An indiscriminate increase of the stocking density in conventional systems may cause degradation of the water quality and initiate a series of chemical and physical problems that endanger the entire production system. Thus, at a certain density level, the adoption of more equipment and proper management and monitoring practices is necessary, even though this increases production costs (Ormond et al. 2004). In addition, the traditional systems used in Brazil have low levels of biosecurity, which increases the possibility of production contamination by pathogens and enables the shrimp to escape to the adjacent environment, a concern because this species is not native to the Atlantic Ocean.

Shrimp farming in a biofloc system, also known as BFT, is one of the technologies developed to improve the management of water resources, minimize environmental impacts, reduce costs and maximize the use of production resources. This system allows for the production of aquatic organisms without water exchange by using high stocking densities (Krummenauer et al. 2011), intense aeration and stimulating the formation of microbial aggregates or flocs (heterotrophic and chemoautotrophic bacteria, protozoan, metazoan, rotifers, microalgae, feces and the remains of dead organisms) (De Schryver et al. 2008). The use of biofloc production systems has demonstrated excellent results in terms of biosecurity, productivity and management of water resources (Wasielesky et al. 2006; Krummenauer et al. 2011).

Bioflocs have great nutritional potential and serve as supplements for the feeding of the reared organisms, which results in a better feed conversion rate. Consequently, production costs are decreased. In traditional systems, production costs are responsible for up to 60 % of the total cost (Smith et al. 2002; Tacon et al. 2002; Cuzon et al. 2004; Wasielesky et al. 2006). The basic characteristics of the BFT system are that it requires large consumption of electrical energy for aeration systems, the use of alkalizing compounds (sodium bicarbonate, hydrated lime) throughout cultivation to correct the pH and alkalinity levels (Furtado et al. 2011), the application of carbon (sugar cane molasses, dextrose, rice bran) to stimulate microorganism production and to control the levels of nitrogen compounds (Avnimelech, 1999; Ebeling et al. 2006; Samocha et al. 2007; Serra et al. 2015), and the control of biofloc volume by filtration or clarification processes, which remove excessive suspended solids (Ray et al. 2010; Gaona et al. 2016). In the absence of water exchange, these measures are necessary to maintain the water quality and maximize shrimp zootechnical performance and culture productivity.

The BFT system allows intensive and super-intensive shrimp production to occur in small areas, with stocking densities that can vary from 100 to 450 shrimp/m^2. Higher stocking densities allow for more efficient use of the production facilities (Sookying et al. 2011) and the smaller area required for implementation means fewer, but more specialized, workers. Despite the various environmental, sanitary and economic advantages, extensive inputs and costs are required to implement and operate the biofloc system (Poersch et al., 2012). Nevertheless, few studies have conducted a cost-benefit analysis of shrimp production in super-intensive systems (Shinji et al., 2019). In this scenario, studies such as those by Poersch et al. (2012), Hanson et al. (2013), Rego et al. (2017), Castilho-Barros et al. (2018), Shinji et al. (2019) and Mauladani et al. (2020), have assessed economic-financial investments in intensive and super-intensive shrimp production in BFT systems. These studies inform the development of intensive shrimp production as they indicate the most relevant bioeconomic factors for projects of this nature. The technology of shrimp production in greenhouses using the BFT system was improved by researchers at the Waddell Mariculture Center in the United States and adapted to meet local needs by Brazilian researchers at the Federal University of Rio Grande (FURG). In this context, shrimp production technology with bioflocs emerges as an important alternative to the conventional system in regions with low temperatures, where shrimp cultivation tends to be a seasonal activity.

The integration of shrimp cultivation in a BFT system with the use of plastic covers in greenhouses allows producers in Southeast Brazil to increase the cultivation period to year-round and produce a greater number of crops (Krummenauer et al. 2011). Considering that the greater the degree of intensification of a production system, the higher the implementation costs and the greater the production and complexity of the enterprise, it is necessary to conduct a detailed bioeconomic analysis of this activity to minimize the investment risk. Currently, in the aquaculture sector, erroneous information obtained using unproven methodologies to analyze investment projects negatively affects the development of the sector. Thus, decisions based on incorrect information can result in financial losses that will have a negative impact on potential investors. The aim of this paper is to analyze the bioeconomic feasibility of the super-intensive cultivation of marine shrimp, *Penaeus* (*Litopenaeus) vannamei*, in greenhouses with bioflocs.

MATERIALS AND METHODS

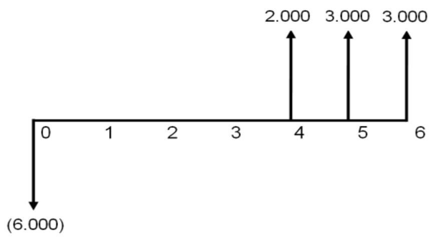
The methods used for this analysis of this investment project are the net present value (NPV), net future value (NFV), equivalent annual value (EAV), payback (PB), discounted payback period (DPP), profitability index (PI), internal rate of return (IRR) and modified internal rate of return (MIRR). A sensitivity analysis based on the bioeconomic variables of greatest relevance to shrimp farming was conducted to determine the effect of these variables on business profitability and financial health. Subsequently, when identifying the two most expressive variables, the Monte Carlo Method was used. In order to carry out these analyses, the project's cash flow was initially assessed. In the mathematical equations of economic and financial indicators this study, and in the calculations, the cost of capital (i) is represented by the Minimum Attractiveness Rate of Return (MARR).

The present study is characterized as an independent project; therefore, its acceptance or rejection does not interfere, or is not conditional on, its acceptance or the results of other projects (Crundwell, 2008; Damodaran, 2014).

Cash flow

According to Mazzarol & Reboud (2020), cash flow is one of the company's most important statements, as it allows managers to quickly and easily understand the basic accounting information of the business. The representation of a project's cash flow can be expressed on a horizontal scale, where time periods are identified and the representation of capital flow occurs with upward arrows as inflows and downward arrows as cash outflows (Figure 1).

Figure 1. Cash flow scheme - cash inflows and outflows over time.



Net Present Value (NPV)

The net present value (NPV) is one of the key methods to assess the viability of any investment project (Zuniga-Jara and Goycolea-Homann, 2014; Brealey et al. 2019). The NPV corresponds to the present value of future payments, discounted at an appropriate interest rate, minus the cost of the initial investment. Fundamentally, it is the calculation of the current worth of future payments minus the initial cost. The criteria for acceptance or rejection of the method is simple: if the NPV is positive, then the project is desirable from the investor's perspective (Ruiz Campo and Zuniga-Jara, 2018; Mejía-Ramírez et al. 2020). Projects are economically unfeasible when they present a negative NPV, which indicates a return below the required minimum rate.

The project NPV can be calculated using the following equation:

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{R_t - D_t}{(1 + i)^t} + \frac{S_t}{(1 + i)^t} - I_0$$

Where:

R_t = Revenues for a period *t*;

D_t = Expenses for a period *t*;

S_t = Project residual value in the last period;

I_0 = Initial investment;

i = Minimum Attractiveness Rate of Return (MARR).

One of the benefits of this method is the fact that it considers the value of money over time, in addition to incorporating all the desirable technical requirements in the economic evaluation of investment projects; thus, it provides an unambiguous interpretation of the results (Ruiz Campo and Zuniga-Jara, 2018). However, one of the main limitations of NPV, and particularly in the economic analysis of complementary or contingent mutually exclusive projects, is that the results are presented in monetary value, which tends to be influenced by the value of the initial investment and does not take into account the scale of the project.

Net Future Value (NFV)

Using a different perspective to NPV, which considers all future cash flow at the present day, the net future value (NFV) measures cash flow at the end of a project. The future value includes money that the entrepreneur will receive on a given future date, considering the value of money over time (Gitman, 2018). According to Gollier (2010), when the results of NFV are positive, the project must be accepted.

The project NFV can be calculated using the following equation:

$$\mathrm{NFV} = \mathrm{NPV}\,.\ (1 + \mathrm{i})^{\mathrm{n}}$$

Where:

NPV = Net Present Value;

i = Minimum Attractiveness Rate of Return (MARR);

n = Number of periods.

This method has several advantages. It includes all cash flow capital and the project's MARR in the calculation, it considers risk and it also informs the decision maker if the investment creates value for the company. However, the disadvantages are that it is necessary to know the project’s MARR, the results are expressed in monetary value and it does not allow comparison between projects with different investments.

Equivalent Annual Value (EAV)

The EAV method consists of presenting the NPV in periodic, annual and continuous installments, over the project planning horizon. Brown and Burrows (2003) argue that EAV reduces cash flow to an annuity so that the annual cash flow from two or more projects can be compared.

Whenever the EAV is positive, the project will be considered viable, with the acceptance or rejection criterion conditioned to the project that has the highest value for this indicator.

The project EAV can be calculated using the following equation:

$$EAV = \frac{NPV\,.\,i}{[1 - (1 + i)^{(-n)}]}$$

Where:

NPV = Net present value;

i = Minimum Attractiveness Rate of Return (MARR);

n = Number of periods.

According to Blank and Tarquin (2012), this method has the advantages of allowing rapid analysis, as only a project life cycle needs to be calculated, and it is suitable for analyzing operational activities with repeated investments.

Payback (PB)

The return period can be defined as the time needed to recover the amount of initial investment. To increase profitability and reduce risk, enterprises seek a return in the shortest period possible (Larson et al. 2004). The payback (PB) method is an evaluation instrument that estimates the recovery period of the initial investment (Engle, 2010; Gitman, 2018).

When the net cash inflows are constant, that is, they have the same cash flow for each period; the PB can be calculated using the following equation:

$$Payback = \frac{I_0}{CF}$$

Where:

I_0 = Initial investment;

CF = Cash flow.

Thus, given the choice between two or more projects, preference will go to those with shorter periods to recoup the invested capital. However, it is important to remember that this is not an indicator of project profitability because the PB method is closely aligned with the liquidity that the project represents.

The advantages of using the PB method are that it is simple to apply, easy to understand, adjusts for uncertainty of later cash flow and is biased towards liquidity. Its disadvantages are that it ignores the value of money over time, requires an arbitrary cutoff point, ignores cash flow beyond the cutoff date and is biased against long-term projects, such as research and development, and new projects (Ross et al, 2002; Blank and Tarquin, 2012; Gitman, 2018).

Discounted Payback Period (DPP)

The discounted payback period (DPP) is the period needed for the investor to recover the invested capital, taking into account the future appreciated value of the investment (Gitman, 2018). In other words, the cash flow of each period is brought to the present value by calculating the value of each flow at the initial date.

The benefits of this method are that it is easy to understand, it considers the opportunity cost and capital value over time and it is biased towards liquidity. Its disadvantages are that the period is established subjectively, it does not recognize future cash flow after the payback period, it may reject positive NPV investments and is biased against long-term projects (Ross et al. 2002; Blank and Tarquin, 2012; Gitman, 2018).

Profitability Index (PI)

The Profitability Index (PI) is the ratio resulting from the present value of cash inflows and outflows of an investment (Gitman, 2018). The PI indicates how much the project offers in return for each unit invested. For the project to be viable, the result of this indicator must be greater than 1.

The PI can be calculated using the following equation:

$$\mathrm{PI} = \frac{\sum_{t=1}^{n} \frac{\mathrm{CF}_t}{(1+i)^t}}{\mathrm{I}_0}$$

Where:

CF = Net cash flow*;*

I_0 = Invested capital;

i = Minimum Attractiveness Rate of Return (MARR);

t = Number of years.

Among the advantages of the IP method are the fact that it is closely related to NPV and generally leads to similar decisions. It is also easy to understand and communicate and may be useful when the availability of investment funds is limited. However, it may lead to incorrect decisions when comparing mutually exclusive investments (Ross et al. 2002). Such a phenomenon can occur because the technique disregards the size of the projects in the analysis. As such, projects with higher cash inflows can result in lower profitability rates, as their profit margins are proportionally lower than smaller projects.

Internal Rate of Return (IRR)

In addition to the NPV, the internal rate of return (IRR) is one of the most important factors in the calculation of a capital budget. The IRR is an efficient tool to evaluate the feasibility of an investment because it reflects the rate of return gained on a project (Larson et al. 2004). If the IRR is greater than or equal to the MARR, then the project will be an attractive investment to investors (Engle, 2010; Gitman, 2018); otherwise, it should be rejected.

Tisdell et al. (1993) argue that IRR is closely related to NPV, and it consists of a discount rate that makes NPV equal to zero.

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{R_t - D_t}{(1 + \mathrm{IRR})^t} + \frac{S_t}{(1 + \mathrm{IRR})^t} - I_0 = 0$$

Where:

R_t = Revenues for a period *t*;

D_t = Expenses for a period *t*;

S_t = Project residual value in the last period;

I_0 = Initial investment;

IRR = Internal rate of return.

Modified Internal Rate of Return (MIRR)

The MIRR is an updated version of the conventional IRR. It seeks to correct a series of structural problems existing in the IRR that tend to overestimate the expected profitability of the investment, among other issues (Kierulff, 2008; Sarsour and Sabri, 2020). When calculating the MIRR, cash flows are brought to present value, with a financing rate compatible with those of the market, while positive intermediate flows are taken to future value in the last period of the cash flow, based on a reinvestment rate comparable with those occurring in the market.

The MIRR can be obtained by applying the following equation:

$$\mathrm{MIRR} = \sqrt[\mathrm{n}]{\frac{\mathrm{FV}}{\mathrm{PV}}} - 1$$

*W*here:

FV = Future value of the net cash inflows discounted at the reinvestment rate;

PV = Present value of the net cash outflows discounted at the financing rate.

MIRR offers a more precise methodology to measure the attractiveness of an investment alternative because the attractiveness will depend not only on the return on investment, but also the expected return on the cash flows generated by it (Kierulff, 2008; Brigham and Ehrhardt, 2019). The method assumes that the returns obtained from positive cash flows of an investment project will be reinvested at the external rate of return, which is equal to the cost of capital (Sarsour and Sabri, 2020). MIRR allows the reinvestment of positive cash flows to occur at a different rate, generally lower than the IRR, producing a more conservative estimate of the rate of return (Watanabe et al. 2015). The criterion for accepting or rejecting the project is the same as for IRR: the investment will be viable if the MIRR is greater than or equal to the MARR (Kierulff, 2008; Mejía-Ramírez et al. 2020; Sarsour and Sabri, 2020). The advantages of this method are that it is an improved version of the IRR, it eliminates problems arising from multiple roots and diverging rates of financing and refinancing and indicates the true

IRR of a project. Furthermore, it is easy to understand and allows direct comparison of the feasibility of different projects.

Minimum Attractiveness Rate of Return (MARR)

To evaluate one or more investment alternatives, the investor requires a parameter rate that guides decision making. At the very least, this rate must consider other investment options (the opportunity cost), risk and the cost of capital. According to Blank and Tarquin (2014), this rate is known as the Minimum Attractiveness Rate of Return (MARR), which indicates the minimum return required by investors in order to efficiently allocate financial resources. MARR is the rate that justifies the acceptance or rejection of the project.

The investor's MARR was determined by the Hybrid Adjusted Financial Assets Pricing Model (AH-CAPM). This model was chosen because it minimizes the limitations of the Capital Asset Pricing Model (CAPM) as first applied (Markowitz, 1959; Sharpe, 1964; Lintner, 1965; Mossin, 1966) in emerging countries, and because it is the most commonly used by investors (Blank et al., 2014; Graham and Harvey, 2001). Several studies have been carried out and tested empirically to minimize the limitations of CAPM, of which the following models stand out: Godfrey-Espinosa (1996); Lessard (1996); Mariscal and Hargis (1999); Damodaran (2002); CAPM by Assaf Neto Benchmarking (2014); and Local CAPM (L-CAPM), Local Adjusted CAPM (AL-CAPM), and Hybrid Adjusted CAPM (AH-CAPM), developed by Pereiro (2001).

The AH-CAPM calculation expression is given by:

$$\mathrm{MARR} = \mathrm{Rf_g} + \mathrm{R_c} + \beta \mathrm{C_{LG}}\left[\beta_{\mathrm{GG}}\left(\mathrm{R_{MG}} - \mathrm{Rf_g}\right)\right](1 - \mathrm{R}^2) + \mathrm{Inf\,BR} + \mathrm{Inf\,USA}$$

Where:

MARR = Minimum Attractiveness Rate of Return;

$\mathrm{Rf_g}$ = Risk-free rate;

$\mathrm{R_c}$ = Country risk;

$\beta \mathrm{C_{LG}}$ = Country beta;

β_{GG} = Unlevered beta of comparable investments in the market;

$\mathrm{R_{MG}}$ = Global market return;

R^2 = Coefficient of determination;

Inf BR = Inflation rate in Brazil;

Inf USA = Inflation rate in the United States.

The following information was used to apply the AH-CAPM model: a) Global risk-free rate (Rf_g): represents the return on a risk-free investment. In this case, it opts for the interest rate paid on bonds issued by the United States Government Treasury (U.S. Department of the Treasury, 2020) with a 30-year redemption term (T-Bonds). The amount used for this rate was 1.49% per annum, obtained on 8/31/2020, which must be adjusted for the average real exchange rate (R$) / US dollar (US$) to obtain the rate real (http://in.investing.com); b) Country risk (Rc): to estimate country risk, EMBI + Brazil was used. This indicator assesses Brazilian foreign debt securities based on assessment by the North American bank JP Morgan. According to Teixeira and Cunha (2017), "for every 100 points expressed by EMBI + Brazil, a surcharge is paid, which works as a risk premium of 1.0% on United States papers". In this study, the value used for the EMBI + Brazil rate is 3.19% per year, obtained on 08/31/2020 (http://ipeadata.gov.br); c) Global market return (R_{MG}): as a proxy for the return of the global market, the Morgan Stanley Capital International All Country World Index (MSCI ACWI) (http://msci.com) was used. This index is released by MSCI (http://msci.com) and measures the performance of the stock market in 46 countries (23 developed and 23 emerging). Therefore, the average annual return for the period from August 2004 to August 2020 was determined, with a value of 6.10% per year; d) Country beta (βC_{LG}): the country beta was obtained by the regression between the local stock market index and the global market index. As a local stock market index, the monthly variation of the IBOVESPA was used, an index that represents the volatility of the Brazilian stock market, from August 2004 to August 2020 (http://br.investing.com). The MSCI ACWI was chosen to estimate the global rate of return. Due to the use of regression, the monthly variation of the MSCI ACWI was collected in the same period as the IBOVESPA index. The result of the slope (slope) of this regression is 1.0603; e) Unlevered Beta (β_{GG}): in this study, the unlevered beta of the Farming / Agriculture sector (β_A = 0.610) was used, as calculated by Aswath Damodaran (http://pages.stern.nyu.edu) and obtained on 08/31/2020; f) Coefficient of determination (R^2): calculated from the regression between the volatility of local market shares, in this study identified by the monthly variation of the IBOVESPA index (http://br.investing.com), against the variation of country risk, given by the monthly variation of the EMBI + Brazil index (http://ipeadata.gov.br), from August 2004 to August 2020. The value determined for the coefficient of determination from the regression proposed in the AH-CAPM model is 0.0102; g) Inflation rate in Brazil: average inflation rate from August 2015 to August 2020 was 5.26%; h) Inflation rate in the United States: average annual inflation in the same period in the US was 1.50%. The values calculated for the variables used in the AH-CAPM model are shown in Table 1.

Table 1. Description of the variables and values used in the application of the AH-CAPM model to define MARR.

Variables	Value
Global risk-free rate (Rf_g)[1]	1.49 %
Country risk (R_c)[2]	3.19 %
Country Beta (βC_{LG})[3]	1.0603
Industry unleveraged beta (β_{GG})[4]	0.610
Global market return (R_{MG})[5]	6.10 %
Determination coefficient (R^2)[6]	0.0102
Average inflation rate in Brazil (*Inf BR*)[7]	5.26 %
Average inflation rate in the USA (*Inf EUA*)[8]	1.50 %
Minimum Attractiveness Rate (MARR)	10.25 %

Source: Prepared by the authors based on data obtained on 08/31/2020 from the following sources: [1]https://www.treasury.gov; [2]http://www.ipeadata.gov.br; [3]http://investing.com; [4]http://pages.stern.nyu.edu; [5]http://investing.com; [6]http://investing.com; http://www.ipeadata.gov.br; [7]http://investing.com; [8]http://investing.com.

Sensitivity Analysis and Monte Carlo Simulation

The aim of this analysis is to verify the degree of sensitivity through an analysis of variations in the main variables of the enterprise, such as variations or oscillations in production, product prices and inputs. After identifying the most relevant variables, the Monte Carlo Method or Simulation (MCS) was used. MCS introduces uncertainty in the variables that most impact the NPV, aiming to observe its behavior in a risky environment (MARTÍNEZ-PAZ; PELLICER-MARTÍNEZ; COLINO, 2014).

MCS consists of a mathematical technique that generates random samples of output variables from several random samples of input variables. The simulation process involves repeated random interactions generating a series of results distribution. By generating a range of random numbers, the investor does not base decision-making on only a small number of possibilities in the analysis of the investment, but rather has the opportunity to evaluate the most likely scenarios through the various interactions carried out between the most relevant variables using the MCS. In the present work, 100,000 iterations were performed for the most relevant variables in the simulations (selling price and average weight), considered inputs, with the objective of verifying the behavior of the output variable, herein considered the NPV.

CHARACTERIZATION OF THE ENTERPRISE

For this study, we determined enterprise installation costs (the acquisition of 2.0 ha of land, plastic greenhouses, water analysis equipment, an aeration system and the construction of the tanks), production costs (commercial feed, electrical energy, organic fertilizers and salaries) and other capital goods (Table 2). Data related to productivity, zootechnical performance and production costs were obtained from information generated over eight cultivation cycles at the Marine Station of Aquaculture, Institute of Oceanography, Federal University of Rio Grande (FURG).

Table 2. Summary of the initial investment, variable and fixed costs and working capital for white shrimp, *P. vannamei*, cultivation in a BFT system in Southeast Brazil.

	Quantity	Unitary value (US$)*	Total (US$)
Investment			**220,829.82**
Land (ha)	02	3,125.36	6,250.71
Production structure (greenhouse)[1]	10	16,603.46	166,034.60
Construction (80 m²)	01	30,588.00	30,588.00
Equipment for parameter measurement	-	-	2,519.21
Networks and equipment of maintenance	-	-	1,259.60
Generator (55 KVA)	01	12,996.64	12,996.64

Catchment pump (7.5 HP)	01	1,181.06	1,181.06
Fixed costs			**63,298.46**
Employee salaries (/year)	02	437.54	10,500.96
Manager salary (/year)	01	1,215.40	14,584.80
Taxes (37 % on payroll)	12	773.48	9,281.76
Accountant (/month)	12	321.20	3,854.39
Electrical energy (/month)	12	1,797.09	21,565.03
Tap water (/month)	12	94.47	1,133.64
RLT (Rural Land Tax) (/year)	01	377.88	377.88
Maintenance	-	-	2,000.00
Variable costs			**138,159.27**
Postlarvae (thousand)	7,200	2.93	21,096.00
Commercial feed (kg)	89,856	1.29	115,914.24
Inputs[2]	-	-	1,149.03
Working capital	**-**	**-**	**147,373.72**
TOTAL			**569,661.27**

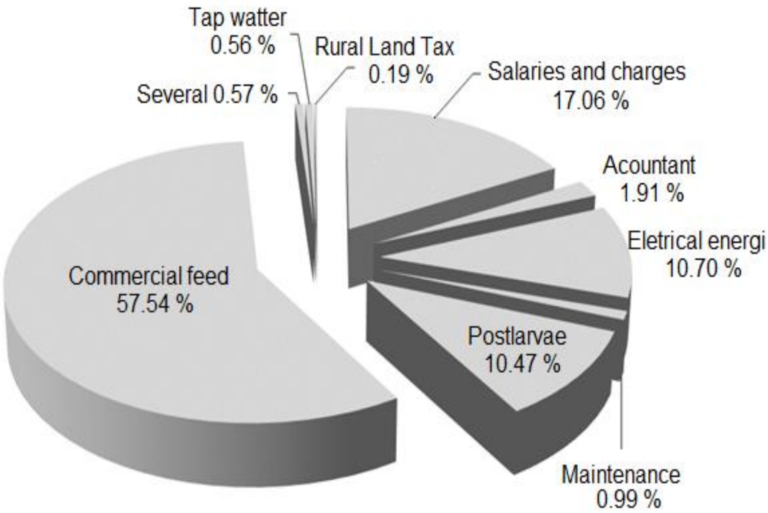
[1]Production structure (greenhouse): galvanized arches, plastic film, wood boxes with geomembrane liner (1.0 mm) and sand bottom, drainage pipe (150 mm), 4.0 HP blowers, primary (60 mm) and secondary (20 mm) aeration tubing and air diffuser.
[2]Compounds for the correction of pH and alkalinity, probiotic and structure maintenance.
*Data of quotation: 10/10/2019, exchange rate: 4.1139 Brazil Real = 1.00 Dollar USA.

A US$ 569,661.27 investment was projected for the enterprise, corresponding to the construction of 10 greenhouses with 600 m² tanks (two tanks 300 m² each), for a total of 6,000 m² of usable production area, including the greenhouse plastic covers, wooden tank structures and 1.0 mm (HDPE) liners, hydraulic and electric networks, 4.0 HP aerators and air tubing with diffusers (Table 2). The simulated stocking density was 400 shrimp/m² with an 80% survival rate, which provided a production of 23,040 kg/cycle and 69,120 kg/year (three cycles/year). The production harvest and commercialization assumed animals with a mean weight of 12 g, which corresponds to a weight associated with higher market prices for the producer. The sale of the product is *in natura*, immediately after the harvest, and is delivered directly to buyers at the gate of the enterprise.

RESULTS AND DISCUSSION

The participation of each item in the total cost can be seen in Figure 2.

Figure 2. Relative proportion (%) of each item in the total cost of white shrimp, P. vannamei, cultivation in a BFT system in Southeast Brazil.



The simplified cash flow is presented in Table 3.

Table 3. Simplified cash flow of the project for white shrimp, *P. vannamei*, cultivation in a BFT system in Southeast Brazil.

Simplified cash flow	
Production (kg)	69,120
Sale price (US$)	7.30
Gross revenue (US$)	504,576.00
Taxes, fixed and variable costs (US$)	262,006.85
Net revenue (US$)	242,569.15

The depreciation calculated for the periods of one to five and six to ten years was US$ 19,662.63 and 19,496.67, respectively. According to Gitman (2018), in addition to avoiding significant variation in the product cost, the depreciation also allows for the formation of funds to renew the asset.

Using data of the initial investment and the costs throughout the production cycle, the cultivation of *P. vannamei* resulted in a final mean weight of 12 g, an NPV of US$ 904,947.21, a Net Future Value (NFV) of US$ 2,401,094.35, an equivalent annual value (EAV) of US$ 148,861.38, a PB of two years and four months, a DPB of two years and ten months, a Profitability Index (PI) of 2.59, an IRR 41.23 %, and MIRR of 21.25 % (Table 4). When simulating investment in super-intensive *P. vannamei* production based on the extrapolation of data from two experiments to commercial levels, Hanson et al. (2013) obtained extremely satisfactory economic results. Based on their study, an initial investment of US$ 992,000.00 resulted in an NPV of US$ 2,900,000.00, a PB of one year and five months and an IRR of 66.6%. Interesting economic results were also obtained by Rego et al. (2017) when carrying out an economic analysis of investment in adapting the ponds of a conventional farm to the BFT system in Northeast Brazil. The investment of US$ 272,699.51 per hectare resulted in an NPV of US$ 142,004.42, a four-year payback and an IRR of 29.44%. The more modest results by Rego et al. (2017) in comparison to the present study and those reported by Hanson et al. (2013), are due to the productive system used (intensive versus super-intensive) and the lower sale price, which was US$ 5.91, US$ 7.30 and US$ 7.20, respectively. The superior results obtained by Hanson et al. (2013) are mainly related to the storage and production strategy used in the simulation. This made it possible to obtain 5.5 harvests/year and, therefore, achieve high productivity and better use of production facilities. Another major factor for these results was the cost of capital (MARR), which was 8.0%, and provided a better NPV and IRR than projects with a higher MARR. In addition, the authors did not consider in their economic analyses the incidence of taxes on the sale of production and they neglected the need for working capital in the initial investment. The latter has a significant impact on fulfilling a project's financial obligations, which makes their results stand out in the face of more conservative studies.

Table 4. Results of bioeconomic analyses for the cultivation of *P. vannamei* shrimp in a BFT system in Southeast Brazil.

Indicators	Results
Net present value (NPV)	US$ 904,947.21
Net future value (NFV)	US$ 2,401,094.35
Equivalent annual value (EAV)	US$ 148,861.38
Payback (PB)	2 years and 4 months
Discounted payback period (DPP)	2 years and 10 months
Profitability Index (PI)	2.59

Internal rate of return (IRR)	41.23%
Modified internal rate of return (MIRR)	21.25%

Next, we performed a sensitivity analysis of the enterprise (Table 6). This analysis took into account the performance of the most relevant bioeconomic variables of shrimp production. Based on the NPV, NFV, EAV, PB, DPP, PI, IRR and MIRR, we simulated variations in biological variables (feed conversion rate, weight and survival), variable cost (feed price), and economy (sale price) (Table 5).

Table 5. Summary of the parameters used in the sensitivity analysis and variations.

Variables	Variation
Biological variables	
FCR*	± 15 %
Weight (g)	± 15 %
Survival (%)	± 15 %
Variable costs	
Commercial feed	± 15 %
Economy	
Sale price	± 15 %

*FCR: Feed conversion rate.

Table 6. Summary of the results of the sensitivity analysis of the enterprise based on the NPV, NFV, EAV, PB, DPP, PI, IRR and MIRR.

	NPV (US$)	NFV (US$)	EAV (US$)	PB (months)	DDP (months)	PI	IRR (%)	MIRR (%)
FCR[1]								
-15	1,022,390.11	2,712,705.32	168,180.42	26	31	2.79	44.84	22.18
+15	796,538.38	2,113,453.46	131,028.42	30	37	2.40	37.86	20.33
Weight[2]								
-15 %	196,578.15	521,580.36	32,336.58	54	77	1.35	17.84	13.57
+15 %	2,233,203.27	5,925,353.11	367,355.92	16	17	4.92	80.72	29.29
Survival[3]								
-15 %	588,135.01	1,560,497.28	96,746.62	36	45	2.03	31.22	18.35
+15 %	1,221,759.40	3,241,691.42	200,976.13	23	27	3.14	50.88	23.63
Feed price[4]								
-15 %	1,008,733,96	2,676,471.49	165,934.02	26	31	2.77	44.42	22.08
+15 %	801,160.46	2,125,717.21	131,788.74	30	37	2.41	38.00	20.37
Sale price[5]								
-15 %	500,052.84	1,326,789.05	82,257.34	40	50	1.88	28.34	10.25

+15 %	1,309,841.58	3,475,399.65	215,465.41	22	26	3.30	53.53	24.23

NPV - Net Present Value; NFV - Net Future Value; EAV - Equivalent Annual Value; Profitability Index; IRR - Internal Rate of Return; MIRR - Modified Internal Rate of Return; FCR - Feed conversion rate. [1]1.3; [2]12 g; [3]80 %; [4]US$ 1.29; [5]US$ 7.30.

The production structure and the improvements represented 80.34 % and 14.80 % of the total initial investment, with values of US$ 166,034.60 and US$ 30,588.00, respectively. Teixeira and Guerrelhas (2011) argued that by adapting commercial shrimp ponds in Brazil (7,800 m^2) from semi-intensive to intensive cultivation using a BFT system, the cost would be US$ 7.56/m^2. Rego et al. (2017), when adapting conventional ponds in Northeast Brazil to intensive production in a BFT system, budgeted an investment of US$ 14.83 per m^2 for the project to operate in the new system. Herein, the cost of implementing the project was US$ 27.67 / m^2, and it is worth noting that our project foresees the implementation of a super-intensive system of shrimp production in greenhouses. The difference between the results obtained in the present study and that of Rego et al. (2017) and Teixeira and Guerrelhas (2011) is related to the characteristics of each project (adaptation of ponds for intensive production versus the implementation of a new project for super-intensive production in greenhouses). In addition, the time difference between the calculation of the budgets by Teixeira and Guerrelhas (2011) and those of the present study may have contributed to the increase in costs due to the variation in prices over time.

In fixed costs, salaries and associated taxes, followed by electricity, were the most relevant items, representing 17.06 % and 10.70 %, respectively, of total production costs. The amount disbursed for employee salaries and taxes by Teixeira and Guerrelhas (2011) comprises 17.16 % of the total cost, followed by electrical energy (10.77 %). Our result for labor costs is in line with those obtained in similar studies, such as Rego et al. (2017a, 2017b) and Mauladani et al. (2020) in which this cost represented 13.66% and 21.52% of the total production cost, respectively.

Among the variable costs, feed (commercial feed) had the highest cost, representing 57.54 % of the total, followed by the cost of postlarvae acquisition, which equaled 10.47 % of these expenditures. These results are similar to those obtained by Poersch et al. (2012), Rego et al. (2017), Cang et al. (2019) and Mauladani et al. (2020) representing between 54.0 % and 66.11 % of the total production costs for feed, and between 13.71 % to 17.63 % for postlarvae acquisition. Due to the location of the studied enterprise, the cost of commercial feed and postlarvae increased because the feed factories and commercial hatcheries are concentrated in Northeast region of Brazil and the products had to be shipped.

Using the sensitivity analysis, we determined which variables had the greatest impact on the enterprise's financial-economic performance. The final mean weight and the sale price were the most relevant factors in the maximization of financial return because better prices are obtained with larger shrimp. In addition, these factors directly affect income, production and final biomass (productivity).

Sensitivity analyses show that the best production strategies correspond to the production of animals with greater average weight (+15 %) (Table 6). In this first simulation, conservative variables were used to avoid overestimation. With this information, we tested the economic performance of shrimp production with an average weight of 15 g, due to the better market price and greater local demand for animals of this size. With conservative production conditions (stocking density of 400 shrimp/m³, survival of 80 %, CAA of 1.3 and sale price of US$ 9.72), in three cycles it achieved a production of 86,400 kg and gross revenue of US$ 839,808.00. The sum of fixed, variable and tax costs resulted in US$ 373,795.68, leaving a net revenue of US$ 464,012.32. The results of the economic analyses were as follows: NPV US$ 2,522,150.62; NFV US$ 6,692,016.44; EAV US$ 414,886.98; PB in one year and two months; DPP in one year and two months; PI of 5.43; IRR of 89.13 %; and MIRR of 30.57 %.

We tested five pessimistic bioeconomic scenarios (Table 7) for the production of *P. vannamei* shrimp with an average weight of 15 g: C1 – conservative survival rate (80 %) and high feed conversion rate (1.7); C2 – low survival rate (70 %) and high feed conversion rate (1.7); C3 – 15 % drop in selling price; C4 – 15 % increase in feed price; and C5 – all pessimistic scenarios simultaneously (high FCR, low survival, drop in sale price and increase in feed price). The results are described in Table 7.

Table 7. Summary of the results of the sensitivity analysis under pessimistic conditions/scenarios of the enterprise based on: NPV - Net Present Value; NFV - Net Future Value; EAV - Equivalent Annual Value; Payback (PB); Discounted Payback (DPP); Profitability Index (PI); Internal Rate of Return (IRR); Modified Internal Rate of Return (MIRR).

	NPV (US$)	NFV (US$)	EAV (US$)	PB (months)	DPP (months)	PI	IRR (%)	MIRR (%)
C0*	2,522,150.62	6,692,016.44	414,886.98	14	14	5.43	89.13	30.57
C1	2,251,128.54	5,972,914.20	370,304.58	15	17	4.95	81.24	29.38
C2	1,833,536.08	4,864,890.53	310,229.95	17	19	4.22	69.03	27.32
C3	1,847,326.67	4,901,507.61	303,880.26	17	20	4.24	69.44	27.39
C4	2,692,491.47	5,839,854.78	402,166.03	14	16	5.20	85.36	30.01
C5	1,094,610.13	2,904,326.56	180,060.42	25	30	2.92	47.04	22.73

**P. vannamei* shrimp production in a BFT system with an average weight of 15 g.

In all simulations of super-intensive *P. vannamei* shrimp production in greenhouses using the BFT system with an average animal weight of 15 g, including the pessimistic bioeconomic scenarios, the project proved to be economically viable. Even in the worst scenario (C5), in which all pessimistic conditions were considered, the economic results were superior to the production of shrimp with an average weight of 12 g. These results demonstrate that the production of shrimp with an average weight of 15 g provides the best economic results due to higher productivity, better sale price, and improved use of production and environmental facilities. Hanson et al. (2009) performed a sensitivity analysis on a marine shrimp culture with bioflocs, evaluating as critical factors the feed and postlarvae price, stocking density, survival rate, growth rate, feed conversion rate and sale price. As the authors argued, the main critical factor was the increase in the survival rate from 70 to 84 %, which resulted in the greatest increase in NPV to US$ 10.48 million and IRR to 13.7 %. The second most important critical factor was the shrimp price, which increased the NPV to US$ 9.57 million and the IRR to 12.5 %. The third factor was the stocking density, which increased from 500 to 800 shrimp/m^3 resulting in an increase in NPV to US$ 6.16 million and IRR to 8.1 %. The feed conversion rate and the postlarvae prices were the seventh and tenth critical factors, respectively, in terms of relevance.

In the sensitivity analysis, the poorest results obtained were with a low survival rate (70 %), reduction in sale price (15 %) and an average weight of 10.0 g. Several economic and biological factors, when improved, can bring significant benefits to the financial health of the enterprise. As Hanson et al. (2009) assert, some critical factors are more easily controlled than others. The location of the enterprise, stocking density, survival, growth and feed conversion rate depend on the decision-making, knowledge and management of the producers. However, the cost of postlarvae and feed and the final product sale price are the most difficult critical factors to control.

In the Monte Carlo simulation, we used a triangular distribution, which is the most common application of the method. This distribution is based on information that can come from specialists or historical series data of the analyzed variables. Based on this information, three scenarios are established: the optimistic, the realistic (most likely) and the pessimistic (Sweeney et al. 2019). The MCS performed 100,000 interactions of the sale price and final weight variables with estimates at 95% probability that the NPV value will be positive, that is, in the range between US$ 308,000.00 and 2,369,000.00. In the simulations performed, the probability of negative NPV is zero. In addition, MCS results demonstrate that NPV is more sensitive to the selling price than to the final weight of the shrimp. Through the simulations, even considering the investment risk, one can infer the economic attractiveness for the investor.

These results demonstrate that appropriate production management and accurate production cost planning and management are equally important. Sampaio et al. (2010) illustrate that, in Brazil, there is currently a well-defined shrimp production chain and accumulated expertise; thus, implementation of the BFT system is relatively easy because of the production systems already in place.

CONCLUSIONS

The cost of marine shrimp production in greenhouses using the BFT system is high compared to the traditional system; however, there is an increase in biosecurity, survival, feed conversion ratio, productivity and predictability of the harvest. Therefore, the optimization of cultivation management throughout the cycles reflect the minimization of costs, making it more attractive to investors and reducing the payback period on capital invested in this type of venture. The project proved to be feasible from a bioeconomic point of view. All investment analysis techniques and methods used in the present study demonstrate positive results for the project.

Although the study was carried out based on real data obtained over 10 years of shrimp *P. vannamei* production, in order to be able to carry out economic analyzes and simulations it was necessary to extrapolate these results to a bigger level production. It is also worth noting that the workforce employed at the Federal University of Rio Grande, origin of the data used here, is made up of trained professionals with high technical knowledge, a reality that does not always correspond with many others aquaculture enterprises in activity and that, in some projects, is neglected in order to reduce labor costs.

Acknowledgments

The authors are grateful to the financial support provided by National Council for Scientific and Technological Development (CNPq), and Coordination for the Improvement of Higher-Level Personnel (CAPES). W.J. Wasielesky and L.H. Poersch are research fellows of CNPq. Marcos de Almeida has a CAPES scholarship.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical statement This article does not contain studies on animals performed by any of the authors.

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CAPÍTULO III

ECONOMIC ANALYSIS OF INTENSIVE AND SUPER-INTENSIVE *Litopenaeus vannamei* SHRIMP PRODUCTION IN A BFT SYSTEM[1]

[1] Boletim do Instituto de Pesca (BIP; IP / SAA) - ISSN 0046-9939 (versão impressa encerrada em 2011); ISSN 1678-2305 (versão eletrônica) - fator de impacto (JIF 2020) = 1,058; Novo Qualis CAPES (2021): B1 .

ECONOMIC ANALYSIS OF INTENSIVE AND SUPER-INTENSIVE *Litopenaeus vannamei* SHRIMP PRODUCTION IN A BFT SYSTEM

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Economic analysis of intensive and super-intensive *Litopenaeus vannamei* shrimp production in a BFT system

Abstract

In recent decades, new aquaculture technologies have been developed and improved, such as the Biofloc Technology System (BFT), considered an alternative to the conventional aquaculture model. The present study compares the bioeconomic viability of intensive production in nurseries and super-intensive production of shrimp *Litopenaeus vannamei* bioflocs greenhouses. The investment for implementing the project was US$ 767,190.18 for intensive production and US$ 807,669.16 for super-intensive production. The analyzes showed NPV of US$ 363,718.21 and US$ 385,477.42, EAV of US$ 59,830.66 and US$ 63,410.00, NFV of US$ 965,052.69 and US$ 1,022,786.35, PP 4.12 and 4.11, DPP 5.64 and 5.63, PI 1.47 and 1.48, IRR 20.49% and 20.55% and MIRR 14.61% and 14.64%. The investment analysis used in this study showed that super-intensive production in a greenhouse is the best investment option. The development of a new scenario simulating the super-intensive production of shrimp in a BFT system, considering land use as a premise, made it possible to observe the possibility of obtaining financial gains in scale, both in the reduction of production costs and in the economic performance of the enterprise. However, the financial contribution for the implementation and operation of the project increased substantially.

Keywords: Biofloc technology; Investment analysis; Sensitivity analysis; Aquaculture management; Modern aquaculture.

Análise econômica da produção intensiva e superintensiva de camarão *Litopenaeus vannamei* em Sistema BFT

Resumo

Nas últimas décadas, novas tecnologias aquícolas têm sido desenvolvidas e aprimoradas, como o Sistema BFT, considerado uma alternativa ao modelo convencional aquícola. O presente estudo compara a viabilidade bioeconômica da produção intensiva em viveiros e da produção superintensiva em estufas, do camarão *Litopenaeus vannamei*, em bioflocos. O investimento para implantação do projeto foi de US$ 767.190,18 para produção intensiva e US$ 807.669,16 para produção superintensiva. As análises apresentaram VPL de US$ 363.718,21 e US$ 385.477,42, VAE de US$ 59.830,66 e US$ 63.410,00, VFL de US$ 965.052,69 e US$ 1.022.786,35, PP 4,12 e 4,11, PD 5,64 e 5,63, IL 1,47 e 1,48, TIR 20,49% e 20,55% e TIRM 14,61% e 14,64%. As análises de investimentos realizadas neste estudo mostraram que a produção superintensiva em estufas é a melhor opção. O desenvolvimento de um novo cenário simulando a produção superintensiva de camarões em sistema BFT, considerando o uso da terra como premissa, permitiu observar a possibilidade da obtenção de ganhos financeiros em escala, tanto na redução dos custos de produção quanto no desempenho econômico do empreendimento. No entanto, a contribuição financeira para a implantação e operação do projeto aumentou substancialmente.

Palavras-chave: Tecnologia de bioflocos; Análise de investimentos; Análise de sensibilidade; Gestão aquícola; Aquicultura moderna.

INTRODUCTION

With a projected increase in the world's population of another two billion people by 2050, global pressure on natural resources will intensify (Godfray et al., 2010; United Nations, 2019). Meanwhile, there is increasing demand from public policymakers and consumers for the implementation of sustainable practices in the agricultural sector (Bartolini et al., 2016; Soto, 2021). In this context, the development of global agribusiness faces two major challenges. The first is to increase food production to ensure food security[5], and the second is to mitigate the environmental impacts generated by this increase in production (Godfray et al., 2010).

According to data from the Food and Agricultural Organization of the United Nations (FAO, 2020a), between 2001 and 2018 aquaculture production grew on average 5.3% per year. Among the various aquaculture sectors, shrimp farming is particularly notable (Almeida et al., 2021) as it is a commercially significant enterprise that includes a group of high market value species (FAO, 2010b), making it one of the most important activities in the sector (FAO, 2016, 2018, 2020a). However, despite the positive growth in aquaculture in recent decades, the FAO (2020b) warns that the COVID-19 pandemic will continue to have a significant impact on the sector, especially the production of shrimp and salmon.

The production of farmed shrimp in Brazil is mainly focused on the Pacific whiteleg shrimp, *Litopenaeus vannamei* (FAO, 2020a). The species has excellent zootechnical performance, rusticity and closed technological package, and well-defined technological practices, factors that make it one of the most commonly produced shrimp species in the world (Cuzon et al., 2004; FAO, 2018, 2020a).

The installation of conventional shrimp production systems requires large areas, proximity to the ocean or estuaries, and the use of large volumes of water to maintain pond water quality within acceptable levels for the species (Silva et al. 2015; Almeida et al., 2021). These semi-intensive systems use low stocking densities, from five to 45 animals/m² and obtain average yields of approximately 4.5 ton/ha/year (Ostrensky et al., 2008).

[5] "Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 2010a).

However, modern aquaculture practices must develop and evolve toward sustainability, finding a balance between environmental, economic, and social concerns (FAO, 2018; Siqueira, 2018). As opposed to the conventional model of shrimp production, modern shrimp farming seeks to be both environmentally sustainable and economically viable. As such, researchers, companies, and producers have engaged in efforts to develop more efficient production systems both in terms of the environment and productivity. New aquaculture technologies have been established and improved, such as the Biofloc Technology System (BFT), which is an alternative to the conventional aquaculture model (Panigrahi et al., 2018; Ren et al., 2019; Yu et al., 2020).

BFT is based on the conversion of organic waste from the cultivation environment into microbial biomass, which can be used as a feed supplement in the nutritional management of the organisms (Avnimelech, 2007; Gaona et al., 2017; Panigrahi et al., 2018). It is particularly noteworthy due to improved biosecurity (Wasielesky et al., 2006; Krummenauer et al., 2011) and the use of smaller areas and less water compared to the conventional system (Krummenauer et al., 2012; Vieira et al., 2019). However, due to the high stocking densities that the system supports, it requires constant monitoring and maintenance of water quality parameters (Wasielesky et al., 2006; Krummenauer et al., 2011; Costa et al., 2018; Nguyen et al., 2019). In terms of nutrition, bioflocs offer significant potential as feed supplements for the produced organisms, resulting in better feed conversion rates and, consequently, reduced production costs (Wasielesky et al., 2006; Panigrahi et al., 2018).

The BFT system makes it possible to optimize the use of production factors, as it allows intensive and super-intensive shrimp production in small areas, with stocking densities that can vary from 100 to 450 shrimp/m^3. According to Taw (2010), the most used densities in intensive cultivation are in nurseries, at the biofloc system, is 130 to 150 shrimp per m^2. Wasielesky et al. (2016) adds that the system allows the use of high stocking densities in intensive grow out ponds, from 100 to 200/m^2, and in raceways, with the possibility of carrying out stocking with 300 to 600 shrimp/m^2 in a super-intensive system.

The possibility of using high stocking densities in the BFT system converges in greater production using smaller spaces, thus overcoming the problem of the lack of areas for the aquaculture projects implementation (Krummenauer et al., 2011) and also the possibility of better financial results for the business (Almeida et al., 2021).

Factors such as intensification, species diversification, as well as the introduction of innovations and technologies, have contributed to the growth of aquaculture (FAO, 2016). In this context, stocking density is an important factor to consider, since it has a direct influence on production (Jackson & Wang, 1998), and the consequent profitability of an enterprise

(Almeida et al., 2021). Despite the environmental, sanitary, and economic advantages (Krummenauer et al., 2012; Rego et al., 2017a; Nguyen et al., 2019; Shinji et al., 2019; Vieira et al., 2019), implementing and operating BFT systems requires significant investment (Poersch et al., 2012). As with other economic activities, production costs in aquaculture are directly related to the profitability of the business (Di Trapani et al., 2014). Although this is an important issue, there are few studies that have examined the costs and benefits of shrimp production in BFT systems (Shinji et al., 2019).

Thus, the present study aims to analyze and compare the bioeconomic viability of intensive and super-intensive production of *Litopenaeus vannamei* in a BFT system located on the south coast of the state of Rio Grande do Sul, Brazil. For this, the costs of implementing and operating two enterprises with distinct production strategies were calculated: intensive shrimp production in a BFT system with rearing ponds; and super-intensive shrimp production in a BFT system with greenhouses. After data collection, a feasibility analysis of the investments was applied.

MATERIALS AND METHODS

Investment analysis methods and criteria

The investment analysis includes tools that enable decision making under conditions of uncertainty, seeking to eliminate or minimize risk. An investment is accepted or rejected based on pre-defined and widely tested criteria.

In the present study, the following investment analysis criteria were applied: Net Present Value – NPV; Equivalent Annual Value – EAV; Payback Period – PP; Discounted Payback Period – DPP; Profitability Index – PI; Internal Rate of Return – IRR; Modified Internal Rate of Return – MIRR. The mathematical equations and decision-making criteria can be found in Gollier (2010), Blank & Tarquin (2011), Blank et al. (2014), Gitman & Zutter (2018), Ruiz Campo & Zuniga-Jara (2018), Mazzarol & Reboud (2020), Mejía-Ramiréz et al. (2020), Sarsour & Sabri (2020), and Almeida et al. (2021).

Production Systems

Intensive production in rearing ponds (intensive system) consists of four ponds with a useful volume of 3,350 m³. The super-intensive production system in greenhouses (super-intensive system) for 10 greenhouses with 600 m³ tanks. The total annual production for both systems is 69,120 kg of shrimp *in natura.*

The evaluated systems are characterized by being mutually exclusive projects. Despite the different characteristics existing between the production of white shrimp *Litopenaeus vannamei*, in an intensive and super-intensive BFT system, the same production volume was adopted as the main parameter for the elaboration of the projects of the two production strategies (23.040 kg per harvest), with the in order to facilitate the comparison between the results of the economic feasibility analyzes of the evaluated Investment projects.

The first production cycle considered the formation of the biofloc from the manipulation of the carbon and nitrogen ratio (C: N) in the environment. For this, fertilization was carried out by adding sugarcane molasses and wheat bran to the cultivation water. In the other cycles, the water with biofloc obtained from the previous cycles was used. Biofloc maintenance is carried out with the addition of sugarcane molasses and wheat bran, along with the feed, maintaining a C: N ratio of 20: 1 (Avnimelech, 1999).

Data on the costs of implementation were budgeted based on quotes from specialized companies in local currency (Real) and converted into US Dollars (exchange rate on 16 Oct. 2021). Data related to productivity, zootechnical performance, and production costs were obtained over eight cycles for both the intensive system with rearing ponds and super-intensive system with greenhouses, installed at the Aquaculture Marine Station, Oceanography Institute of the Federal University of Rio Grande (FURG), in the state of Rio Grande do Sul, Brazil. For the study, the average cost of land in the region was considered.

In the economic analyzes of super-intensive production, we also used data obtained by Almeida et al. (2021). Due to the exchange variation of the Brazilian currency (Real) against the US Dollar that occurred in the period between the studies, it was necessary to update these data.

Intensive system

The fixed investment corresponds to the construction of four excavated ponds with a useful area of 3,350 m³ each, for a total of 13,400 m³ of total useful production area. This amount includes costs related to excavation and earthmoving services for pond construction, geomembrane lining (HDPE), bird-proof mesh covering to avoid shrimp predation, a 7.5 HP water pump, hydraulic and electrical networks, aerators, a 55 kVA generator, parameter monitoring equipment, nets, maintenance equipment, fixed costs, variable costs, and working capital. Other budgeted costs include the acquisition of a three hectare (ha) area to establish the enterprise, the construction of a footbath and shower arch at the entrance of the PUs to disinfect vehicles entering the vicinity (biosecurity), and the construction of an 80 m² building that serves as a feed and supply storage area, guard house, and employee break area.

The stocking density used was 179.11 shrimp/m³ and the survival rate was 80%, resulting in a production of 23,040 kg/shrimp/cycle and 69,120 kg/shrimp/year (three cycles/year) (Table 1). Harvesting and commercialization is based on live animals with an average weight of 12 g.

For the formation and maintenance of bioflocs in the BFT system, 6,699.80 and 2,999.81 kg of sugarcane molasses and 669.77 and 299.98 kg of wheat bran were used in the intensive production and super-intensive, respectively.

Table 1 provides a summary of the zootechnical variables, production unit (PU) characteristics, and production strategies used in the bioeconomic analysis.

TABLE 1. Summary of zootechnical variables, production unit (PU) characteristics, and production strategies used in the bioeconomic analysis of intensive production and super-intensive production BFT systems of whiteleg shrimp, *Litopenaeus vannamei*.

Variables	***Quantity***
Stocking density intensive production (shrimp/m³)	179.11
Stocking density super-intensive production (shrimp/m³)	400
Average weight (kg)	0.012
Survival (%)	80
FCR[1]	1.6
Useful volume of PUs intensive production (m³)[2]	13,400
Useful volume of PUs super-intensive production (m³)[2]	6,000
Production per harvest (kg)	23,040
Harvests (per year)	3
Total Production (kg/year)	69,120
Productivity intensive production (kg/m³/year)	5.16
Productivity super-intensive production (kg/m³/year)	11.52

[1]Feed Conversion Ratio (FCR); [2]The intensive system includes four rearing ponds each with a useful volume of 3,350 m³; the super-intensive system consists of 10 greenhouses, each with two adjoined tanks, for a total useful volume of 600 m³.

The summary of the fixed investments and working capital for intensive production of *Litopenaeus vannamei* in rearing ponds in a BFT system are listed in Table 2.

TABLE 2. Summary of fixed investments and working capital for intensive production of *Litopenaeus vannamei* in a BFT system.

	Quantity	***Unit value (US$)***	***Total (US$)***
Fixed investment			***252,326.84***
Land (ha)	3	4,140.71	12,422.13
Production structure*	4	32,110.35	128,441.41
Paddlewheel Aerators 1.0 CV	48	982.25	47,147.93
Edifications (80 m²)	1	40,525.25	40,525.25

Equipment of parameters measurement	-	-	3,337.64
Networks and equipment of maintenance	-	-	1,668.81
Generator (55 KVA)	1	17,218.91	17,218.91
Catchment pump (7.5 HP)	1	1,564.76	1,564.76
Working capital			***198,475.27***
TOTAL			***450,823.64***

[*]Excavated nurseries with HDPE geomembrane coating (1.0 mm), anti-bird mesh, footbath / whirlpool, hydraulic network and electrical network. US Dollar quotation on 16/10/2021: 5.4504 Brazil Real.

Super-intensive system

The fixed investment for the super-intensive system considers 10 PUs, with a total individual useful volume of 600 m³. Each PU consists of a greenhouse constructed with galvanized steel arches and covered in plastic sheeting, two wooden boxes covered with PEAD geomembrane (1.0 mm) with a sand bottom (tanks), and a footbath. The hydraulic network includes water inlet pipes (60 mm), drainage pipes (150 mm), a 4.0 HP aerator, primary (60 mm) and secondary (20 mm) aeration pipes, and diffusers.

The following costs were also considered: acquisition of an area of two ha to establish the enterprise; equipment for monitoring water quality parameters, maintenance, and shrimp management; fixed costs; variable costs; and working capital. As with the intensive system, the construction of an 80 m² building was also included in the budget (Table 3).

For the super-intensive system, the zootechnical variables used in the simulations were: stocking density of 400 shrimp/m³; survival rate of 80%; production of 23,040 kg/cycle and 69,120 kg/year (three cycles/year) (Table 1). Harvesting and commercialization is based on live animals with an average weight of 12 g.

TABLE 3. Summary of fixed investment and working capital for the super-intensive production of *Litopenaeus vannamei* in a BFT system[1].

	Quantity	***Unitary value (US$)***	***Total (US$)***
Fixed investment			***292,571.75***
Land (ha)	2	4,140.71	8,281.42
Production structure[2]	10	21,997.49	219,974.96
Edifications (80 m²)	1	40,525.25	40,525.25
Equipment of parameters measurement	-	-	3,337.64
Networks and equipment of maintenance	-	-	1,668.81
Generator (55 KVA)	1	17,218.91	17,218.91
Catchment pump (7.5 HP)	1	1,564.76	1,564.76
Working capital			***208,947.35***
Total			***501,519.09***

[1]Updated data from Almeida et al. (2021). [2]Production structure (greenhouse): galvanized arches, plastic film, wooden box with geomembrane coating (1.0 mm) and sand bottom, clarifiers, hydraulic network, electrical network,

4.0 HP blower, aeration pipe primary (60 mm) and secondary (20 mm) and air diffusers. US Dollar quotation on 16/10/2021: 5.4504 Brazil Real.

Based on land use, a new scenario was drawn up comparing the economic performance of super-intensive production in greenhouses, in an area of the same size, in which the economic feasibility analyzes of intensive production in nurseries were carried out (total area of 3.0 ha and structures of production with a total useful volume of 13,400 m³). The zootechnical variables were maintained (stock density 400 shrimp/m³, FCA 1.6 and 80% survival and average final weight of 12 g).

RESULTS

For the intensive system, the fixed investment for the implementation of the enterprise was US$ 252,326.84 (Table 2) and the total capital contribution[6] was US$ 767,190.18; for the super-intensive system, the fixed investment was US$ 292,571.75 (Table 3) and total capital contribution was US$ 807,669.16.

The most significant cost in the implementation of the enterprises were the PUs, which represents 50.90% of the fixed investment (US$ 128,441.41) (Table 2) and 16.74% of the total investment in the intensive system, and 75.19% of the initial investment (US$ 219,974.96) (Table 3) and 27.23% of the total investment in the super-intensive system. This difference is mainly due to the greater number of PUs in the super-intensive system and the fact that the greenhouses require more investment in infrastructure and equipment (i.e., aerators, aeration pipes, and covered structures) compared to the intensive system (see table note in Tables 2 and 3).

The working capital for both projects corresponds to 34.90% of the sum of the total amount of fixed investment, fixed costs, and variable costs of each enterprise, corresponding to US$ 198,475.27 (Table 2) and US$ 208,947,35 (Table 3), for the intensive and super-intensive systems, respectively.

To implement the super-intensive production system in greenhouses, the cost was US$ 48.76/m³, a value 2.59 times greater than that obtained for the rearing ponds (US$ 18.83/m³). This significantly higher value is related to the costs associated with the greenhouses.

Among the fixed costs of the intensive and super-intensive enterprises, salaries and taxes were the most significant, corresponding to US$ 45,532.61 (Table 4).

[6] The total capital contribution consists of the sum of Fixed investment, Working capital, Fixed costs, and Variable costs. Updated data from Almeida et al. (2021).

The fixed costs of both BFT system projects are listed in Table 4.

TABLE 4. Fixed costs of intensive production in rearing ponds and super-intensive production in greenhouses of *Litopenaeus vannamei* in a BFT system.

Item	***Value (US$)***
Employees salary (/year)	13,912.45
Manager salary (/year)	19,323.03
Charges (37% upon the payroll) (/year)	12,297.33
Accountant (/year)	5,106.60
Electrical energy building and security (/year)	2,898.45
Tap water (/year)	1,501.93
RLT* intensive production (/year)	750.89
RLT* super-intensive production (/year)	500.64
Maintenance (/year)	2,649.75
TOTAL INTENSIVE PRODUCTION (US$)	***58,440.22***
TOTAL SUPER-INTENSIVE PRODUCTION (US$)	***58,189.27***

* Rural Land Tax. US Dollar quotation on 16/10/2021: 5.4504 Brazil Real.

Feed, electricity, post-larvae acquisition, sugar cane molasses and wheat bran are the main variable costs for the intensive and super-intensive production systems of *Litopenaeus vannamei* (Table 5).

TABLE 5. Variable costs for intensive production in rearing ponds and super-intensive in greenhouses of *Litopenaeus vannamei* in a BFT system.

Item	***Value (US$)***
Postlarvae (thousand)[1]	27,949.25
Commercial feed[1]	189,011.43
Sugar cane molasses intensive production	4,890.86
Wheat bran intensive production	120.56
Sugar cane molasses super-intensive production[1]	2,189.86
Wheat bran super-intensive production[1]	54.00
Electrical energy intensive production	34,453.14
Electrical energy super-intensive production[1]	27,232.94
Several intensive production[2]	1,522.32
Several super-intensive production[1,2]	1,584.02
TOTAL INTENSIVE PRODUCTION	***257,947.85***
TOTAL SUPER INTENSIVE PRODUCTION	***247,960.09***

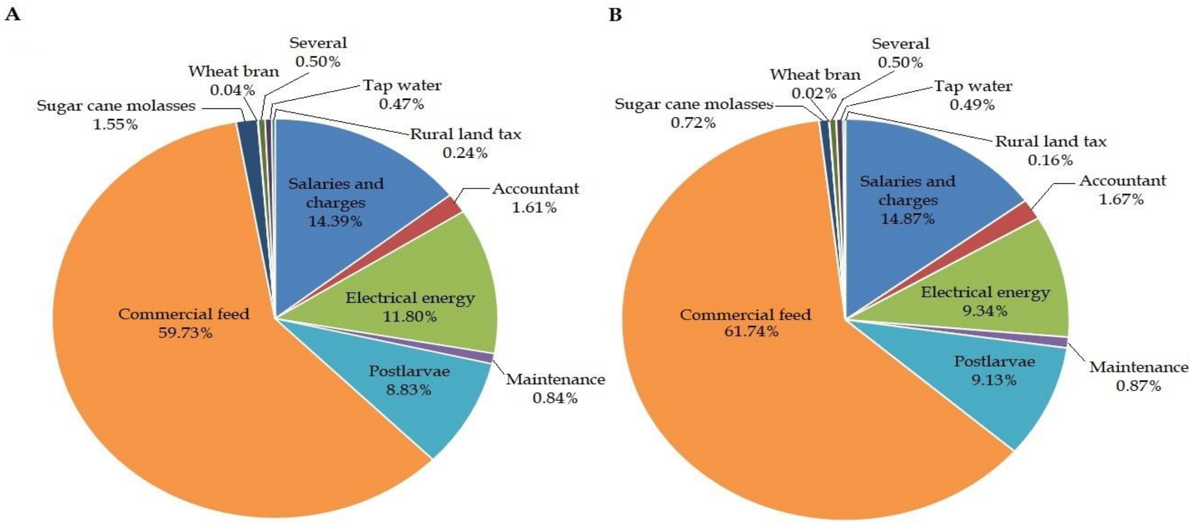
[1]Compounds for the correction of the pH and alkalinity, probiotic, sodium hypochlorite and structure maintenance. US Dollar quotation on 16/10/2021: 5.4504 Brazil Real. [2]Updated data from Almeida et al. (2021).

Among the variable costs, nutrition (commercial feed) was the most significant, representing 59.73% of total production costs (fixed and variable costs) in the intensive system and 61.74% in the super-intensive system, followed by electricity at 11.80% and 9.34%, and the cost of post-larvae acquisition at 8.83% and 9.13%, respectively. Salaries and taxes represents 14.39% of the total production cost in the intensive enterprise, and 14.87% in the super-intensive system. The inputs used in the formation and maintenance of the biofloc, although essential for the BFT System, were the items that were less relevant in terms of production costs. Sugar cane molasses and Wheat bran represented 1.55% and 0.04% of the total production costs in intensive production and 0.72% and 0.02% in super-intensive production, respectively (Figure 1).

The relative participation of each item (%) in the total costs for intensive production and super-intensive production of *Litopenaeus vannamei* in a BFT system, can be seen in Figure 1.

FIGURE 1. Relative participation of each item (%) in the total cost of intensive production in rearing ponds (A)

and super-intensive production in greenhouses (B) of *Litopenaeus vannamei* in a BFT system.



The commercialization of 69,120 kg of live shrimp at a sale price of US$ 8.26 generates a gross revenue of US$ 570,931.20 for each enterprise. From this value we subtracted US$ 384,899.82 for the intensive system, and US$ 374,661.81 for the super-intensive system, which corresponds to fees and fixed and variable costs. Net profits were US$ 186,031.38 for the intensive system and US$ 196,269.39 for the super-intensive production system (Table 6).

TABLE 6. Simplified cash flow for intensive production in rearing ponds and super-intensive production in greenhouses of *Litopenaeus vannamei* in a BFT system.

Item	***Value/quantity***
Production (kg)	69,120
Sale price (US$/kg)	8.26
Gross revenue (US$)	570,931.20

Tax, fixed and variable costs intensive production (US$)	- 384,899.82
Tax, fixed and variable costs super-intensive production (US$)	- 374,661.81
NET PROFIT INTENSIVE PRODUCTION (US$)	***186,031.38***
NET PROFIT SUPER-INTENSIVE PRODUCTION (US$)	***196,269.39***

US Dollar quotation on 16/10/2021: 5.4504 Brazil Real.

The net profit generated per m³ of the PUs was US$ 13.88 for the intensive system (total useful volume of 13,400 m³ and shrimp with an average weight of 12.00 g/unit) and US$ 32.71 for the super-intensive system (total useful volume of 6,000 m³ and shrimp with average weight of 12.0 g).

A second scenario was designed to evaluate super-intensive production considering the same area used in intensive production in nurseries, presented a fixed investment for the implementation of the project of US$ 607,162.36 and the total capital contribution was US$ 1,633,710.34. The estimated annual production was 154,368 kg (51,456 kg per harvest, three harvests/year), generating the value of US$ 1,275,079.68 as gross incomes. Total production costs amounted to US$ 756,909.93 (taxes US$ 153,009.56, fixed cost US$ 83,715.20 and variable cost US$ 520,185.17). The amount referring to depreciation was US$ 55,826.75/year. Net income was US$ 518,169.75.

The super-intensive production in scenario 2 provided an increase of 123.33% in production (going from 69.120 to 154,368 kg). The enterprise's net profit in this new context was US$ 38.67/m³, 178.60% higher than the intensive system (US$ 13,88) and 18.24% higher than the same system operating in a smaller area (US$ 32.71).

The projection of cash flow, payback, and discounted payback of intensive production in rearing ponds and super-intensive production in greenhouses of *Litopenaeus vannamei* in a BFT system are presented in Tables 7 and 8.

Table 7. Projection of cash flow, payback, and discounted payback of intensive production in rearing ponds of *Litopenaeus vannamei* in a BFT system, with an average final weight of 12 g, a 10 year horizon, and a Minimum Attractive Rate of Return (MARR) of 10.25%.

Period (year)	***Production (kg)***	***SP[1] (US$)***	***Revenue (US$)***	***PT[2] (US$)***	***Fixed costs (US$)***	***Variable costs (US$)***	***Balance (US$)***	***Payback Period (US$)***	***Discounted Payback (US$)***
0	0						-767,190.18	-767,190.18	-767,190.18
1	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	-581,158.80	-598,454.24
2	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	-395,127.42	-445,405.76
3	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	-209,096.04	-306,586.28
4	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	-23,064.66	-180,672.92
5	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	162,966.72	-66,465.79
6	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	348,998.11	37,123.45
7	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	535,029.49	131,081.94
8	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	721,060.87	216,305.06
9	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	907,092.25	293,604.94
10	69,120	8.26	570,931.20	-68,511.74	-58,440.22	-257,947.85	186,031.38	1,093,123.63	363,718.21

[1]Sale price; [2]Production tax.

Table 8. Projection of cash flow, payback, and discounted payback of super-intensive production in greenhouses of *Litopenaeus vannamei* in a BFT system, with an average final weight of 12 g, a 10-year horizon, and a Minimum Attractive Rate of Return (MARR) of 10.25%.

Period (year)	***Production (kg)***	***SP[1] (US$)***	***Revenue (US$)***	***PT[2] (US$)***	***Fixed costs (US$)***	***Variable costs (US$)***	***Balance (US$)***	***Payback period (US$)***	***Discounted Payback (US$)***
0	0	-	-	-	-	-	-807,669.16	-807,669.16	-807,669.16
1	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	-611,399.76	-629,647.03
2	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	-415,130.37	-468,175.71
3	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	-218,860.97	-321,716.47
4	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	-22,591.58	-188,873.62
5	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	173,677.82	-68,381.24
6	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	369,947.21	40,908.91
7	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	566,216.60	140,038.29
8	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	762,486.00	229,951.56
9	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	958,755.39	311,505.55
10	69,120	8.26	570,931.20	-68,511.74	-58,189.97	-247,960.09	196,269.39	1,155,024.79	385,477.42

[1]Sale price; [2]Production tax.

The results of the economic analyses showed that the super-intensive system presented better results in the eight applied methods. The results of these analyses can be seen in Table 9.

Table 9. Results of bioeconomic analyses of intensive production in rearing ponds and super-intensive production in greenhouses of *Litopenaeus vannamei* in a BFT system.

Indicators	***Results***		
	Intensive	***Super-intensive***	***Super-intensive (scenario 2)***
Net present value (NPV) (US$)	363,718.21	385,477.42	1,516,309.37
Equivalent annual value (EAV) (US$)	59,830.66	63,410.00	249,428.80
Net future value (NFV) (US$)	965,052.69	1,022,786.35	4,023,220.18
Payback (PP)	4.12	4.11	3.18
Discounted payback period (DPP)	5.64	5.63	4.0
Profitability index (PI)	1.47	1.48	1.93
Internal rate of return (IRR)	20.49%	20.55%	29.29%
Modified internal rate of return (MIRR)	14.61%	14.64%	17.73%

DISCUSSION

Teixeira & Guerrelhas (2011) found that when adapting commercial shrimp ponds (7,800 m²) from semi-intensive to intensive production using a BFT system, the result was a cost of US$ 7.56/m². In the present study a cost of US$ 18.83/m^3 was found for the implementation of an intensive production enterprise with rearing ponds. This value higher than that obtained by Rego et al. (2017a, 2017b) of US$ 14.83/m² when adapting conventional rearing ponds in the state of Pernambuco, Northeast Brazil, to an intensive BFT production system. This difference is partly related to the US Dollar quotation in November 2014, when the study was carried out (US$ 1.00 = R$ 2.49). Similarly, Mauladani et al. (2020) reported a cost of US$ 16.23/m² for the implementation of intensive production ponds in a BFT system while testing the influence of nano-bubbles on *Litopenaeus vannamei* survival in a super-intensive system in Indonesia.

The use of greenhouses for shrimp production has attracted the attention of researchers and producers in several countries, as they offer the possibility of producing shrimp in subtropical and temperate climate regions. Greenhouses are used to maintain a consistent water temperature, avoiding fluctuations and abrupt temperature drops, which can be harmful, or even lethal, to shrimp (Castilho-Barros et al., 2018; Van Wyk & Scarpa, 1999; Ponce-Palafox et al., 1997). However, their use has some disadvantages, including higher installation costs, greater electricity consumption due to the need for intensive aeration and removal of suspended solids in the water column, and increased operating costs, among others (Krummenauer et al., 2012; Gaona et al., 2017). Furthermore, these structures have higher maintenance costs when compared to other systems, along with a greater risk of structural damage as they are more exposed to extreme weather conditions, such as windstorms and hurricanes.

Our results are similar to those obtained in similar studies for labor costs of 17.16% (Teixeira & Guerrelhas, 2011), 13.66% (Rego et al., 2017a, 2017b), and 21.52% (Mauladani et al., 2020) in relation to the total cost of production.

The results of the present study are similar to those reported in previous studies on the economic performance of aquaculture production in BFT systems, with feed representing between 54.00% and 66.11% of total production costs. The proportion is lower for post-larvae acquisition, being between 13.71% and 17.63% (Teixeira & Guerrelhas, 2011; Poersch et al. 2012; Yuan et al. 2017; Rego et al. 2017a, 2017b; Cang et al. 2019; Mauladani et al. 2020.

In terms of feed provision, our results were superior to those obtained by Rego et al. (2017a, 2017b) and Mauladani et al. (2020) in intensive and super-intensive productions of *Litopenaeus vannamei*, which were 54% and 53.17%, respectively. The impact of the amount spent on feed on total costs is also similar to the values found by Poersch et al. (2012), with 62.22%, and by Teixeira & Guerrelhas (2011), with 62%, but higher than those obtained by Hanson et al. (2009) of approximately 37.10% (Table 10).

The stocking density significantly influences production levels, enabling greater productivity in a smaller cultivation area. Consequently, it offers more efficient use of production factors and improves profitability of the enterprise (Jackson & Wang, 1998; Krummenauer et al., 2011; Almeida et al., 2021). Furthermore, the sale price used by Rego et al. (2017a) was considerably lower than the one used herein (US$ 5.91 compared to US$ 8.26), which is related to the different markets considered in each study and the influence of supply and demand on the sale price of shrimp.

Rego et al. (2017a) studying intensive shrimp production in a BFT system in Northeast Brazil, projected a net profit of US$ 5.19 per m^2. The difference between the previous and the present study is mainly related to stocking densities (113 shrimp/m^2 by Rego et al. (2017a) vs. 179.11 shrimp/m^3 herein) and the consequential difference in production (2.90 kg/m^2 compared to 5.15 kg/m^3). We obtained a net profit of US$ 14.25 per m^3, with a sale price of US$ 8.26 per kg. Such divergent results are likely related to the difference in sale price of shrimp as well as the time between the two studies (eight years difference). Nevertheless, the productivity was similar between both studies (5.48 kg/m^2 versus 5.16 kg/m^3). Poersch et al. (2012) obtained a net profit per m^2 of US$ 3.32 for intensive shrimp production (sale price of US$ 2.67 per kg), with stocking densities and survival rates similar to those used herein.

TABLE 10. Summary of the results found in the literature of the proportion (%) of the most relevant costs in terms of total production costs of aquaculture enterprises using a BFT system.

Itens	***Authors***							
	Teixeira & Guerrelhas (2011)[1]	***Poersch et al. (2012)[2]***	***Yuan et al. (2017)[3]***	***Rego et al. (2017[a], 2017[b])[1]***	***Cang et al. (2019)[4]***	***Mauladani et al. (2020)[2]***	***Present study Is[5]***	***Present study Ss[6]***
Implementation (US$/m² or m³)	7.56	8.79	-	14.83	-	16.23	18.83	48.76
Labor (%/total costs)	17.16	3.68	-	13.66	-	21.52	14.39	14.87
Electrical energy (%/total costs)	-	7.45	-	14.46	-	6.39	11.80	9.34
Commercial feed (%/total costs)	62.00	62.22	66.11	54.00	65.00	53.17	59.73	61.74
Postlarvae (%/total costs)	15.00	13.71	-	17.63*	-	14.71	8.83	9.13

[1]Adaptation of conventional semi-intensive to intensive BFT system; [2]Implementation of a project to operate in the BFT system; [3]Analysis of the profitability of carp production using the BFT system; [4]Analysis of tilapia profitability in BFT system; [5]Intensive system; [6]Super intensive system.
*Value considered with other entries not detailed by the authors.

Mauladani et al. (2020), when testing the influence of nano-bubbles on survival in a super-intensive BFT production system, using a density of 400 shrimp/m² and considering an average final weight of 10.10 g, obtained a net profit of US$ 13.81 per m². It is important to highlight that their study produced smaller shrimp than those considered in the present study, which resulted in a lower sale price.

Our results demonstrate that, under the analyzed conditions, intensive production in rearing ponds and super-intensive production in greenhouses of *Litopenaeus vannamei* in a BFT system, are feasible and present positive economic results. However, the super-intensive system showed better results in the eight economic analysis methods used.

Methodologies to assess the environmental impacts of products and production systems have the potential to complement, from an environmental perspective, the decision making process in aquaculture and agribusiness. In order to ensure the economic and environmental efficiency of the enterprise, methods that compare the impact of the enterprise on the environment can inform investor decision making. For this, we suggest the methodology Life Cycle Assessment (LCA) that can be used to identify the critical points of the system in order to reduce its environmental impacts or compare different systems to determine which alternative results in the least impact on the environment (Bohnes et al., 2019).

CONCLUSION

The implementation of intensive production systems in rearing ponds and super-intensive production in greenhouses in a BFT system of whiteleg shrimp, Litopenaeus vannamei, requires a considerable capital input. However, our results show that, from a bioeconomic perspective, these projects are viable.

The investment analysis used in this study showed that super-intensive production in a greenhouse is the best investment option**.** The development of a new scenario simulating the super-intensive production of shrimp in a BFT system, considering land use as a premise, made it possible to observe the possibility of obtaining financial gains in scale, both in the reduction of production costs and in the economic performance of the enterprise. However, the financial contribution for the implementation and operation of the project increased substantially.

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APPENDIX

FIGURE 1. Basic sketch of the enterprise for the intensive production of *Litopenaeus vannamei* shrimp in BFT system.

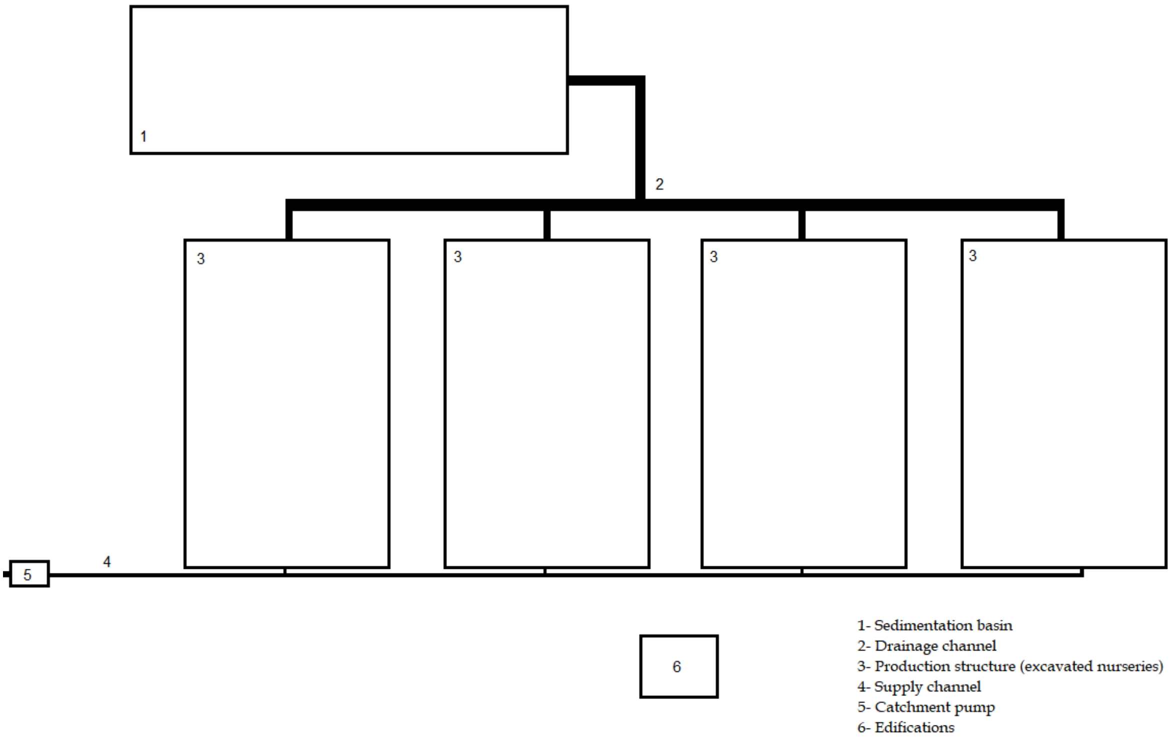
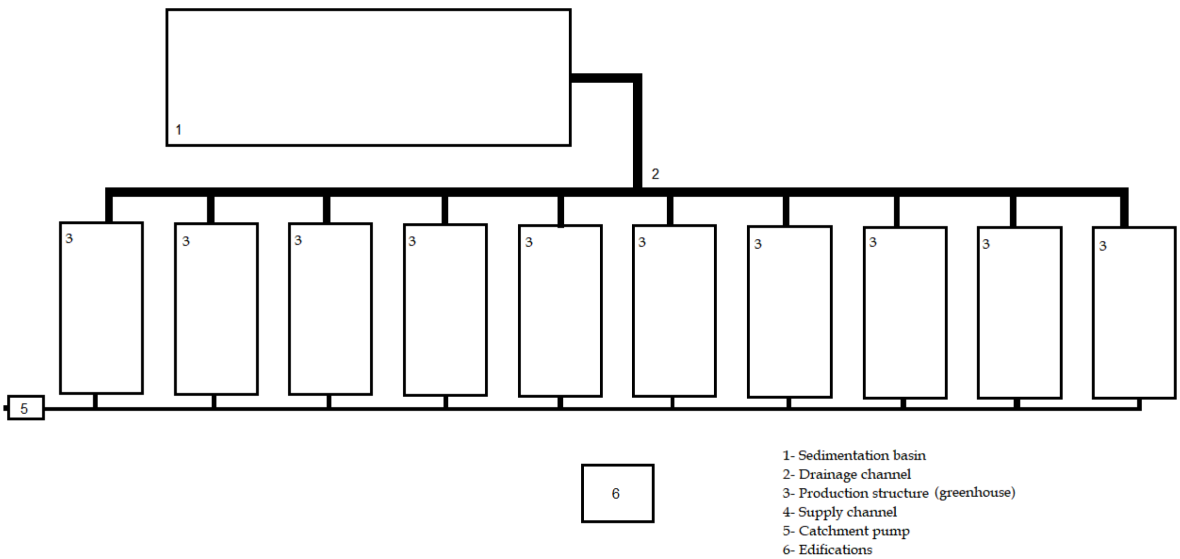


FIGURE 2. Basic sketch of the enterprise for the super-intensive production of Litopenaeus vannamei shrimp in BFT system.



CAPÍTULO IV

ENVIRONMENTAL IMPACTS OF *Litopenaeus vannamei* SHRIMP PRODUCTION IN INTENSIVE AND SUPER-INTENSIVE BIOFLOC SYSTEMS

ABSTRACT

For decades, shrimp farms worldwide have been responsible for a series of social and environmental issues that affect their surrounding regions. Modern aquaculture seeks to achieve sustainable growth that offers a balance between environmental, economic, and social perspectives, and in recent decades new aquaculture technologies have been developed and improved. One such innovation is the biofloc technology (BFT) system, which is considered an alternative to conventional aquaculture. The BFT system allows for aquatic organism production with minimal water exchange, high stocking densities, and the possibility of high levels of productivity. Life Cycle Assessment (LCA) is one of the most common methodologies used to compare the environmental performance of different systems, considering resource consumption and the emission of pollutants during the productive life cycle. LCA in aquaculture enables us to obtain a detailed overview of environmental impacts as it measures the positive and negative impacts of the entire life cycle of a product, service, process, or activity. The present study uses LCA to compare the environmental performance of *Litopenaeus vannamei* shrimp production in two BFT systems, an intensive system in a nursery and a super-intensive system in a greenhouse. The Functional Unit used was 1 ton of shrimp (each shrimp with 12 g). The boundaries of the system were defined as the nursery to the farm gate. Input data related to the use of natural resources, energy consumption, and environmental emissions were obtained over eight cycles of intensive and super-intensive production, from 2009/2010 to 2019/2020, at the Marine Aquaculture Station - Federal University of Rio Grande (FURG), in Rio Grande do Sul, Brazil. The following results were obtained for intensive and super-intensive systems, respectively: global warming (GWP100a) 5,691.12 and 5,512.42 kg CO_2-eq; acidification 59.57 and 59.05 kg SO_2-eq; eutrophication 25.96 and 25.80 kg PO_4-eq; ozone layer depletion (ODP) 0.000319 and 0.000311 kg CFC-11-eq; human toxicity 1,165.98 and 1,233.33 kg 1.4-DB-eq; aquatic ecotoxicity 1,344.13 and 1,925.96 kg 1.4-DB-eq; marine ecotoxicity 1,881,643.65 and 2,070,517.23 kg 1.4-DB-eq; terrestrial ecotoxicity 24.26 and 33.54 kg 1.4-DB-eq; photochemical oxidation 2.10 and 2.03 kg C_2H_4-eq; abiotic depletion 0.006487 and 0.008359 kg Sb-eq; abiotic depletion of fossil fuels 35,612.80 and 34,504.39 MJ. Based on these results, we conclude that feed and electricity had the most environmental impact in both systems. Among the evaluated impact categories, super-intensive production showed better results than intensive shrimp production in a BFT system.

Keywords: Life Cycle Assessment, Biofloc Technology System, Environmental performance, Shrimp farming, Aquaculture.

INTRODUCTION

Worldwide, shrimp farming has resulted in a series of social and environmental problems affecting their surrounding regions (HOSSAIN; UDDIN; FAKHRUDDIN, 2013; PAUL; RØSKAFT, 2013; KABIR et al., 2016; LOLA; ISA; RAMLEE, 2017). These problems range from pressure on traditional communities for land use and occupation, spread of pathogens, soil salination, and modifications to the landscape due to the construction of large nurseries and extensive water catchment channels. Shrimp farms also cause coastal ecosystem degradation due to the release of large volumes of effluents rich in organic matter into these environments (LOPES, 2008; REKHA et al., 2015; WILMS; GOOT; DEBROT, 2017; KAIS; ISLAM, 2019; SOTO, 2021). Shrimp production is also closely linked to several potential environmental impacts, such as eutrophication of aquatic ecosystems, intensive use of land and water, ecotoxicity in local ecosystems due to the use of chemicals, in addition to the introduction of exotic species (BOHNES et al., 2019; DIANA, 2009; OTTINGER; CLAUSS; KUENZER, 2016).

As a response, modern aquaculture has begun to focus on sustainable growth, searching for a balance between environmental, economic, and social impacts. The development of sustainable aquaculture could contribute to the United Nation’s Sustainable Development Goals (SDG) by reducing poverty (SDG 1), ending hunger, achieving food security, and improving nutrition (SDG 2), and promoting sustainable economic growth (SDG 8) (FAO, 2017b; 2017c; BOSSIER; EKASARI, 2017).

As one of the most environmentally efficient modes of animal food production (HALL et al., 2011; HELLER; KEOLEIAN, 2015), aquaculture has the potential to help meet future demands for animal protein, while reducing the environmental impacts associated with animal production systems (HALL et al., 2011; KOBAYASHI et al., 2015; FAO, 2018).

In recent decades, new aquaculture technologies have been developed and improved, such as the Biofloc Technology System (BFT), which is considered an alternative to conventional aquaculture (PANIGRAHI et al., 2018; REN et al., 2019; YU et al., 2020). This system allows for the production of aquatic organisms with high stocking densities and minimal use of water (KRUMMENAUER et al., 2011; PANIGRAHI et al., 2018).

Sustainable intensification consists of producing more food in the same area while also reducing the environmental impacts of production (THE ROYAL SOCIETY, 2009). The BFT system meets this demand, as it reduces the use of natural resources, while obtaining high levels of productivity (ALMEIDA et al., 2021).

One of the most common methods used to assess the environmental impacts of products and production systems is the Life Cycle Assessment (LCA) (RUVIARO et al., 2012; DE FEO & FERRARA, 2016; DAS & JHARKHARIA, 2018). In aquaculture, LCA can help to support decision making, identify critical points in the system to reduce environmental impacts, or compare alternate systems to determine which has the lowest environmental impacts (BOHNES et al., 2019).

LCA is an international standard regulated in Europe by EN 15804, ISO 14040, and ISO 14044. In Brazil, these ISOs were translated and redeployed as ABNT NBR ISO 14040 and ABNT NBR ISO 14044. LCA is an environmental accounting tool that can provide essential information to improve aquaculture system sustainability (PHILIS et al., 2019). Cao et al. (2013) argue that LCA can be used to quantify such assessments with clear indicators of sustainability. According to Diana (2009), LCA is one of the few methods that allow quantitative and scientifically proven assessments of aquaculture sustainability, which is reflected in the increasing number of scientific studies applying such a methodology in aquaculture (AUBIN, 2013; BOHNES et al., 2019; BOHNES & LAURENT, 2019).

De Feo and Ferrara (2016) clarify that LCA enables comparisons between the environmental performance of different systems that considers resource consumption and pollutant emissions that may occur during the productive life cycle. For Bohnes et al. (2019), LCA also stands out as it measures the environmental performance of any production chain or system, thus offering a management tool that can help inform decision making. Therefore, LCA can be used to increase production chain efficiency as it identifies the production phases that have the greatest negative environmental impact (WIEDEMANN et al. 2015).

The intensification of aquaculture is occurring alongside greater environmental awareness and concern by most stakeholders in the system. Natale et al. (2013) report high energy consumption and high values of carbon dioxide (CO_2) emissions in closed aquaculture systems with cages and tanks, which vary according to the degree of intensification of the system. According to the authors, this has led industries to adopt measures to make production more sustainable, with LCA offering a standard and reliable methodology to compare the environment impacts of different production systems, which in turn demonstrates concern with sustainability.

Ruviaro et al. (2012) state that the LCA adequately addresses Greenhouse Gases (GHG) mitigation strategies, as it measures the positive and negative environmental impacts of the entire life cycle of a product, service, process, or activity (BHATT; BRADFORD; ABBASSI, 2019). In this sense, Ziegler et al. (2016) emphasize that LCA in aquaculture makes it possible to obtain a more detailed picture of environmental impacts.

The selection of impact categories is one of the key items in a LCA study. Most scientific literature on LCA in aquaculture has addressed the categories of global warming potential (GWP100a), acidification potential (AP), eutrophication potential (EP), ozone depletion (ODP), human toxicity (HT); aquatic ecotoxicity (AE), marine ecotoxicity (MT); terrestrial ecotoxicity (TE); photochemical oxidation (PO); abiotic depletion (AD); abiotic fossil fuel depletion (AFFD); accumulated energy demand (AED), water dependence (WD), net use of primary production (NUPP), and competition for land (LC) (MUNGKUNG; UDO DE HAES; CLIFT, 2006; AUBIN et al., 2009; HENRIKSSON et al., 2012; AVADÍ et al., 2015; YACOUT; SOLIMAN; YACOUT, 2016; BOHNES et al., 2019; NOGUERA-MUÑOZ et al., 2021).

In this context, the present study uses the LCA methodology to evaluate and compare the environmental performance of *Litopenaeus vannamei* shrimp production in two BFT systems: intensive production in nurseries and super-intensive production in greenhouses.

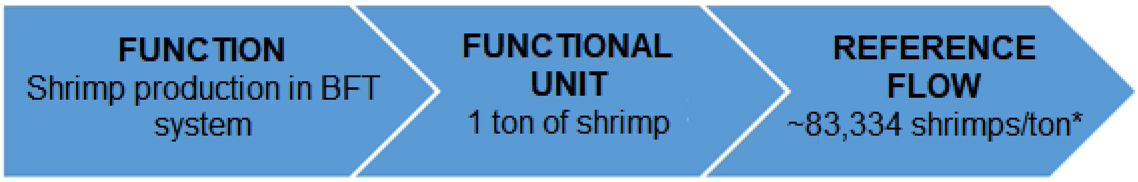
MATERIAL AND METHODS

LIFE CYCLE ASSESSMENT – LCA

Objective and scope

The LCA of the present study aims to quantify and compare the environmental benefits and impacts of the life cycle of *L. vannamei* shrimp production in an intensive BFT system in nurseries and a super-intensive BFT system in greenhouses. Herein, 1 ton of *in natura* shrimp was chosen as the functional unit (FU) in both production strategies. The system boundaries were defined as the nursery to the farm gate. The reference flow is approximately 83,334 shrimp with an average weight of 12 g (Figure 1).

FIGURE 1. Definition of objective and scope: Function, Functional Unit, and Reference Flow.



* Shrimp with an average weight of 12 g.

Preliminary inventory

The inputs required for the production of 1 ton of *L. vannamei* whiteleg shrimp in intensive (SI) and super-intensive (SS) BFT systems, can be seen in Table 1.

TABLE 1. Inventory of inputs to produce 1 ton of *Litopenaeus vannamei* whiteleg shrimp in intensive (SI) and super-intensive (SS) BFT systems.

Inputs	*SI*	*SS*
Sodium hypochlorite[1] (kg)	11.63	5.21
Sea water (m^3)[2]	1,376	675
Total electrical energy (kw/h)	4,939.47	4,188.94
Wheat bran[3] (kg)	9.69	4.34
Molasses[3] (kg)	96.93	43.4
Lime[4] (kg)	480	220
Probiotic (kg)	12.47	5.58
Feed 40% crude protein (kg)	1,600	1,600

Potable water (l) (ice for slaughter - 400 kg)	422	422
Fuel for generator (diesel) (l)	8.68	8.68
Fuel for feed shipping (diesel) (l) 1,740km	696	696

[1]Tank disinfection; [2]Estimated based on ANA's water demand methodology for aquaculture; [3]Formation and maintenance of bioflocs; [4]Correction of pH and alkalinity.

Impact categories

This study assesses the following impact categories: global warming potential (GWP100a); acidification potential; eutrophication potential; ozone depletion (ODP); human toxicity; aquatic ecotoxicity; marine ecotoxicity; terrestrial ecotoxicity; photochemical oxidation; abiotic depletion; abiotic fossil fuel depletion.

In the LCA of this study, we used the software SimaPro® 9.2.0.1 (System for Integrated Environmental Assessment of Products), a tool for collecting data and analyzing the environmental performance of products and services. Secondary data were obtained from the EcoInvent database v. 3.7.1, and through a literature review.

CHARACTERIZATION OF PRODUCTIVE SYSTEMS AND PRODUCTION UNITS

BFT SYSTEM

The BFT System is based on the stimulation of natural productivity in cultivation tanks (SAMOCHA et al., 2007; AVNIMELECH, 2009). This system encourages the formation of bioflocs, which are suspended particles from the development of a microbial community in a culture medium. The bioflocs aggregate autotrophic and heterotrophic bacteria, protozoa, metazoa, microalgae, invertebrate larvae, feces, remains of dead animals, exoskeletons, and other particles present in the tanks (BURFORD et al., 2003; BALLESTER et al., 2010).

The formation of bioflocs occurs through the transformation of nitrogen compounds dissolved in water into microbial flakes by adding carbon sources (molasses, dextrose, wheat bran, among others) to tanks or nurseries. Organic fertilization (addition of wheat bran and molasses) in the system optimizes the growth of heterotrophic bacteria and, consequently, bioflocs (FÓES; GAONA; POERSCH, 2012). This microbial community is responsible for recycling nitrogenous compounds, contributing to the maintenance of water quality and complementing the peneid shrimp diet (AVNIMELECH, 1999; MCINTOSH et al., 2000; BRATVOLD; BROWDY, 2001; BOYD; CLAY, 2002; BURFORD et al., 2003; WASIELESKY et al., 2006; BALLESTER et al., 2010; KUMAR et al., 2017).

The BFT system enables the optimization of production as it allows intensive and super-intensive production of shrimp in small areas, with relatively safe stocking densities that can vary from 100 to 450 shrimp/m^3. In the BFT system, the most commonly used densities in intensive cultivation in nurseries are 130 to 150 shrimp per m^2 (TAW, 2010). The system allows the use of high stocking densities of 1000 to 5000/m^2 in nurseries, of 100 to 200/m^2 in fattening ponds and raceways, and the possibility of obtaining a density of 300 to 600 shrimp/m^2 in a super-intensive system (WASIELESKY et al., 2016).

The ability to use high stocking densities in the BFT system results in greater production in smaller spaces, addressing the issue of lack of area available for the implementation of aquaculture projects (KRUMMENAUER et al., 2011). In this sense, Otoshi et al. (2009) tested high density levels in fattening ponds of *L. vannamei* shrimp, at a rate of 828 shrimp/m^2. The authors obtained a productivity of 10.3 kg/m^2 and an average survival of 67.9% in the BFT system in a greenhouse. Similarly, using stocking densities of 530 shrimp/m^2, Samocha et al. (2010) reached a productivity of 9.75 kg/m^2 and 95% average survival.

As they provide high levels of protein, bioflocs also offer an extra source of feed with high nutritional value (WASIELESKY et al., 2006; MISHRA et al., 2008; KUMAR et al., 2017), thus providing a better feed conversion rate (0.8 to 1.4 kg of feed for each kg of shrimp produced) and reducing production costs (SMITH et al., 2002; TACON et al., 2002; CUZON et al., 2004; WASIELESKY et al., 2006). In traditional systems, feed is responsible for up to 60% of total costs (BOYD; CLAY, 2002; SMITH et al., 2002; TACON et al., 2002; BURFORD et al., 2003; CUZON et al., 2004; BALLESTER et al., 2010; POERSCH et al., 2012; ROY; DAVIS; WHITIS, 2012), and as such, it is one of the most significant inputs in shrimp production (TEIXEIRA; GUERRELHAS, 2011; POERSCH et al., 2012; REGO et al., 2017; ALMEIDA et al., 2021).

In conventional aquaculture production systems, the greater the degree of intensification, the greater the need for feed, fertilization, and water exchange, which substantially increases the discharge of waste from the system and, consequently, production costs (PÁEZ-OSUNA, 2001). The releasing of effluents into adjacent ecosystems can contribute to the degradation of the natural environment and the spread of diseases (SAMOCHA et al., 2007), and is an obstacle to the sustainable development of shrimp farming (ALMEIDA et al., 2021).

Another highly significant issue when comparing conventional shrimp production with the biofloc system is the use of water resources and the potential for eutrophication of the environment. In conventional systems, approximately 64 thousand liters of water are needed to produce 1 kg of shrimp (HOPKINS et al., 1993), while in the biofloc system, between 98 and 169 liters are needed to produce the same amount (OTOSHI et al., 2009; SAMOCHA et al., 2010; GAONA et al., 2011; KRUMMENAUER et al., 2011, 2012). Furthermore, the water used in the biofloc system can be recycled in successive production cycles (KRUMMENAUER et al., 2013; MACIEL; FRANCISCO; MIRANDA-FILHO, 2018), while in the conventional system, the water that is rich in organic matter, nutrients, and nitrogen compounds, is normally released into water bodies and adjacent environments, causing substantial changes to the surrounding biota (RIBEIRO et al., 2014; SUÁREZ-ABELENDA et al., 2014; CARDOSO-MOHEDANO et al., 2016).

The BFT system is considered ecologically sound because it can improve water quality conditions and, for some species, it can be a supplementary source of food and nutrition for improved health (AHMAD et al., 2017; AVNIMELECH, 2009; EMERENCIANO et al., 2017; FISCHER et al., 2020).

The intensive system (SI) evaluated herein consists of four productive units (PUs) which are nurseries with a useful volume of 3,350 m^3 each. The super-intensive system (SS) consists of 10 PUs, greenhouses with tanks of 600 m^3 of useful volume (each PU in this system has four combined tanks, with a useful volume of 150 m^3 each). The estimated total annual production for the two systems is 69,120 kg of shrimp *in natura.*

Table 2 provides a summary of zootechnical variables, characteristics of PUs, and production strategies used in the study.

TABLE 2. Summary of zootechnical variables, characteristics of productive units (PUs), and strategies used in the production of *Litopenaeus vannamei* whiteleg shrimp in intensive (SI) and super-intensive (SS) BFT systems.

Variables	***SI***	***SS***
Stocking density (shrimp/m³)	179.11	400
Average weight (g)	12	12
Survival (%)	80	80
FCR*	1.6	1.6
Total useful volume of PUs (m³)	13,400	6,000
Production per harvest (kg)	23,040	23,040
Number of crops (per year)	03	03
Total production (kg/year)	69,120	69,120
Productivity (kg/m³/year)	5.16	11.52

* Feed conversion ratio.

In both systems, water exchange is minimal and only occurs when necessary. Water lost through evaporation is replaced, and in the intensive system input of water from precipitation is also considered. In the two evaluated systems, the water is completely replaced for each new crop cycle. Water demand for the two systems was calculated based on the methodology of the National Water and Basic Sanitation Agency (2018). Although water use was estimated (Table 1), the water footprint is not accounted for in the LCA, as sea water is seen as an abundant resource and its use is not considered in studies of this nature.

Intensive System (SI)

The SI was implemented in excavated ponds, covered with a 0.8 mm thick geomembrane of high-density polyethylene (HDPE). The PUs also include hydraulic and electrical networks, a 7.5 HP water intake pump for washing and to fill the nurseries, and a 55 kVA generator that is automatically activated in the event of interruptions to the energy supply. The area also has security lighting, activated at night. Aeration is carried out continuously by 1 CV aerators (two aerators in each nursery).

The stocking density used in the intensive system was 179.11 shrimp/m³, with 80% survival, resulting in a production of 23,040 kg/shrimp/cycle and 69,120 kg/shrimp/year (three cycles/year) (Table 2). Harvesting and commercialization assume the production of animals *in natura*, delivered at the farm gate with an average weight of 12 g.

Super-intensive system (SS)

The super-intensive system was implemented in greenhouses, composed of arched galvanized structures covered with plastic film, wooden boxes lined with HDPE (1.0mm), hydraulic and electrical networks, primary (60mm) and secondary (20mm) aeration piping, and 4 HP air diffusers and blowers. As with the SI, the PUs also include hydraulic and electrical networks, a 7.5 HP water intake pump, a 55 kVA generator to avoid disruptions in energy supply, and security lighting activated at night.

In this system, the zootechnical variables used were stocking density of 400 shrimp/m³, 80% survival, and production of 23,040 kg/cycle and 69,120 kg/year (three cycles/year) (Table 2). The harvesting and commercialization assume animals *in natura*, delivered at the farm gate with an average weight of 12 g.

Commercial feed

In all production phases, the feed used in both systems was a commercial feed with 40% crude protein (minimum). Due to the lack of information on feed ingredients and manufacturing process, a reference diet was formulated according to the nutritional requirements of Pacific whiteleg shrimp to obtain 40% crude protein and 10% lipids. The formula was based on Scopel et al. (2011)[1], and priority was given to ingredients commonly used to formulate shrimp feed that are available nationally. As primary protein sources, soybean bran, fish meal, meat meal, cane yeast, and hydrolyzed feathers were used. Fish fat and tuna oil were the primary sources of lipids. Data regarding the protein and lipid levels of each ingredient contained in the base formula were collected from the scientific literature (soybean meal - UNITED STATES SOYBEAN EXPORT COUNCIL, 2017; fish meal - CHO; KIM, 2011; meat meal -

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[1]In the study by Scopel et al. (2011), the authors describe the ingredients and their amounts used in commercial feed formula with 35% raw protein as prepared, manufactured, and supplied by the company Guabi Nutrição Animal (Campinas, SP, Brazil).

SIMONOVA et al., 2020; sugarcane yeast, liquid molasses, rice bran, and hydrolyzed feathers - ROSTAGNO et al., 2011; fish oil - USDA, 2021).

For 1 ton of *L. vannamei* shrimp, with a feed conversion ratio of 1.6, 1,6 ton of feed are required. The complete formula of the diet and the quantities of ingredients used in the feed to produce 1 ton of *L. vannamei* shrimp in the intensive and super-intensive production systems are shown in Table 3.

TABLE 3. Reference diet ingredients and quantities used in the feed formula to produce 1 ton of *L. vannamei* whiteleg shrimp in intensive and super-intensive systems.

Ingredients	***Quantity (g/kg)***	***Quantity (Kg)***
Soybean meal	235.0	376.00
Fish meal	250.0	400.00
Meat meal	110.0	176.00
Cane yeast	85.0	136.00
Rice bran	50.0	80.00
Liquid molasses	50.0	80.00
Rice chirella	80.0	128.00
Hydrolyzed feathers	50.0	80.00
Fish fat	15.0	24.00
Tuna oil	35.0	56.00
Mono-calcium phosphate	13.5	21.60
Refined salt	5.0	8.00
Mineral and vitamin supplementation[a]	21.5	34.40
Total	***1,000.00***	***1,600.00***

[a] Vitamin A = 4000 iu; Vitamin E = 150 iu; Vitamin d3 = 2000 iu; Vitamin k3 = 30 mg; Vit C = 130 mg; Tiancin (B1) = 14 mg; Riboflovin (B2) = 25 mg; Pyredoxine (B6) = 30 mg; B12 = 20 mcg; Folic acid = 6 mg; Biotin = 0.2 mg; Ca pathothenate = 55mg; Choline = 1500mg; K = 8g; Cr=0.2g; Co=40mg; Cobalt = 0.5mg; Mg = 20mg; I = 1mg; If = 0.3g; Zn = 100mg; Ca=20g; Betoin = 2g; Inusitol = 50 mg; Manno-oligosaccharide = 60 mg (Scopel et al., 2011).

Zootechnical performance and final biomass estimate

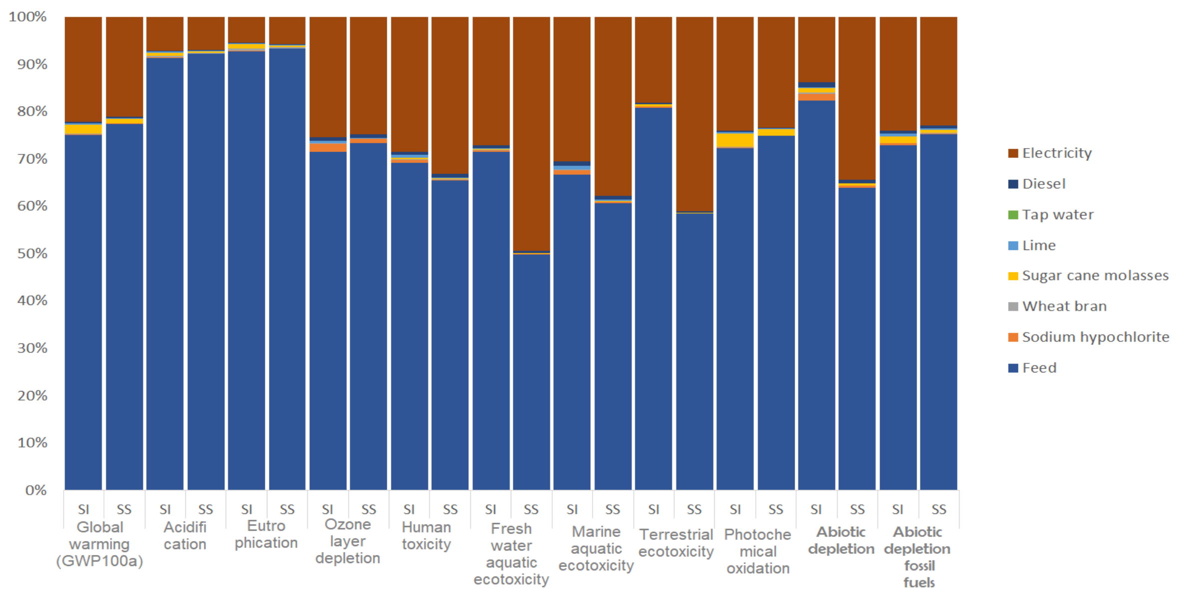
To monitor the zootechnical performance of shrimp, and adjust the amount of feed offered, biometrics were collected fortnightly. For this, 30 shrimp were randomly collected from each experimental unit. The animals were weighed individually and returned to their respective tank/nursery. At the end of the experiment, the entire production stock was weighed to estimate the survival rate and final biomass.

To assess the zootechnical performance of shrimp, the following parameters were used: survival (%) = [(final biomass / mean individual weight) / number of stocked shrimps] x 100; average individual weight (g); weight gain (g) = final weight – initial weight; specific growth rate (% day) = [(ln final weight – ln initial weight) / time] x 100; Final biomass (kg); feed conversion ratio (FCR) = amount of feed offered (g) / (final biomass (g) – initial biomass (g)); productivity = final biomass/m³.

RESULTS AND DISCUSSION

For all impact categories (Figure 2), the most relevant items of the total environmental impacts of intensive and super-intensive production were feed, with values between 66.74% and 92.80% in the SI and 49.91% and 93.35% in the SS, and electricity, with percentages between 5.35% and 30.44% in the SI and 5.72% and 49.43 in the SS. The other items showed low contribution to environmental impacts, with a maximum of 2.90% for the contribution of sugar cane molasses to intensive production in nurseries (Photochemical oxidation in SI).

FIGURE 2. Participation of each input on the environmental performance indicator for *Litopenaeus vannamei* whiteleg shrimp production in intensive and super-intensive BFT systems.



In most LCA studies carried out to date, feed stands out as the main contributor to most of the negative environmental impacts of aquaculture production (BOHNES et al., 2019; BOHNES; LAURENT, 2021). According to FAO (2020), this is considered one of the main limitations for the development of shrimp farming, because in addition to the significant environmental impacts of essential ingredients for its formulation, such as fishmeal, there is still the high cost of this input, highly demanded by the industry and necessary for the formulation of shrimp diets, since crustaceans are the group with the highest consumption of the ingredient among all cultivable aquatic organisms.

The use of ingredients alternative to fish meal and oil are necessary to ensure the sustainability of aquaculture (COTTRELL et al. (2020). From this perspective, a number of alternative ingredients have been successfully tested in nutritional terms in the formulation of shrimp diets, however, the production and supply of these inputs on a large scale are some of the limitations for the industry (HUA et al., 2019; TURCHINI et al., 2019). However, when evaluating the environmental performance of the ingredients used in the manufacture of feed, we observed that inputs such as fish oil and fat presented a modest contribution, when compared with cane yeast, meat meal and soybean meal, for example (Table 4).

Quang Tran et al. (2022), comparing the environmental performance of potential substitutes for fishmeal in the production of feed for aquaculture, found that of all evaluated raw materials, the fish by-product presented the best results. Pahlow et al. (2015) add that alternative ingredients can increase pressure on the environment due to increased demand for water and land resources for their production, a surprise ending as the aquaculture industry's greater need for this type of protein. In addition, in some cases, the digestibility of these ingredients is not as efficient as fish meal and oil, thus generating more residues that negatively impact the quality of aquaculture effluent (KOKOU; FOUNTOULAKI, 2018).

TABLE 4. Contribution of feed inputs on the environmental performance of *Litopenaeus vannamei* whiteleg shrimp production in intensive BFT systems.

Impact Categories/Inputs	***Soybean meal***	***Liquid molasses***	***Rice bran***	***Rice chirella***	***Hydrolyzed feathers***	***Phosphate fertiliser***	***Fish meal***	***Tuna oil***	***Cane yeast***	***Refined salt***	***Meat meal***	***Electricity***	***Transport***	***Fish fat***
Global warming[1]	703.73	83.57	143.91	166.77	721.26	40.66	54.60	10.92	1,907.70	2.18	1,161.94	33.40	47.10	-2.65
Acidification[2]	3.72	0.3580	1.61	0.6301	10.85	0.58	0.15	0.0298	8.96	0.0155	27.21	0.11	0.25	-0.0072
Eutrophication[3]	2.33	0.2037	0.7075	1.02	5.17	0.27	-2.83	-0.5664	7.88	0.0070	9.67	0.0368	0.0584	0.1374
ODP[4]	0.3580	2.50E-07	1.64E-06	5.45E-06	7.79E-07	6.12E-06	1.5E-05	3E-06	5.93E-05	2.07E-07	5.81E-06	2.15E-06	8.65E-06	-7.3E-07
Human toxicity[5]	0.2037	3.54	43.97	26.96	3.58	42.48	23.40	4.68	298.54	2.37	24.89	8.79	21.70	-1.13
Aquatic ecotoxicity[5]	82.90	1.39	13.88	16.49	1.55	23.67	7.82	1.56	744.60	1.55	50.48	9.66	6.05	-0.3794
Marine ecotoxicity[5]	200,627.70	812.75	51,303.87	42,530.09	2,689.29	202,660,00	44,554.67	8,911.84	644,259.40	3,884.63	26,156.14	15,201.62	14,303.99	-2.161.12
Terrestrial ecotoxicity[5]	0.7547	0.0773	0.2796	0.2289	0.0200	0.28	0.13	0.0261	6.10	0.0065	11.52	0.1164	0.0806	-0.0063
Photochemical oxidation[6]	0.1287	0.0504	0.0433	0.0355	0.43	0.0241	-0.0018	0.0298	0.3137	0.0007	0.4710	0.0134	0.0090	8.56E-05
Abiotic depletion[7]	0.0018	5E-05	9.23E-05	0.0004	1.49E-05	0.58	-8.7E05	-1.74E05	0.0020	3.72E-05	0.0001	2.36E-05	0.0001	4.22E-06
Abiotic depletion of fossil fuels[8]	10,452.54	385.71	1,026.01	576.19	65.03	0.27	1,328.85	265.80	6,824.14	25.61	3,402.47	226.14	749.70	-64.46

[1](GWP100a) kg CO^{2} eq; [2]kg SO^{2} eq; [3]kg PO^{4} eq; [4]Ozone layer depletion - kg CFC-11 eq; [5]1.4 DB eq; [6]kg $C^{2}H^{4}$ eq; [7]kg Sb eq; [8]MJ.

Feed was the most prominent input in the LCA of intensive and super-intensive shrimp production in the BFT System. As the amount of feed used was the same for the SI and SS, its contribution to the environmental performance of the evaluated systems showed no difference.

Among the inputs used in the formulation to shrimp *L. vannamei* feed, Cane yeast showed the highest values in six of the eight impact categories evaluated, Global warming (GWP100a) (25.71%), Eutrophication (32.72%), Human toxicity (37.00%), Aquatic ecotoxicity (77.46%), Marine ecotoxicity (51.31%) and Photochemical oxidation (20.60%), followed by Meat meal in Global warming (GWP100a) (27.22%), Acidification (49.97%), Eutrophication (40.13%) %), Terrestrial ecotoxicity (58.72%), Photochemical oxidation (30.94%) and Abiotic depletion of fossil fuels (13.10%) and by Soybean meal in Ozone layer depletion (52.82%), Aquatic ecotoxicity (8.62%), Marine ecotoxicity (15.98 %) and Abiotic depletion of fossil fuels (40.23%) (Table 4).

The data presented in Table 5 shows the environmental performance indicators of *L. vannamei* shrimp production in intensive and super-intensive BFT systems. It appears that among eleven categories of environmental impact assessed, six are higher in the intensive system.

Regarding the use of electricity, evaluating the performance of super-intensive *L. vannamei* production in Mexico, Noguera-Muñoz et al. (2021) found that electricity and feed were also the items with the most environmental impact. In their study, electricity was the most significant, with 62.41% of the total environmental impacts, while feed corresponded to 34.02%.

This disparity in the impact of electricity between the two studies can be explained by the differences between the Mexican and Brazilian energy grid. In Mexico, 79% of electricity is generated from fossil fuels (natural gas, oil, coal, and diesel), and only 16% of the country's energy is produced by renewable sources (VILLAVICENCIO; MILLÁN, 2020). In contrast, 48% of the Brazilian energy production is generated from renewable energy sources (GOVERNO DO BRASIL, 2021).

TABLE 5. Environmental performance indicators of *Litopenaeus vannamei* whiteleg shrimp production in intensive and super-intensive BFT systems.

Impact Categories	*Total SI*	*Total SS*	*Feed*	*SI*	*SS*
GW[1]	5,691.12	5,512.42	4,269.19	1,421.93	1,243.23
AC[2]	59.57	59.05	54.46	5.11	4.58
EU[3]	25.96	25.80	24.09	1.87	1.71
ODP[4]	0.000319	0.000311	0.000228	0.000091	0.000083
HT[5]	1,165.98	1,233.33	806.85	359.14	426.48
AE[6]	1,344.13	1,925.96	961.22	382.90	964.74
ME[7]	1,881,643.65	2,070,517.23	1,255,734.84	625,908.81	814,782.39
TE[8]	24.26	33.54	19.61	4.65	13.93
PO[9]	2.10	2.03	1.52	0.58	0.51
AD[10]	0.0065	0.0084	0.0053	0.0011	0.0030
ADFF[11]	35,612.80	34,504.39	25,979.99	9,632.81	8,524.40

[1]Global warming (GWP100a) - kg CO^2 eq; [2]Acidification - kg SO^2 eq; [3]Eutrophication - kg PO^4 eq; [4] Ozone layer depletion - kg CFC-11 eq; [5]Human toxicity - kg 1.4 DB eq; [6] Aquatic ecotoxicity - kg 1.4 DB eq; [7]Marine ecotoxicity - kg 1.4 DB eq; [8]Terrestrial ecotoxicity - kg 1.4 DB eq; [9]Photochemical oxidation - kg C^2H^4 eq; [10]Abiotic depletion - kg Sb eq; [11]Abiotic depletion of fossil fuels - MJ.

The global warming potential (GWP100a) was more relevant for the intensive system, with 5,691.12 kg CO_2 eq, compared to 5,512.42 kg CO_2 eq for the super-intensive system (Table 5). The items that were most relevant in these results were feed (75.01% and 77.45%, respectively for SI and SS) and electricity (22.11% and 21.03%) (Figure 1).

Our results agree with those obtained by Sun (2009)[1], Cao et al. (2011)[1] and Noguera-Muñoz et al. (2021)[2], who, evaluating the environmental performance of intensive[1] and superintensive[2] production of *L. vannamei*, obtained 5,910, 5,280 and 5,079 kg CO^2-eq, respectively. In contrast, Cao et al. (2011) and Orozco and Ramírez (2015) had found lower values when evaluating the global warming potential (GWP100a) of semi-intensive shrimp production (2,750 and 3,600 kg CO^2-eq). The best performance obtained by the studies mentioned for this impact category is related to the less intensive use of inputs.

For global warming potential, sodium hypochlorite, wheat bran, sugarcane molasses, lime and electricity were the SI inputs that most contributed to an inferior performance to the SS (Appendix 1 and 2).

For acidification, the intensive system presented 59.57 kg SO_2-eq, while the super-intensive system presented 59.05 kg SO_2-eq (Table 5). For this parameter, the impact of feed was even more significant (91.42% and 92.24%, respectively for SI and SS), followed by electricity (7.09% and 6.98%) (Figure 2).

The works of Sun (2009) and Cao et al. (2011) presented results similar to those obtained in the present study, 50.60 and 43.90 SO_2-eq, respectively, while for this impact category Noguera-Muñoz et al. (2021), also evaluating super-intensive shrimp production, obtained 26.20 SO_2-eq, a value similar to that obtained by Orozco and Ramírez (2015) (24.00 SO_2-eq) when evaluating the acidification potential in semi-intensive production of prawns.

In addition to food, for this impact category, the SI was the least efficient in environmental terms, highlighting again the inputs sodium hypochlorite, wheat bran, sugar cane molasses, lime and electricity (Appendix 1 and 2).

The result for eutrophication in the intensive system was 25.96 kg PO_4-eq, and in the super-intensive system it was 25.80 kg PO_4-eq (Table 5). Feed is again the most prominent item (92.80% and 93.35%) for the intensive and super-intensive systems, followed by electricity (5.35% and 5.72%) (Figure 2).

For this impact category Sun (2009), Orozco and Ramírez (2015) and Noguera-Muñoz et al. (2021), obtained better results in the environmental performance of production when compared to the present study (1.5, 4.7 and 10.70 PO_4-eq, respectively). On the other hand, for eutrophication, our result showed greater environmental efficiency than Cao et al. (2011) when evaluating the environmental performance of intensive production. Our result is similar to that obtained by the aforementioned authors, who in the same study also evaluated the semi-intensive production of shrimp (63.00 and 32.30 PO_4-eq, respectively).

In the SI, sodium hypochlorite, wheat bran, sugar cane molasses and lime were the most relevant inputs for this impact category in addition to food, so that this system was the least environmentally efficient when compared to the SS. In contrast, the contribution of electricity to eutrophication was higher in SS (Appendix 1 and 2).

For the impact of ozone layer depletion (ODP), the result was 0.00032 kg CFC-11-eq and 0.00031 kg CFC-11-eq (Table 5), in the intensive and super-intensive systems, respectively. Feed was responsible for 71.58% and 73.46%, and electricity for 25.38% and 24.71%, respectively for SI and SS (Figure 2). Our results were similar to those obtained by Noguera-Muñoz et al. (2021) (0.000387 kg CFC-11-eq).

In this impact category, SI was the one that presented the worst results in environmental terms. Sodium hypochlorite, wheat bran, sugar cane, molasses and electricity were the inputs that most contributed to this result.

Human toxicity showed values of 1,165.98 kg 1.4-DB-eq in the intensive system and 1,233.33 kg 1.4-DB-eq in the super-intensive system. In this category, feed was responsible for 69.20% and 65.42% and electricity for 28.41% and 33.17% in the two evaluated systems (Figure 2). Noguera-Muñoz et al. (2021) obtained a higher value for the aforementioned impact category, 2,250 kg 1.4-DB-eq when evaluating super-intensive shrimp production in Mexico.

Additionally, sodium hypochlorite, wheat bran, sugar molasses and lime were the inputs with the greatest negative impact on the performance of SI in relation to SS in human toxicity. Although electricity was the only input to present higher results in the SS, this element contributed with the worst environmental performance of the system for this impact category. (Appendix 1 and 2).

The impact of aquatic ecotoxicity was 1,344.13 kg 1.4-DB-eq and 1,925.96 kg 1.4-DB-eq in the intensive and super-intensive systems, respectively (Table 5). In the intensive system, feed was again the most relevant item, contributing 71.51%, while electricity contributed 27.07%. The super-intensive system showed similar results for these two inputs, with 49.91% for feed and 49.43% for electricity (Figure 2). Our results were lower than those obtained by Noguera-Muñoz et al. (2021), who found 2,670 kg 1.4-DB-eq for the impact category, demonstrating better environmental performance. The SS sodium hypochlorite, wheat bran, sugar cane molasses and lime were the most relevant inputs for the negative environmental performance of the SS, and electricity to the SS. The impact of electricity on aquatic ecotoxicity was 261.67% higher in the

SS (952.04 kg 1.4 DB eq) than in the SI (363.87kg 1.4 DB eq), which was a preponderant factor for the environmental performance of the system in this impact category (Appendix 1 and 2).

The results for marine ecotoxicity were 1,881,643.65 kg 1.4-DB-eq and 2,070,517.23 kg 1.4-DB-eq for intensive and super-intensive systems, respectively (Table 5). Feed contributed 66.74% and 60.65%, and electricity 30.44% and 37.69%, respectively for SI and SS (Figure 1). In the present study, the environmental performance of the two systems evaluated was superior to that obtained by Noguera-Muñoz et al. (2021), 4,010,000 kg 1.4-DB-eq. In the SI, sodium hypochlorite, wheat bran, sugarcane molasses and limestone were the inputs that most contributed to the inferior performance of the SI compared to the SS. On the other hand, for this impact category, electricity had the most impact on the environmental performance of the SS, thus for a lower environmental performance than SI in marine ecotoxicity.

Terrestrial ecotoxicity presented values of 24.26 kg 1.4-DB-eq and 33.54 kg 1.4-DB-eq in the intensive and super-intensive systems, respectively (Table 5). Feed contributed 80.85% and 58.47, and electricity 18.08% and 41.08% (Figure 1). In the study by Noguera-Muñoz et al. (2021) the authors found 52.10 kg 1.4-DB-eq for the mentioned impact category, values higher than those obtained in the present study. The sodium hypochlorite, wheat bran, sugar cane molasses and lime were the most relevant inputs for this impact category in SI. In contrast, the contribution of electricity to eutrophication was higher in SS (314.61%), which favored the inferior environmental performance of the system compared to the SI (Appendix 1 and 2).

The results for photochemical oxidation were 2.10 kg C_2H_4-eq and 2.03 kg C_2H_4-eq in the intensive and super-intensive systems, respectively (Table 5). The contribution of feed to this impact category was 72.05% and 74.87%, while electricity contributed 24.03% and 23.30% (Figure 2). Our results for both systems were lower than those obtained by Noguera-Muñoz et al. (2021), which was 0.957 kg C_2H_4-eq, thus demonstrating better environmental performance for this impact category evaluated in the present study.

For photochemical oxidation, sodium hypochlorite, wheat bran, sugarcane molasses, lime and electric energy were the inputs of the SI that most contributed to an environmental performance inferior to the SS (Appendix 1 and 2).

Abiotic depletion resulted in 0.006487 kg Sb-eq and 0.008359 kg Sb-eq in the two systems, respectively (Table 5). Feed contributed 82.32% and 63.88% to this impact category, and electricity 13.73% and 34.29% (Figure 2). For this impact category Noguera-Muñoz et al. (2021) found in their study 0.0301 kg Sb-eq, a value higher than those obtained in the evaluation of the two systems in the present study.

In addition to feed and electricity, the inputs with the greatest emphasis on the environmental performance of the SS were sodium hypochlorite and sugar cane molasses, which contributed to a worse environmental performance of the system for this category (Appendix 1 and 2).

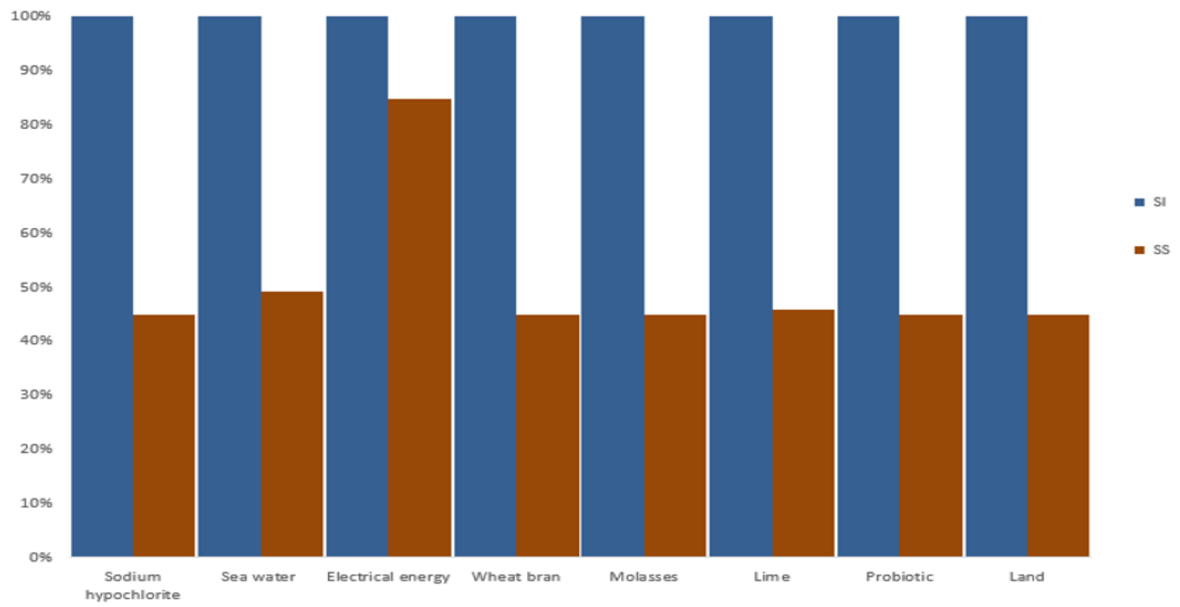
The abiotic depletion of fossil fuels was 35,612.80 MJ in the intensive system and 34,504.39 MJ in the super-intensive system (Table 5). The contribution of feed for this impact category was 72.95% and 75.29%, while electricity was 23.92% and 22.87%, respectively for SI and SS (Figure 2). In the work by Noguera-Muñoz et al. (2021), the abiotic depletion of fossil fuels was 64,800 MJ, a value significantly higher than those obtained in the present study for this impact category.

In the SI, sodium hypochlorite, wheat bran, sugar cane molasses, lime and electricity were the most relevant inputs for this impact category in addition to food, so that this system was the least environmentally efficient when compared to the SS (Appendix 1 and 2).

Because both water and diesel are not useful, because they are not useful for both water and the systems to be used (Appendix 1 and 2).

It is important to point out that the SS showed greater efficiency in the use of inputs, water and land than the SI (Figure 3). In the SS System there was a saving of 123.22% of Sodium hypochlorite, 103.85% of water resources, 17.92% of electricity, 123.34% of Wheat bran and molasses, 118.18% of lime, 123.48% probiotic and 123.33% land use. In addition, the annual production per m^3 was 123.26% higher. The amount of other inputs used (feed, drinking water for ice making, diesel for the generator and feed transport) did not show any difference between the systems.

FIGURE 3. Comparison of the use of inputs of *Litopenaeus vannamei* whiteleg shrimp production in intensive and super-intensive BFT systems.



FINAL CONSIDERATIONS

Achieving sustainability is one of the greatest challenges for modern aquaculture, and studies that assess the sustainability of different aquaculture production systems help to define the path towards this goal.

The present study evaluates the environmental performance of *L. vannamei* whiteleg shrimp production in intensive and super-intensive BFT systems. Among the eleven evaluated impact categories, the intensive system showed better results in five categories (human toxicity, aquatic ecotoxicity, marine ecotoxicity, terrestrial ecotoxicity, and abiotic depletion), while the super-intensive system showed better performance in six categories (global warming, acidification, eutrophication, depletion of the ozone layer, photochemical oxidation, and abiotic depletion fossil fuels). In general terms, when comparing the use of production factors and productivity between the systems, it becomes more evident that the SS is more efficient than the SI.

Feed was the most significant factor in the environmental performance of the evaluated systems. In terms of acidification and eutrophication potential, feed contributed more than 90% to the environmental impact. In this sense, the strategic management of aquaculture enterprises, with efficient operational management, employee training involving operational, environmental and nutritional issues, and also special care with food management aiming at the rational use and non-waste of feed, tend to contribute to the environmental performance of the activity.

The use of electricity is vital for the intensification of aquaculture systems; however, this item also contributed significantly to the environmental performance of the evaluated systems. It is worth noting that the use of alternative energy sources such as photovoltaics and wind energy to replace or complement current sources of electricity can improve the environmental performance of intensive and super-intensive shrimp production systems.

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CAPÍTULO V

CONCLUSÃO GERAL

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Alcançar a sustentabilidade é um dos desafios da aquicultura moderna. Estudos direcionados a avaliação do desempenho econômico e ambiental dos diferentes sistemas produtivos aquícolas fornecem dados para ajudar a definir as melhores estratégias dentro da atividade.

Neste sentido, a presente tese se propôs a avaliar a viabilidade econômica e o desempenho ambiental da produção intensiva e superintensiva do camarão *Litopenaeus vannamei*, em sistema BFT. Para isso foram utilizados métodos e técnicas de análise de investimento amplamente testados na literatura. O desempenho ambiental foi avaliado sob a ótica da metodologia de Avaliação do Ciclo de Vida (ACV), considerada um dos métodos mais eficientes em estudos dessa natureza, pois permite melhorar a eficiência dos sistemas produtivos através da identificação das fases que mais impactam negativamente na atividade.

Ao implementar empreendimentos aquícolas que operem no sistema intensivo em viveiros e superintensivo em estufas, utilizando a tecnologia BFT, para a produção do camarão *L. vannamei*, será necessário considerável aporte de capital. No entanto, nossos resultados demonstram que esses projetos são economicamente viáveis.

Verificamos também que os custos de produção de camarões marinhos, tanto no sistema intensivo em viveiros quanto no superintensivo em estufas, são elevados. Entretanto, com o uso da tecnologia BFT há aumento na biosseguridade, taxa de sobrevivência, conversão alimentar, produtividade e previsibilidade das despescas, fatores de importantes na obtenção de resultados financeiros positivos.

Dentre os oito métodos utilizados nas análises de viabilidade econômica, o sistema superintensivo foi o que apresentou melhores resultados. No desenvolvimento de um novo cenário, simulando a produção superintensiva considerando o uso da terra como premissa, foi possível observar a possibilidade da obtenção de ganhos financeiros em escala, alcançando um excelente desempenho econômico com redução dos custos de produção. No entanto, a contribuição financeira para a implementação e operação do projeto aumenta substancialmente.

Na ACV da produção intensiva e superintensiva de camarões *L. vannamei* em sistemas BFT, verificamos que o sistema superintensivo apresentou melhor desempenho ambiental frente ao sistema intensivo. Outro sim, no sistema superintensivo, após o domínio da tecnologia, o empreendedor tem a possibilidade de testar outras estratégias de produção, de acordo com a demanda de mercado, que proporcionem maior retorno econômico (ex. produção de animais maiores, aumento da densidade de estocagem e realização de despescas parciais), sem degradar o ambiente. Por outro lado, o sistema intensivo possui menos flexibilidade e segurança para este tipo estratégia.

Além disso, o sistema superintensivo possui como vantagens a necessidade de menores áreas para sua implantação e menos volumes de água nas operações, fatores que contribuem para melhores resultados em termos de desempenho ambiental, biossegurança e redução de custos. Em suma, o sistema superintensivo conduz a uma aquicultura sustentável, com melhor aproveitamento dos fatores de produção e menor impacto ambiental.

A principal contribuição deste trabalho está em propor a utilização de uma ferramenta de Gestão Ambiental, a ACV, no apoio à tomada de decisão em projetos de viabilidade econômica no seguimento aquícola. A avaliação ambiental associada à econômica apresenta ao empresário um panorama amplo e sistêmico do empreendimento.

Os consumidores estão cada vez mais conscientes das suas responsabilidades nas questões ambientais e nos impactos ao meio ambiente por parte dos diversos atores das cadeias produtivas globais, e a ACV é uma ferramenta capaz de atender à diferentes propósitos, mas que conduz a um objetivo em comum, uma melhor relação do setor produtivo com o meio ambiente.

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APPENDIX 1

TABLE 1. Contribution of inputs in the environmental assessment of *Litopenaeus vannamei* whiteleg shrimp production in intensive BFT systems.

Impact Categories	*Feed*	*Sodium hypochlorite*	*Wheat bran*	*Sugar cane molasses*	*Lime*	*Tap water*	*Diesel*	*Electricity*
Global warming[1]	4,269.19	11.52	12.55	101.26	19.03	0.19	18.83	1,258.57
Acidification[2]	54.46	0.80	0.13	0.43	0.13	0.0014	0.1120	4.22
Eutrophication[3]	24.09	0.03	0.13	0.25	0.03	0.0003	0.04	1.39
ODP[4]	0.00023	5.3790E-06	2.2298E-07	3.0231E-07	1.4406E-06	1.3305E-08	2.3489E-06	8.0902E-05
Human toxicity[5]	806.85	7.50	1.58	4.29	5.81	0.07	8.66	331.23
Aquatic ecotoxicity[5]	961.22	5.34	0.91	1.68	3.63	0.08	7.40	363.87
Marine ecotoxicity[5]	1,255,734.84	16,556.41	2,305.49	984.74	14,465.50	248.42	18,595.02	572,753.22
Terrestrial ecotoxicity[5]	19.61	0.05	0.02	0.09	0.03	0.00	0.06	4.38
Photochemical oxidation[6]	1.52	0.0033	0.0007	0.06	0.0056	6.0201E-05	0.0055	0.50
Abiotic depletion[7]	0.0053	9.0899E-05	1.9094E-05	6.0555E-05	1.6329E-05	2.3958E-07	6.9308E-05	0.0009
Abiotic depletion of fossil fuels[8]	25,979.99	138.60	25.86	467.34	239.79	2.24	238.68	8,520.30

[1](GWP100a) kg CO^2 eq; [2]kg SO^2 eq; [3]kg PO^4 eq; [4] Ozone layer depletion - kg CFC-11 eq; [5]1.4 DB eq; [6]kg C^2H^4 eq; [7]kg Sb eq; [8]MJ.

APPENDIX 2

TABLE 1. Contribution of inputs in the environmental assessment of *Litopenaeus vannamei* whiteleg shrimp production in super-intensive BFT systems.

Impact Categories	*Feed*	*Sodium hypochlorite*	*Wheat bran*	*Sugar cane molasses*	*Lime*	*Tap water*	*Diesel*	*Electricity*
Global warming[1]	4,269.19	5.16	5.62	45.37	8.73	0.19	18.83	1,159.38
Acidification[2]	54.46	0.04	0.06	0.19	0.06	0.0014	0.11	4.12
Eutrophication[3]	24.09	0.01	0.06	0.11	0.01	0.0003	0.04	1.47
ODP[4]	0.0002	2.41E-06	9.99E-08	1.35E-07	6.60E-07	1.33E-08	2.35E-06	7.67E-05
Human toxicity[5]	806.85	3.36	0.71	1.92	2.66	0.07	8.66	409.10
Aquatic ecotoxicity[5]	961.22	2.39	0.41	0.75	1.67	0.08	7.40	952.04
Marine ecotoxicity[5]	1,255,734.84	7,416.93	1,032.59	440.91	6,630.02	248.42	18,595.02	780,418.47
Terrestrial ecotoxicity[5]	19.61	0.02	0.01	0.04	0.01	0.0004	0.06	13.78
Photochemical oxidation[6]	1.52	0.0015	0.0003	0.03	0.0026	6.02E-05	0.0055	0.47
Abiotic depletion[7]	0.0053	4.07E-05	8.55E-06	2.71E-05	7.48E-06	2.40E-07	6.93E-05	0.0029
Abiotic depletion of fossil fuels[8]	25,979.99	62.09	11.58	209.25	109.91	2.24	238.68	7,890.65

[1](GWP100a) kg CO^2 eq; [2]kg SO^2 eq; [3]kg PO^4 eq; [4] Ozone layer depletion - kg CFC-11 eq; [5]1.4 DB eq; [6]kg C^2H^4 eq; [7]kg Sb eq; [8]MJ.

APPENDIX 3

TABLE 1. Contribution (%) of inputs in the environmental assessment of *Litopenaeus vannamei* whiteleg shrimp production in intensive and super-intensive BFT systems.

Impact Categories	***Feed (%)***		***Sodium hypoc. (%)***		***Wheat bran (%)***		***Sugar cane molasses (%)***		***Lime (%)***		***Tap water (%)***		***Diesel (%)***		***Electricity (%)***	
	SI	***SS***	***SI***	***SS***	***SI***	***SS***	***SI***	***SS***	***SI***	***SS***	***SI***	***SS***	***SI***	***SS***	***SI***	***SS***
Global warming[1]	75.01	77.45	0.20	0.09	0.22	0.10	1.78	0.82	0.33	0.16	0.003	0.003	0.33	0.34	22.11	21.03
Acidification[2]	91.42	92.24	0.13	0.06	0.22	0.10	0.73	0.33	0.22	0.10	0.002	0.002	0.19	0.19	7.09	6.98
Eutrophication[3]	92.80	93.35	0.11	0.05	0.51	0.23	0.95	0.43	0.12	0.06	0.001	0.001	0.16	0.16	5.35	5.72
ODP[4]	71.58	73.46	1.69	0.78	0.07	0.32	0.09	0.04	0.45	0.21	0.004	0.004	0.74	0.76	25.38	24.71
Human toxicity[5]	69.20	65.42	0.64	0.27	0.14	0.06	0.37	0.16	0.50	0.22	0.006	0.006	0.74	0.70	28.41	33.17
Aquatic ecotoxicity[5]	71.51	49.91	0.40	0.12	0.07	0.02	0.13	0.04	0.27	0.09	0.006	0.004	0.55	0.38	27.07	49.43
Marine ecotoxicity[5]	66.74	60.65	0.88	0.36	0.12	0.05	0.05	0.02	0.77	0.32	0.013	0.012	0.99	0.90	30.44	37.69
Terrestrial ecotoxicity[5]	80.85	58.47	0.22	0.07	0.10	0.03	0.39	0.13	0.11	0.04	0.002	0.001	0.26	0.18	18.08	41.08
Photochemical oxidation[6]	72.35	74.87	0.16	0.07	0.03	0.02	2.90	1.35	0.27	0.13	0.003	0.003	0.26	0.27	24.03	23.30
Abiotic depletion[7]	82.32	63.88	1.40	0.49	0.29	0.10	0.93	0.32	0.25	0.09	0.004	0.003	1.07	0.83	13.73	34.29
Abiotic depletion of fossil fuels[8]	72.95	75.29	0.39	0.18	0.07	0.03	1.31	0.61	0.67	0.32	0.006	0.006	0.67	0.69	23.92	22.87

[1](GWP100a) kg CO^2 eq; [2]kg SO^2 eq; [3]kg PO^4 eq; [4] Ozone layer depletion - kg CFC-11 eq; [5]1.4 DB eq; [6]kg C^2H^4 eq; [7]kg Sb eq; [8]MJ.