

UNIVERSIDADE ESTADUAL PAULISTA –
UNESP CENTRO DE AQUICULTURA DA UNESP

**Viabilidade técnica e econômica da tilápia
vermelha em sistema de produção intensiva
em bioflocos (BFT) na Colômbia**

Daniel Leonardo Cala Delgado

Jaboticabal, São Paulo
2021

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Orientadora: Dra. Fabiana Garcia Scaloppi

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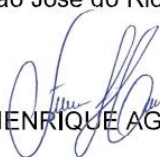
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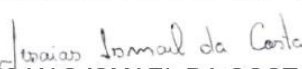
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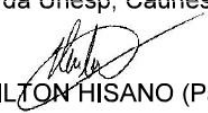
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Provérbios 22: 29

Introdução Geral

O estudo intitulado “Viabilidade técnica e econômica da tilápia vermelha em sistema de produção intensiva em bioflocos (BFT) na Colômbia”, foi realizado porquê em diferentes regiões dos países sul americanos, se apresentam problemáticas com sistemas semi-intensivos e intensivos de produção aquícola, principalmente de viabilidade técnica e econômica. Porém a pesquisa foi relevante por se tratar de um estudo a campo em condições reais de unidade piscícola.

O trabalho foi desenvolvido com ajuda da Asociación Piscícola el Vergel (ASOVERGEL), localizada no leste de Colômbia, ASOVERGEL é um projeto importante para a região e o Departamento de Arauca, pois é integrada por 93 sócios, principalmente mulheres responsáveis pela manutenção do núcleo familiar, também como jovens rurais empreendedores e pessoas com limitações físicas. O terreno de 4 hectares da ASOVERGEL foi uma doação de um dos associados, com condições apropriadas para a piscicultura.

Os fundadores da associação (13 pessoas da família Bravo) tem experiência empírica de mais de 20 anos na piscicultura tradicional, mas por condições ambientais precisavam mudar de sistema para evitar que as inundações originadas pelo rio Mata palito gerem perdas na produção feita em viveiros escavados. Esse motivo levou os produtores ao Ministério de agricultura colombiano para serem apoiados com recursos econômicos e técnicos para desenvolver produção de tilápia vermelha em sistemas de bioflocos (BFT).

Nos primeiros ciclos de produção de tilápia em ASOVERGEL, diferentes problemas técnicos tais como: falta de equipamentos apropriados para manter os aeradores funcionando quando a energia elétrica falhava, alta mortalidade de alevinos por causa de parasitas monogênicos y mortalidade de animais de mais de 350 gramas por causa de vírus da tilápia do lago (TiLV) levaram a implementação de protocolos de boas práticas de produção aquícola.

Os custos mensais de energia eram de mais de 5 mil reais e não existia uma densidade de estocagem padronizada para a produção da tilápia vermelha. Com ajuda dos produtores foi possível realizar o estudo e determinar os principais indicadores e falhas no sistema, particularmente de ASOVERGEL, os recursos econômicos do governo colombiano ajudaram a que o projeto produtivo se

implementara, mas dificilmente um pequeno produtor poderia ter a oportunidade de investimento em produção BFT.

O capítulo I intitulado Revisão bibliográfica: aspectos gerais da produção piscícola na Colômbia em sistema de bioflocos (BFT), tem por objetivo apresentar informação relevante da produção de tilápia a nível mundial e particularmente a história produtiva da tilapicultura em Colômbia. Também são considerados aspectos importantes para a produção de tilápia em sistemas de BFT, tais como aeração, fontes e relação de carbono, densidade de estocagem e finalmente a composição proximal da farinha de bioflocos em produções de tilápia.

O capítulo II foi titulado “Stocking density of red tilápia (*Oreochromis sp.*) in a commercial biofloc system in Colombia”. O objetivo do trabalho foi identificar os efeitos das densidades de estocagem (30 e 40 peixes / m³) da tilápia vermelha em sistemas de BFT em parâmetros de desempenho produtivo, indicadores de qualidade da água e do produto final (avaliação bromatológica e microbiológica). Também foi realizada a descrição da composição nutricional, micro e macroelementos da farinha de BFT dependendo da densidade.

No último capítulo “Economic analysis of solar energy alternatives in the production of red tilápia (*Oreochromis sp.*) in a commercial biofloc system in Colombia” são apresentados os resultados de indicadores econômicos da implementação de energia convencional e sistemas fotovoltaicos para a produção de tilápia em sistema de BFT. Para este estudo foram comparados os custos de produção, custos de inversão, indicadores econômicos e parâmetros de desempenho produtivo em sistema de BFT utilizando energia convencional; energia fotovoltaica parcial e energia fotovoltaica com acumuladores de energia. Também foi feita uma simulação com produção excedente de energia para venda.

1. Capítulo I

Revisão bibliográfica: aspectos gerais da produção piscícola na Colômbia em sistema de bioflocos (BFT)

Resumo Geral

A tilápia é a terceira espécie mais produzida no mundo. Espera-se que em 2030 a produção de tilápia seja duplicada em relação a 2010. O aumento da produção de organismos aquáticos implica na intensificação dos sistemas de aquicultura. O sistema de Bioflocos (BFT) é considerado uma alternativa intensiva para a aquicultura. O BFT apresenta vantagens relacionadas ao menor consumo de água, diminuição da conversão alimentar aparente, melhora do estado sanitário e aumento das densidades quando comparado com sistemas tradicionais de produção aquícola. No entanto, não há conhecimento das densidades adequadas e dos efeitos na produção das diferentes espécies, sendo necessária a realização de estudos mais adequados às condições do país e de cada espécie. As avaliações económicas tem focado nos efeitos da alimentação, densidades, fontes de carbono, mas ainda não foram avaliadas as fontes de energia na aquicultura BFT. O objetivo do trabalho foi apresentar informação relevante da produção de tilápia a nível mundial e particularmente a história produtiva da tilapicultura na Colômbia. Também são considerados aspectos importantes para a produção de tilápia em sistemas de BFT, tais como aeração, fontes e relação de carbono, densidade de estocagem e finalmente a composição proximal da farinha de bioflocos em produções de tilápia. A revisão de literatura amostra diferentes artigos com resultados positivos para aspectos técnicos de produzir tilapia em sistemas de BFT, densidades de estocagem entre 30 e 60 peixes / m³, também fontes de carbono, principalmente melão de cana e outros produtos com conteúdo de carbono e a relação Carbono: Nitrogênio. Concluindo-se que a produção de tilapia em sistemas de BFT é possível e viável tecnicamente considerando as características próprias do sistema intensivo.

Palavras chaves: bromatológico, desempenho produtivo, densidade, energia, aquicultura

General Abstract

Tilapia is the third most produced species in the world, by the year 2030 the production of tilapia may double the quantities produced in 2010. The increase in the production of aquatic organisms implies the intensification of aquaculture systems. The Biofloc system (BFT) is considered an intensive alternative for aquaculture. BFT presents advantages related to lower water consumption, decreased apparent feed conversion, improved sanitary status, and increased densities when compared to traditional aquaculture production systems. However, there is no knowledge of the adequate densities and the effects on the production of different species, requiring studies more adequate to the conditions of the country and each species. Economic evaluations have focused on the effects of feeding, densities, carbon sources, but energy sources have not yet been evaluated in BFT aquaculture. The objective of the work was to present relevant information of tilapia production worldwide and particularly the production history of tilapiculture in Colombia, also important aspects for tilapia production in BFT systems are considered, such as aeration, carbon sources and ratio, stocking density and finally the proximate composition of biofloc meal in tilapia productions. The literature review samples different articles with positive results for technical aspects of tilapia production in BFT systems, stocking densities between 30 and 60 fish / m³, also carbon sources, mainly cane molasses and other products with carbon content and the Carbon: Nitrogen ratio. In conclusion, tilapia production in BFT systems is possible and technically feasible considering the characteristics of the intensive system.

Keywords: bromatological, growth performance, stocking density, energy, aquaculture

Introdução

A aquicultura mundial é conhecida como o setor produtivo de alimentos de mais rápido crescimento no mundo (Azra et al., 2021). Esse setor passou de uma produção global de menos de 10 milhões de toneladas em 1985 para 73,8 milhões de toneladas em 2014 (FAO, 2016) e alcançou outro recorde histórico de 114,5 milhões de toneladas, representando 263.600 milhões de USD em 2018 (FAO, 2020). A aquicultura é identificada como uma forma diferenciada de obtenção de

organismos aquáticos frente às atuais necessidades de segurança alimentar, diminuindo a captura de estoques naturais de peixes (World Bank, 2013). O crescimento da produção tem sido impulsionado pela existência de novos empreendimentos, investimentos em novas tecnologias, melhora no processo produtivo e, conseqüentemente, ganhos em produtividade (Costa, 2016).

A América do Sul é conhecida por sua alta produção e exportação de organismos aquáticos, produto da pesca e da aquicultura, mas não conseguiu atingir todo o seu potencial na piscicultura (Valladão et al., 2018). Depois do continente Asiático que aporta 88% da produção aquícola, o continente Americano é o segundo produtor na aquicultura mundial, com valores maiores a três milhões de toneladas em 2014. Em 2018, aproximadamente, 20,53 milhões de pessoas foram empregadas na aquicultura e na América foram reportadas 388 mil pessoas trabalhando na produção de organismos aquáticos. Segundo Valenti et al (2021) o Brasil duplicou a produção em menos de 10 anos, de 400 mil toneladas em 2009 a aproximadamente 800 mil toneladas em 2018. Colômbia também teve o mesmo comportamento produtivo nos últimos anos, passou de 80 mil toneladas a 134 mil toneladas, aumentando 68% de 2010 a 2018 (Roca-Lanao et al, 2020). Mais de 13 mil toneladas de peixe são exportadas da Colômbia, sendo o maior país exportador de filé de tilápia para os Estados Unidos (Portafolio, 2019).

Na América do Sul os sistemas de produção mais utilizados são extensivos e semi-intensivos (Valladão et al., 2018). Colômbia implementa tanques-rede e viveiros escavados para produção de tilápia vermelha (*Oreochromis sp.*) e tilápia nilótica (*Oreochromis niloticus*), tambaqui (*Colossoma macropomum*) e pacu (*Piaractus mesopotamicus*). O Estado de Huila é o maior produtor, com a represa de Betania (Garcia et al., 2021) e O Estado de Meta, o maior produtor de peixes em viveiros escavados (Merino et al., 2013). Existem outros sistemas de produção para piscicultura, tendo o Sistema de Recirculação Aquícola (RAS) (Ornelas-Luna et al., 2017) e Tecnologia de Bioflocos (BFT) (Betancur González et al., 2016).

A tecnologia de bioflocos (BFT) é um sistema de produção considerado alternativa aos sistemas tradicionais usados na aquicultura em Colômbia (Collazos-Lasso et al., 2015). Principalmente por se basear na troca limitada de água, o fundamento é o uso de resíduos alimentares, compostos orgânicos e inorgânicos tóxicos, por meio de microorganismos presentes na água, proporcionando

condições favoráveis às bactérias quimiotróficas, autotróficas e heterotróficas, que reduzem saturação de nutrientes para reutilização (Avnimelech, 2009). Diferente a os sistemas usados de maneira habitual na produção de peixes onde o uso da água não é eficiente, além da eutrofização dos recursos hídricos e outros problemas ambientais (Wilfart et al., 2013). Mas é preciso avaliar os diferentes sistemas produtivos de maneira holística, para confirmar qual dos sistemas realmente é o mais eficiente, sustentável e produtivo.

A análises econômicas também são importantes para identificar custos de produção, permitindo a gestão do empreendimento, além possibilita observar problemas no processo de produção, diminuir os riscos, melhorar a produção e porem os indicadores econômicos e finalmente ajuda para a toma de decisões (Costa et al., 2018).

Para realizar as avaliações econômicas é preciso fazer uma análise técnica e de desempenho zootécnico (Domínguez-May et al., 2020). Ao se observar os ganhos de peso, consumo de ração, sobrevivência, fator de conversão alimentar, uso de insumos para manutenção do sistema, pode ser avaliada a viabilidade técnica e os dados podem ser usados para fazer as avaliações econômicas (Castilho-Barros et al., 2020).

Estudos de avaliação econômica tem sido feito nos últimos anos para diferentes espécies de organismos aquáticos. Na Colômbia, são reportadas avaliações econômicas para *Piaractus brachypomus* e tilápia do Nilo em ambientes controlados de laboratório em pequena escala (Brú-Cordero et al., 2017). Mas não foram feitas análises para tilápia vermelha em condições de produção implementando a tecnologia de bioflocos (BFT). Por tanto é necessário fazer estudos que permitam evidenciar a viabilidade técnica, econômica e sustentabilidade da produção de tilápia vermelha em sistema de produção intensivo (BFT) na Colômbia.

Tilapicultura

A tilápia é considerada uma das espécies aquícolas de maior importância no mundo, principalmente para aquicultura tropical e subtropical (Prabu et al., 2019). Na lista de espécies produzidas ocupa o terceiro lugar, com uma produção de 2,6 milhões de toneladas no ano 2020 (FAO, 2020). Tilápia é fonte importante de

proteína de origem animal, bem-estar social e ganhos econômicos (Sosa et al., 2005; Ansah et al., 2014; Yue et al., 2016).

Mundialmente, foram descritas 77 espécies de tilápia (Thys, 1968), porém somente 22 espécies foram cultivadas ou estudadas em pesquisa ou produção (Prabu et al., 2019). A tilápia do Nilo (*Oreochromis niloticus*) é a espécie mais cultivada (Peñaloza et al., 2020), outras espécies estudadas e produzidas são *Oreochromis mossambicus* (Russell et al., 2012), *Oreochromis aureus* (Al-Wan e Mohamed., 2019) e tilápia vermelha (*Oreochromis* spp.) (Sukhavachana et al., 2019). As espécies anteriormente mencionadas são parte do grupo dos ciclídeos omnívoros de água doce, nativas da África e que foram introduzidas no mundo inteiro (Eknath e Hulata, 2009). As tilápias tem a capacidade de suportar condições ambientais adversas, altas densidades de estocagem, desovar com facilitada, aceitar dietas alternativas de custo baixo (Ng e Romano, 2013), sobreviver em habitats com concentrações baixas de oxigênio dissolvido e salinidade alta (Eknath e Hulata, 2009; Uchida et al., 2000; Zhou et al 2020). O desempenho produtivo e resistência a doenças gera um alto interesse pela produção de tilápia (Van Hai, 2015).

As características mencionadas com anterioridade fazem com que a tilapicultura seja realizada em mais de 100 países (Norman-López y Bjorndal, 2009; Ng y Romano, 2013). Em 2030 a produção de tilápiatilápia dobrou os volumes produzidos em 2010 (Kobayashi et al., 2015). Os maiores produtores estão localizados na Ásia e geram o 80% da produção. Somente a China produziu um terço da produção total mundial com 1,86 milhão de toneladas em 2018 (Yuan et al., 2020). A Colômbia tem produzido mais de 77 mil toneladas por ano de tilápia desde 2018 (FAO, 2018), e é o maior exportador da espécie para o mercado dos Estados Unidos (Dai et al., 2020).

Em 2016 a tilápia foi exportada por 104 países e importada por 179 países, com quantidades superiores a um milhão de toneladas (FAO, 2018). Os produtos da tilapicultura tem sido importado principalmente pelos Estados Unidos desde 1992, principalmente pela produção interna insuficiente para satisfazer a demanda dos consumidores norte-americanos (Fitzsimmons, 2000). Os principais produtos comercializados para mercado dos Estados Unidos são filé fresco, refrigerados e congelados e tilápia inteira congelada, de origem Chinesa, da Colômbia e Indonésia

(Dai et al., 2020). A China teve uma diminuição das exportações de 69% a 63% no período de 2014 a 2017, principalmente pela qualidade do produto congelado pouco aceitado pelos consumidores do mercado internacional (Zhu e Yang, 2011). Diferente aos produtos exportados pela Colômbia, que pela sua proximidade com os Estados Unidos melhora o processo da comercialização de filé fresco ou refrigerado (Dai et al., 2020), sendo estes produtos produzidos em sistemas de tanques-rede flutuantes na represa hidroelétrica de Betania no Departamento de Huila (Camero-Escobar e Calderón, 2018).

Existem outros sistemas para a produção da tilápia, que vão desde sistemas tradicionais e sistemas superintensivos com tecnologia avançada (Norman-López e Bjorndal, 2009). Sistemas de produção que são classificados segundo a utilização de insumos e tecnologia como sistemas extensivos, semi-intensivos e intensivos (Mengistu et al., 2019). A produção varia desde nível de subsistência rural até níveis de grande escala (Prabu et al., 2019). Mas a produção de tilápia maiormente é feita em viveiros escavados que são frequentemente fertilizados com diversos insumos (Duodu et al., 2020). Os poli cultivos de tilápia com outras espécies e organismos aquáticos são comuns (Wang e Lu, 2015), que também são denominados sistemas multi tróficos, Co cultivo ou aquicultura integrada (Bunting, 2020). Exemplo do sistema anterior é a integração de tilápia nilótica (*Oreochromis niloticus*) e camarão amazônico (*Macrobrachium amazonicum*) em viveiros escavados (Rodrigues et al 2019). Outros sistemas utilizados para a produção de tilápia são sistemas de recirculação aquícola (RAS) sendo uma opção para aumentar a produção onde o espaço e a disponibilidade da água é limitada, diminuindo o impacto ambiental (Wambua et al., 2020). Característica similar na produção de tilápia em sistemas de bioflocos (BFT), sistema com fundamento de zero troca da água (Avnimelech, 2009)

Produção da tilápia em Colômbia

No ano 1957 foi introduzida do Brasil a tilápia moçambicana (*Oreochromis mossambicus*) na Colômbia. Originária do continente Africano, chegou ao Instituto Nacional de Piscicultura Tropical, na cidade de Buga, estado Valle, com objetivo de subsistência adicional para os produtores, mas a produção desta espécie não foi totalmente controlada e alguns exemplares escaparam dos tanques de produção

para os rios, se tornando ameaça para as espécies nativas pela sua fácil adaptação ao ambiente (Castillo, 2002).

Posteriormente ingressou a tilápia rendalli no ano 1960. A Universidade de Caldas importou dos Estados Unidos indivíduos desta espécie e em 1964 esta foi levada para o instituto da cidade de Buga para investigar o impacto ambiental, sendo que o uso da tilápia rendalli seria para o controle das plantas aquáticas prejudiciais, mas a viabilidade econômica foi deficiente pela sua baixa taxa de crescimento e reprodução descontrolada (Gómez et al., 2014).

Depois de 15 anos o Instituto Nacional de Recursos Naturales Renovables (INDERENA) faz a introdução da tilápia nilótica (*Oreochromis niloticus*) no ano 1979, quando chegou à piscicultura Gigante, no Estado de Huila e na piscicultura Repelón, no Estado do Atlántico, sendo depois distribuída em represas, iniciando desta forma a atividade piscícola do país (Gómez et al., 2014).

No ano 1982 a tilápia vermelha chegou pelo interesse de piscicultores que trouxeram esta espécie e, em pouco tempo, 70% da produção de tilápias na Colômbia foi representada pela tilápia vermelha. Esta espécie foi obtida de diferentes cruzamentos de espécies de tilápia, *Oreochromis mossambicus*, *Oreochromis niloticus*, *Oreochromis aureus* e *Oreochromis hornorum*. Sua coloração melhora o valor comercial, principalmente pela semelhança com a Pargo Vermelho (*Lutjanus guttatus*) (Castillo, 2002).

Entretanto, no ano 2008 foi considerada uma espécie exótica invasora, mas o Ministério de Agricultura y Desarrollo Rural (MADR) junto a Autoridad Nacional de Acuicultura y Pesca (AUNAP) declaram no ano de 2015 a espécie como domesticada (OECD., 2016).

A maior superfície de espelho de água na Colômbia está dedicada ao cultivo de tilápia (65,26%). Em 2011 a produção de tilápia no país foi dominada pelo estado do Huila com mais de 20 mil toneladas de tilápia vermelha que correspondeu a 53% da produção desta espécie, seguido pelo estado de Meta com 6 mil toneladas e em terceiro lugar encontrou-se o estado de Tolima aportando 2 mil toneladas na produção de tilápia vermelha do país. A produção de tilápia nilótica chegou a 10 mil toneladas no mesmo ano, sendo que no estado do Huila a produção foi de 9 mil

toneladas e o restante foram produzidas pelos estados de Sucre, Caldas, Cauca entre outros.

A produção de tilápia na Colômbia representa 65,21 % da produção piscícola, seguida do pacu (Valladão., 2018). No ano 2011 a represa de Betânia, no estado do Huila logrou a produção do 32,3% da piscicultura nacional principalmente das duas espécies de tilápia. Esta represa tem a capacidade de produzir 22 mil toneladas por ano, mas em 2011 o volume produzido ultrapassou 2 mil toneladas o recomendado pelo INCODER (Incoder., 2005), causando a eutrofização do ambiente de produção e, conseqüentemente, grandes mortalidades o que representou déficit econômico no setor (Merino et al., 2013).

A oferta hídrica na Colômbia faz com que o país seja um potencial produtor de organismos aquáticos, com mais de 742 mil bacias hidrográficas, um total de 2112 km³ de oferta em volume de água em áreas hidrográficas. Além da redução da quantidade de peixes nas áreas continentais onde tradicionalmente se fazia captura, a piscicultura pode se considerar uma boa alternativa (MADR, 2014).

As características da espécie e do país permitem que a produção de tilápia seja ótima, no entanto a tilápia vermelha exige maior atenção técnica em seu processo produtivo. Por exemplo, requer proteção especial em todas suas fases, pois é vulnerável à predação, pelo fato de carecer de camuflagem natural (Amado, Amado et al., 2015). Aspectos técnicos da tilapicultura, para ter em conta em qualquer sistema de produção são, os parâmetros físico-químicos da água, fatores nutricionais, ambientais e de manutenção.

Sistema de bioflocos para tilápia

O sistema de bioflocos, conhecido também como tecnologia de bioflocos BFT, é uma alternativa para a produção aquícola mundial (Durigon et al., 2020). BFT tem requerimentos importantes, por exemplo aeração 24 horas do dia durante todo o período produtivo (Malpartida et al., 2018), uso de uma fonte de carbono (Ahmad et al., 2017), principalmente é usado melaço pelo efeito de dar cor na água e diminuir a penetração de luz solar evitando o crescimento de algas (Lima et al., 2019). Além disso o melaço é uma fonte barata de carbono usada para várias fermentações industriais (Najafpour e Shan, 2003). Más também tem sido usados outros produtos tais como farinha de batata doce (Caipang et al., 2015). A mão de

obra especializada é importante para ter melhores resultados técnicos (Almeida et al., 2021). Também a fonte de carbonato de cálcio para manter os níveis de alcalinidade que funciona como buffer para que o pH não flutue no tempo de produção (Martins et al., 2017; Fakhari et al., 2020).

A aeração tem duas funções específicas, a primeira é manter oxigênio dissolvido na água (Morais et al., 2020) para a respiração dos peixes e microrganismos aeróbicos que precisam do oxigênio para fazer processos metabólicos (Lim et al., 2021; Ebeling e Timmons et al., 2010). Baixos níveis de oxigênio prejudicam a qualidade da água de produção, portanto causam problemas no crescimento e na imunidade das tilápias (Mahasri et al., 2018), sendo o responsável por mais do 60% das perdas na tilapicultura (Boyd, 1979). Os níveis recomendados de oxigênio, conhecido como normóxia para a produção de tilápia é de 3 a 6 mg.l⁻¹ (Valbuena-Villarreal et al., 2006; Ngoepe et al., 2021). A segunda função é manter em movimento a água, possibilitando uma melhor integração dos produtos e partículas que integram os flocos, que devem manter-se em suspensão (Vinatea et al., 2010). Em BFT são usados diferentes aeradores (Tabela 1) para a criação de tilápia (Tabela 1). Nos trabalhos apresentados pode se observar diferentes modelos de aeradores, o importante no sistema BFT é manter níveis de oxigênio dissolvido ótimos para a espécie cultivada, no caso dos estudos com tilápia tem media de 7 ± 0,4 mg/L em períodos menores de 150 dias e em diferentes densidades, o aerador mais usado em estudos de BFT em condições de laboratório é blower, pois com um só aerador pode-se subministrar ar a varias unidades experimentais.

Tabela 1. Estudos com diferentes modelos de aeradores usados na produção de tilápia em sistema de bioflocos

Referência	Modelo de aerador	OD (mg/L)	Dias	*peixes/m ³
El-Hawarry et al. (2021)	Blower 2.5 HP / Aerotube®	6,40 ± 0,16	98	280
Kumari et al. (2021)	Hiblow® HP 200 air pumps de 150 W capacidade 200 L min ⁻¹	6,85 ± 0,15	90	150
Mohammadi et al (2021)	Compressor de ar / pedra difusora capacidade 70 L min ⁻¹	7,33 ± 0,06	112	55
Tubin et al (2020)	Soprador 2 HP / Aerotube® e pedra porosa de 20 mm	7,43 ± 1,05	48	526

	de diâmetro e 30 mm de altura			
Malpartida et al (2018)	Blower 1/3 HP – mangueira difusora micro perfurada	6,85 ± 0,44	56	70
	Aerador Splash (chafariz) 1/3 HP	7,39 ± 0,61		

*Densidade usada nos estudos

A fonte de carbono é importante para o crescimento dos microrganismos que diminuem os compostos nitrogenados, mediante o processo de nitrificação e desnitrificação (Wang et al, 2015; Khanjani et al, 2020). Os microrganismos importantes no processo são os heterótrofos que também podem ser usados como fonte de proteína pelos peixes mediante a filtração (De Schryver e Verstraete, 2009; Avnimelech, 2012). As fontes de carbono como melão e dextrose influem na relação carbono / nitrogênio e aumentam a atividade das bactérias heterotróficas, protozoários, algas, bem como compostos microbianos e estruturas sociais nos bioflocos (de Lorenzo et al., 2015). A tabela 2 apresenta relação de C: N em estudos de bioflocos realizados sobre tilápia, adicionando diferentes fontes de carbono. A relação C: N pode variar dependendo das características da fonte, segundo os estudos incluídos na revisão, a fonte de carbono líquida é fácil de dissolver, porém o efeito é rápido, mas também é importante a qualidade e quantidade de carbono por quilograma, as relações C: N mais usadas em sistemas BFT são de 15: 1 até 20: 1.

Tabela 2. Estudos com diferentes fontes de carbono usados na produção de tilápia em sistema de bioflocos e a relação carbono: nitrogênio

Referência	Fonte de carbono	Relação C: N
Laice et al (2021)	Melão de cana Açúcar	20: 1
Silva et al (2017)	Melão de cana Amido de mandioca	20: 1
Mirzakhani et al (2019)	Melão de beterraba Glicerol	20: 1
El-Hawarry et al. (2021)	Melão de cana Amido	15: 1
Caipang et al (2015)	Farinha de batata doce	16: 1

Densidades de estocagem de tilápia em bioflocos

Uma vantagem da produção em sistemas bioflocos é o aumento de densidades de estocagem (Khanjani et al., 2020). Em tilapicultura tem se estudado os efeitos das densidades de estocagem principalmente no desempenho produtivo (Tabela 3). Em alevinos desta espécie as baixas e médias densidades, 166 e 333 peixes por m³ respectivamente, apresentaram melhores resultados de peso corporal e sobrevivência do que os alevinos mantidos em altas densidades de 600 peixes por m³ (Liu et al., 2018). Na engorda de tilápias com peso inicial de 133 gramas, a densidade recomendada é de 33 peixes por m³ para levá-los a um peso aproximado de 700 gramas (Manduca et al., 2021). Para animais de 50 gramas e cultivados por 84 dias, a densidade de 40 peixes por m³ mostra melhores rendimentos produtivos do que densidades de 20 e 60 peixes por m³ (Zaki et al., 2020). Para tilápia vermelha (*Oreochromis* sp.) não revertida e mantida por 14 semanas em um sistema BFT experimental de pequena escala, foi determinado que a densidade de 50 peixes por m³ foi a que apresentou o menor fator de conversão alimentar (Ekasari et al., 2012) (Tabela 3).

Tabela 3. Desempenho produtivo de tilápias em diferentes densidades em sistema de bioflocos

Referência	Tempo (D)	PI (g)	P/m ³	AP (g)	CE%	FCA	S%
Bañuelos-Vargas et al., (2021)	49	6,7 ± 0,2	120	45	4,9	0,9	95
			240	35	4,2	1,1	90
El-Hawarry et al., (2021)	98	5,2 ± 1,1	140	35,7	2,14	1,03	-
			280	35	2,11	0,98	-
Aliabad et al., (2021)	53	3,2 ± 0,1	500	9,7	3,21	0,91	100
			1000	7,7	2,77	0,95	97
			18,7	842	2,7	2,23	93
Manduca et al., (2021)	260	133 ± 6.7	37,5	738	2,3	2,06	95
			56,2	672	2,07	2,11	94
			75	539	1,56	2,15	87
			20	68,6	0,77	1,95	-
Zaki et al., (2020)	84	50,47 ± 0,1	40	85,9	1,02	1,79	-
			60	47,5	0,57	2,47	-
			150	16,1	2,9	1,21	69
Liu et al., (2018)	120	0.51 ± 0.1	300	15,1	2,9	1,25	65
			600	13,38	2,75	1,44	26

D= dias; P/m³= densidade (Peixes/m³); PI= peso inicial; AP= aumento de peso; CE= crescimento específico; FCA= fator de conversão alimentar; S= sobrevivência.

A tilápia pode tolerar altas densidades; no entanto, a tilápia é um peixe territorial e agressivo e o efeito adverso da densidade no crescimento pode ser explicado pela competição por territórios, bem como pelo constante estresse decorrente da superlotação (Zhang et al., 2016). A densidade, além de afetar os parâmetros de desempenho da produção, pode afetar a composição química dos peixes. Densidades mais altas podem reduzir os níveis de lipídios presentes na carne de peixe quando o sistema BFT é usado para ensaios experimentais (Zaki et al., 2020; Battisti et al., 2020). O extrato etéreo de corpo inteiro da tilápia apresenta alteração com os níveis de densidade, peixes criados a 60 peixes por m³ registra o menor valor de extrato etéreo comparado com densidades de 20 e 40 peixes por m³, pode ser devido ao efeito de estresse do aumento na densidade (Zaki et al., 2020). Tilápias com peso inicial de $5,2 \pm 1,1$ g criados em sistema BFT até peso de 35 g em densidades de 140 e 280 peixes m³ amostram que a densidade menor amostra os melhores resultados de lipídios e proteínas (El-Hawarry et al., 2021). Em condições similares e com densidade de 120 e 240 peixes por m⁻³ a porcentagem de proteína do filet foi de 84 ± 5 e 91 ± 1 respectivamente com diferença significativa, mas no peixe inteiro os resultados amostram que a densidade não apresenta diferença significativa em humidade e proteína, porem a menor densidade tem menor níveis de lipídios (Bañuelos-Vargas et al., 2021). Em tilápias de 7,7 a 9,7g a proteína pode variar entre 70,3 a 69,3%, as densidades de 500 até 1000 juvenis não tem efeitos em proteína, lipídios, cinza nem humidade (Aliabad et al., 2021). Manduca et al (2021) estudo densidades em tilápia criadas por um período prolongado até obter peixes de peso maior a 700 g e os resultados amostram que densidades de 18,75; 37,5; 56,25; 75 peixes por m³ não apresentam diferenças significativas em humidade, proteína crua, extrato etéreo, mas peixes em densidades menores apresentam níveis de cinza maior, o que é provavelmente devido a uma relação C: N mais baixa em comparação com as densidades mais altas. Um estudo anterior de Manduca et al (2020) por um período de 120 dias amostra redução da proteína bruta na carcaça de tilápia criada em maiores densidades de estocagem, provavelmente devido ao grande estresse do manejo de troca zero de água. Os pesquisadores justificam que por causa da taxa de renovação de água aplicada neste estudo pareceu ser suficiente para prevenir distúrbios metabólicos e, portanto, alterações na composição corporal dos peixes.

Composição proximal dos Bioflocos

Os bioflocos têm um valor nutricional dinâmico (Ekasari et al. 2010) e podem ser usados como uma fonte completa de alimentos aquáticos, além de serem capazes de fornecer compostos bioativos (Ahmad et al. 2017). Portanto, a análise dos fatores que afetam o valor nutricional do bioflóco, como a prioridade da nutrição aquática, sua capacidade de ingerir e digerir proteína microbiana e a densidade do bioflóco na água são de interesse (Hargreaves 2006). A proteína monocelular formada por bactérias heterotróficas através da absorção de N inorgânico pode ser usada como fonte alimentar para espécies aquáticas cultivadas, como camarão, tilápia e carpa (Burford et al. 2004; Monroy-Dosta et al. 2013; Khanjani et al. 2019a; Ebrahimi et al. 2020). O valor nutricional dos bioflocs para um determinado organismo depende do tamanho das partículas, da digestibilidade e dos compostos bioquímicos. Ekasari et al. (2014) relataram que flocos com tamanho de partícula > 100 e < 48 µm devido ao maior valor nutricional e recuperações de N são mais favoráveis para camarão *L. vannamei*, tilápia vermelha *Oreochromis niloticus* e mexilhão *Perna viridis*. Eles também descobriram que com tamanho de partícula > 100 µm continham níveis mais altos de proteínas e lipídios, enquanto os flocos < 48 µm eram ricos em aminoácidos essenciais.

A análise proximal dos bioflocos, em termos de matéria seca contem 38% de proteína, 3% de lipídios, 6% de fibra, 12 de cinza e 19 kJ g⁻¹ (Azim e Little, 2008), o trabalho concluiu que a composição nutricional dos bioflocos é independente da qualidade do alimento fornecido no sistema de produção. Outros estudos usaram trigo e melação como fonte de carbono e observaram que os bioflocs continham 30,4% de proteína bruta, 4,7% de gordura bruta, 8,3% de fibra, 39,2% de cinzas e 29,1% de extrato livre de nitrogênio em matéria seca (Ballester et al., 2010). Quando é usado glicerol como fonte de carbono os bioflocos contem maior n total⁶ PUFAS que quando é fornecido glucose diluída (Ekasari et al., 2010).

Numerosos estudos relataram que o bioflóco fornece nutrientes essenciais como proteínas, lipídios, ácidos graxos essenciais, minerais, vitaminas, carotenóides e enzimas digestivas para facilitar a digestão e conseqüentemente melhorar o estado nutricional (Crab et al. 2012; Xu & Pan 2012; Xu et al. 2012; Khanjani et al. 2016; Abbaszadeh et al. 2019; Ahmad et al. 2019). Ahmad et al. (2019) investigaram os efeitos de diferentes fontes de carbono orgânico em índices

hematológicos, atividades enzimáticas digestivas e metabólicas da criação de alevinos de *Labeo rohita* sob condições bioflocoso. Eles relataram que as atividades das enzimas amilase e protease em todo o intestino eram significativamente mais altas no sistema de bioflocos tapioca, enquanto a atividade da lipase não mostrava diferenças significativas nos sistemas de bioflocos com diferentes fontes de carbono. De et al. (2015) afirmaram que a digestibilidade dos nutrientes está positivamente associada à atividade da enzima digestiva e atividades mais altas das enzimas digestivas nos sistemas bioflocos podem melhorar a utilização de macromoléculas (Ahmad et al. 2019). Ahmad et al. (2019) sugeriram que estas mudanças podem ocorrer devido à característica composicional das fontes de carbono utilizadas. Mahanand et al. (2013) observaram que o conteúdo de nutrientes dos bioflocos indica que os bioflocos podem ser usados com sucesso para alimentar peixes herbívoros e omnívoros e alcançar um crescimento ideal. Estudos anteriores mostraram que o uso de bioflocos no sistema de troca de água zero contribui significativamente para o crescimento e produção de tilápia (Avnimelech 2007; Azim & Little 2008). Além disso, o valor nutricional dos bioflocos extraídos de diferentes estudos é mostrado na Tabela 4.

Tabela 4. Valor nutricional de bioflocos obtidos em diferentes estudos

Referencia	%					
	PB	Carb	Lip	FB	Cinza	H
Aliabad et al., (2021)	70,3	-	-	-	24,7	
Bañuelos-Vargas et al., (2021)	31	-	4,4	-	-	87
Sousa et al (2021)	38,7	-	7,2	-	11,8	93
Manduca et al., (2021)	28	-	-	-	25	92
Manduca et al., (2020)	47	-	-	-	14	93
Delgado et al., (2020)	30	27	-	4,4	30	90
Sgnaulin et al., (2020)	18,8	-	0,8	-	-	92
Khanjani et al., (2017)	30,7	-	2,18	-	29	-
Emerenciano et al., (2012)	28	18	0,5	3,1	35	90

*PB= Proteína bruta; Carb= Carboidratos; Lip= Lipídios; FB= Fibra Bruta; H= Humidade

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2. Capítulo II

Stocking density of red tilapia (*Oreochromis* sp.) in a commercial biofloc system in Colombia

Stock density of red tilapia (*Oreochromis* sp.) in a commercial biofloc system in Colombia

Abstract

Tilapia is the third most-produced species globally, and it is projected that the tilapia production volumes of 2010 will double by 2030. Increasing the production of aquatic organisms implies the intensification of aquaculture systems, and biofloc technology (BFT) is considered an intensive alternative for aquaculture. BFT has advantages in terms of reduced water supply, reduced apparent feed conversion ratio (FCR), improved health status and increased densities compared to conventional systems. However, there is no information on adequate densities and their impact on large-scale production of the different species. This study aimed determining the effects of monosex red tilapia stocking density in BFT on the growth performance, water quality parameters, and chemical characteristics of fish on a large scale and under culture conditions in eastern Colombia. The water quality parameters of the two densities were within the normal ranges for the species, but dissolved oxygen tended to decrease throughout the production process. Stocking densities of 30 fish/m³ (T30) and 40 fish/m³ (T40), respectively, did not result in significant differences in growth performance. At the end of the trial, FCR were 1.6 and 1.7 from T30 and T40, respectively. Fish produced at a lower density had similar weight gain; however, the final biomass had no significant differences. BFT did not affect the fish's nutritional characteristics or microbiological concentrations, and the red tilapia produced in these systems is safe for human consumption.

Keywords: aeration, flour, nutritional quality, innocuousness, aquaculture

1. Introduction

Tilapia is considered one of the principal aquaculture species worldwide, mainly in tropical and subtropical aquaculture (Prabu et al., 2019). It is third on the list of species produced, contributing 2.6 million tonne of production in 2020 (FAO, 2020). It is an important source of protein of animal origin, social welfare, and economic income (Sosa et al., 2005; Ansah et al., 2014; Yue et al., 2016). In 2030, tilapia culture is expected to double the volumes produced during 2010 (Kobayashi et al., 2015). The largest producers are in Asia and account for 80% of the production. China alone produced one-third of the world's total production with 1.86

million tonnes in 2018 (Yuan et al., 2020). Colombia has produced more than 77 thousand tonnes per year of tilapia since 2018 (FAO., 2018), and it is among the largest exporters of tilapia for the United States (Dai et al., 2020).

In total, 70% of products exported from Colombia to the United States are generated mainly in floating cage systems in the department of Huila in the Betania Dam (Camero-Escobar and Calderón, 2018). Red tilapia is also produced using traditional and super-intensive systems with state-of-the-art technology (Norman-López and Bjorndal, 2009), ranging from rural subsistence to large-scale (Prabu et al., 2019). Although inland pond cultures generally fertilized with various inputs are most common (Duodu et al., 2020), tilapia polyculture with other species and aquatic organisms is frequent (Wang and Lu, 2015). Aquaculture recirculation systems (RASs) could be used for increasing production in regions with limited water and space, and they also lower the burden on water resources (Wambua et al., 2020). These characteristics are similar to a production system where biofloc technology (BFT) is implemented, which is based on zero or null water replacement (Avnimelech, 2015). Some advantages of the BFT over the RAS are lower operating and implementation costs of the entire structure (Luo et al., 2014) and the use of microbial flocs as a source of protein (Hisano et al., 2019).

In BFT, bacteria convert fish waste into microbial biomass (Adineh et al., 2019), which serves as fish food and helps control nitrogen compounds and other nutrients levels, thereby reducing water use and conversion factors (Pérez-Fuentes et al., 2016). This positive characteristic translates into a reduction in water treatment costs compared with other production systems (De Schryver et al., 2008). An additional benefit of BFT is the increase in density by up to 20% compared with extensive systems (Khanjani et al., 2020). However, to increase the densities, the levels of nitrogen compounds have to be controlled by inoculating microorganisms and supplying carbon sources (Crab et al., 2007).

The effect of varying densities has been determined for different species using BFT systems. Investigations of common carp (*Cyprinus carpio*) have demonstrated that BFT improves growth and decreases feed conversion rates as opposed to keeping fish in clear water. The authors attributed these positive effects that BFT systems reduce stress in densities ranging from 12 to 25 kg/m³, which is

not an effect of production systems in transparent waters (Adineh et al., 2019). The BFT systems used for polyculture of the main carp species in India showed a specific growth of 0.96%/day at densities of 4.28 fish/m³ and 0.76%/day at densities of 12.8 fish/m³. These results are better than those for animals produced at the same densities in systems with water exchange (Deb et al., 2020). BFT did not improve growth or survival in species such as piracanjuba (*Brycon orbignyanus*) at a density of 24 animals/m³ (Sgnaulin et al., 2018). Growth improved and the lipid content of fillets decreased in *Rhamdia quelen* grown in BFT systems at a density of 30 g/L compared with lower densities (10 and 20 g/L) (Battisti et al., 2020).

The BFT system has been extensively studied with Nile tilapia (*Oreochromis niloticus*) under laboratory conditions and strictly controlled environments. Low and medium densities of 166 fish/m³ and 333 fish/m³, respectively, of fingerlings of this species showed better body weight and survival results than fingerlings kept at high densities of 600 fish (Liu et al., 2018b). A density of 33 fish/m³ is recommended to grow out tilapia with an initial weight of 133 g and gain an approximate of 700 g, (Manduca et al., 2021). For animals weighing 50 g and grown for 84 days, a density of 40 fish/m³ provides better productive yields than the densities of 20 fish/m³ and 60 fish/m³ (Zaki et al., 2020). It was determined that a density of 50 fish/m³ showed the lowest feed conversion factor for red tilapia (*Oreochromis* sp.), which was not reversed and kept for 14 weeks in a small-scale experimental BFT system (Ekasari et al., 2012).

Ekasari et al. (2012) reported a need for studies with monosex red tilapia (*Oreochromis* sp.), because uncontrolled reproduction interrupted growth in their study. Considering this, and what was suggested by Collazo-Lasso and Arias-Castellanos (2015), it is necessary to conduct studies more appropriate to the conditions of the country and of each species. Therefore, this investigation aimed at determining the effects of monosex red tilapia stocking density in BFT on the growth performance, water quality parameters, and chemical characteristics of large-scale fish culture in eastern Colombia.

2. Materials and Methods

2.1. Experimental location

This investigation was conducted in the production facilities of Asociación Piscícola el Vergel (ASOVERGEL) located in the municipality of Arauquita, Vereda la Arenosa, at 6°58'N latitude and 71°07' longitude, 143 m above the sea level.

2.2. Experimental design

A total of six 14-m diameter circular tanks of 1-m height and 153-m³ capacity were used in this investigation. To avoid spillage, 5 cm of freeboard was left, as established by Deb et al. (2020). Constant aeration was provided by 1.5-hp radial (Fig.1).



Fig. 1. Tank equipped with radial-type splash aerator

This investigation was conducted using a randomized design; two stocking densities were considered: treatment 1 (T30—30 fish/m³) and treatment 2 (T40—40 fish/m³), each with three replicates. The monosex tilapia used in the culture had an initial weight of 1 ± 0.2 g. Feeding was carried out according to the feed manufacturer's recommendations (Table 1), starting with 40% protein and ending with 20% protein pellets. The study was carried out under fish farm conditions during a 210-day production process.

Table 1. Food management used during the study

Weeks	Weight range gr	CP %	Avg. feeding rate %	Times
1 – 6	20 - 28	40	7.1	9
7 – 13	100 – 120	34	3.6	6
14 – 19	220 – 245	30	2.3	5
20 – 25	370 – 395	24	1.5	4
25 – 28	370 - 470	20	1.3	4

*CP = Crude protein

The formation of the biofloc inoculums was carried out in each tank following the methodology proposed by Shourbela et al. (2021). Three weeks before the start of the trial for each tank was added 20 g of pond bottom soil in well aerated water (1 L) with 10 mg/L urea and 400 mg/L molasses and 20 g of yeast. When the tanks contained 0.2 mL/L concentration of biofloc bacteria, juvenile tilapia were placed in the tanks, and the tanks were filled with water.

After having matured biofloc, the parameters were maintained as follows cane molasses was dissolved in water from the same tank, distributed homogeneously, and added periodically to avoid accumulation in a single area of the tank. Molasses was added as a carbon source at 15 times the total ammonia nitrogen concentration (TAN) to maintain a C:N ratio of 15:1 (Avnimelech, 1999). Liquid cane molasses was used as an external source of carbon because of its availability in the region where the study was carried out, its efficiency in controlling TAN, and the production of microbial flocs (Lima et al., 2018). Aeration in this study was constant and provided by 1.5-hp radial splash aerators. Calcium hydroxide (2.0–50 mg/L) was supplied daily to maintain an alkalinity of 120 ppm, following the recommendations of Martins et al. (2017). Settleable solids (SS) were monitored using 2,000-liter plastic tanks (decanter) connected to the production tank's drainage by means of an airlift system. They were used once it reached 50 mL/L as measured using the Imhoff cone.

2.3. Water quality

Water quality parameters were evaluated for each tank temperature (T), dissolved oxygen concentration (DOC) and saturation (DOS), were measured with YSI EcoSense® DO200A probe, and pH was evaluated daily using a Hanna® Model

991300 device. Ammonium ($\text{NH}_4\text{-N}$), nitrite ($\text{NO}_2\text{-N}$), nitrate ($\text{NO}_3\text{-N}$), and alkalinity (A) were evaluated once a week with colorimetric methodologies established for each parameter (APHA, 2005). Biofloc settleable solids (SS) were determined weekly using Imhoff cones according to the method of Avnimelech (2009). In brief, biofloc suspension in the biofloc tanks was collected (1 L of water of each experimental tank) using Imhoff cones and then let to settle for 10–15 min. The volume of the accumulating flocs on the bottom of the cone was the number of settleable solids (mL/L) (Hoang et al, 2020).

2.4. Productive performance

Biometric samplings were carried out every 70 days, following the evaluations made during the production process, where the individual weight of 5% of the population was recorded. All fish were weighed together at the end of the production cycle and then counted to calculate survival, and final biomass was calculated. Food consumed per group was also recorded. The following equations were used for the zootechnical performance analysis:

- **Survival (S, %):** the percentage of fish that survived until the end of each evaluation period was obtained using the following equation:

$$S (\%) = (\text{Final number of fish}) / (\text{Initial number of fish}) \times 100$$

- **Average weight gain (AWG)**

$$\text{AWG (g)} = \text{Final average weight} - \text{Initial average weight}$$

- **Average feed intake (AFI)**

$$\text{AFI (g/fish)} = [\text{Total food intake (g)}] / (\text{Number of fish})$$

- **FCR ratio between AFI and AWG**

$$\text{FCRR} = [\text{Amount of feed consumed (AFI)}] / [\text{weight gain (AWG)}]$$

- **Final biomass (B)**

$$B \text{ (kg)} = \text{Final number of fish} \times \text{Final average weight}$$

2.5. Proximal analysis of fish and biofloc

A total of five fish per tank were randomly collected for the proximal composition analysis, and they were analyzed according to AOAC procedures (2012). The samples were oven-dried at 110°C to constant weight, ground, and their composition was determined. The water content was quantified according to the AOAC 925.10 gravimetric method, by drying the sample in a hot air oven at 105°C for 1 h. Further, the moisture content was obtained by weighing the sample and comparing its weight before and after drying. The lipid content was determined using the acid hydrolysis method, AOAC 920.85 Soxhlet extraction. Total protein content was measured using the GOMEPL.01-Kjeldahl method. The ash analysis involved charring the sample in a muffle furnace at 550°C (AOAC 923.03). Fiber content was determined using the enzymatic-gravimetric method (AOAC 978.10). Energy content was found to be 16.7, 16.7, and 37.7 kJ/g of protein, carbohydrate, and lipid, respectively (Association of Official Analytical Chemists, 2012). Nitrogen content was measured using the Kjeldahl method.

The SS samples were collected every 3 days during the production process, by extracting them from the bottom of the settler of each tank by the drainage system. The settled and collected floccules were dried at room temperature and then stored. For each treatment, a sample was pooled and homogenized in a TECNAL® Y-type mixer. A sample of the mixture was used to measure moisture, ash, protein, fat, crude fiber, total carbohydrates, and caloric value, in addition to the proximal composition of micro and macronutrients. The tests were carried out in triplicates. The methodologies used for the bromatological proximal evaluation are described in section 2.4, and the macro and micronutrients were evaluated using spectrophotometry and atomic absorption spectrophotometry.

2.6 Microbiological analysis of fish

A total of five fish were collected per replicate for microbiological testing, which was carried out quickly once the samples were taken. The methodology

proposed by Alsaggaf et al. (2017) was used for bacterial load recovery. For this, 10 g of sample were taken from the back of each fish, deposited individually in 90 mL of sterilized saline solution (0.85% NaCl), and homogenized in a Stomacher® 400 Seward device. Further, serial dilutions were prepared and plated on appropriate microbiological media. Microbiological counts were made in triplicate and recorded as CFU/g.

The following standardized methods were applied for determining the microbiological groups:

- The ISO 16649-2: 2001 method was used for the *E. coli* count.
- The APHA method (2021) was used for coagulase-positive *Staphylococcus aureus*. 0.1 mL of the homogenized solution of the fish tissue samples were inoculated on Baird–Parker agar and incubated for 24–48 h at a temperature of 35°C–37°C. Colonies were identified with the coagulase test.
- A pre-enrichment was performed for *Salmonella* spp. by incubating the tissue sample dilutions at 37°C for 24 h. 1.0 mL and 0.1 mL samples were then inoculated in Selenite Cysteine and Rappaport–Vassiliadis broths, respectively, both with 1.0 mL of 0.4% novobiocin; they were incubated for 24 h at 37°C. The enriched solutions were inoculated on Brilliant Green and MacConkey agars followed by incubation at 37°C for 24 h. Suspected colonies were inoculated on Triple Sugar Iron and Trypticase Soy agars for serological testing (APHA, 2021).
- The qualitative analysis carried out for *Vibrio cholerae* followed ISO standard 21872-1: 2017. Biochemical confirmation (gram negativity, oxidase-positivity) was carried out for the determination of *V. cholerae*, and we recorded its absence in 25 g of the sample.

2.7. Statistical analysis

The data were analyzed using the R Project program for Windows (Version 3.6.3). The percentage data were transformed into arcsine before the statistical analyses, and the nontransformed data are presented in tables and figures. The mean values between densities were compared using independent samples t-test

to evaluate the differences between T30 and T40 densities. The least significant difference test was used to compare the mean values to identify significant differences between factors. The effects of density on performance, water quality, and microbiological analysis were analyzed with factorial ANOVA. The proximal analysis of the biofloc was descriptive and not comparative.

2.8. Ethical consideration

This study complied with current Colombian regulations for the treatment of animals. The following laws were considered: Law 84 of December 27, 1989 of the Congress of the Republic of Colombia; Resolution 008430 of October 4, 1993; Law 576 of 2000; and Law 1774 of January 6, 2016. This study was endorsed by the Cooperative University of Colombia Bioethics Subcommittee, with endorsement code 008-202.

The fish were kept under optimal conditions before and during the study. They were checked every day and clove oil (1 mg/100 mL of water) was used as a sedative to avoid the animals' stress and suffering for the three individual biometrics carried out at 70, 140, and 210 days. To sacrifice the fish at the end of the production process, the thermal shock technique was applied in ice water at temperatures between 2°C–4°C.

3. Results

3.1. Water quality

Water quality parameters are fundamental for aquaculture production, particularly when the systems handle high densities. Table 2 shows the final values of the water quality parameters. There were no significant differences between densities among the parameters measured during the production process.

Table 2. Values of the water quality parameter for the biofloc red tilapia production system at densities of 30 fish/m³ and 40 fish/m³

Parameter	T30	T40
Temperature (°C)	30,0 ± 1,2	29,9 ± 1,4
Dissolved oxygen (mg/L)	4,9 ± 1,1	4,8 ± 1,2

pH	$7,0 \pm 0,4$	$6,9 \pm 0,4$
NH ₄ -N (mg/L)	$0,6 \pm 0,3$	$0,7 \pm 0,2$
NO ₂ -N (mg/L)	$0,5 \pm 0,1$	$0,5 \pm 0,1$
NO ₃ -N (mg/L)	$0,5 \pm 0,5$	$0,6 \pm 0,5$
Alkalinity	201 ± 7	198 ± 5
SS (mL/L)	$35,9 \pm 11,5$	$36,2 \pm 11$

*SS = Sedimentable Solids

DOC (Fig. 3) tended to decrease as the production process progressed. Fig. 4 shows the results for nitrogenous compounds. NH₄-N fluctuated throughout the production process, with a maximum concentration of 1 mg/L in the two densities, whereas NO₂-N and NO₃-N fluctuated in an increasing trend in the two densities. It is not easy to control water temperature in open-air systems and under farm conditions because it depends on environmental conditions. The results show fluctuations between 27°C and 32.1°C for the two densities, which are among the recommended values for the species (Chervinski, 1982). pH and alkalinity were kept at suitable levels for production in BFT. SS increased as production time progressed (Fig. 5), starting at 20 mL/L and ending at an average of 50.4 mL/L and 51.6 mL/L for T30 and T40, respectively.

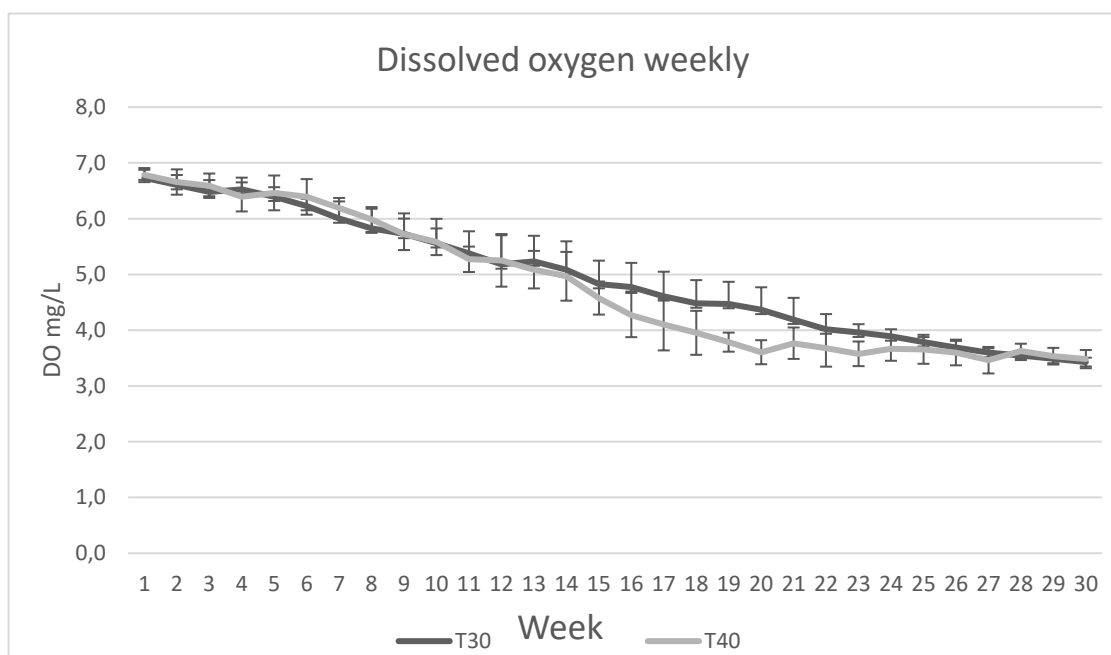


Fig. 3. Variation of dissolved oxygen concentrations over time in a red tilapia biofloc production system at different densities.

3.2. Zootechnical performance

Table 3 shows the results of the productive performance. No significant differences were found between values obtained for the three biometrics performed during the production process.

Table 3. Mean values (\pm standard deviation) of zootechnical performance of tilapia after 30, 140, and 210 days of production in biofloc systems at different densities

Days	Density	Zootechnical performance parameters				
		S (%)	AWG (g)	FC	FCR	B kg
70	T30	98,5 \pm 0,5	65,3 \pm 3,2	80 \pm 0,01	1,2 \pm 0,1	320
	T40	98,2 \pm 0,5	62,2 \pm 2,5	80 \pm 0,01	1,3 \pm 0,1	396
140	T30	98,1 \pm 0,4	259,4 \pm 7,2	344 \pm 0,01	1,3 \pm 0,1	1251
	T40	97,6 \pm 0,3	255,0 \pm 7,9	344 \pm 0,02	1,3 \pm 0,1	1589
210	T30	97,7 \pm 0,8	494,4 \pm 13	803 \pm 0,01	1,6 \pm 0,1	2332
	T40	97,1 \pm 1,3	476,7 \pm 17,2	799 \pm 0,02	1,7 \pm 0,1	2879

Note: The zootechnical performance parameters are: S (survival), AWG (average weight gain), FC (average feed consumption), and FCR (apparent feed conversion), B (biomass final period)

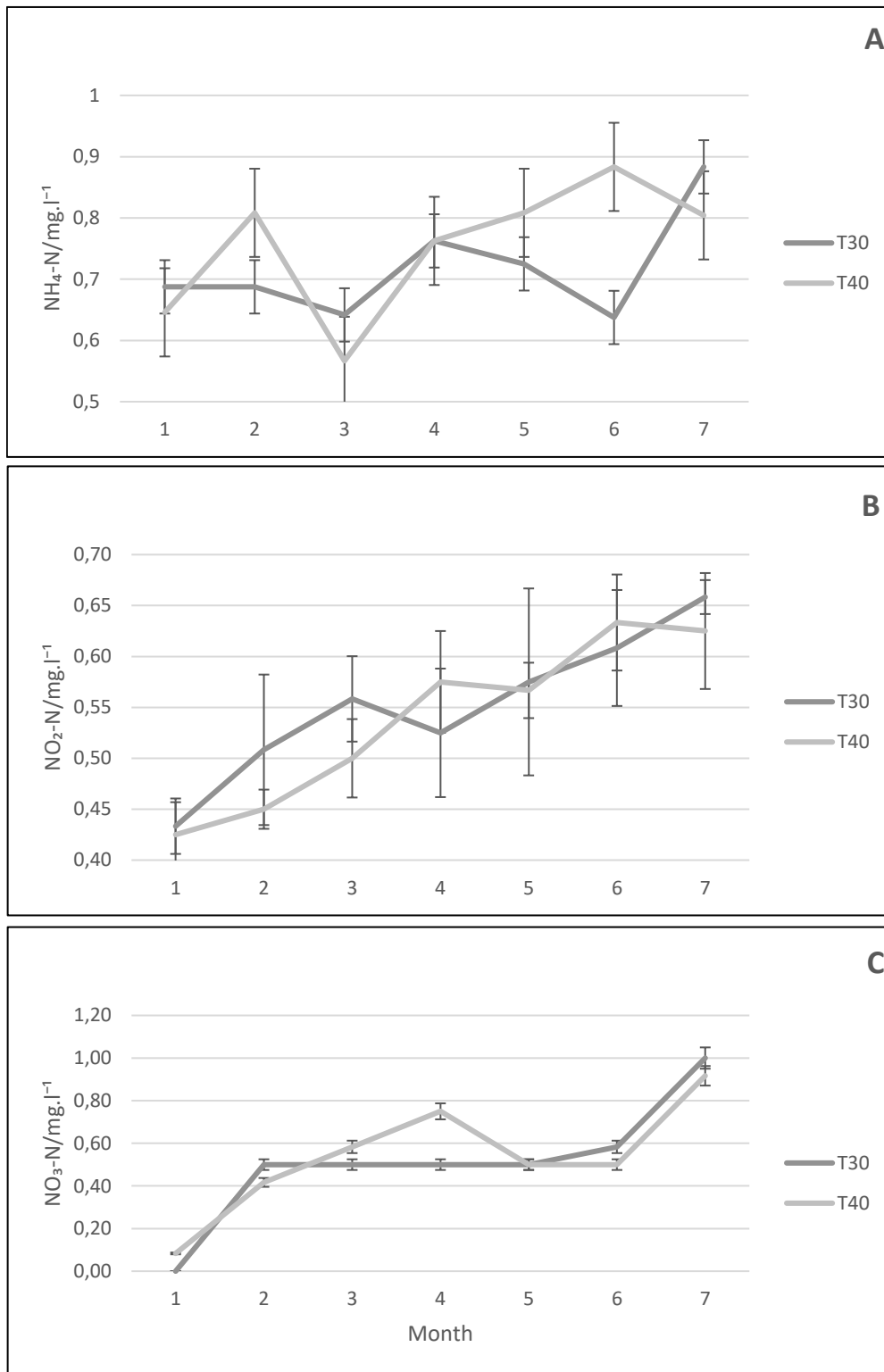


Fig. 4. Variation of $\text{NH}_4\text{-N}$ A), $\text{NO}_2\text{-N}$ B) y $\text{NO}_3\text{-N}$ C) in a red tilapia biofloc production system at different densities.

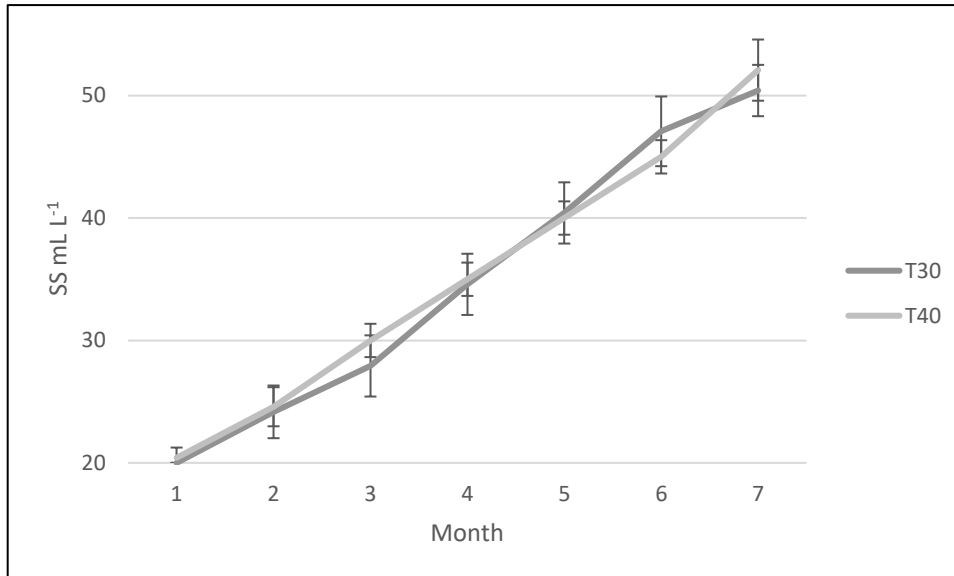


Fig. 5. Settleable solids in a red tilapia biofloc production system at different densities

After 210 days of production, the biomass was $2,332 \pm 20.4$ Kg and $2,879 \pm 14.2$ kg, $15,2 \text{ kg/m}^3$ and $18,8 \text{ kg/m}^3$ for T30 and T40, respectively. This occurred because there was a greater number of fish at T40; therefore, although individual weights were lower, total biomass was greater at T40 than at T30. At the end of production, fish weighed an average of 494.4 ± 13 and 476.7 ± 17.2 g at T30 and T40, respectively, but there were no significant differences.

3.3. Proximate and microbiological analysis of fish

Table 4 shows the chemical composition of red tilapia. Humidity was 76.23% and 77.01% at densities of 30 fish/m³ (T30) and 40 fish/m³ (T40), respectively; protein content decreased as humidity increased; and fat content was lower at higher densities, with values of 4.15% and 3.8% at T30 and T40, respectively.

Table 4. Mean values (\pm standard deviation) of centesimal composition (%) of red tilapia produced in a biofloc system at different densities

Item (%)	T30	T40
Humidity	$76,23 \pm 1$	$77,01 \pm 0,9$
Ash	$1,29 \pm 0,1$	$1,15 \pm 0,1$
Fat	$4,15 \pm 0,09$	$3,87 \pm 0,1$
Protein	$17,81 \pm 1$	$16,72 \pm 1$
Total carbohydrates	$0,49 \pm 0,02$	$0,38 \pm 0,03$
Calories	$136,34 \pm 3$	$130,18 \pm 3,5$

Crude fiber	ND	ND
ND = Not detected		

Red tilapia reared in a biofloc system at the study densities did not present microbiological alterations (Table 5). The microbial quantification showed that they were within the ranges allowed for human consumption, and *Salmonella* spp. and *V. cholerae* were not found in the evaluated samples. Therefore, we can deduce that it is safe to consume red tilapia produced in biofloc systems at densities of 30–40 fish/m³ with respect to microorganisms that cause foodborne diseases.

Table 5. Microbiological analysis of red tilapia grown in a biofloc system at different densities.

Analysis	Criterion or specifications	T30	T40
		Results	Results
<i>E. coli</i>	10–400 UFC/g	40	40
<i>S. aureus</i> coagulase-positive	100–1000 UFC/g	100	<100
<i>Salmonella</i> spp.	Absence/25 g	Absence	Absence
<i>V. cholerae</i>	Absence/25 g	Absence	Absence

3.4. Biofloc chemical analysis

Biofloc formation increased with an increase in culture time. The initial concentration for the two densities was 20 mL/L, and at the end of production it was 50.4 mL/L and 52.08 mL/L at T30 and T40, respectively. The biofloc composition (Table 6) showed a protein content of 29.3% ± 0.5% and total carbohydrates of 25.58% ± 0.27% at T30. The nutrients found in the largest concentration at T30 were calcium and nitrogen (6.96% ± 0.1% and 3.03% ± 0.07%, respectively).

Table 6. Mean values of the proximate analysis and nutrients present in the biofloc meal in the red tilapia production system.

Bromatological proximate analysis		
Parameters	Value (%)	
	T30	T40
Humidity	12,1 ± 0,1	11,3 ± 0,3
Ash	28,8 ± 0,5	27,5 ± 0,2
Fat	0,38 ± 0,03	0,37 ± 0,01

Protein	29,3 ± 0,5	30,7 ± 0,4
Fiber	4,1 ± 0,2	5,21 ± 0,1
Total carbohydrates	25,3 ± 0,27	25,58 ± 0,3
Caloric value	236,51 ± 23	233,14 ± 11
Micro and macronutrient values (%)		
Nitrogen	3 ± 0,02	3.02 ± 0,01
Phosphorous	0,92 ± 0,07	0,97 ± 0,09
Potassium	0.29 ± 0,05	0.31 ± 0,03
Calcium	6.89 ± 0,1	6.77 ± 0,4
Magnesium	0,27 ± 0,1	0,24 ± 0,3
Manganese	0.01 ± 0	0.01 ± 0
Iron	0,63 ± 0,01	0,64 ± 0,02
Copper	0.01 ± 0	0.01 ± 0
Zinc	0.08 ± 0	0.09 ± 0
Boron	0,01 ± 0	0,01 ± 0
Sulfur	0,91 ± 0	0,92 ± 0

4. Discussion

Water exchange is minimized or avoided in biofloc systems, unlike traditional and cage systems (Avnimelech, 2015), In this case, water use was 89 l/kg and 72 l/kg of fish produced, for T30 and T40 respectively, showing that in BFT, increasing the density can improve water use efficiency. In this study, only water lost by evaporation was replaced, as in the study by Manduca et al. (2020) for Nile tilapia under laboratory conditions. Here, the continuous supply of nutrients (provided by commercial feed, molasses, and calcium hydroxide) increased SS accumulation, an effect also described by Gaona et al. (2016) for the shrimp, *Litopenaeus vannamei*, cultured using a biofloc system. Although settlers were used in our production system, SS increased during the production process, as observed by Deb et al. (2020) in experimental studies of carp in a biofloc system. The flow of water can explain the increase in SS into the settlers (Gaona et al., 2016) or the low retention efficiency of the sedimentation tanks (Jung et al., 2020).

The gradual increase of settleable solids SS in the two densities in this study could have resulted in elevated oxygen demand, aerobic metabolization of organic matter. In addition, the increase in biomass along with the increase in SS reduced DOC, which reached values of ~3 mg/L at the end of the production process. This was also shown in the study by Ekasari & Maryam (2012), in which DOC decreased

as the biomass increased at different densities of red tilapia; however, they found no difference in DOC between densities of 25, 50, and 100 fish/m³. The present investigation confirms that red tilapia densities of 30 fish/m³ and 40 fish/m³ did not significantly affect DOC; however, they lowered it drastically. Therefore, adequate calculations for optimal aeration during the entire production process are essential, depending on the densities and solids as well as depending on the aeration system used (Malpartida et al., 2018).

Regardless of stocking density, water quality parameters are usually not affected and remain within the recommended ranges for tilapia production (Avnimelech 2009; Monsees et al. 2017; Alverenga et al., 2018). Several studies have shown that an increase in density results in decreased oxygen levels and increased or fluctuating levels of nitrogen compounds, thus corroborating our results (Ekasari et al., 2012; Liu et al., 2018b; Wu et al., 2018; Deb et al., 2020; Manduca et al., 2021). Dissolved oxygen is the main limiting factor in fish production (Ngoepe et al., 2021), as well as NH₄-N and NO₂-N, which are highly toxic at alkaline pH (Boyd and Tucker, 2012; Putra et al., 2020). Nitrogen compounds accumulate as fish consume increasing amounts of food (Ogbonna and Chinomso, 2010), observed in our study; however, our results show that the densities of 30 fish/m³ and 40 fish/m³ did not affect the concentration of these compounds. Ekasari and Maryam (2012) reported that red tilapia cultivated in biofloc at densities of 100 fish/m³ did not result in NH₄-N values of >1.1 mg L; these authors also concluded that NO₂-N remained stable during the 14 weeks of the study at the evaluated densities. These results differ from those obtained in this study, in which a gradual increase in NO₂-N was observed, although the recommended limit was not achieved. In our investigation, this can be explained by the use of molasses only when NH₄-N was ≥1 mg L. Similar results were obtained by Manduca et al. (2021), who observed a lower accumulation of SS and a reduction in costs by applying this strategy. Deb et al. (2020) employed the opposite strategy, replacing 50% of water when NO₂-N exceeded the limit of 1 mg/L (Mahanand et al., 2013). This methodology is not often recommended in biofloc systems, since the microorganisms that carry out the transformation processes of nitrogen compounds are eliminated with each replacement (Ebeling et al., 2006; Liu et al., 2018a; Green et al., 2019). The same is observed with SS that accumulate with increasing

biomass, food, feces, and carbon source (Long et al., 2015; Silva et al., 2018). In our study we observed that SS increased from the start of the study until day 210. Other researchers have reported a decrease in SS linked to climatic changes (Manduca et al., 2021), but other authors have reported a decrease in SS at higher densities, due to progressive filtration by tilapia (Yuan et al., 2010). This decrease did not occur at the densities studied by us, even though our study was conducted with red tilapia in an open-air system.

Density did not affect parameters such as temperature, which was maintained within optimal ranges for red tilapia (El-Sayed and Kawanna, 2008; Abdel-Tawwab and Wafeek, 2017); in case it fluctuated, it could be attributed to environmental changes (Deb et al., 2020). pH remained stable throughout the red tilapia culture at the two evaluated densities; this was also observed in studies with red tilapia at densities of 25, 50, and 100 fish/m³, in which pH values ranged from 6.3 to 7.5 (Ekasari and Maryam, 2012). Another study reported a decrease in pH at densities of 45 Nile tilapia/m³ and 69 Nile tilapia/m³ under laboratory conditions using a biofloc system but with partial replacement (Manduca et al., 2021). Maintaining alkalinity is necessary to avoid fluctuations in pH (Martins et al., 2017). There are various recommendations for biofloc systems regarding alkalinity levels, mainly for minimal or nonexistent water renewal rates (Furtado et al. al., 2014). Boyd and Tucker (1998) recommended that alkalinity should be maintained above 75 mg CaCO₃/L, whereas Ebeling et al. (2006) recommended concentrations of 150 mg/L and Cheng et al. (2006) suggested that alkalinity should be maintained above 200 mg/L. Furtado et al. (2011) confirmed that alkalinity levels below 100 mg CaCO₃ and pH levels below 7 negatively affected nitrification rates in biofloc systems, but pH values above 7.5 increased the possibility of toxicity owing to the presence of nitrogen compounds in systems with zero water exchange. Therefore, during our study, calcium hydroxide (Ca (OH)₂) was supplied daily, which is recommended for biofloc systems at a ratio of 7.18 ± 0.32 (Martins et al., 2017). This is necessary because it reduces half the alkalinity produced during nitrogen absorption by heterotrophic processes that probably dominate the biofloc system, and each gram of NH₄-N requires 3.57 g of alkalinity (Ekasari and Maryam, 2012). Density does not affect on alkalinity when calculated based on pH and when alkalinity is measured regularly

to correct it and maintain its stability (Martins et al., 2017). This in turn maintains pH stability and renders it unaffected to density (Furtado et al., 2015).

Increasing stocking densities tend to reduce fish growth in different production systems, such as RAS (Ridha, 2006; Wu et al., 2018), cages (Garcia et al., 2013; Moniruzzaman et al., 2015), and biofloc systems (Haridas et al., 2017; Manduca et al., 2020; Zaki et al., 2020), regardless of the growth stage. This has also been observed in red tilapia cultivated for 14 weeks in small-scale biofloc. At a density of 25 fish/m³, the average individual weight was 190.86 ± 12.34 g, and at a density of 50 fish/m³, the average individual weight was 161.04 ± 13.05 g (Ekasari and Maryam, 2012). This confirms the results of our study, where there was no significant difference in weight gain. The fish in the T30 density were heavier during the entire production process, even though we used masculinized them, unlike the study conducted by Ekasari and Maryam (2012), which justified the interruption of growth in red tilapia. This effect also occurs in Nile tilapia fingerlings, with higher densities negatively influencing weight (Liu et al., 2018). This is usually due to the stress generated by crowding, competition for food, and social dominance that can modify the expenditure of metabolic energy that is reserved for growth and homeostasis (Martínez-Porchas et al., 2009; Manduca et al., 2021).

The increase in the density of fish/m³ tends to increase the time necessary for tilapia to reach the harvest weights required by producers (Garcia et al., 2013). In biofloc systems, a density of 180 fingerlings/m³ resulted in FCR values of 1.44, whereas a density of 50 fingerlings/m³ resulted in FCR values of 1.21, demonstrating that high densities lead to an increase in this parameter (Liu et al., 2018). This increase was not observed in any of the phases of our study, but FCR values of 1.6 and 1.7 were observed at T30 and T40, respectively. Possibly due to the amount of protein in the final phases, a higher conversion was observed. FCR values under two have been recommended to improve the economic efficiency of Nile tilapia production systems since feed is considered the main production cost in fish production (Manduca et al., 2021). Average feed consumption (FC) and survival were not affected at the studied densities.

Studies of tilapia stocking densities in BFT have generally been conducted during a short growth period, mainly with Nile tilapia at the larval and juvenile stages

(Haridas et al., 2017; Lima et al., 2018; Liu et al., 2018b; Zaki et al., 2020; Manduca et al., 2020) or during the entire production phase, but on a small scale, in tanks no larger than 1,000 L (Manduca et al., 2021). A study was carried out with red tilapia at different densities in a small-scale biofloc system and with animals of mixed sex. The productive performance parameters were affected by uncontrolled fish reproduction in the system, but the densities studied did not result in significant differences in the main parameters of productive performance (Ekasari and Maryam, 2012). These results confirm the results of our study, which is possibly the first to evaluate densities of 30 and 40 fish/m³ of monosex red tilapia under culture conditions and on a large scale, using 153,000-L production tanks. No differences were seen in terms of the zootechnical performance parameters, but biomass was greater at the highest density, even though the fish presented lower weights. This is logically explained by the presence of a greater number of fish; different densities could therefore be implemented depending on the possible market. Densities of <40 fish/m³ are recommended if the market requires larger fish, such as the demands of the North American market. Conversely, if smaller animals, but a greater amount of biomass, are to be marketed, red tilapia can be cultivated at densities >40 fish/m³.

The body composition of fresh red tilapia produced at two densities in a biofloc system was very similar to that reported by Silva et al. (2018) for Nile tilapia at a density of 60 animals/m³, where the average crude protein of fresh tilapia was 14.3% and humidity was 72.46%. *Piaractus brachypomus* cultivated for 84 days in a biofloc system at a density of 42 fish/m³ and fed with a commercial balance of 25% crude protein, presented body composition values of 74% humidity, 18% crude protein, and 1.2% ash (Díaz et al., 2020). This is consistent with values obtained in the proximate analysis in this study; however, it differs from the study by Manduca et al. (2021), in which animals at densities between 18 and 75 fish/m³ had crude protein > 47%. This may be because the value was expressed on a dry-weight basis (DM); however, the animals were processed whole and weighed 700 g at harvest. Parameters of the proximate analysis were within the range of values commonly found in fish (Ayanda et al., 2019).

In biofloc systems, microorganism concentrations tend to increase throughout the production process (Monroy-Dosta et al., 2013). Microbiological communities within the digestive system and in culture water of shrimp (*Litopenaeus vannamei*)

increased with higher stocking density in biofloc systems (Deng et al., 2019). However, our study shows that the concentrations of bacteria, such as *Staphylococcus aureus* and *E. coli* are present in fresh tilapia, but at safe concentrations, whereas *Salmonella* spp. and *V. cholerae* were not present at the studied densities. Studies to evaluate possible correlations between the concentrations of bacterial communities present in the water of biofloc systems and the presence of these bacteria in fresh fish or tilapia fillets produced at different stocking densities are necessary.

Fish tissues can become contaminated throughout the fish production chain (Roberts et al., 2005), mainly with foodborne pathogens that affect humans, such as *Vibrio* spp., *Staphylococcus aureus*, *Escherichia coli*, and *Salmonella* spp. (Gatti et al., 2014). Bacteria were responsible for 37% of cases of foodborne illness reported in 2017, and *Escherichia coli* and *Salmonella* spp. accounted for 9% and 55% of diseases associated with outbreaks, respectively (Dewey-Mattia et al., 2017). These pathogens are found in the environment and can survive in fish tissue (Suhaimi et al., 2008; Boari et al., 2008). Studies have reported that bacterial concentrations in fish tissues and organs, such as *E. coli*, *Salmonella* spp., and *S. aureus*, are directly proportional to the levels of bacteria found in water (Amagliani et al., 2012; Kim and Lee, 2017; Ali et al., 2020).

Due to its nutritional characteristics, biofloc flour has been recommended as a complementary feed in fish production for human consumption (Díaz et al., 2020; Deb et al., 2020). Biofloc flour has average crude protein levels ranging from 18.2 to 29.3% (Emerenciano et al., 2013; Minabi et al., 2020), which is very similar to what was found in our study. These protein levels may be related to heterotrophic bacteria that convert directly and rapidly accumulated ammonia into bacterial protein, which is reflected in the levels of protein found in biofloc meal sediments (Ebeling et al., 2006).

This means that flour from biofloc SS is a protein alternative for fish feed, preferably in small-scale production systems because quantities of dry biofloc are not regular or sufficient for commercial-scale feed production (Delgado et al., 2020). The ash levels found in biofloc flour in this investigation may be related to the levels of salt dissolved in the water, which has already been observed in other shrimp

(Bauer et al., 2012) and Nile tilapia cultivation systems (Prabu et al., 2017). Biofloc flour used at adequate levels in the diet of sea cucumbers (*Apostichopus japonicas*) improved growth by accelerating protein renewal (Chen et al., 2018).

Biofloc flour has also been recommended as food flakes for ornamental fish, as a dry organic fertilizer for plants (Ramírez-Núñez et al., 2019), or as liquid fertilizer in the production of cherry tomatoes (Pickens et al., 2020). It has also been studied as a supplement for vegetable production in hydroponic systems (Fimbres-Acedo et al., 2020) and biofloc-rich water has been used as a nutritional substitute in pak choi hydroponic systems (Panggabean et al., 2020). Calcium was the nutrient with the greatest concentrations in the biofloc meal in our study, but levels were lower than those reported by Mabroke et al. (2019) for biofloc meal used in Nile tilapia feed. Calcium levels may be linked to the continuous input of calcium hydroxide to maintain alkalinity, which is reflected in the sediment (Furtado et al., 2014). High calcium levels may also occur because of low quantities of available P (Pickens et al., 2020). Nitrogen in biofloc flour is directly proportional to floc size (Ekasari et al., 2014). It is estimated that 88% of the accumulated nitrogen in a fish farming system is associated with food and that it accumulates in sediment at approximately 2.6% of nitrogen (Gross et al., 2000). In our study, macronutrient concentrations (N, P, K, and Mg) were below values reported by Fimbres-Acedo et al. (2020), which often occurs with the micro- and macronutrient composition of effluents in different systems. Delaide et al. (2017) reported P, K, Fe, Mn, and S deficiency in sediments in a RAS system. Studies have recommended adding other components or supplementing the mineral deficiencies of biofloc flour with other products if biofloc is intended for use as a nutritional supplement for plants in other systems (Fimbres-Acedo et al., 2020).

5. Conclusion

The work was done under commercial conditions, lasted the entire 30-week (210-day) production cycle and makes an important contribution to the breeding of red tilapia in Colombia. No effects were detected on the physical and chemical parameters of red tilapia (*Oreochromis* spp.) reared in a biofloc system at densities of 30 fish/m³ and 40 fish/m³, and parameters remained within suggested ranges. It is important to perform adequate calculations for the aeration systems to ensure that

at the end of large-scale production oxygen levels do not reach lower limits and thereby risk fish survival. Density was not seen to affect productive performance indicators, but it is important that fish farmers establish the weight and size required by the buyer to decide which stocking density should be used and the estimated production time for obtaining fish that are ideal for marketing. The biofloc system did not affect the nutritional characteristics or microbiological concentrations of fish and the red tilapia produced in these systems was safe for human consumption. In addition, biofloc flour can be used as a nutritional supplement for fish due to its nutritional characteristics, but the amount produced is variable, becoming a limitation for its large-scale implementation.

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3. Capítulo III

Economic analysis of solar energy alternatives in red tilapia (*Oreochromis* sp.) production in a commercial biofloc system in Colombia

Economic analysis of solar energy alternatives in red tilapia (*Oreochromis* sp.) production in a commercial biofloc system in Colombia

Abstract

Sustainability in Action is the central theme of the FAO 's 2020 edition of The State of World Fisheries and Aquaculture. It presents the sustainable development goals that promote economic growth via strategies adapted to climate change. Nevertheless, investments and cost-benefit analyses should be evaluated for different production strategies. These evaluations should be made based on local specifications of the production systems. We analyzed the economic aspects of red tilapia (*Oreochromis* sp.) production in a system with biofloc technology using different sources of electrical energy. We monitored the production and economic indicator records of El Vergel Fish Farming Association in the Department of Arauca, a facility that produces monosex red tilapia in nine 143m³ tanks, with independent supply and aeration system. The treatments comprised tanks with conventional energy (CE), tanks with combined conventional energy/night + photovoltaic energy/day (CPVE), tanks with full photovoltaic energy and batteries (PVE), and a simulation with tanks with energy that generate surplus energy for use at night without batteries (PVES). The results of water quality and zootechnical performance were within the ranges suggested for the species for all treatments. Dissolved oxygen decreased throughout the production due to increase in fish size and biomass. The economic analysis showed increased initial investment costs when the technology used to modify the electrical energy source included solar panels and accumulator batteries. The PVE treatment represented the highest investment cost; however, it showed the lowest effective operating cost because it did not consume energy from the conventional power grid. Nevertheless, the total operating cost directly increased due to depreciation and system maintenance costs. Feed represented the highest percentage in production costs for all treatments followed by labor in CE, CPVE, and PVES treatment. Depreciation was the second highest cost for PVE treatment. Power was the third highest cost for CE and CPVE treatments. The sales price was the most important factor in maximizing financial profitability because the cost of the product when sold was below the production cost. The implementation of electrical energy sources enhances the viability of red

tilapia production in biofloc systems; however, strategies must be sought to improve product sales price and make economic viability possible.

Keywords: photovoltaic energy, BFT, solar panels, aquaculture, selling price

1. Introduction

In recent decades, aquaculture has become the best option for providing aquatic-derived protein (Zaki et al., 2020). The FAO has reported the aquaculture production of 466 individual species worldwide, including tilapia (FAO, 2020). By 2030, tilapia production is expected to double that of 2010 (Kobayashi et al., 2015). Efficient use of resources (Avnimelech, 2009), development of sustainable and environment friendly aquaculture systems (Naylor et al., 2000), and building systems that provide an equitable cost/benefit ratio to support economic and social sustainability are required to improve production (Avnimelech, 2009). According to Crab et al. (2012), biofloc technology (BFT) meets these requirements for the sustainable development of aquaculture.

BFT is an aquaculture production system based on efficiently using nutrients with minimum or zero water exchange (Ekasari and Maryam, 2012). It involves fusing food waste, toxic organic and inorganic compounds, by microorganisms present in the water, thus providing favorable conditions for chemoautotrophic, autotrophic, and heterotrophic bacteria to reduce the saturation of nutrients, making them available for reuse by fish (Avnimelech, 2009). Further, this technology depends on factors that are not taken into account in other systems, such as carbon sources to stimulate the growth of heterotrophic communities (Ridha et al., 2020) and electrical energy for the operation of aerators (Malpartida et al., 2018) used to maintain dissolved oxygen levels and turbulence.

The BFT system was originally used to produce different Penaeid species such as *Penaeus monodon*, *Fenneropenaeus merguensis*, and *Litopenaeus vannamei* (Emerenciano et al., 2013). The BFT system is extensively studied in white shrimp (*L. vannamei*) production (Tinh et al., 2021), including the analysis of bioeconomy indicators to assess the system's economic viability in shrimp production (Almeida et al., 2021), and productive integration studies of white shrimp and Nile tilapia (Poli et al., 2019). However, further studies are required to prove the technical and economic viability of the BFT system for red tilapia in monoculture.

Fuel and electricity are the main power sources used to produce aquatic organisms (Kim and Zhang, 2018). They are used for pumping water, cooling, processing, and aeration (Badiola et al., 2018; Ullah and Kim, 2018; Ghamkhar et al., 2020). Power costs depend on the regional location of the system. Electrical power consumption is directly proportional to the intensification of production and the technology used (Muir, 2015), and it is important in the environmental impact of aquaculture (Ghamkhar et al., 2020). Electrical power use can put the viability of production systems at financial risk because of the increase and instability of power prices (Pelletier et al., 2014; Badiola et al., 2017).

Electricity bills account for 10%–25% production costs in systems with electricity intensive load (Muir, 2015; Engle et al., 2020), especially in the recirculating aquaculture system (RAS). Oxygenation equipment in RAS consumes 20% of the total power used (Roque d'orbcastel et al., 2009) and adds 5% to the final product cost per kg (Badiola et al., 2018). Kubitzka (2011) reported that the cost of electrical power in BFT systems in Brazil could account for up to 15% of the production costs. Another study conducted in Brazil reported that the power used for aeration represents 11.96% of the production costs for Nile tilapia (*Oreochromis niloticus*) production in a BFT system with 1000 L tanks (Manduca et al., 2021). In Mexico, although the government provides a subsidy to a part of the electricity used for aquaculture production, implementation of the BFT system is limited by the cost of electricity bills (Betanzo-Torres et al., 2020). Experimental projects with *Piaractus brachypomus* and *O. niloticus* using BFT in Colombia reported that electrical power represents between 10% and 14% of the production costs (Brú-Cordero et al., 2017).

In aquaculture, different energy sources have been proposed for use according to the availability of resources in each country and the technologies developed (Badiola et al., 2018). An example of this is the use of geothermal power in systems for catfish production in countries such as Iceland (Ragnarsson et al., 2014) and Egypt (Farghally et al., 2014). The residual heat from thermoelectric or hydroelectric energy is used to aquatic organisms (Badiola et al., 2018; Liu et al., 2016). In addition, biogas is recommended to useful power in this activity (Kim et al., 2015). There are limited studies on the use of biomass, wind, or tidal power in fish farming (Toner and Mathies, 2002). Photovoltaic power is proposed as an

alternative in aquaculture (Troell et al., 2004; Kim et al., 2015; Muir et al., 2015), and is studied in tilapia hatcheries (Clough et al., 2020), recirculation systems (Fuller, 2007), and marine fish production (Château et al., 2019).

Collazos-Lasso and Arias-Castellanos (2015) suggested that studies on the BFT system should be conducted under specific conditions of each country and the production costs, especially the costs of electricity, should be calculated in detail. Thus, from an economic standpoint, this study aimed to analyze red tilapia production in a BFT system using conventional electrical (hydroelectric) energy and to determine whether photovoltaic energy, with its variations, can improve the economic viability of the activity.

2. Materials and Methods

2.1. Production system The study was conducted under field conditions, without disturbing the production process, at the facilities of El Vergel Fish Farming Association (ASOVERGEL, for its name in Spanish) located in the municipality of Arauquita, Vereda la Arenosa, at 6° 58' north latitude and 71° 07' longitude, at 143 m above mean sea level.

The production system included nine tanks (143m³), each with an independent supply and aeration system (Figure 1). Each year, 1.7 production cycles are performed with an average density of 6,500 fish per tank (45,4 fish/m³). The fish used weighed 5 g each and were previously masculinized with 17 alpha methyltestosterone. Aeration was constant during the study that was provided by radial splash aerators (1.5 hp) connected to the electrical power sources under study. For pH maintenance, 25 g/m³/day¹ calcium hydroxide was added when the values fell below 6.5 (Manduca et al. 2021). For the maintenance and control of nitrogen compound levels, liquid molasses (50% carbon) was used at a C:N ratio of 6:1 when ammonium values exceeded 1 mg/L (Ebeling et al. 2006).



Fig. 1. Image of the production system, high-density polyethylene (HDPE) geomembrane tanks and photovoltaic system.

Feeding was performed according to the feed manufacturer's instructions (Table 1), starting with 40% protein powdered feed and ending with 20% protein pelleted feed.

Table 1. Feed management during red tilapia production cycles

Weeks	Weight range (g)	CP %	Avg. feeding rate %	Times
1–6	20 - 28	40	7.1	9
7–13	100 – 120	34	3.6	6
14–19	220 – 245	30	2.3	5
20–25	370 – 395	24	1.5	4
25–30	370 - 470	20	1.3	4

*CP = Crude protein

2.2. Experimental design

The following treatments were included in the production cycle under evaluation: tanks with conventional energy (CE), tanks with combined conventional energy/night + photovoltaic energy/day (CPVE), tanks with full photovoltaic energy and batteries(PVE), and a simulation with tanks with energy that generate surplus energy for use at night without batteries (PVES).

1. CE: The source of energy was conventional electricity, 24 h a day throughout the production, provided by the public services company of the Department of Arauca. A fuel generator was used during power outage.

2. CPVE: The source of energy was combined (conventional and photovoltaic). No accumulator batteries were used in this system; therefore, electrical energy consumption was necessary at night. A fuel generator was used during power outage.

3. PVE: A photovoltaic energy source with infrastructure and accumulator batteries was used, thus making the system independent of conventional electric power or fuel generators.

4. PVES: This simulation system used photovoltaic energy connected to a conventional electrical network (on-grid). Solar panels were used to produce sufficient energy to run the system 24 h a day. No accumulator batteries were used; therefore, fuel generators were used during power outage, which is common in the rural areas where the study was conducted.

2.3. Water quality

Water quality parameters were assessed on a daily basis. Temperature, and dissolved oxygen concentration and saturation were measured using an YSI EcoSense® DO200A instrument , and pH was determined using a Hanna® meter (Model 991300). Ammonium, nitrite, nitrate, and alkalinity were weekly monitored using colorimetric methodologies. Weekly the volume of settleable solids (SS) was measured using an Imhoff cone.

2.4. Zootechnical performance

The zootechnical performance was analyzed in biometrics conducted at begin and harvest. All animals were weighed in groups, they were counted to calculate the survival, and final biomass was also calculated. Food intake by each group was recorded. The following equations were used for the zootechnical performance analysis:

- **Survival (S)%:** The percentage of individuals who survived till the end of each evaluation period.

$$S(\%) = (\text{Final number of individuals}) / (\text{Initial number of individuals}) \times 100$$

- **Average weight gain (AWG) g**

$$\text{AWG} = \text{Final average weight} - \text{Initial average weight}$$

- **Average food intake (AFI) g/day**

$$\text{AFI (g/individual)} = [\text{Total food intake (g)}] / (\text{Number of individuals})$$

- **Apparent feed conversion ratio (FCR) between AFI and AWG**

$$\text{FCR} = \text{AFI} / \text{AWG}$$

- **Final biomass (B) kg**

$$B = \text{Final number of individuals} \times \text{Final average weight}$$

2.5. Economic analysis

For the economic analysis, the production data obtained from the production cycles evaluated and the production models of the ASOVERGEL fish farm were used. Each treatment included three tanks, for a total of nine tanks of 143 m³ each equipped with radial splash aerators (1.5 hp). After obtaining the results, a financial projection and economic analysis was carried out for 6 tanks per treatment, each equipped with radial splash aerators (1.5 hp). The farm had a water use permit; the water resource came from the Matapalito River. Conventional electricity was provided by the public services company of the Department of Arauca. In addition, the fish farm had a 48 kVA fuel generator. Commonly used infrastructure included 20 m² warehouse, 9.5 m² office, and 10 m² bedroom.

The production data used for the economic analysis were obtained from three production cycles of monosex red tilapia. To obtain the fixed capital needed to start the activities, an inventory of the fish farm was made including tanks, aerators, support equipment, common use infrastructure, and an electrical power system. The

ratio of the capital invested in the tanks to the other investment items as well as the investment per m³ was determined. The hiring of two specialized professionals and two field technicians responsible for the daily tasks was also included in the analysis. The final product was marketed directly to the distributor, with no intermediaries for the sale of the fish.

With the parameters of zootechnical performance, costs of production factors and prices of fresh fish marketed, production costs and profitability indexes were calculated. The costs were obtained based on the Total Operating Cost (TOC) structure (Matsunaga et al., 1976), by adding the Effective Operating Cost (EOC) with depreciation. In the EOC, the costs of fry, feed, hired labor, maintenance of fixed capital, electric power in cases where electric power is used, fuel and inputs for the development of the BFT system were added. For this study, the value of Kw/h of 0.17 was taken into account, and as well as the monthly billing reports from the electric energy service provider. Depreciation of infrastructure, equipment and utensils was calculated using the linear method.

The economic indicators were determined using the method proposed by Martin et al. (1995) and Costa et al. (2018). Implementation investment, TOC, unit costs or average costs, gross revenue, operating profit = gross revenue – TOC and profit index = operating profit/gross profit × 100.

To determine profitability, operating profit, and profit index, the percentage of fresh fish destined for wholesale trade was considered. The investment values were corrected by the general price index (exchange rate: 3,994 Colombian pesos = 1.00 US dollar in January 2022, reference month for all prices).

The cash flow was elaborated over a 10-year horizon using fixed capital and outflows. The minimum attractiveness rate of return (MARR) was 5% and was determined by the highest value of a certificate of deposit offered by banks in Colombia. The outflows considered were investment in fixed capital to start the process, reinvestments in fixed capital over the horizon, operating cost, and working capital. The inflows included were gross profit on the sale of fresh fish, residual value, and working capital. The implementation of the project was considered as the initial time. Economic viability indicators such as net present value, internal rate of

return, and simple and economic payback period were calculated from the cash flow (Kassai et al., 1999; Almeida et al., 2021).

The net present value (NPV) is calculated to assess the viability of investment projects (Abdelhady, 2021). 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 (Almeida et al., 2021). If the NPV is positive, the investment in the project is favorable; on the contrary, if the result is negative, the investment is unviable and this indicates a profitability below the minimum required rate (Imron et al., 2021).

The NPV was calculated using the following equation: $NPV = \sum_{t=1}^T \frac{R_t - D_t}{(1+i)^t} + \frac{S_t}{(1+i)^t} - I_0$

where R_t is the revenue for a period t ; D_t is the expense for a period t ; S_t is the project residual value in the last period; I_0 is the initial investment; i is the MARR.

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 (Almeida et al., 2021). It functions as a tool to evaluate the viability of the investment, allowing to reflect the rate of return of the project (Larson et al., 2004). If the IRR is greater than or equal to the minimum attractive rate of return (MARR), the project may be attractive for investment. The IRR has a close relationship with NPV, and is a discount rate that makes the NPV equal to 0.

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

where R_t is the revenue for a period t ; D_t is the expense for a period t , S_t is the project residual value in the last period; I_0 is the initial investment; IRR is the internal rate of return.

The Payback (PB) is return period can be defined as the time needed to recover the amount of initial investment (Almeida et al., 2021). Entrepreneurs seek profitability in the shortest possible time, increasing profitability and reducing risk

(Larson et al., 2004). The PB is used as a tool to evaluate the recovery period of the investment (Gitman, 2018).

when cash flow for each period is equal, i.e. effective net inflows are constant, the PB can be calculated as follows:

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

Where I_0 is the initial investment; CF is the cash flow.

The PB 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, is easy to understand, adjusts for uncertainty of later cash flow, and is biased towards liquidity (Almeida et al., 2021).

In this case, production, harvest, and commercialization were based on animals with an average weight of 450 g, which was the weight associated with the highest market price for the producer. Fish was sold in its natural state, immediately after harvest and slaughter, and was directly delivered to buyers at the production facilities.

3. Results

3.1. Water quality

The water quality parameters (Table 2) remained within the normal ranges for the cultivated species and for the BFT system.

Table 2. Mean values (\pm standard deviation) average values of the water quality parameters during red tilapia production process using the BFT system

Parameter	Treatment		
	CE	CPVE	PVE
Temperature ($^{\circ}\text{C}$)	$28 \pm 2,3$	$29 \pm 1,9$	$28 \pm 2,1$
Dissolved oxygen (mg.L^{-1})	$5,3 \pm 1,5$	$5,1 \pm 2,1$	$5 \pm 1,3$
pH	$6,4 \pm 1$	$6,2 \pm 0,5$	$6,7 \pm 0,5$
$\text{NH}_4\text{-N}$ (mg.L^{-1})	$1 \pm 0,5$	$1 \pm 0,1$	$1 \pm 0,1$
$\text{NO}_2\text{-N}$ (mg.L^{-1})	0	0,01	0,01
$\text{NO}_3\text{-N}$ (mg.L^{-1})	$0,6 \pm 0,1$	$0,5 \pm 0,1$	$0,5 \pm 0,1$
Alkalinity (ppm)	139 ± 23	141 ± 19	137 ± 21

SS (mL.L-1)	39 ± 9	38 ± 10	39 ± 11
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BFT, biofloc technology; CE, tanks with conventional energy; CPVE, tanks with combined conventional energy + photovoltaic energy; PVE, tanks with full photovoltaic energy and batteries; NH₄-N, ammonium; NO₂-N, nitrite; NO₃-N, nitrate; SS, settleable solids

3.2. Productive performance

The electrical system implemented in the production of red tilapia in the BFT system did not affect the zootechnical performance (Table 3) as well as the production factors. Nevertheless, to avoid compromising fish survival, electrical support equipment was necessary to generate energy to operate the aerators in the CE, CPVE, and PVES systems.

Table 3. Mean values (\pm standard deviation) zootechnical performance of red tilapia cultivated in BFT with different sources of electrical energy

Treatment	Zootechnical performance parameters				
	S%	AWG (g)	AFI (kg)	FCR	TB (kg)
CE	94 \pm 1,0	0,430 \pm 0,02	0,647 \pm 0,002	1,46 \pm 0,05	2627
CPVE	94 \pm 0,5	0,428 \pm 0,02	0,648 \pm 0,002	1,51 \pm 0,07	2615
PVE	93 \pm 0,5	0,435 \pm 0,01	0,649 \pm 0,005	1,51 \pm 0,05	2629,5

BFT, biofloc technology; S, survival; AWG, average weight gain; AFI, average food intake; FCR, apparent feed conversion ratio; and B, total biomass of whole fish (TB). CE, tanks with conventional energy; CPVE, tanks with combined conventional energy + photovoltaic energy; PVE, tanks with full photovoltaic energy and batteries

3.3. Economic analysis

The investment costs (Fig. 2) for the CE, CPVE, and PVE systems were US\$ 45,831.39, US\$ 58,035.91, and US\$ 147,219.67, respectively. For the simulation PVES system the investment could reach up to US\$ 100,690.39. Commonly used infrastructure was the item with the highest percentage share of investment costs for CE and CPVE, 52.29% and 41.29%, respectively. The highest investment for

PVE and PVES was in the purchase of photovoltaic electric power systems, US\$ 103,507.90 and US\$ 56,978.62, respectively. Moreover, the investment cost in the purchase of splash aerators was between 12.17% and 3.79% in different systems (Table 4).

Table 4. Investment in dollars (US\$) for red tilapia production in BFT with different sources of electrical energy

Item	CE	CPVE	PVE	PVES
Infrastructure	11,601.88	11,601.88	19,363.52	11,601.88
Tank	10,065.10	10,065.10	10,065.10	10,065.10
Aerators	4506.76	4506.76	4506.76	4506.76
Electrical installations	9474.21	19335	110,614.67	53,798.20
Cable	210.32	210.32	1156.74	1156.74
Elec.consoles	1502.25	1502.25	1502.25	7511.27
Solar panels	-	4102.15	9858.54	18,590.39
Inverter	-	3004.51	3,004.51	6259.39
Frame	-	2754.13	9,764.65	6259.39
Batteries	-		75,112.67	
Regulator	-		10,215.32	
Transformer	-			6259.39
Fuel generator	7761.64	7761.64		7761.64
Others	1382.07	1382.07	1382.07	1382.07
Total	37,030.02	46,890.81	145,932.13	81354

* Trading date: 01/20/2022 Exchange rate: 3,994 Colombian pesos = 1.00 US dollar. BFT, biofloc technology; CE, tanks with conventional energy; CPVE, tanks with combined conventional energy + photovoltaic energy; PVE, tanks with full photovoltaic energy and batteries; PVES, a simulation with tanks with energy that generate surplus energy for use at night without batteries

The investment value varied depending on the energy system used. Photovoltaic energy storage batteries increased the total investment cost threefold compared to that of production with conventional energy or a partial photovoltaic system. The investment in electrical installations for the PVE system doubled that of the PVES system, although the number of panels purchased for PVES was greater than that for PVE. Batteries cost was thrice as much as the panels.

The photovoltaic system reduced the production costs (Table 5). The use of energy storage batteries in the PVE system decreased the total EOC by

approximately 7.7% compared to the PVES system and by 27.4% compared to the CE system (Fig. 3).

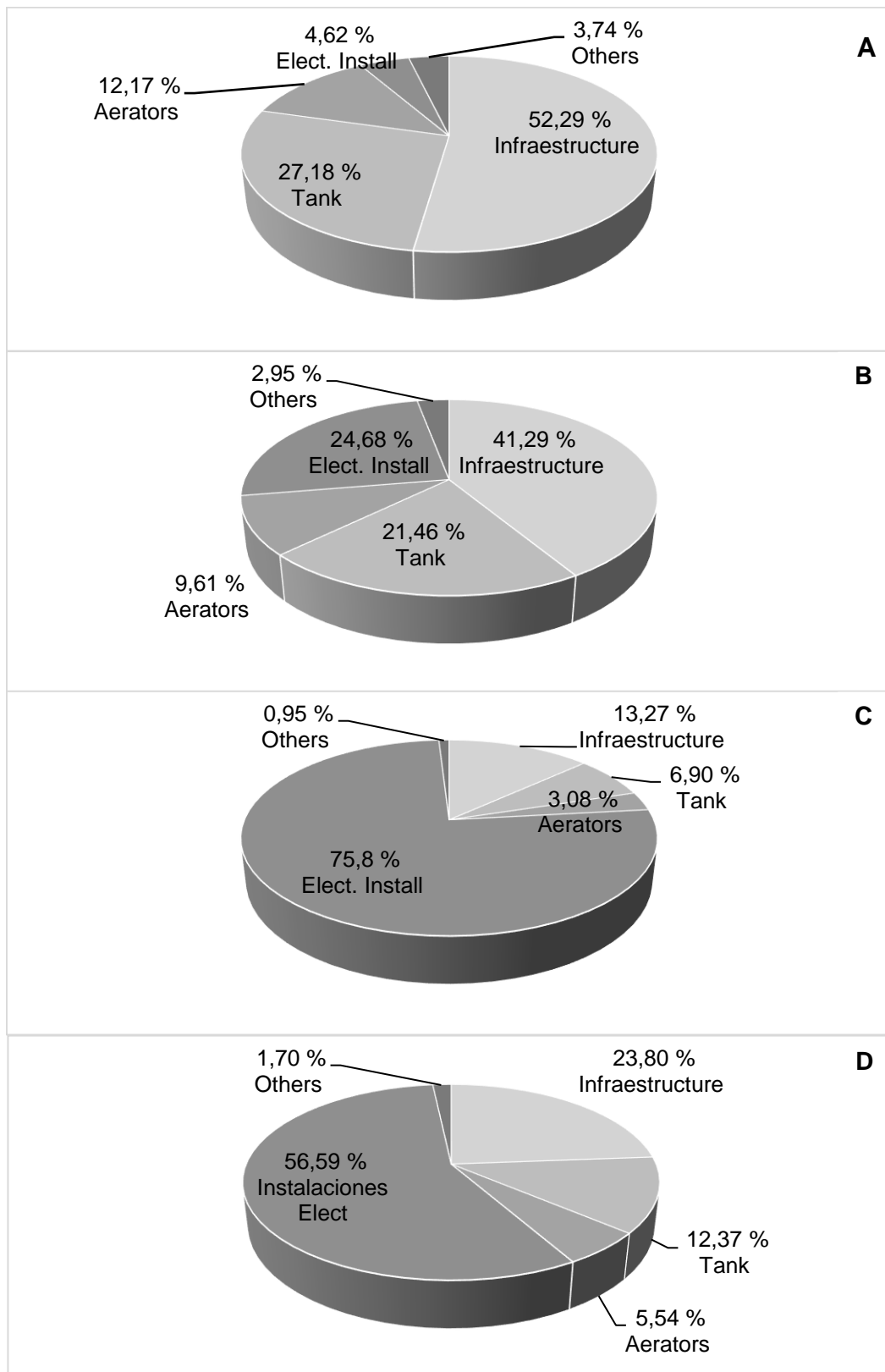


Figure 2. Percentage share of initial investment costs for fish farming in BFT with different sources of electrical energy in the eastern region of Colombia. **A. CE, B. CPVE, C. PVE, D. PVES.** BFT, biofloc technology; CE, tanks with conventional energy; CPVE, tanks with combined conventional energy + photovoltaic energy; PVE, tanks with full photovoltaic energy and batteries; PVES, a simulation with tanks with energy that generate surplus energy for use at night without batteries

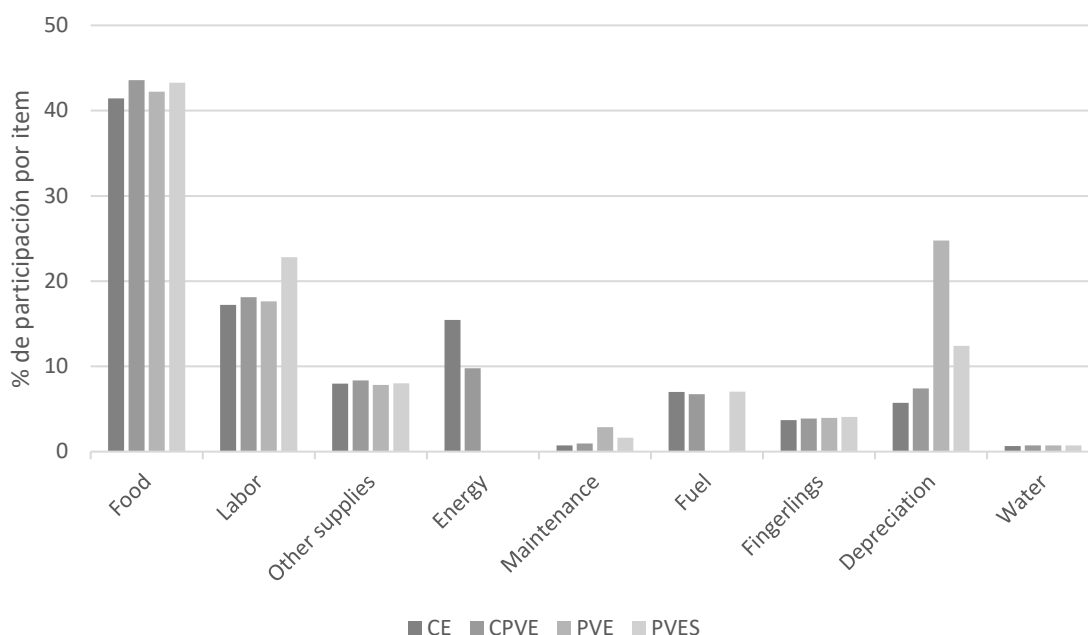


Figure 3. Percentage share of production costs for red tilapia production in BFT with different sources of electrical energy in the eastern region of Colombia. BFT, biofloc technology

The cost of food was 41% for CPVE and 39% for CE and PVE (Fig. 3). The highest cost of food in the entire study was observed for the PVES simulation with 43% share in the production costs. The values were not affected by the energy system implemented for the operation of the aerators.

The specialized labor to implement the BFT system was the second item with the highest share in the production costs, with 20%, on average, for all the electrical energy systems studied.

The cost of water supply was the same for all systems. Electricity billing costs decreased with the implementation of photovoltaic systems. In PVE, the costs of power or fuel were not considered because of the storage batteries. Conversely, those systems without batteries consumed between 6% and 8% of fuel costs due to

the use of electric generators during a power outage. This represented 9% and 14% in the CE and CPVE systems, respectively. The maintenance costs were US\$ 587.36 for PVES and US\$ 858.78 for PVE. This can be attributed to the equipment installed, whose cost was higher than that of conventional electrical installations. The battery life (5 years) and equipment necessary for PVE represented 26% of the TOC in depreciation, making this system the one with the highest depreciation.

Table 5. Total operating cost and production indices obtained from the production of red tilapia in BFT with different sources of electrical energy

Costs	Treatments			
	CE	CPVE	PVE	PVES
Inputs	18,218.68	18,175.37	15,991.76	18,023.20
Food	12,595.66	12,567.20	12,506.00	12,506,00
Cane molasses	1,381.65	1351.49	1355.51	1.355,51
Calcium hydroxide	713.28	728.61	633.61	633,61
Hypochlorite	71.36	71.36	71.36	71,36
Urea	7.03	7.03	7.03	7,03
Fingerlings	1171.76	1171.76	1171.76	1.171,76
H ₂ O quality reagents	246.50	246.50	246.50	246,50
Fuel	2031.44	2031.44	-	2031.44
Labor	5225.01	5225.01	5225.01	5225.01
Utilities	4908.50	3028.06	210.32	210.32
Power	4,698.18	2,817.74	-	-
Water	210.32	210.32	210.32	210.32
Maintenance	216,01	273,53	851.27	474.57
EOC	28,568.20	31,926.98	22,278.36	23,933.1
Depreciation	1815,94	2,132.76	7,336.87	3588.31
Total operating cost	30,384.14	34,059.74	29,615.23	27,521.40
Production (kg.cycle ⁻¹)	14,229.24	13,767.98	13,673.56	13,673.56
Sales price (US\$.kg ⁻¹)	2.30	2.30	2.30	2.30
Gross income	32,776.42	31,713.94	31,496.42	31,496.42
Gross profit	2392.27	2345.81	1881.19	3975.02
Breakeven point (US\$.kg ⁻¹)	2.14	2.47	2.17	2.01
Breakeven point (K)	13.190,68	14.786,37	12.856,87	11.947,88

BFT, biofloc technology; CE, tanks with conventional energy; CPVE, tanks with combined conventional energy + photovoltaic energy; PVE, tanks with full photovoltaic energy and batteries; PVES, a simulation with tanks with energy that generate surplus energy for use at night without batteries; NPV, net present value

4. Discussion

The BFT system is proposed to be a substitute for aquaculture production systems that use large quantities of water (Crab et al., 2012). Collazos-Lasso and Arias-Castellanos (2015) stated that BFT is a good alternative for fish farming in Colombia because it reduces the contamination of tributaries also because of prolonged droughts in some regions of the country. However, they recommended making detailed calculations of the production costs, especially those related to electricity. In commercial aquaculture, it is important to consider the economic performance (Ponce-Marbán et al., 2006) because it provides vital support for the sustainability and continuity of an aquaculture farm (King et al., 2018).

In aquaculture, the use and dependence on energy increases as the production increases. In turn, this increases the cost per kg of fish produced, making the sector vulnerable due to the energy costs and instability of prices (Pelletier et al., 2014). The product cost increases by 5% in the production systems that include aeration (Badiola et al., 2018). In the present study, based on the total EOC, the product cost was 23% higher under conventional energy than that in the system using PVE. but the TOC result shows that the difference in the cost of the product is 2.5% higher in conventional energy, this will depend on the useful life of the batteries and panels, because the shorter the useful life, the greater the depreciation that will be reflected in the TOC of the product. Energy is mainly used for mechanical support processes, such as aeration to maintain oxygen levels as well as to maintain particles or flocs in suspension, and represents one of the main drawbacks of the BFT systems (Brú-Cordero et al., 2017; Rego et al., 2017; Almeida et al., 2020). According to Almeida (2021) the cost of energy is the second fixed cost with the highest effect on the TOC of shrimp production in the BFT system with a value of 10.7%. In the present study, energy represented 15.46% and 8.27% in the CE and

CPVE systems, respectively. In contrast, PVE and PVES systems had no costs of energy because of the use of batteries and surplus energy production.

In Egypt, intensive fish farming systems have increased energy use by 25% (Soliman and Yacout, 2016). Power requirements in the biofloc system are approximately 22.4 kW per kg of fish, whereas the production in RAS requires 11.2 kW per kg of fish (Luo et al., 2014). In the present study, 2.3 kW were necessary for the production of 1 kg of red tilapia, considering only the energy consumption of the aerator, i.e., excluding any other energy consumption in the farm. In Brazil, electricity represents 15% of the production costs for tilapia production in BFT systems (Kubitza, 2011). In Mexico, energy costs affected profitability, increasing the costs by 6% to 15% for the production of Nile tilapia in BFT systems compared to green water systems (Suárez-Puerto et al., 2021). Although 50% of the total cost of energy is subsidized in that country, it is still a constraint for the implementation of the BFT system. Studies conducted in Colombia have concluded that the energy cost to produce *Piaractus brachypomus* and Nile tilapia in polyculture with the BFT system is 14% (Brú-Cordero et al., 2017). The above confirms the results of 15% of energy costs obtained in the present work, specifically in the TEC treatments.

Therefore, developing aquaculture production systems based on alternative energy sources has become a topic of general interest (Badiola et al., 2012). Solar energy is proposed as a substitute for conventional energy sources for the production of aquatic organisms in intensive systems that depend on an energy source for the operation of equipment (Badiola et al., 2018).

Photovoltaic systems used exclusively during daytime (daylight hours) reduce the consumption of conventional electricity by 34% in in-ground ponds for tilapia production (Numpha and Polvongsri, 2020). In Korea, energy savings of approximately 19.9% were observed after the implementation of solar panels in aquaculture farms. In the present study, partial implementation of photovoltaic energy decreased 40% of the energy cost, and the implementation of photovoltaic energy along with storage batteries decreased energy costs in the EOC by 100%.

The use of solar panels in a recirculation system for the production of Nile tilapia fingerlings in Kenya, Africa, reduced energy costs by US\$ 120 per month. Pereira (2020) stated that the BFT system is viable for *Colossoma macropomum*

production only if solar panels are used to generate energy. Although there are proprietary photovoltaic energy systems for the BFT system (Lee, 2018), there are no studies comparing the strategies and models that implement solar panels for the production of aquatic organisms in the BFT system.

The different strategies and energy source models assessed in the present study showed a variety of investments. The systems that include batteries to store energy and keep the equipment running without depending on conventional energy, represented the largest investment and tripled the investment required for systems that use conventional energy. Costa et al. (2018) stated that the cost of cages is the largest investment in the production of Nile tilapia; however, the use of new technologies reduces the share of cages in the total investment. Similarly, in the present study, the share of geomembrane tanks was higher in the initial investment costs for those systems that used less technological equipment.

The greenhouse structure represented 75% of the initial investment in the production of white shrimp (*L. vannamei*) in the BFT system. Among the components included were galvanized arches, polyethylene sheets, geomembrane-lined wooden boxes, pipes, aerators, and air diffusion pipes (Almeida et al., 2020). In this study, the initial investment in production infrastructure was lower because greenhouses were not considered.

The energy sources and systems implemented in red tilapia production did not affect the total quantity of supplies used; however, they affected the costs of energy, fuel, maintenance, and depreciation. Fish farming systems that use batteries to keep the equipment running during hours when there is no sunlight have reported a 5-year lifetime for the batteries (Amin et al., 2020), requiring replacement twice during the lifetime of the photovoltaic panels (Koyuncu et al., 2020). In our work we used lithium batteries, which despite having a higher cost, have a useful life of 10 years, thus reducing reinvestment costs and depreciation costs. According to Yuan et al. (2017), aerators used in tilapia production in China have a 5-year lifetime under production conditions. However, the current equipment for aquaculture aeration has UV protection and is made of high-density polyethylene, which can extend the lifetime by 15–20 years. Therefore, the depreciation of aerators did not represent an important share of costs in this study.

Labor is essential in the BFT system for technical management and high densities allow for efficient use of the facilities (Sookying et al., 2011). Moreover, the implementation of smaller areas translates into hiring fewer but more specialized personnel. According to Almeida et al. (2021), specialized labor accounted for 17% in the production of marine shrimp using the BFT system, and it was not always hired to avoid increasing labor costs. Labor represented more than 20% of the costs for tilapia production in the BFT system; however, a larger fish farm could be managed with the same labor considered in the present study for the production using six tanks. Less intensive systems and less specialized management usually involve family labor, and the professional visits for technical assistance are paid for by several producers jointly. Therefore, labor costs would not represent a significant percentage of production costs (Zuniga-Jara y Goycolea-Homann, 2014).

Tilapia sales costs in Colombia are steady even when farmed in systems that use fewer liters of water per kg of fish produced. Red tilapia has a higher sales price than Nile tilapia. However, as reported by Yuan et al. (2017), the lack of knowledge and lack of commercial organization of producers prevents them from getting competitive prices for their product. This situation forces fish farmers to depend on wholesale buyers who set the price for 300–500 g tilapia. Similarly, in the present study, the price was set by intermediaries. Although the prices reported at the main supply centers are higher, the producers are paid 22% less. Buyers do not pay more for larger fish (Yuan et al., 2017), and fish are sold from 350 g (Betanzo-Torres et al., 2020). It is therefore imperative to search for strategic markets by assessing the value chains for red tilapia that will allow higher gross profit. This is observed in the commercialization of shrimp wherein the average final weight and sales price represent the most relevant factors in maximizing financial return. This occurred because better prices were obtained for larger shrimp, with the lowest commercialization price reported at US\$ 7.20 (Almeida et al., 2021). In contrast, in the present study, the sales price for whole tilapia was US\$ 2.3, and did not vary depending on the size. Further, the sales value directly affects the return on investment and the TOC. Despite the fact that tilapia has a lower cost of sale, it was observed that the economic viability is positive, and this viability improves depending on the energy source used.

Gross profit is important while analyzing cash flow, which in turn is an indicator of the financial viability of production projects (Mazzarol and Reboud, 2020). The present study shows that red tilapia production under the studied conditions, using partial or complete photovoltaic systems or surplus energy production models, they manage to have cash flow in future projections with positive indicators, similar to those shown for marine shrimp production in Brazil, where sales prices allow gross profits higher than production costs. (Almeida et al., 2021).

Conclusion

The production of red tilapia using the BFT system is technically feasible in the eastern region of Colombia. However, the results of this economic analysis show the need to develop sale strategies for the product to improve financial returns and to ensure positive economic viability.

Further studies should be conducted to evaluate the value chain of red tilapia, thus improving economic results. Research should be conducted on energy sources for the biofloc system and tools should be sought that allow more efficient use of specialized labor, e.g. increase the productive units and calculate the number of workers needed for the units, without negatively affecting the production costs.

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Considerações finais

Os resultados dos estudos foram importantes para determinar que densidades de 30 e 40 peixes/m³ não tem diferença nos indicadores de desempenho produtivo, qualidade da água e características nutricionais da tilápia vermelha, as tilápias usadas nos estudos foram monosexo e não se apresentaram reproduções no sistema BFT, as densidades estudadas amostram que no sistema BFT a densidade de 40 peixes/m³ resulta em uma maior biomassa final, mas os peixes são de menor tamanho, por tanto se o mercado exige animais de maior tamanho o produtor deveria prologar o tempo de criação ou diminuir a densidades para obter peixes de maior tamanho em menor tempo. Os peixes em densidades de 30 ou 40 peixes/m³ tem qualidade e inocuidade segura para o consumo humano, mesmo sendo produzidos em um sistema onde a água tem alta quantidade de microrganismos, devido a que as principais comunidades microbiológicas no BFT são benéficas, se o protocolo é feito corretamente. O resíduo dos sedimentos no sistema BFT muitas vezes é eliminado, mas o estudo conclui que estes sedimentos poderiam ser transformados em farinha e que pelas suas características bromatológicas e de micro e macronutrientes possibilitando o uso em suplementos alimentícios para animais ou fertilizantes para plantas ornamentais, porem as quantidades de farinha obtidas flutuam nos ciclos de produção. A energia elétrica usada principalmente para que os aeradores estejam em funcionamento 24/7 tem uma alta implicação nos custos de produção, as opções estudadas em nosso trabalho, amostram uma melhora no rendimento econômico do sistema BFT, mesmo não obtendo uma viabilidade financeira o uso de energia fotovoltaica em nosso estudo, amostra que o uso eficiente dos recursos levam a ter resultados econômicos próximos dos ótimos, para que a empresas piscícolas que por condições ambientais, geográficas ou por necessidades particulares, precisam implementar sistemas em BFT tenham uma viabilidade monetária. Mas o mais importante é que o custo do produto gerado em sistemas com uso eficiente do recurso hídrico (maior quilogramas de carne de peixe produzido por litro de água) poderia ter um maior custo de venda, mas isto vai depender da politica publica de cada pais, tendo países que estimulam produções aquícolas com menor impacto ao ambiente porem regulam os preços dos produtos, diferenciando de produções com uso ineficiente do recurso hídrico. Também é importante as agremiações de produtores para que o produto final seja comprado o comercializado sem a intervenção dos atravessadores os intermediários que diminuem o preço para ele obter maiores ganancias, isto dificulta a viabilidade econômica dos sistemas com maior densidades que precisam de tecnologias para manter densidades de estocagem semi-intensivas ou intensivas. Como conclusão geral do trabalho, é que o sistema BFT tecnicamente usando densidades de 30 e 40 peixes é viável, más para que seja economicamente viável é necessário estudar cadeias de comercialização e continuar pesquisando metodologias que reduzam os custos de produção principalmente da energia e dos alimentos balanceados.