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AQUAPONIA MEDICINAL: UM MÉTODO SUSTENTÁVEL E EFICIENTE PARA PRODUÇÃO INTEGRADA DE PEIXES E PLANTAS MEDICINAIS

Bernardo Ramos Simões Corrêa

Brasília, 2022

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Tese apresentada ao curso de Doutorado do Programa de Pós-Graduação em Ciências Ambientais (PPGCA), da Faculdade UnB de Planaltina (FUP), da Universidade de Brasília (UnB), como requisito para o título de Doutor.

Orientador: Prof. Dr. Rodrigo Diana Navarro

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“*It takes a revolution to make a solution,*
So my friend I wish that you could see,
like a bird in the tree, the prisoners must be free.
We got lightning, thunder, brimstone and fire.
Kill, cramp and paralyse all weak at conception.
Let rightousness cover the earth, like the water
cover the sea.”
Trechos de *Revolution* (Bob Marley)

“*Lovin’ is what I got...*”

(Sublime)

RESUMO

A atenção aos aspectos ambientais está cada vez mais atrelada à produção agrícola, altamente dependente de água e nutrientes. Tanto os problemas relacionados com a escassez e poluição hídrica, quanto à produção e utilização indiscriminada de nutrientes, causam impactos na sanidade ambiental dos ecossistemas. Outro aspecto que agravam estes impactos são as mudanças climáticas, que devem ampliar a deterioração da qualidade de água em muitas regiões. A aquaponia tem como fundamento aliar sinergicamente as produções aquícolas (principalmente piscícola) com a produção vegetal em hidroponia (meio aquoso) em sistema fechado, a partir da reciclagem do efluente aquícola, rico em nutrientes (principalmente nitrogênio e fósforo). A técnica aquapônica diminui a quantidade de água utilizada em cada uma dessas produções, sendo que o efluente piscícola passa por tratamento biológico a partir da absorção de nutrientes na produção vegetal e a água "polida" retorna para a produção de peixes. A escolha de espécies animal e vegetal de alto valor agregado pode se aliar aos aspectos sustentáveis da produção aquapônica e ser mais atrativa aos produtores rurais. Sendo assim, a presente tese teve como objetivo realizar experimentos e análises que remetem a produção de plantas medicinais em aquaponia. Foram realizados dois experimentos práticos em sistemas aquapônicos idênticos instalados em estufa, visando analisar o desempenho da produção de espécies de plantas medicinais em associação com a produção de peixes ornamentais, além de uma revisão bibliográfica acerca do tema da aquaponia utilizando plantas medicinais. Ainda que seja um tema incipiente, a produção de espécies medicinais em aquaponia demonstrou ser viável e uma opção para produtores aquapônicos.

Palavras-chave: Sistemas aquapônicos; Reciclagem de água; Ciclagem de nutrientes; Sustentabilidade; Sinergia.

ABSTRACT

The attention to environmental aspects is increasingly linked to agricultural production, which is highly dependent on water and nutrients. Both problems related to water scarcity and pollution, and the indiscriminate production and use of nutrients, impact the environmental health of ecosystems. Another aspect that exacerbates these impacts is climate change, which should increase the deterioration of water quality in many regions. Aquaponics is based on synergistically combining aquaculture production (mainly fish) with plant production in hydroponics (aqueous medium) in a closed system, from the recycling of aquaculture effluent, rich in nutrients (mainly nitrogen and phosphorus). The aquaponic technique reduces the amount of water used in each of these productions, and the fish effluent undergoes biological treatment from the absorption of nutrients in plant production and the "polished" water returns to fish production. The choice of high added value animal and plant species can be combined with the sustainable aspects of aquaponic production and be more attractive to rural producers. Therefore, the present thesis aimed to carry out experiments and analyzes that refer to the production of medicinal plants in aquaponics. Two practical experiments were carried out in identical aquaponic systems installed in a greenhouse, aiming to analyze the performance of the production of medicinal plant species in association with the production of ornamental fish, in addition to a literature review on the topic of aquaponics using medicinal plants. Besides being an incipient topic, the production of medicinal species in aquaponics proved to be viable and an option for aquaponic producers.

Keywords: *Aquaponic system; Water recycling; Nutrient cycling; Sustainability; Synergy.*

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SIGLAS

FAO	Organização das Nações Unidas para Alimentação e Agricultura
OCDE	Organização para Cooperação e Desenvolvimento Econômico
DWC	*Deep Water Culture*
NFT	*Nutrient Film Technique*
MBT	*Media Bed Technique*
WOS	*Web of Science*
N	*Nitrogen*
P	*Phosphorous*
EC	*Electrical Conductivity*
TDS	*Total Dissolved Solids*
HLR	*Hydralic Loading Rate*
Ca	*Calcium*
NaCl	*Sodium chloride*
NPK	*Nitrogen, Phosphorous and Potassium*
CFDA	*China Food and Drug Administration*

1- INTRODUÇÃO

A produção de alimentos, além de envolver aspectos econômicos que englobam várias cadeias de atores sociais, é altamente dependente dos aspectos ambientais para manutenção da produtividade, sendo a água o elemento de maior preocupação e discussão entre entidades de importância global (FAO, 2020). Segundo a Organização das Nações Unidas para Alimentação e Agricultura – FAO (2020), a conscientização das interações entre alimentos, energia, pobreza, meio ambiente e mudanças climáticas está aumentando, bem como o reconhecimento de que a água desempenha um papel central em todas essas questões.

A Organização para Cooperação e Desenvolvimento Econômico – OCDE (2020) indica que, além de a produção agrícola ser altamente dependente da água e cada vez mais sujeita a riscos hídricos, é também o maior setor de uso e um dos principais poluidores da água. Melhorar a gestão da água na agricultura é, portanto, essencial para um setor agroalimentar sustentável e produtivo. Juntamente com essas mudanças, os agricultores de muitas regiões enfrentarão uma concorrência crescente de usuários não agrícolas, devido ao aumento da densidade populacional urbana e à demanda de água dos setores de energia e indústria. Além disso, é provável que, devido ao crescimento das atividades poluidoras e à salinação das águas doces causada pelo aumento do nível do mar, a qualidade da água se deteriore em muitas regiões. (OCDE, 2020).

De acordo com a FAO (2020), um dos principais problemas relacionados à água que precisam ser abordados é a produção de mais alimentos enquanto se utiliza menos água. Enquanto a agricultura enfrenta desafios complexos para satisfazer uma população estimada em nove bilhões, entre agora e 2050, será necessária mais água para produzir os estimados 60% extra de alimento, sendo necessários trabalhos que se concentram em um uso mais eficiente, equitativo e ecológico da água na agricultura (FAO, 2020).

A agricultura irrigada continua sendo o maior usuário de água do mundo, uma tendência incentivada pelo fato de os agricultores na maioria dos países não pagarem pelo custo total da água que usam. A irrigação agrícola é responsável por 70% do uso da água em todo o mundo e o bombeamento intensivo de águas subterrâneas para irrigação pode esgotar os aqüíferos e levar a externalidades ambientais negativas, causando um impacto econômico significativo no setor. Além disso, a agricultura continua sendo uma importante fonte de poluição da água através do escoamento de fertilizantes agrícolas e do uso de pesticidas que contribuem para a poluição dos cursos d’água e das águas subterrâneas (OCDE, 2020).

Para o Banco Mundial (2020), mudanças significativas nas alocações intersetoriais de água serão necessárias para apoiar o crescimento econômico contínuo. Devido ao crescimento populacional, urbanização, industrialização e as mudanças ambientais e climáticas, a eficiência do uso da água aprimorada precisará ser correspondida pela realocação de até 25 a 40% da água nas regiões afetadas pela água, de menor para maior produtividade e atividades de emprego. Na maioria dos casos, espera-se que essa realocação venha da agricultura, devido à sua alta participação no uso da água.

As mudanças climáticas levarão a eventos extremos climáticos mais frequentes e intensos, como secas e inundações, com impactos devastadores nos sistemas de produção de alimentos, e uma gestão sólida da água é essencial para criar resiliência social contra esses riscos crescentes (FAO, 2020). Para muitas pessoas do campo, a água é frequentemente o principal fator de produção que precisa ser assegurado. Para enfrentar esse desafio, devem-se apoiar modelos de intensificação limpos e eficientes em termos de recursos, aumentando a produtividade da água nos usos doméstico, industrial e agrícola (FAO, 2020).

O conceito das fronteiras planetárias para os processos do sistema terrestre proposto por Steffen et al. (2015), em que o ser humano vem impactando desde a industrialização, se baseia em evidências científicas para definir um espaço operacional seguro para a humanidade, como uma condição prévia para o desenvolvimento sustentável. De acordo com o conceito, transgredir uma ou mais fronteiras pode ser prejudicial ou até catastrófico, devido ao risco de cruzar limiares que desencadearão mudanças ambientais abruptas e não lineares em sistemas de escala continental a planetária.

A fim de associar a redução no consumo de água na produção e uma agricultura mais limpa, Goddek et al. (2019) trazem uma discussão referente a teoria das fronteiras planetárias, apresentados por Steffen et al. (2015), para a melhor compreensão da sustentabilidade na aquaponia, delimitando, também, a atuação dos efeitos positivos da tecnologia na integridade da Biosfera (Figura 1).

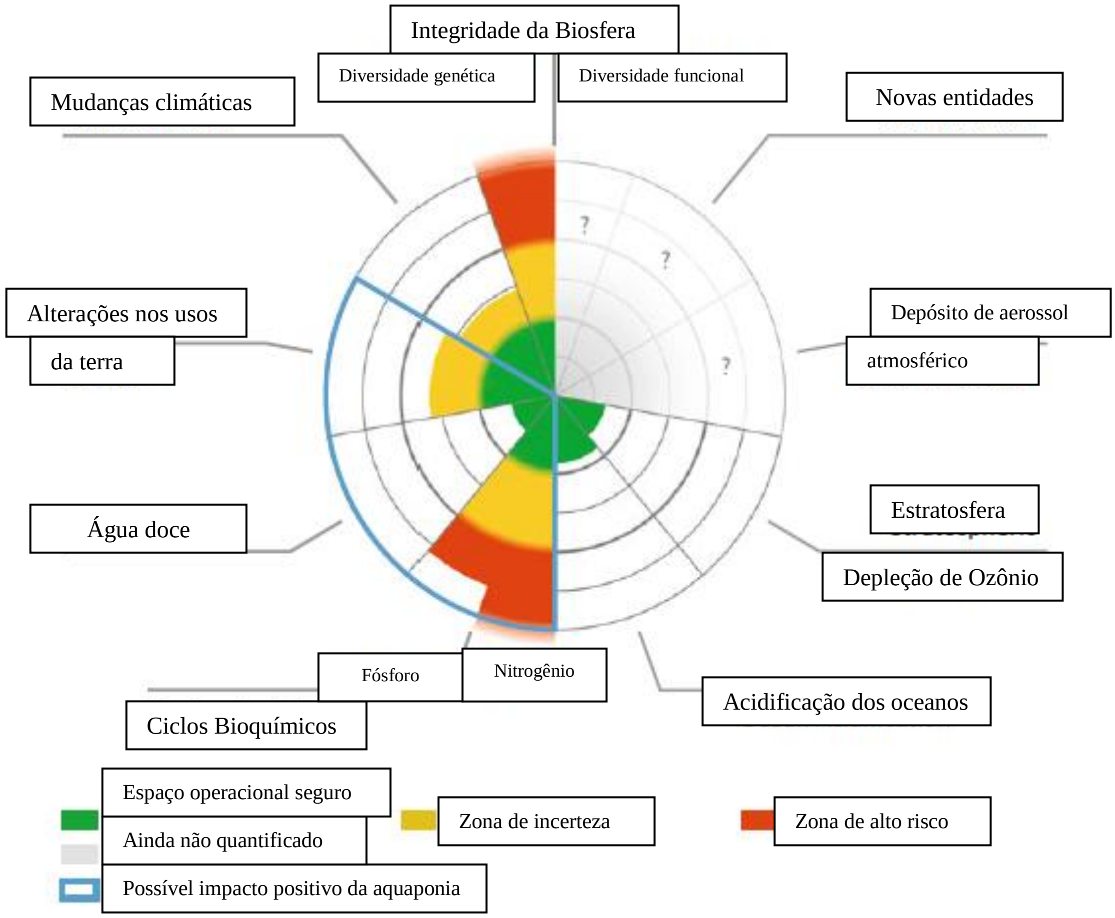

Figura 1. Status atual das variáveis de controle para sete dos limites planetários, conforme descrito por Steffen et al. (2015). A zona verde é o espaço operacional seguro, o amarelo representa a zona de incerteza (aumento do risco), o vermelho é uma zona de alto risco e os limites da zona cinza são aqueles que ainda não foram quantificados. As variáveis descritas em azul (ou seja, alterações no uso da terra, água doce e os ciclos bioquímicos) indicam os limites planetários onde a aquaponia pode ter impactos de efeito positivo. Fonte: Adaptado de Goddek et al. (2019).

Apesar de relatado por Steffen et al. (2015), assim como em Goddek et al. (2019), que o planeta já atingiu a zona de alto risco em relação aos seus limites na questão do nitrogênio e fósforo, a tendência da utilização do nitrogênio na agricultura no Brasil é crescente, tendo sido registrado um aumento das média de 34,84 Kg/ha, em 2002, para 81,63 Kg/ha em 2017 (últimos dados). Para o fosfato, forma de disponibilização do fósforo, ocorre a mesma tendência, aumentando de 47,8 Kg/ha, em 2002, para 81,34 Kg/ha, em 2017 (FAOSTAT, 2020).

As crescentes restrições e custos quanto ao uso da água tem obrigado produtores rurais, em inúmeros países, a buscarem alternativas mais econômicas com respeito ao uso da água para viabilizar a produção de alimentos e, dentre as diversas alternativas, a aquaponia tem sido indicada como uma solução eficaz para as restrições (Braz, 2000; Lennard, 2004). A aquaponia pode produzir alimentos a partir da integração de organismos aquáticos, vegetais e microrganismos, podendo reduzir o consumo de água em até 90%, se comparada aos sistemas convencionais, promovendo o reaproveitamento integral do efluente gerado dentro do próprio sistema (Carneiro et al., 2015). Também, pode de ser utilizada em regiões onde o solo apresenta baixa fertilidade química (solos distróficos) e a água é escassa, por exemplo, em áreas urbanas, climas áridos e ilhas abaixo do nível do mar (FAO, 2016), além de poder resultar em um aumento da eficiência na utilização do espaço (menos custos e materiais, maximizando o uso da terra) (Goddek et al., 2019).

A aquaponia permite que as plantas utilizem os nutrientes provenientes da água do cultivo de peixes, melhorando a qualidade da água, podendo esta, ser reutilizada na produção de peixes (Hundley e Navarro, 2013; Hundley et al., 2013; 2018; Kodama et al., 2019; Navarro et al., 2021). A partir da combinação destes sistemas, a aquaponia se ajusta à definição de agricultura sustentável combinando a produção de plantas e animais, integrando o fluxo de nutrientes por ciclos biológicos naturais (nitrificação) e fezendo uso mais eficiente dos recursos não renováveis. Portanto, sistemas de aquicultura e hidroponia adequadamente projetados e bem manejados podem ser considerados alternativas ambientalmente responsáveis para produção de hortaliças cultivadas em campo e para a pesca silvestre (Tyson et al., 2011).

O desenvolvimento da aquaponia foi muito influenciado pelo movimento de agricultura sustentável e os refinamentos adicionais na técnica foram promovidos por investigadores universitários, que procuram estabelecer a aquaponia como um viável setor agrícola. A aquaponia é apresentada como uma forma de agricultura sustentável porque imita os sistemas naturais, é eficiente quanto à água e produz menos impactos ambientais, ao reutilizar o efluente piscícola na produção vegetal, que algumas formas de aquicultura (Love et al., 2014). Aquaponia é uma tecnologia emergente de produção de alimentos que tem a capacidade de condensar e comprimir a produção em espaços e lugares que normalmente não seriam usados para cultivar alimentos (Goddek et al., 2019), como telhados, locais industriais abandonados e, geralmente, áreas não-aráveis ou contaminadas (Reinhardt et al., 2019) e assim, evitando o desmatamento.

Embora a aquaponia possa ser vista como parte de uma solução global para aumentar a produção de alimentos de maneiras mais sustentáveis e produtivas, atualmente, cultivar mais alimentos nas áreas urbanas está se tornando reconhecidamente como parte da solução para a segurança alimentar e uma possível crise no sistema global de alimentos (Konig et al., 2016). Os sistemas aquapônicos podem se tornar mais produtivos e sustentáveis ao adotar tecnologias alternativas de cultivo e aprendendo com tecnologias emergentes, como agricultura vertical e paredes vivas (Khandaker e Kotzen, 2018). Além disso, por serem eficientes em termos de espaço, os sistemas aquapônicos podem ser mais bem integrados em áreas urbanas (Kotzen et al., 2018). A aquaponia é considerada um exemplo promissor e vem potencialmente contribuindo para a sustentabilidade, produzindo peixe fresco e vegetais de qualidade, utilizando sistemas intensivos de ciclo tecnológico, sendo interessante para a comunidade científica, formuladores de políticas e empresários (Konig et al., 2018).

2- REFERENCIAL TEÓRICO

À medida que a população mundial cresce as demandas por maior produção de alimentos se expandem e à medida que as pressões sobre recursos como terra, água e nutrientes se tornam cada vez maiores, há uma necessidade urgente de encontrar métodos alternativos, sustentáveis e confiáveis para fornecer esses alimentos (Maucieri et al., 2019). A aquaponia, uma tecnologia que integra aquicultura e hidroponia, fornece parte da solução (Goddek et al., 2019). O problemático descarte de efluente de sistemas aquícolas levou ao advento da aquaponia, em que a reciclagem de nutrientes produzidos pelos peixes como fertilizante para plantas provou ser uma solução inovadora para descarte de resíduos, que também teve vantagens econômicas ao produzir um segundo produto comercializável (Joyce et al., 2019).

Em essência, os sistemas de produção de plantas terrestres e animais aquáticos compartilham um recurso comum: a água, enquanto as plantas geralmente consomem água por transpiração e a liberam para o ambiente gasoso circundante, os peixes geralmente consomem menos água, mas sua cultura contida produz fluxos substanciais de águas residuais devido a resíduos metabólicos acumulados (Maucieri et al., 2019). Portanto, a aquicultura pode ser integrada na via de abastecimento de água da produção vegetal de forma não consumista, de modo que duas culturas (peixes e plantas) possam ser produzidas a partir de uma fonte de água que geralmente é usada para produzir uma cultura (plantas) (Lennard & Goddek, 2019).

Maurieci et al. (2019) indica que a combinação de piscicultura com cultivo de plantas terrestres de base aquática via aquaponia pode ser melhor definida por meio de suas credenciais de compartilhamento de recursos de nutrientes, aplicando vários princípios, incluindo, mas não limitado a, uso eficiente da água, uso eficiente de nutrientes, reduzido ou negado impacto ambiental e a aplicação de abordagens biológicas e ecológicas à produção agrícola de peixes e plantas. As fontes de água são importantes para que os nutrientes necessários para a produção de peixes e plantas estejam disponíveis e equilibrados, e a química da água do sistema é fundamental para otimizar a produção de peixes e plantas (Maucieri et al. 2019). A aquaponia procura aplicar métodos que forneçam vantagens técnicas, biológicas, químicas, ambientais e econômicas (Lennard & Goddek 2019).

Aquaponia têm o potencial para o aumento de produtividade de vegetais e proteína de peixes com menor mão de obra, utilizando menos solo e pouca água. Sendo um sistema estritamente controlado, geralmente instalado em ambientes protegidos, combina o alto nível de biossegurança resultante do baixo risco de doenças e da contaminação externa, com a produção sem a necessidade de químicos e pesticidas (FAO, 2016). Além disso, é uma ferramenta potencialmente usual para transpassar alguns desafios da agricultura tradicional em frente à escassez hídrica, mudanças climáticas e a degradação do solo (FAO, 2016).

De acordo com estudo de revisão sobre a aquaponia (Palm et al., 2018), os autores propõem uma padronização nas nomenclaturas associadas, no intuito de evitar confusões, além de oferecer uma nova definição para a aquaponia, como sendo um sistema de produção de organismos aquáticos e plantas, onde a maioria (> 50%) dos nutrientes que sustentam o crescimento ideal das plantas deriva de resíduos originados da alimentação dos organismos aquáticos. Também, os autores trazem classificações em termos do tamanho dos sistemas, sendo classificados como mini sistemas, para *hobby*, de fundo de quintal, de pequena escala, de escala semi comercial e escala comercial, se diferenciando pelas áreas que ocupam em m^2, volumetria total do sistema (m^3), número de tanques piscícolas ou complexidade dos sistemas (utilização de sistemas de filtragem, sistema de desgaseificação e diferentes eficiências desses), além da distinção entre as formas de associar os sistemas de produção, acoplados ou desacoplados.

Carneiro et al. (2015), afirmam que o volume de água necessário é muito menor se comparado aos sistemas tradicionais de agricultura e aquicultura, pois uma vez o sistema é abastecido e está em funcionamento, pode ficar tempo indeterminado sem a necessidade da troca de água, sendo necessário somente um pequeno volume para repor as quantidades perdidas por evaporação e manejo, como colheitas. Também, é mais eficiente na utilização da água e geração de efluente que a própria hidroponia, que necessita constantemente de renovar a solução nutritiva. Segundo os mesmos autores, nos sistemas aquapônicos a única entrada de insumos é o fornecimento de ração aos peixes, que ao se alimentarem produzirão excretas, posteriormente convertidas em nutrientes que serão absorvidos pelas plantas (Figura 2).

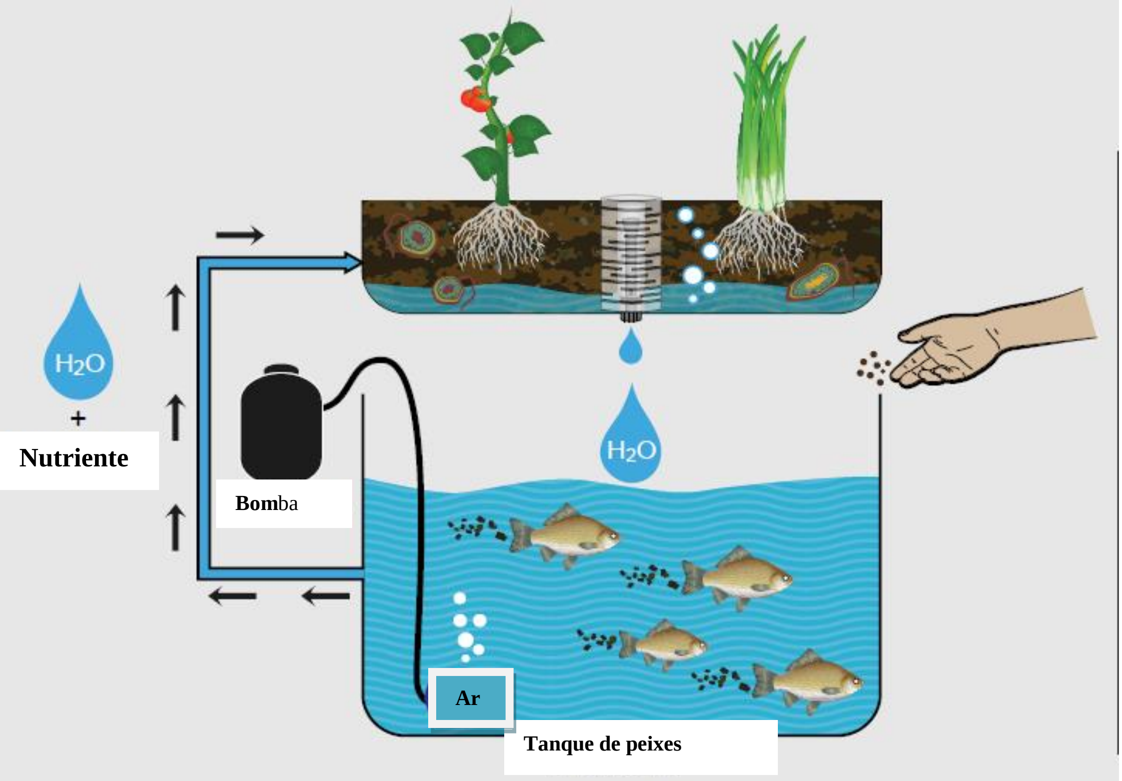

Figura 2. Esquema simples de aquaponia. É representado o tanque de peixes, o aporte de ração na produção piscícola, o oxigênio necessário para os peixes, que advêm de uma bomba aeradora, o ciclo dos nutrientes e de água dos peixes para os vegetais e a água que volta dos vegetais para os peixes. Fonte: Adaptado de Somerville *et. al*., 2014.

Segundo Carneiro et al. (2015), a aquaponia envolve três organismos muito distintos (peixes, bactérias e plantas) num mesmo corpo de água, e que é de extrema importância conhecer as necessidades de cada um deles para que a faixa de pH possa atender satisfatoriamente a todos. As bactérias nitrificantes são predominantemente aeróbicas e tem como ótima faixa de pH valores entre 7 e 8. A maioria das plantas cultivadas em hidroponia se desenvolvem melhor em intervalo de pH entre 5,5 a 6,5 e ainda, que a maioria das espécies cultivadas em água doce de interesse econômico, que podem ser utilizadas em sistemas aquapônicos, a faixa ideal de pH encontra-se entre 7 a 9. Consequentemente, recomenda-se manter a faixa de pH da água em sistemas aquapônicos entre 6,5 a 7,0 a fim de atender satisfatoriamente aos três organismos presentes no sistema (Carneiro et al., 2015).

Somerville et al. (2014) descrevem o ciclo de recirculação da aquaponia pelo processo natural de nitrificação (Figura 3), pelo qual excrementos dos peixes, ricos em amônia, são convertidos por bactérias naturalmente presentes na água, em nitrito e nitrato, que por sua vez são facilmente absorvidos pelas plantas. Este processo é responsável por gerar nutrientes assimiláveis às plantas e eliminar a amônia tóxica aos peixes.

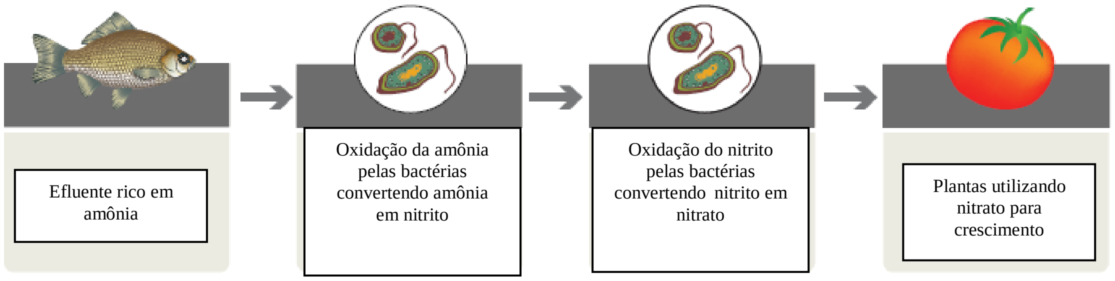

Figura 3. Processo de nitrificação. Fonte: Adaptado de Somerville et al. (2014).

As colônias de bactérias podem se estabelecer em vários tipos de materiais, como nas paredes do tanque de peixes, nas raízes das plantas e, até mesmo, nas tubulações do sistema, sendo que a disponibilidade total da área de superfície é que vai determinar a quantidade de amônia que poderá ser metabolizada. Em sistemas de produção intensiva de peixes, onde há maior adensamento de animais por tanque, há necessidade de se fazer um biofiltro externo, utilizando-se de materiais inertes a fim de aumentar as áreas de superfície para produção de colônias de bactérias e favorecendo o processo de nitrificação (Somerville et al., 2014).

A temperatura da água ideal para o crescimento e proliferação das bactérias nitrificantes está na faixa entre 17ºC a 34ºC, e temperaturas abaixo dos 10ºC a produção de bactérias pode reduzir a metade, desfavorecendo o processo de nitrificação. O oxigênio dissolvido também é um item muito importante na produção e manutenção das colônias de bactérias, sendo o processo de nitrificação uma reação de oxidação, ou seja, necessita do oxigênio como reagente. Níveis excelentes de oxigênio dissolvido se encontram entre 4 a 8 miligramas por litro e se no sistema não tiver oxigênio dissolvido disponível, outros tipos de colônias de bactérias indesejáveis ao sistema poderão se estabelecer, algumas são capazes de até converter o nitrato já nitrificado de volta para forma molecular de nitrogênio não disponibilizado, um processo anaeróbico conhecido como desnitrificação. Outro aspecto importante na manutenção das colônias de bactérias é o fato destas serem sensíveis, ou seja, a luz solar pode ser uma ameaça a sua manutenção, necessitando assim de sombra (Somerville et al., 2014).

O ecossistema presente na aquaponia está totalmente relacionado às bactérias, portanto, se as bactérias não estiverem presentes ou mesmo não estiverem funcionando apropriadamente, a concentração de amônia irá aumentar e poderá causar morte de animais. Nestas condições é vital ao sistema manter saudáveis as colônias de bactérias responsáveis por controlar a concentração de amônia. Para se manterem saudáveis estas colônias, devem ser considerados alguns parâmetros, como área de superfície, pH da água, temperatura da água, oxigênio dissolvido e radiação solar (Somerville et al., 2014).

Um sistema aquapônico clássico consiste em três unidades principais: (1) a unidade de aquicultura que compreende tanques de peixes, (2) sistema de filtragem que compreende dispositivos de remoção de lodo (por exemplo, sedimentador) e biofiltração opcional (por exemplo, filtro de gotejamento) e (3) um componente hidropônico para as plantas, sendo geralmente em cultura em águas profundas (*Deep Water Culture* - DWC), em técnica de filme de nutrientes (*Nutrient Film Technique* - NFT), camas de substrato (*Media Bed Technique* - MBT) ou em mesas de fluxo contínuo e sistemas de gotejamento (Somerville et al., 2014). A unidade de criação de peixes pode ser operada a partir de baixas densidades de lotação a altas densidades em tanques únicos ou combinação de diferentes espécies aquáticas. O cultivo de plantas também pode variar de algumas plantas a sistemas intensivos de produção hidropônica (Palm et al., 2018).

Para manter a máxima qualidade da água, o dispositivo de remoção de resíduos deve ser adaptado para cobrir o aumento da produtividade, para que os sistemas aquapônicos possam variar de extensos a altamente intensivo. Contudo, soluções técnicas simples também são viáveis através do uso de águas superficiais quase naturais (lagoas), em oposição às águas de sistemas intensivos de produção aquapônicos com tecnologia complexa em estufas. Assim, o princípio agro-técnico de produção aquaponica oferece maior variabilidade no *design* do sistema em comparação com outros sistemas de produção integrados (Palm et al., 2018).

Segundo Junge et al. (2017), o avanço dos sistemas aquapônicos sugerem que a tecnologia deve se desenvolver em ao menos duas direções: uma através das baixas tecnologias (em países em desenvolvimento e para *hobby*), e outra através das altas tecnologias (em países desenvolvidos e com atores profissionais e comerciais). Ainda que a aquaponia se desenvolva em grande parte por altas tecnologias, Love *et al*. (2015) indicam que 71% dos sistemas aquapônicos comerciais analisados pelo seu estudo foram desenhados e implantados pelos próprios produtores, enquanto os 29% foram concebidos por consultores ou comprados. Também, quase 80% de empreendimentos aquapônicos de escala comercial estão localizados nos Estados Unidos.

Konig e associados (2018), apontam que a aquaponia na Europa ainda é principalmente formada por atores de pesquisa. Villarroel et al. (2016), encontraram 68 atores aquapônicos distribuídos em 21 países europeus, 75% envolvidos em atividades de pesquisa e 30,8% na produção. Apenas 11,8% dos pesquisados venderam peixes ou plantas nos últimos 12 meses, indicando que a produção da aquaponia e o *marketing* ainda são atividades menores entre os atores europeus e a tecnologia ainda está em ascensão.

Também, persistem visões diferentes sobre o futuro da aquaponia no que diz respeito à localização (urbana ou rural), tamanho (pequena escala versus escala industrial), estratégia de *marketing* (quantidade versus qualidade, certificação) e papel dos consumidores (*marketing* direto ou *marketing* via supermercados). A interação entre especialistas em aquaponia ocorre tanto dentro das redes de pesquisa de horticultura e aquicultura (Villarroel et al., 2016).

Dos sistemas aquapônicos comerciais analisados por Love *et al*. (2015), 69% desses utilizam tilápias (*Oreochromis niloticus*), principalmente por serem peixes altamente tolerantes à água com baixos parêmetros de qualidade, com variações de temperatura e pH (Lennard, 2018). Apesar de ser um dos maiores produtores de tilápia do mundo, o Brasil possui um enorme potencial para produção piscícola para consumo humano, quanto para ornamentação, utilizando espécies exóticas e principalmente espécies nativas. De acordo com anuário da Associação Brasileira da Piscicultura (PeixeBR, 2019), as espécies nativas representaram 39,8% da produção nacional no ano de 2018, tendo como seu principal representante o tambaqui, *Colossoma macropomum*. Dentre as espécies nativas de água doce que possuem expressiva produção aquícola para consumo humano, são contabilizados dados de produção de doze espécies nativas e uma híbrida, entre peixes de escamas, da ordem dos perciformes e de couro, da ordem dos siluriformes.

A piscicultura ornamental destaca-se como um valioso recurso, sendo uma atividade em constante crescimento, apesar das lacunas de informações sobre as variedades ainda existentes (FAO, 2009). Para a aquicultura nacional de espécies de água doce, chama atenção o crescimento da produção de lambari (Gonçalves, 2017), gênero *Astyanax*, que representa aproximadamente cem espécies, com ampla distribuição geográfica e cujo conhecimento taxonômico é bastante confuso. São espécies nativas de pequeno porte e com ciclo de vida rápido, aceitam alimentação artificial com bastante facilidade e apresentam elevada produtividade em cultivo intensivo, podendo atingir uma produtividade de 100 $t.ha^{-1}$ por ano, demonstrando seu potencial à piscicultura (Garutti, 2003; Porto-Foresti et al., 2010).

Dentre as espécies exóticas de peixes ornamentais com grande popularidade, destaca-se o *Carassius auratus*, pertencente à classe Actinopterygii, ordem Cypriniformes e família Cyprinidae, denominada popularmente como kinguio ou *goldfish*, que ocupa lugar de destaque na comercialização mundial em função da sua aparência, docilidade durante o manejo e adaptação ao confinamento (Taghizadeh et al., 2013). Além disso, são muito resistentes às variações dos parâmetros físico-químicos da água na criação, apresentam altas taxas de prolificidade e variados padrões de coloração e polimorfismo, principalmente, nos olhos e nadadeiras (Rosa et al., 1994; Soares et al., 2002; Silva et al., 2006).

Para piscicultura é importante salientar que cada sistema será mais adequado para diferentes situações, devendo-se ter em mente os objetivos do empreendimento, o mercado a ser atingido, a espécie de cultivo, a disponibilidade de água e de energia elétrica, a área disponível, o custo dessa área, as características climáticas da região, os aspectos legais e socioculturais (Crepaldi et al., 2006).

No caso da escolha das espécies vegetais a serem cultivadas em aquaponia existem trabalhos consagrados que relatam o desempenho de diferentes espécies alimentícias em sistemas aquapônicos (Rakocy et al., 2004; 2006; 2010; Lennard & Leonard, 2006; Graber & Junge, 2009). Giurgiu et al. (2014) apontam que o cultivo de ervas medicinais é generalizado e o interesse por esse tipo de cultura cresce rapidamente. A colheita da matéria-prima na natureza pode ser muito difícil devido ao pouco controle que se pode ter sobre problemas como: identificação incorreta, variabilidade genética e fenotípica, variabilidade de substâncias ativas e compostos tóxicos. O cultivo de plantas medicinais em um ambiente mais controlado pode superar essas dificuldades e, mais do que isso, estudos recentes mostraram que o cultivo de plantas medicinais em ambiente controlado melhora a concentração de substâncias bioativas (Giurgiu et al., 2014).

O cultivo hidropônico possui como vantagem poder auxiliar os vegetais a alcançar um crescimento inigualável, aliado à excelente qualidade das culturas e alta substância bioativa, sendo os riscos a baixa taxa de germinação e problemas ecológicos, que podem ser superados através do controle dos parâmetros ideais para obter o melhor ambiente para germinação, além de poder precisar de polinização artificial. As culturas hidropônicas podem ter resultados relevantes, como rendimento uniforme, com alta porcentagem de substâncias bioativas e esse tipo de sistema pode ser a maneira de cultivar as plantas medicinais para fins comerciais. Além das vantagens econômicas e químicas, os sistemas hidropônicos de cultivo de plantas medicinais ajudam a proteger a flora espontânea e a diversidade de espécies encontradas na natureza (Giurgiu et al., 2014).

Tendo que as potencialidades da produção aquapônica, que tratam da reciclagem de água e a ciclagem de nutrientes, são de suma importância para a redução nos impactos ambientais da produção de alimentos. Ainda, a utilização de espécies de alto valor agregado poder favorecer financeiramente o produtor rural tornando-se importante a experimentação de diferentes espécies em sistemas aquapônicos. Frente a esse contexto, a presente tese tem como objetivo analisar a produção e o desempenho de plantas medicinais em sistemas aquapônicos.

Esta tese foi dividida em 03 (três) capítulos, sendo cada capítulo um artigo científico já encaminhado (submetido) para periódico da área das Ciências Ambientais. Os artigos estão formatados nos modelos requeridos pelas diferentes revistas, sendo solicitados em língua inglesa e alterados suas numerações de seções para melhor visualização na tese.

3 - CULTIVATION OF MEDICINAL PLANTS IN AQUAPONIC SYSTEMS: A SYSTEMATIC REVIEW

Cultivo de plantas medicinais em sistemas de aquaponia: uma revisão sistemática

Aquaponics medicinal plants: a review/ Plantas medicinais aquapônicas: uma revisão

ABSTRACT

Aquaponics, a technique that combines aquaculture and hydroponics in a closed system of water recirculation and nutrient cycling, grows exponentially in studies that seek to evaluate the technique by testing different species in these systems, and the choice of species may be fundamental to result in a high development in the system, through high productivity and profitability. Medicinal plants are an interesting option for further analysis of aquaponic systems. The objective was to analyze peer-reviewed articles recovered on Web of Science plataform, published in journals, dealing with practical experiments that used medicinal plants in aquaponics. Initially, from the search terms that associate aquaponics with scientific names of medicinal species, previously chosen for been known to be produced in aquaponic systems, and terms that refers to medicines, been 33 articles, which after an initial analysis, with the reading of the abstracts and, later, reading in full, decreased to 15 articles selected. The main research themes of the works were identified, such as the effect of plants nutritional supplementation; different water flows in aquaponic systems that use medicinal species; as well as the types of aquaponic systems used. The results showed that aquaponics is on the rise and that all associative conformations of animal and plant species must be analyzed in order to contribute effectively to the ecological and economic sustainability of producers, in addition to the aquaponic medicinal production could be able to add value to the products derived from this production, stimulating their adoption.

Keywords: Aquaponics, Nutrient recycling, Aquaculture, Hydroponics.

RESUMO

A aquaponia, técnica que combina aquicultura e hidroponia em um sistema fechado de recirculação de água e ciclagem de nutrientes, cresce exponencialmente em estudos que buscam avaliar a técnica testando diferentes espécies nestes sistemas, e a escolha das espécies pode ser fundamental para resultar em um alto desenvolvimento no sistema, através de alta produtividade e lucratividade. As plantas medicinais são uma opção interessante para uma análise mais aprofundada de sistemas aquapônicos. O objetivo foi analisar artigos revisados por pares, publicados em periódicos, tratando de experimentos práticos que utilizaram plantas medicinais em aquaponia. Inicialmente, a partir da busca de termos que associam aquaponia a nomes científicos de espécies medicinais, previamente escolhidas por serem conhecidas em produção em sistemas aquapônicos, e termos que se referem a medicamentos, foram encontrados 33 artigos, que após uma análise inicial, com a leitura dos resumos e, depois, leitura na íntegra, diminuiu para 15 artigos selecionados. Foram identificados os principais temas de pesquisa dos trabalhos, como o efeito da suplementação nutricional de plantas; diferentes vazões de água em sistemas aquapônicos que utilizam espécies medicinais; bem como os tipos de sistemas aquapônicos utilizados. Os resultados mostraram que a aquaponia está em ascensão e que todas as conformações associativas das espécies animais e vegetais devem ser analisadas a fim de contribuir efetivamente para a sustentabilidade ecológica e econômica dos produtores, além da produção medicinal aquapônica podendo agregar valor aos produtos derivados dessa produção, estimulando sua adoção.

Palavras-chave: Sistemas aquapônicos, Reciclagem de nutrientes, Aquicultura, Hidroponia.

3.1-INTRODUCTION

The measures adopted to produce more with less water and reduce losses in the agricultural sector bring benefits, including aspects related to extreme poverty, hunger, malnutrition, and climate change, and should address water use, agricultural production, food security and climate change in an integrated way (FAO, 2018). Aquaponics, synergistic production between aquaculture and hydroponics, is an alternative to produce food in a less impactful way to the environment through characteristics that refer to sustainability, such as the implantation of small family systems, the cycling of nutrients and the recycling of water (Diver, 2006; Rakocy, Losordo & Masser, 2006; Love et al., 2015). This integration allows plants to use nutrients from the fish farming, improving water quality, which can be reused on the fish production (Hundley & Navarro, 2013).

A classic aquaponic system consists of three main units: the aquaculture unit, which comprises fish tanks; the filtration system, which includes sludge removal devices (for example the sedimenter) and optional biofiltration (for example, the drip filter); and the hydroponic component for plants, which usually occurs on deep water culture (DWC), on nutrient film technique (NFT), on media bed technique (MBT) or on continuous flow tables and drip systems and the fish farming unit can be operated with low stocking densities or high densities in single tanks, and also by combining different aquatic species (Somerville, Cohen, Pantanella, Stankus & Lovatelli, 2014).

The development of aquaponics was greatly influenced by the sustainable agriculture movement and further refinements in the technique were promoted by university researchers, who seek to establish it as a viable agricultural sector (Love et al., 2014). Aquaponics is a sustainable production of fresh fish and vegetables using intensive technology cycle systems and its interesting study for the scientific community, policy makers and entrepreneurs (König, Janker, Reinhardt & Villarroel, 2018). It is not only a future-oriented technology, but also a tool for teaching natural sciences at all school levels, from primary school to university (Maucieri et al., 2018).

As reported by Hart, Webb, Hollingsworth & Danylchuk (2014), aquaponic systems can be used in educational configurations to model natural aquatic systems and academic learning providing students with the possibility to explore biology through observations of animal and plant life cycles, to chemically investigate by analyzing water quality, to employ mathematical skills calculating water flow rates, and practicing financial skills by selling harvested products. Currently, most applications of aquaponics focus on research questions in aquaculture, hydroponics, water quality, microbiology, and engineering (König et al., 2018).

The uses of plants as a source of research in the search for active compounds for medicine have a significant scientific output with the necessity of production of new medicines with scientific tests of safety and activeness, with a great collaboration between the countries (Salmerón-Manzano, Garrido-Cardens & Manzano-Agugliano, 2012). However, it should be noted that the possible trend to return to this type of traditional medicine may have two major drawbacks. The first is the use of medicinal plants without sanitary control, without thinking about the possible harmful aspects for health (Chan, 2003). Although many plants do not have side effects like the aromatic plants used in infusions: chamomile, rosemary, mint, or thyme; however, others may have dangerous active principles (Salmerón-Manzano et al. 2012).

Aquaponics, as an emerging technology for a more sustainable production, allows its implantation in all regions of the globe, becoming a strategic technology for the current food production. The objective of this research was to identify and analyze on the recent literature primary studies that refer to the application of the aquaponic technique to produce medicinal plants, to present the current state of the art of aquaponics using medicinal plants.

3.2 – MATERIALS AND METHODS

Scientific articles published in peer-reviewed journals on the Web of Science - WOS (Clarivate Analytics) platform were retrieved and analyzed for the relationship between aquaponics and the cultivation of medicinal plant species and also relating aquaponics and medicinal plant species cited on a first general analysis (*Mentha piperita*, *Peumus boldus*, *Centella asiatica*, *Cannabis sativa*) to increase the number of retrivied articles, with the terms aquapon* AND medic* OR aquapon* AND herb* OR aquapon* AND mint* OR aquapon* AND ment* OR aquapon* AND bold* OR aquapon* AND cente* OR aquapon* AND cannab*. The search terms were searched in the title, abstract and keywords of the articles, and there were no restriction for the year. The searches were carried out on February 18th, 2022, by two researchers and analysis and presentation of results follow the PRISMA Protocol.

Among the inclusion criteria should be articles dealing with practical experiments that analyzed production data for medicinal plant species in aquaponic systems. The exclusion criteria were established as articles that do not deal with medicinal species, are not experimental research and are not in English, Portuguese and Spanish. It is noteworthy that numerous food plants have medicinal characteristics, but in this study only experiments that used species that were primarily known as raw material for medicines were considered.

Searches were carried out with the keywords in the advanced search source of the main WOS collection, and, from the recovered works, abstracts were read, and a pre-evaluation was carried out, based on the inclusion and exclusion criteria, selecting only the texts that should be read in their entirety and considered valid or invalid for the purposes of this review. Data extraction forms were filled in for each text read in full. In addition to the basic information (bibliographic data, date of publication, abstract, among others), the forms contained the synthesis of the work, written by the researchers who led the review and their personal reflections on the content and conclusions of the study. Each article was identified by year, country of origin, authorship, type of hydroponic system used, species of medicinal plant grown and the focus of the discussion. The temporal analysis of the data was performed using a frequency histogram generated by Clarivate Analytics (2022), with the number of articles being the response variable and the year of publication being the exploratory variable.

3.3- RESULTS AND DISCUSSION

3.3.1 Quantitative analysis

Initially, 33 articles were retrieved, combining all search terms in the advanced search of WOS in its main collection. With the reading of the abstracts, 15 articles were included and, after reading in full all these articles were selected (Table 1). A total of 06 (six) papers were found dealing with the production of medicinal plants in MBT type aquaponic systems, 03 (three) papers about the production in the DWC type, 02 (two) in the NFT system, 02 (two) in MBT / DWC mixed system, 01 (one) in DWC / NFT mixed systems and 01 (one) in MBT / NFT mixed systems. There was also a predominance of studies with the genus *Mentha*, with 10 (ten) articles out of 15 (representing 66.6 % of the total), with the species *Mentha piperita* corresponding to a total of 05 (five) studies as plant study model, 01 (one) that used *Mentha spicata* in addition to this specie, 02 (two) used *Mentha spicata*, 01 (one) used *Mentha arvensis* and 01 (one) used *Mentha haplocalyx*. Other 03 (three) studies used *Centella asiatica* and other 02 (two) researched *Cannabis sativa* (Table 2).

Table 1. Methodology and results of the searches at the WOS (18/02/2022).

Initial Search TS=(aquaponic* AND medic*) OR TS=(aquaponic* AND herb*) OR TS=(aquaponic* AND mint*) OR TS=(aquaponic* AND ment*) OR TS=(aquaponic* AND boldu*) OR TS=(aquaponic* AND cente*) OR TS=(aquaponic* AND cannab*) (n=33) ↓
Reading the abstracts and applying the exclusion factors (not being experimental articles and not using medicinal species) ↓
Selected articles after reading the abstract (n=15) ↓
Selected articles after reading in full (n=15)

Table 2. Selected articles of the systematic review at the WOS (18/02/2022).

Reference	Authors' country	Aquaponic system	Medicinal plant
Moya et al. (2016)	México	MBT	*Mentha piperita/Mentha spicata*
Roosta (2014)	Iran	DWC	*Mentha piperita*

Reference	Authors' country	Aquaponic system	Medicinal plant
Shete et al. (2016)	Índia	MBT	*Mentha piperita*
Shete et al. (2017)	Índia	MBT/DWC	*Mentha arvensis*
Nozzi et al. (2018)	Italy/Switzerland	DWC	*Mentha piperita*
Zheng et al. (2020)	China	DWC/NFT	*Mentha haplocalyx*
Nuwansi et al. (2019)	Índia	MBT	*Centella asiatica*
Nuwansi et al. (2020)	Índia	MBT	*Centella asiatica*
Nuwansi et al. (2021)	Índia	MBT	*Centella asiatica*
Ogah et al. (2020a)	Malaysia/Nigéria	NFT	*Mentha piperita*
Ogah et al. (2020b)	Malaysia/Nigeria/South Korea	NFT	*Mentha piperita*
Knaus et al. (2020)	Germany/Israel	MBT	*Mentha spicata*
Knaus et al. (2022)	Germany/Israel	MBT/NFT	*Mentha spicata*
Yep et al. (2020a)	Canada	DWC	*Cannabis sativa*
Yep et al. (2020b)	Canada	MBT/DWC	*Cannabis sativa*

Among the subjects addressed in the selected articles are seven research areas (Figure 4), with four areas highlighted, with most of the works being classified by the search platform, Web of Science, as fisheries, followed by the plant sciences, environmental sciences ecology and agriculture. However, knowing that aquaponics involves aquatic and plant organisms, these results were expected.

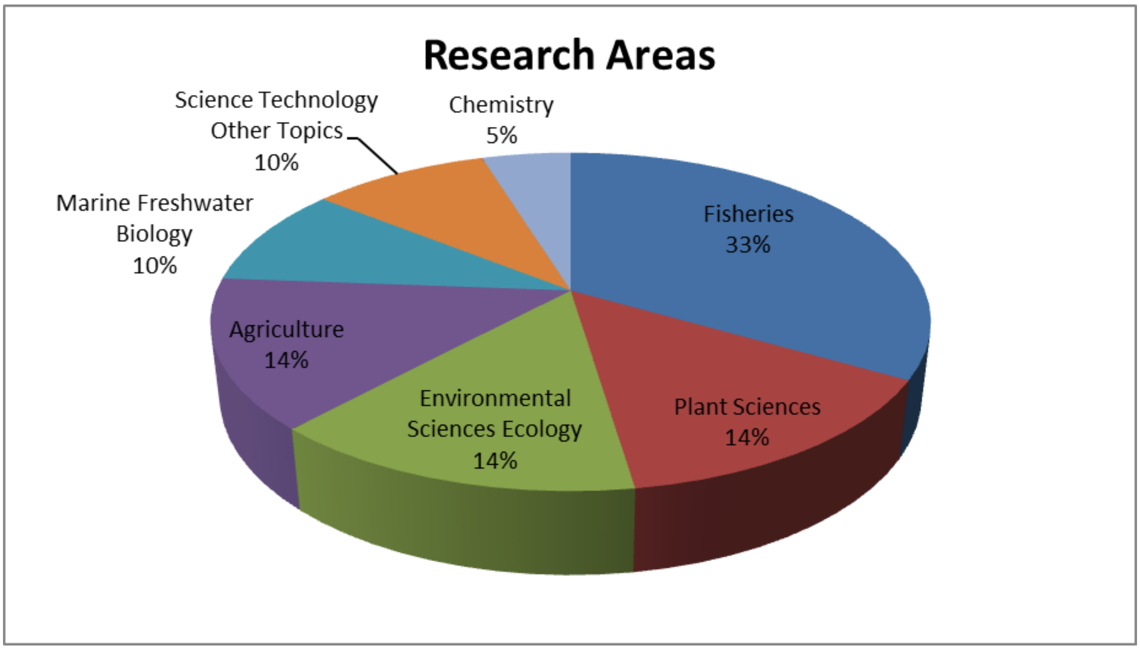

Figure 4. Graph of the research areas of WOS.

The number of articles published by the same authors and countries was significant, in which Nuwansi, KKT (five) and Verma, AK (five) and Chandrakant, MH (four) stand out, all from India (Figure 5). The two main countries that conducted published research containing medicinal plant species in aquaponic systems were India [five articles], followed by Canada, Germany, Israel, Malaysia and Nigeria [two articles], and the other six countries that carried out research on the topic published only one article (Figure 6).

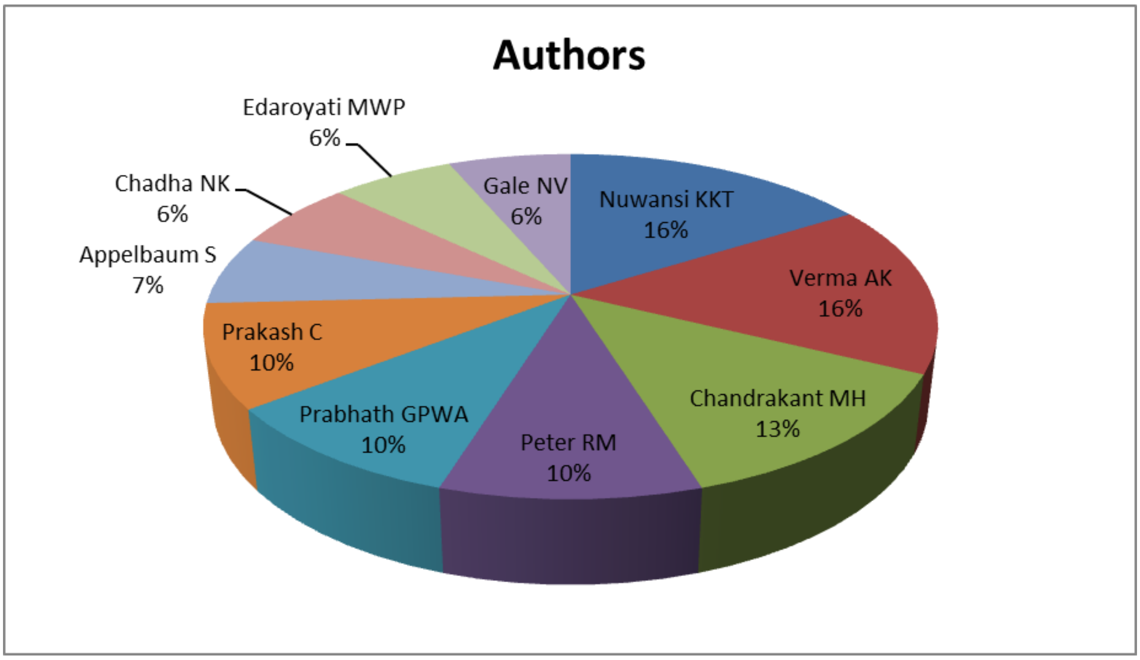

Figure 5. Graph of the published authors.

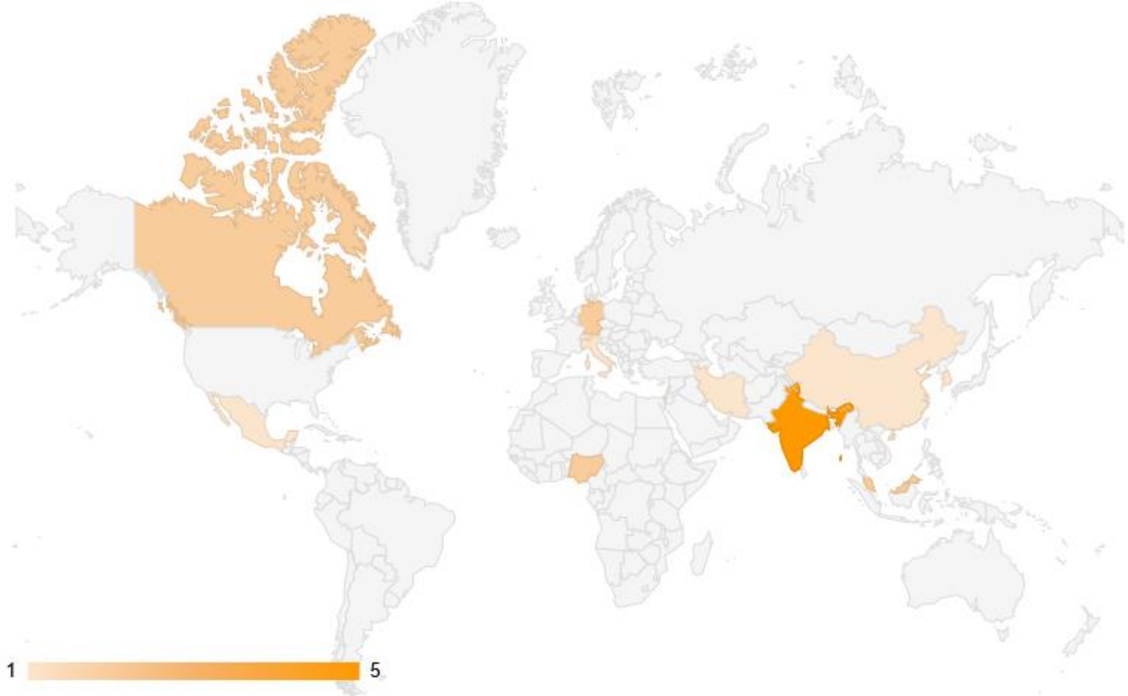

Figure 6. Graph of the countries that published on the theme. Source: The authors.

The frequency histogram on the number of annual publications on the subject shows that 2020 and 2016 were years of more published articles, with seven and two papers, respectively. However, since 2014, the first year of a publication on the topic, at least one article was published each year, but none in 2015 (Figure 7).

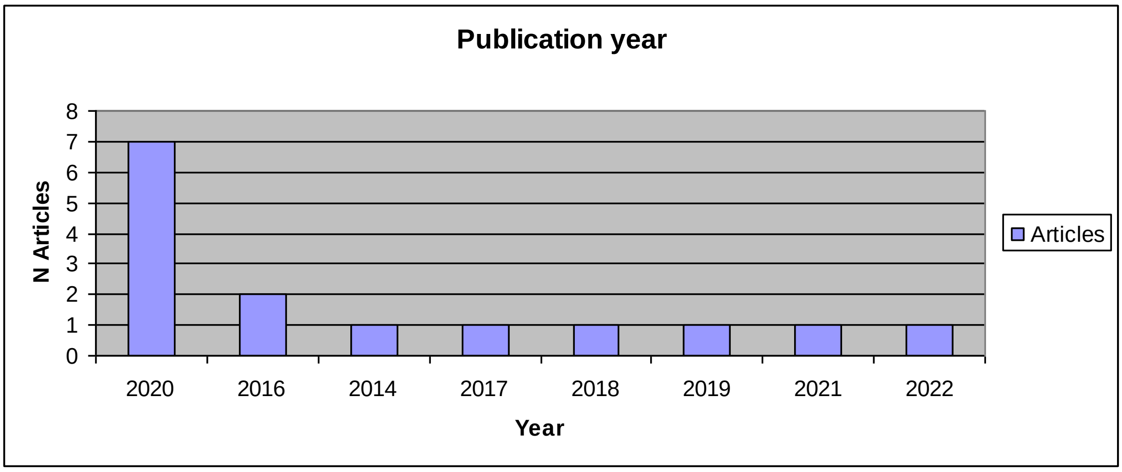

Figure 7. Graph of the publication year.

3.2 Qualitative analysis

Moya et al. (2016) evaluated the ability of peppermint, *Mentha piperita*, spearmint, *Mentha spicata*, and basil, *Ocimum basilicum*, as part of the biological filters for intensive tilapia production in three identical media bed aquaponic systems. River stones were used as media and physicochemical parameters of water quality were evaluated, in addition to Nitrogen (N) and Phosphorus (P), and the results showed that the three species did not show differences in water quality and could be used as part of biological filters in aquaponics, removing significant concentration in nitrogen and phosphorus compounds. Also, a positive relationship was established between time and the levels of ammonium ions (NH_4^+) in the water, in addition to the pH, temperature and dissolved oxygen maintained at appropriate intervals for tilapia. The electrical conductivity (EC) and total dissolved solids (TDS) were present in suitable levels for growing herbaceous, which are adapted to flooded substrates, with constantly moving water and high oxygen concentration.

Shete et al. (2016), biointegrated on media bed aquaponic systems peppermint, *Mentha piperita*, and common carp, *Cyprinus carpio*, to determine the optimal hydraulic loading rate (HLR) for the best performance of the system. The authors used gravel as a substrate and three different flow rates (3 m day^{-1}, 6 m day^{-1} and 12 m day^{-1}), founding better results in the second treatment and a significant effect of flow rates on fish growth, in terms of length and weight gain, survival and specific growth rate. Total mint yield after both the harvests varied significantly among treatments and control. Maximum yield was obtained intreatment T2 followed by control, T1 and T3. Mint growth rate at showed significant variation and got affected by different HLRs with better results obtained in treatment T2 (6 m day^{-1}). Overall water quality parameters, nutrient removal and biofilter performance were better at HLR 6 m day-^{1}, treatment T2, been recommended for culturing Common carp and Mint in aquaponic system.

Three different hydroponic media crushed stones (T1), river stones (T2), and floating raft (T3) were compared in an aquaponic system by Shete, Verma, Chadha, Prakash & Chandrakant (2017) to evaluate the production of wild mint, *Mentha arvensis* in association with *Cyprinus carpio*. Total mint yield (kg) after both the harvests varied significantly ($p < 0.05$). T1 (1.076 ± 0.048) yielded the maximum mint, whereas minimum mint yield was recorded in T2 (0.386 ± 0.020). Control (0.916 ± 0.028) and T3 (0.950 ± 0.034) did not show any significant difference. The authors found better performances in crushed stones at first, then in flotation, and in river stones for the last. Also, the first two systems were significantly efficient when compared to river stones in terms of nutrient removal and water quality maintenance of fish farming.

Nozzi, Graber, Schmautz, Mathis & Junge (2018) sought to determine the necessary level of supplementation of micro and macro nutrients on DWC aquaponic systems composed of Nile tilapia (*Oreochromis niloticus*) with lettuce (*Lactuca sativa*), peppermint (*Mentha piperita*) and mushroom herb (*Rungia klossii*). Three identical aquaponic systems (A, B, and C) and one hydroponic system (D) were used. System A only received nutrients derived from fish feed; system B received nutrients from fish feed as well as weekly supplements of micronutrients and Fe; system C received the same nutrients as B, with weekly supplements of the macronutrients, P and K; in system D, a hydroponic inorganic solution containing N, Calcium (Ca), and the same nutrients as system C was added weekly. The study demonstrated that the nutritional needs of mint and mushroom herb make them suitable for production in aquaponic systems because they require low levels of supplement addition and, therefore, little management effort, resulting in minimal cost increases. For lettuce, the addition of supplements accelerated growth and even surpassed growth in hydroponics, while nutritional quality (polyphenols, nitrate content) was better without supplementation.

To determine the biological filtration capacities of the herbs peppermint (*Mentha piperita*), celery (*Apium graveolens*) and coriander (*Coriandrum sativum*) co-cultivated with lemon fin barb hybrid (*Barbonymus gonionotus* x *Hypsibarbus wetmorei*), on nutrient film technique aquaponic systems Ogah, Kamarudin, Nurul Amin & Puteri Edaroyati (2020a) carried out an experiment. The authors found water purification potential in varying degrees as significantly lower levels of nitrogen compounds (ammonium, nitrite and nitrate) after herbal filtration. According to the authors, the plant's growth seemed to be affected by its ability to absorb nutrients and, consequently, purify the culture medium. Interestingly, the lemon fin hybrid also showed significant differences in terms of weight gain, although retention of nutrients between fish treatments was not statistically different. Plants absorbed less phosphorus and potassium than fish and, after calculating the total percentage of the recovered NPK (Nitrogen, Phosphorous and Potassium) system, nitrogen was the most retained nutrient, with mint being the species that showed superiority in terms of biomass and water purification potential compared to Chinese celery (*Apium graveolens* var. *secalinum*) and coriander.

The effects of foliar applications of potassium on growth and physiological characteristics of mint, radish, parsley, and coriander on floating aquaponic systems, DWC, using the common carp (*Cyprinus carpio*) and supplementing chelated iron (Fe) in the solution for plants were investigated by Roosta (2014). The author found higher dry and fresh masses in all species in treatments with K, as well as increased mineral concentration in all species. Also, he found positive relationships between the use of the nutrient and accumulation of Fe and chlorophyll in the sprouts, as well as for magnesium (Mg), manganese (Mn), and zinc (Zn) in plants, while negative effects were observed in sodium concentrations (Na). Finally, he concludes that the results indicated that the foliar spraying of K can effectively alleviate nutrient deficiencies in vegetables with leaves and roots grown in aquaponics.

Zheng et al. (2020) conducted an experiment to investigate the presence of methomyl pesticide residue and the rate of disappearance in mint (*Mentha haplocalyx*) cultivated in the aquaponics system with tilapia (*Oreochromis niloticus*) based on the application of Ultrahigh-Performance Liquid Chromatography-Tandem Mass Spectrometry (UPLC-MS) to establish a safety time interval before crop harvesting. The initial residue level was much higher in roots (79.52 μg/kg), and it can be decreased to 16.73 (after 15 days) μg/kg and 3.31 (20 days) μg/kg, while the least was detected on the mix leaves and stems (44.54 μg/kg), and it can be decreased to 15.35 (after 20 days). In our case, we suggest that a safety interval in the range of 15–20 days should be allowed after the detection of methomyl in water, and the concentration of methomyl was lower than the acceptable daily intake (ADI) of the China Food and Drug Administration (CFDA) (20 μg/kg).

The aquaponic production of spearmint, *Mentha spicata*, on ebb-and-flood planting tables was evaluated by Knaus, Wenzel, Appelbaum & Palm (2020), using the African catfish, *Clarias gariepinus,* compared to a liquid fertilizer control in northern Germany. Fish production took place from different stocking densities, one extensive and the other intensive, and plant production was also analyzed in a control treatment using liquid fertilizer. The best results of *M. spicata* growth parameters were found under the intensive stocking density of the catfish, such as leaf area, leaf length and fresh shoot biomass, with both aquaponic treatments having better results than the control treatment. The authors indicate that the initial proportion of the number of fish between the extensive and the intensive system (1/4) increased the leaf area of *M. spicata* twice in the second system, concluding that aquaponics, using only treated effluent from intensive cultivation systems of African catfish, is efficient in the production of spearmint without the addition of liquid fertilizer. Knaus, Zimmermann, Appelbaum & Palm (2022), conducted research to evaluate mint (*Mentha spicata*) cultivated in different hydroponic components: grow pipes, a raft and an ebb-and-flood gravel substrate system irrigated with aquaculture effluents from intensive African catfish (*Clarias gariepinus*) production under decoupled aquaponic conditions in northern Germany. The spearmint grew well and plant heights above ground were not significantly different between the gravel (57.7 ± 13.1 cm), raft (58.0 ± 17.7 cm) and grow pipe components (63.6 ± 9.9 cm). Root lengths and root fresh weights were two-fold and four-fold higher in raft (64.3 ± 20.5 cm; 42.8 ± 29.9 g) and grow pipes (59.4 ± 15.2 cm; 41.3 ± 25.7 g) compared with gravel substrate (29.7 ± 7.8 cm; 9.4 ± 9.4 g; raft = grow pipes > gravel). Spearmint leaf number was significantly higher in the grow pipes (770.0 ± 224.4) than in the gravel substrate (499.8 ± 228.4) with intermediate values in the raft. Significantly highest mean fresh biomass was found in the raft (1275.6 ± 33.4 g), followed by grow pipes (1042.0 ± 35.8 g) and gravel substrate (686.3 ± 98.2 g; raft > grow pipes > gravel). *M. spicata*, under aquaponics, grows best in grow pipe and raft components. An increase in pipe diameter for the grow pipes and a reduction in the channel height for the raft components could optimize aquaponic culture conditions for both industrial production and the hobby sector in the future.

An experiment to evaluate the effects of night lighting on peppermint, *Mentha piperita,* production on NFT aquaponic systems with juveniles of lemon fin barb hybrids (*Barbonymus gonionotus* x *Hypsibarbus wetmorei*) was carried out by Ogah, Kamarudin, Nurul Amin & Puteri Edaroyati (2020b), subjecting the 12 sampled systems to 12-hour natural daylight treatments (control) and night lighting of 0 (zero), 6 (six) and 12 (twelve) hours, respectively, for a period of 14 weeks (two batches of 7 weeks each). Physico-chemical parameters of water quality, dissolved oxygen, pH, TDS, conductivity, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen and temperature were measured, in addition to NPK concentrations in plants and fish. The authors observed that night lighting did not affect the composition of NPK and fish growth, with plants responding positively to the increase in hours of night lighting, obtaining a significant increase in stem length, number of leaves and production mass (19% higher with 12 hours of night lighting) observed at harvest. Approximately 18% more nutrients were absorbed with night lighting and full recovery of the lemon fin barb hybrid and peppermint system with 12 hours of natural light and 12 hours of night lighting ranged from 27-34% for N, 41-49% for P and 25-31% for K. The authors conclude that peppermint production and nutrient recovery in the aquaponic system were increased with higher photoperiods.

The purpose of the work by Nuwansi et al. (2019) was to evaluate the efficiency of aquaponic systems with gotukola, *Centella asiatica*, and common carp on MBT, adding different concentrations of borewell water (0, 25%, 50%, 75%) to analyze four different dilutions in the treated effluent. Considering all the plant growth indicators evaluated, leaf width, number of leaves, number of seedlings, number of stolons, length of stolons and final yield, the first treatment (0% bore well water), presented better parameters. For fish weight gain, the third treatment, with 50% dilution, presented better results, followed by the first (0%) and second (25%) treatments, respectively. In the study, gotukola plants grew actively in the hydroponic component and did not show any nutrient imbalance or deficiency symptoms during the experimental period of 60 days.

The optimal rate of hydraulic load (HLR) on aquaponic systems using substrate bed, MBT, for the cultivation of medicinal specie gotukola, *Centella asiatica* and the animal model *Cyprinus carpio* of the Koi variety was investigated by Nuwansi et al. (2020). The authors used nine identical systems, with three treatments and three flow rates (2.6 m day^{-1}, 7.8 m day^{-1} and 13.0 m day^{-1}) with three repetitions, verifying that the average body weight of the carp koi, at the time of the final harvest, did not vary significantly. Considering the plant leaf width, the number of leaves, the number of runners, the length of runners, and the number of plantlets, the best performance was obtained in T2 and it significantly differed with the other treatments. The final plant yield of the experiment significantly varied among the treatments. The highest value was obtained in the control treatment C2 (269.13 ± 10.88 g), but not significantly different to T2 (257.66 ± 12.34 g), and the lowest value was obtained in T1 (163.13 ± 6.89 g). The authors suggest T2 as the best HLR for optimum production of gotukola and koi carp in aquaponics. The stocking densities of *Cyprinus carpio* fingerlings, 1.4 (T1), 2.1 (T2), 2.8 kg m^{-3} (T3), was optimized with *Centella asiatica* in an aquaponic system using phytoremediated aquaculture wastewater, with two control treatments, without hydroponic component by Nuwansi, Verma, Chandrakant, Prabhath & Peter (2021). For the fish results the performances were better at the T1, however, without significance difference between the T2. For the plant performance T3 was the best treatment, but also, showing no difference between T2. Considering the water quality parameters, nutrient dynamics, plant growth as well as fish health monitoring parameters, the authors conclude the stocking density of 2.1 kg m^{-3} (T2) could be suggested as the optimum stocking density for this system. *C. asiatica* showed considerably high growth in the aquaponic system and no nutrient imbalance or deficiency symptoms were observed throughout the study period.

To test the effects of increasing sodium chloride (NaCl) concentrations in aquaponics and hydroponic solutions for *Cannabis sativa* production, during the flowering stage, Yep, Gale & Zheng (2020a) measured growth parameters (height, canopy volume), plant physiology (chlorophyll content, leaf-gas exchange, chlorophyll fluorescence, and water use efficiency), and solution physicochemical properties (pH, EC, and nutrients). The growth and physiological responses to NaCl in hydroponic—but not the aquaponic solution— became negatively affected at 40 mM. The mechanisms of aquaponic solution which allow this potential enhanced NaCl tolerance is worthy of future investigation. NaCl exceeding 5 mM resulted in decreased potency in plants grown in both solutions and decreased yield in plants grown in hydroponic solution.

Another experiment was realized by Yep, Gale & Zheng (2020b) to determine if rootzone systems can affect *C. sativa* growth, physiology, and inflorescence biomass and phytochemicals, comparing aquaponics and hydroponics production. The aquaponics systems tested were MBT, using peat-based growing substrate, and MBT associated with DWC, and the hydroponic unit was also constituted by peat-based growing substrate. The authors indicates that the rootzone-effects were significant on most growth and physiological traits measured, founding better growth performances in hydroponics, but greater concentrations of active principles at the aquaponic treatment. Pronounced differences in substrate macro-nutrient availability and foliar nutrient content occurred among the rootzones, suggesting a potential mechanism to explain the observed growth, physiological, yield and potency responses, underscoring the importance of the rootzone environment for the cultivation of *C. sativa*, specifically in indoor systems focused of medical or research production.

When analyzing the recovered works, we noticed that there is no consensus regarding the best aquaponic system, despite the MBT systems being more common. As each system has its particularities, and can develop different performances in nutrient cycling and, thus, plant and animal growth performances. The *Mentha* genus is a focal point in the analysis on the topic of medicinal aquaponics, being studied in different locations around the globe and with different potentialities. *Centella* and *Cannabis* genus have high potential for the pharmaceutical industry. The relationship between the keywords and main terms allows the visualization of what are most studies in the topic (Figure 8).

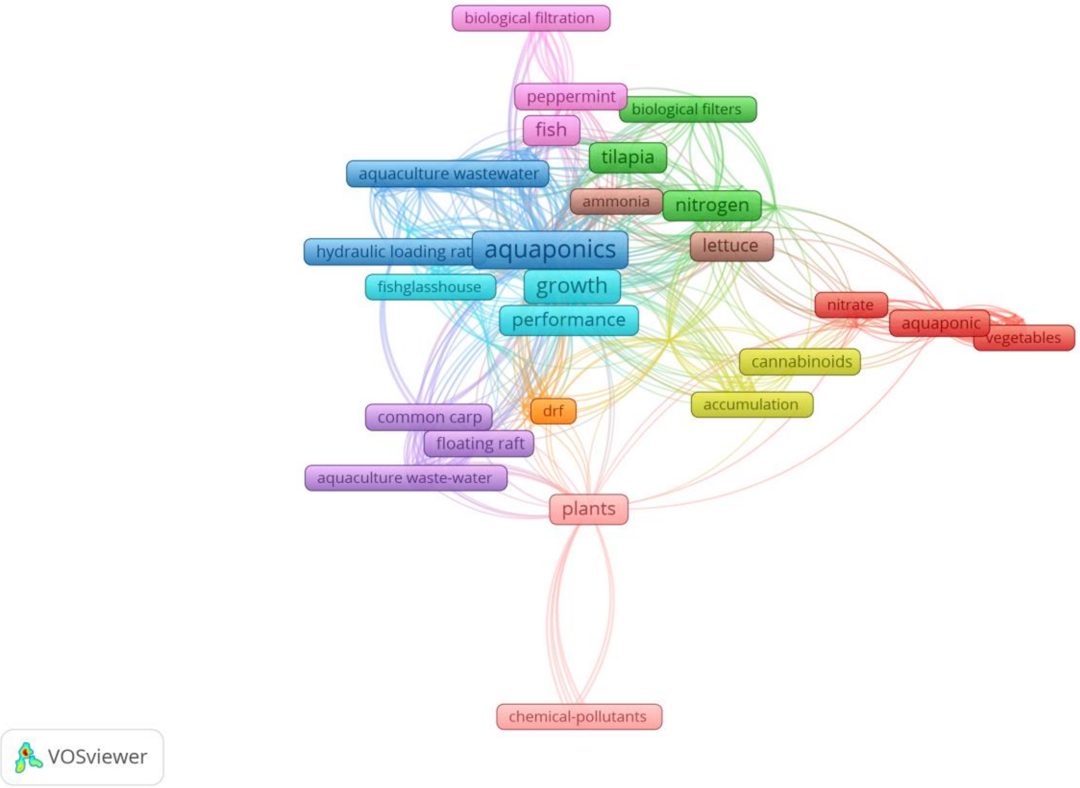

Figure 8. Cluster map of the articles keywords and terms. Source: The Authors.

Among the countries that publish on the subject, there is a good representation of developing countries, enabling the dissemination of the technique in rural extension and technical assistance for rural producers. Although all articles are practical experiments, some of them explore the plant physiological context more than species production data, creating a gap in the data. All articles recovered were developed on a laboratory scale, but all studied species are of great interest to industries and can be produced on a commercial scale. Even though there have been few works analyzed, it is remarkable how the theme has over the years a gradual increase, being essential to pay attention to this new topic of study.

3.4- CONCLUSION

It was noted that among the medicinal plant species studied, the genus *Mentha* is the most studied and has a character more of a culinary herb than a medicinal one. Studies showed that, in addition to the species studied, they presented satisfactory performances in aquaponic systems, and they produced similarly or better than in conventional methods. Still, with the production of medicinal plants, there is the possibility of adding value to the final aquaponic product, while studies must be carried out to better understand the concentrations of bioactives.

In view of the review and information obtained in this research, we observed that the spectrum of research activities in aquaponics includes a few related scientific fields, but with the intention of restricting research to the production of medicinal plants in aquaponics, different conformations, and models of aquaponic systems help to identify gaps that can be filled in the construction of knowledge about aquaponics and medicinal plants. Reviews of aquaponic research should increasingly broaden the understanding of the paths that aquaponic research is taking, improving discussions about the potential of this production, and generating information to future scale up of the systems for further commercial application with favorable technical and economical viabilities.

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4 - TROPICAL AQUAPONIC PRODUCTION OF MEDICINAL PLANTS IN ASSOCIATION WITH GOLDFISH

PRODUÇÃO AQUAPÔNICA TROPICAL DE PLANTAS MEDICINAIS EM ASSOCIAÇÃO COM GOLDFISH

ABSTRACT

Aquaponics is an emerging technology that synergistically combines aquaculture and hydroponic production through nutrient cycling and water recycling. As aquaponics grows exponentially, studies that evaluate the technique by testing different species in these systems make this choice fundamental resulting in a high development in the system, through high productivity and profitability. Ornamental fish, as well as medicinal plants, are interesting options for a more in-depth analysis of aquaponic systems. In this context, the objective was to analyze the performance of four plant species: Chilean boldo, *Peumus boldus*; peppermint, *Mentha piperita*; terramycin, *Alternanthera brasiliana*; and oregano, *Origanum vulgare*, as well as the growth of goldfish, *Carassius auratus*, and physicochemical aspects of water quality in identical aquaponic systems installed in a greenhouse during 91 days of cultivation. The experimental design consisted of four treatments and four replications, using in all treatments a density of 21 fish per fish tank (310L) and four seedlings, in cuttings, of each plant species studied. The vegetable cultivation systems were composed of expanded clay sediments in a 0.25m² planter, using a density of 16 plants/m², repeated, each treatment, in four aquaponic systems, totaling 16 aquaponic systems analyzed. The results showed that, of the four plant species studied, only oregano did not develop as expected, and Chilean boldo, peppermint and terramycin showed a representative increase in the analyzed parameters, as well as the animal species, goldfish. The water quality parameters analyzed were within the range recommended by reference authors, as well as for the well-being of the goldfish. The systems have demonstrated efficiency in vegetative and animal growth, and can help to add value to products from aquaponics, corroborating the evolution of technology.

Keywords: Aquaponic system; Closed system; Nutrient cycling; Recirculation

RESUMO

A aquaponia é uma tecnologia emergente que alia sinergicamente a produção aquícola e hidropônica, através da ciclagem de nutrientes e reciclagem de água. Como a aquaponia cresce exponencialmente, estudos que avaliam a técnica testando diferentes espécies nesses sistemas torna essa escolha fundamental para que possa resultar num alto desenvolvimento no sistema, através da alta produtividade e lucratividade. Os peixes ornamentais, assim como as plantas medicinais são opções interessantes para uma análise mais aprofundada nos sistemas aquapônicos. Objetivou-se, nesse contexto, analisar o desempenho de quatro espécies vegetais: boldo do Chile, *Peumus boldus*; menta, *Mentha piperita*; terramicina, *Alternanthera brasiliana;* e orégano, *Origanum vulgare*, assim como o crescimento de exemplares de goldfish, *Carassius auratus,* e aspectos físico-químicos da qualidade de água em sistemas aquapônicos idênticos instalados em estufa durante 91 dias de cultivo. O delineamento experimental foi composto de quatro tratamentos e quatro repetições, utilizando em todos os tratamentos densidade de 21 peixes por tanque piscícola (310L) e quatro mudas, em estaca, de cada espécie vegetal estudada. Os sistemas de cultivo vegetal foram compostos por sedimentos de argila expandida em jardineira de 0,25m², utilizando densidade de 16 plantas/m², repetidos, cada tratamento, em quatro sistemas aquapônicos, totalizando 16 sistemas aquapônicos analisados. Os resultados demonstraram que, das quatro espécies vegetais estudadas, apenas o orégano não se desenvolveu como o esperado, sendo que o boldo do Chile, menta e terramicina, apresentaram aumento representativo dos parâmetros analisados, assim como a espécie animal, goldfish. Os parâmetros de qualidade de água analisados estiveram dentro da faixa preconizada por autores de referência, assim como para o bem estar dos goldfish. Os sistemas demonstraram eficiência no crescimento vegetativo e animal, podendo auxiliar a agregação de valor dos produtos oriundos da aquaponia corroborando com a evolução da tecnologia.

Palavras-chave: Sistema aquapônico; Sistema fechado; Ciclagem de nutrientes; Recirculação

4.1. INTRODUCTION

Aquaponics is an alternative for the production of food with less impact on the environment through characteristics that refer to sustainability, such as the implementation of small family systems, the cycling of nutrients and the recycling of water resources (Diver 2006; Rakocy et al. 2006; Love et al. 2015). This integration allows plants to use nutrients from fish farming water, improving water quality, which can be reused in fish production (Hundley & Navarro 2013; Hundley et al. 2013; 2018; Kodama et al. 2019; Navarro et al. 2021).

Production systems that minimize impacts on the environment are the scientific-technological basis for a sustainable development project and aquaponics, as a system of low water consumption and nutrient reuse, can help to promote agroecological principles and the use of social and appropriate technologies (Corrêa et al. 2016). Aquaponics is an emerging food production technology that has the ability to condense and compress production into spaces and places that would not normally be used to grow food (Goddek et al. 2019), such as rooftops, abandoned industrial sites, and generally areas non-arable or contaminated (Reinhardt et al. 2019) and thus avoiding deforestation.

Aquaponic systems exist at a variety of scales and for different uses: personal or hobby use, for developing communities, as a teaching tool in science education, or as a means of increasing food production in urban settings (Love et al. 2015). However, in addition to being made up of different vegetable cultivation systems, such as: cultivation in pipes, cultivation in media beds or in flotation, are the main ones listed (Sommervile et al. 2014) and the scale of production determines whether the system is micro, small, semi-commercial or commercial (Palm et al. 2018).

The production of ornamental fish is one of the most profitable in fish farming and the success is mainly due to the high individual values that many species reach in the market, being sold per unit and not per kilogram, raising their price (Pessoa 2009). Ornamental fish are commonly associated with small, colorful species with beautiful and elegant shapes, such as goldfish (*Carassius auratus*), betta fish (*Betta splendens*) and guppy (*Poecilia reticulata*), considered aquarism icons with great popularity and acceptance by its practitioners around the world, however, there are a number of fish species that are not so small and that do not have any, or even none, of these characteristics (Ribeiro et al. 2010).

The goldfish is one of the most commercialized and well-known ornamental fish in the world (Rosa et al. 1994; Lima et al. 2001; Lima 2003) and according to Froese & Pauly (2009), they reach an average of 15 cm. The ideal range of water temperature for the species to reach well-being varies from 15 to 24ºC and the pH can be neutral or slightly alkaline. The commercialization potential of goldfish is commonly known, but more recent studies (Yin et al. 2014; Mohammad et al. 2018) seek to test profitability in different production systems.

Medicinal plants have been used by man since the beginning of his history and long before the emergence of writing, humanity already used herbs for medicinal purposes (Barata 2005; Toscano Rico 2011). Currently, medicinal plants are used by a large part of the world population, as an alternative medicinal resource for the treatment of various diseases, since in many communities, they represent a more accessible resource in relation to allopathic medicines (Bevilacqua 2010). Another aspect that should be highlighted is that the plant only has medicinal value, when used correctly, due to the risk of intoxication and emergence of several side effects, therefore, studies related to plants in alternative medicine have deserved increasing attention, due to the successive information and clarifications they provide to science (Carneiro et al. 2014).

The Chilean boldo, *Peumus boldus*, is a tree species, belonging to the Monimiaceae family and native to the central and southern regions of Chile, where it occurs abundantly. Its leaves are used in folk medicine to treat digestive and liver problems, and pharmacological studies found mostly describe the activities observed for the alkaloid boldine, described as the main component of boldo tea (Ruiz et al. 2008).

Peppermint, *Mentha* X *piperita* L., is among the most popular tea ingredients, having medicinal actions on biliary disorders, dyspepsia, enteritis, flatulence, and intestinal spasms (Mckay & Blumberg 2006). Also, the species is a source of one of the most popular essential oils, with several applications in the food, cosmetic and pharmaceutical industries (Costa et al. 2012).

In folk medicine, terramycin, *Alternanthera brasiliana*, is widely used in the treatment of several pathologies, and its anti-inflammatory and analgesic action, as well as an inhibitory activity against the herpes simplex virus, has been proven (Delaporte et al. 2002). Grenand et al. (1987) found that Guyana Indians use the leaves of *A. brasiliana* as an astringent and antidiarrheal, while the macerate from the plant is used against constipation.

Oregano, *Origanum vulgare*, an aromatic and medicinal plant is considered a tonic plant and has a great diversity of medicinal properties, with the digestive and expectorant properties being the most emphasized (Clevely & Richmond 1998). It is mainly due to its bechyco-expectorant power that it has greater medicinal utility, having been recognized as effective against whooping cough in children aged 2 to 12 years, and in adults its ability to calm the violent coughs accompanied by bronchorrhea and, also, in the elderly, it was found that this plant calmed the attacks of strenuous coughs, followed by flu and bronchial catarrh (Pires & Delgado 2013). Oregano has always been used by peasants in infusions and inhalations against bronchial disorders, being considered “a chest plant” (Lientaghi 2002).

Knowing that, in addition to some ornamental fish tolerate cultivation in low quality waters (Santos et al. 2015), studies that use medicinal plant species in aquaponic systems are scarce, as well as those that use species of ornamental interest. However, aquaponics grows exponentially and the productivity of both fish and plants follows this growth in line with the technological evolution of these systems and all the potential of these systems must be reported. Since there is a large number of reference works on the production of plant species for food, it is necessary to analyze these systems for the production of species of medicinal interest.

Also, the production of ornamental fish can add greater sales value to fish from aquaponic production, allowing greater economic sustainability to the system. Therefore, it becomes evident the need to analyze the performance of medicinal plant species and ornamental fish in aquaponic systems, economically enhancing and valuing aquaponic production.

The present study aimed to use the experimental technique in aquaponics to analyze the performance of ornamental goldfish in association with four medicinal plants, Chilean boldo, peppermint, terramycin and oregano, in addition to the water quality in micro identical aquaponic systems of sediment filled with expanded clay.

4.2 - METHODOLOGY

The experiment was carried out between April 18th to July 17th 2019, totalizing 91 days of cultivation, in 16 aquaponic systems installed in a greenhouse (Figure 9). The climate in the region is tropical with a dry season, type Aw in the Köppen-Geiger climate classification, with monthly average temperatures always above 18º C and annual rainfall around 1,540 millimeters, concentrated between October and April. The aquaponic units are made up of 310L volume polypropylene water tanks for fish production, filled until 300L, and 0.25 m² polypropylene planters filled with expanded clay, in addition to a water pump (Grupo Sario®, Sariobetter SB1000C, Brazil), that transports water from the fish pond to the vegetable crop. Aeration was constant by an air compressor (Group Boyu®, ACQ-003, Guangdong, China).

The experimental design, completely randomized, consisted of four treatments, being differentiated only by plant species, and four replications of each treatment, totaling sixteen aquaponic units. The distribution of species in the systems was random, and in the four rows of four systems, the four species would have been distributed.

For animal culture, juvenile individuals of goldfish, *Carassius auratus*, were used (weight 9.95g; total length 8.00cm; standart length 5.00cm), which were already being bred at the Sustainable Aquaculture Center and the matrices were acquired from a reputable supplier. A single density of 21 fish/water box (310L) was used, being fed with extruded ration of 42% of crude protein, according to what is recommended by the literature for the species and its life cycle (Craig & Helfrich 2017). For the planting of seedlings, four seedlings of the species chosen per planter were inserted, so that, for each plant species, 16 individuals were allocated in total, totaling 64 plants throughout the experiment (Figure 10).

Figure 9. Aquaponic systems in a greenhouse.

Figure 10. Seedlings implanted in the systems.

In vegetable cultivation, the species of Chilean boldo, *Peumus boldus*, peppermint, *Mentha piperita*, terramycin, *Alternanthera brasiliana*, and oregano, *Origanum vulgare* were used. The seedlings were acquired from planting the species in the soil and pricked for installation in planters, in the aquaponic system. As for plant growth, the parameters of weight (g), height (cm), width (cm), number of leaves and leaf length (cm) were evaluated using a precision electronic digital scale (B-max® - SF-400, China) and tape measure.

For the analysis of animal growth, initial and final biometrics were performed (Figure 11), considering parameters of weight (g), total length (cm) and standard length (cm), using a precision electronic digital scale (SF-400, manufactured in China) and tape measure. Also, analyzes of Total Nitrogen were performed using the Kjeldahl method (1883), with adaptations (Galvani & Gaertner, 2006).

Figure 11. Measurement of lengths in a goldfish specimen.

In terms of water quality, the parameters of temperature (°C), pH and dissolved oxygen concentration (mg/L) were measured weekly using specific probes for this purpose (Hanna® - HI 9813-6, Italy and Alfakit® - AT – 160, Brazil). Also, ion analyzes were performed to determine the cation (NH4+ and anions (NO^{2-}, NO^{3-} and PO_4^{3-}) using the Ion Chromatograph (SeQuant 2007), model 761 Compact IC, Methrohm (Herissau, Switzerland). Metrosep C2 ion exchange solution and as eluent a buffer solution of 4.0 mM Tartaric Acid and 0.75 mM Dipicolinic Acid (2,6-pyridinedicarboxylic acid). of 3.2 mM sodium carbonate and 1.0 mM sodium hydrogen carbonate and a suppressor solution of 100 mM sulfuric acid used in the ion suppression branch, parallel to ultrapure water, with a pre-set gradient of 50% (water/acid).

Comparative statistical analyzes of the biometric performances of animals and plants and of the water quality between the batteries of each system were performed using MaxStat® Lite version 3.60 and Statistica version 10 (Statsoft®), and analyzes were carried out by one-way ANOVA test and Tukey test, with a significance index set at 5%.

4.3 - RESULTS

4.3.1 *Water Quality*

The physical and chemical parameters of water in the analyzed systems showed an average temperature of 19.3 ± 3.2°C, pH of 6.43 ± 1.53 and dissolved oxygen concentration of 8.22 ± 2.74mg/L, with no statistical differences between the treatments. The ions and cations analyses from the water systems did not show significant differences between the treatments (Figure 12 to 15).

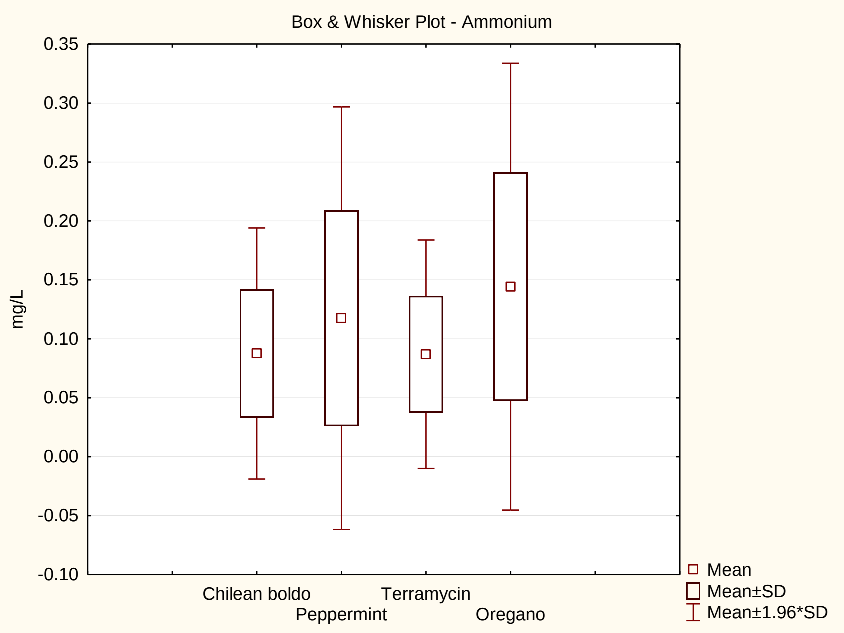

Figure 12. Graph of the content (mg/L) of Ammonium between the treatments.

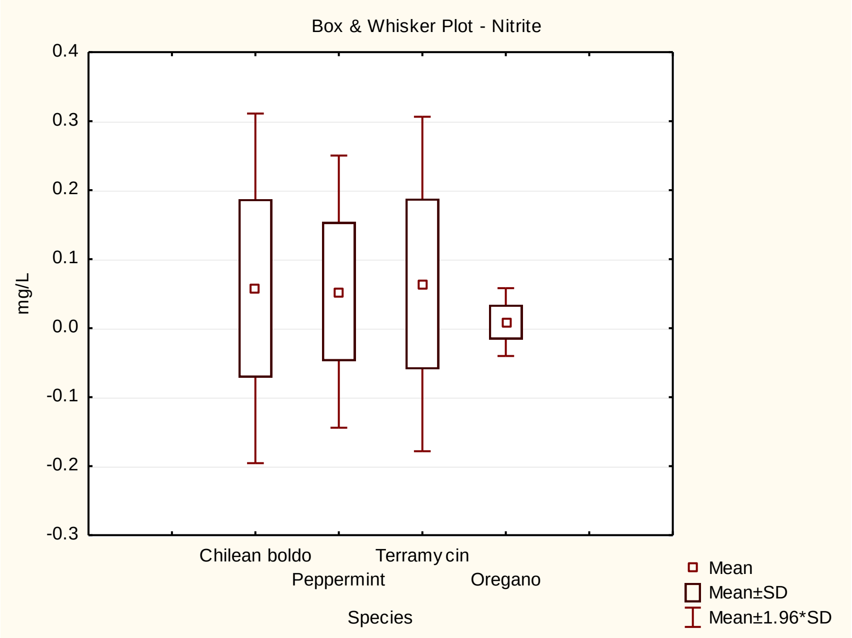

Figure 13. Graph of the content (mg/L) of Nitrite between the treatments.

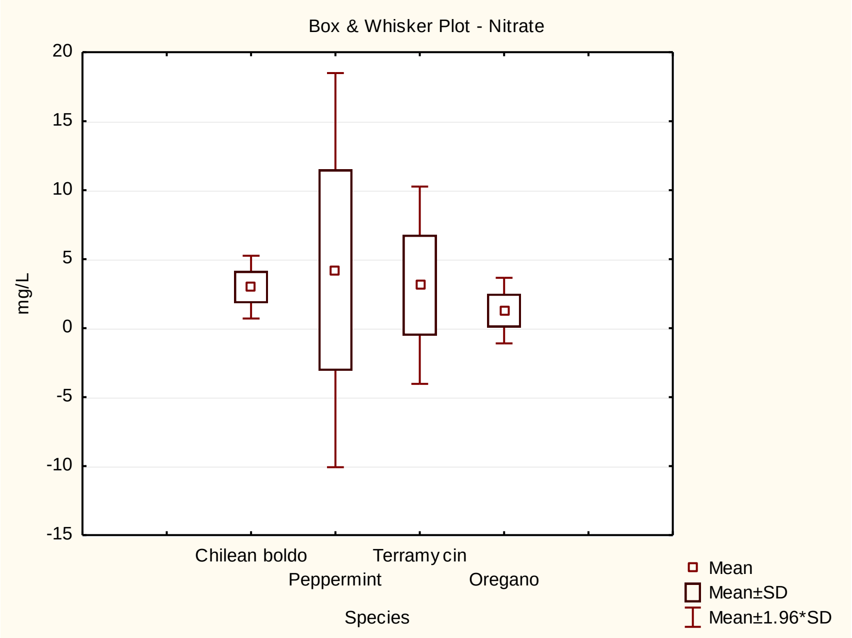

Figure 14. Graph of the content (mg/L) of Nitrate between the treatments.

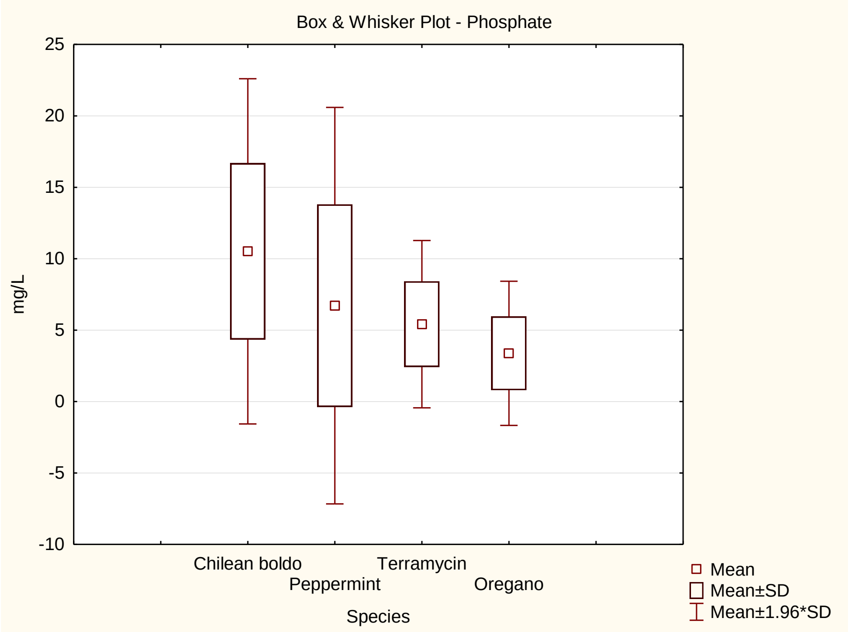

Figure 15. Graph of the content (mg/L) of Phosphate between the treatments.

4.3.2 *Fish*

Initial and final biometrics were performed to measure fish growth, and considering that in each system there were 21 individuals, 336 individuals were analyzed. During the experiment, 42 deaths of individuals were recorded, mostly in the oregan system, representing 12.5% of mortality, and the animals were substituted by another animal. The initial biometric mean for the weight parameter (g) was 9.95^a ± 6.85 and final was 18.91^b ± 9.36 (Figure 16), and for the initial total length it was 8.00^a and final of 10.17^b ± 1.72 (Figure 17) and standard length (cm) of initial 5.00^a and final of 6.90^b ± 1.14 (Figure 18).

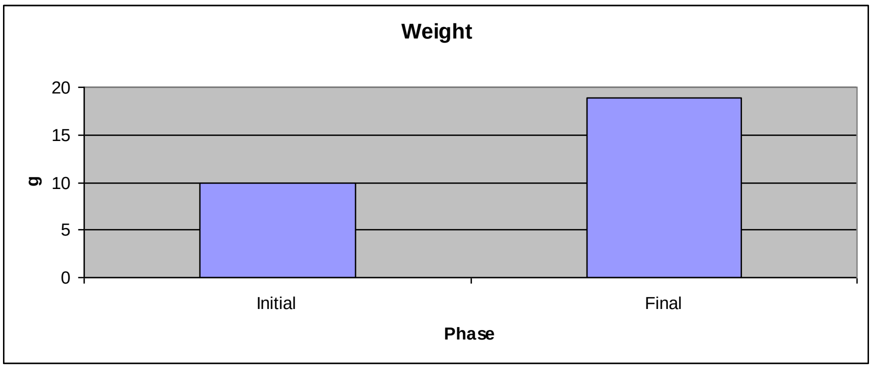

Figure 16. Graph of fish initial and final weight (g).

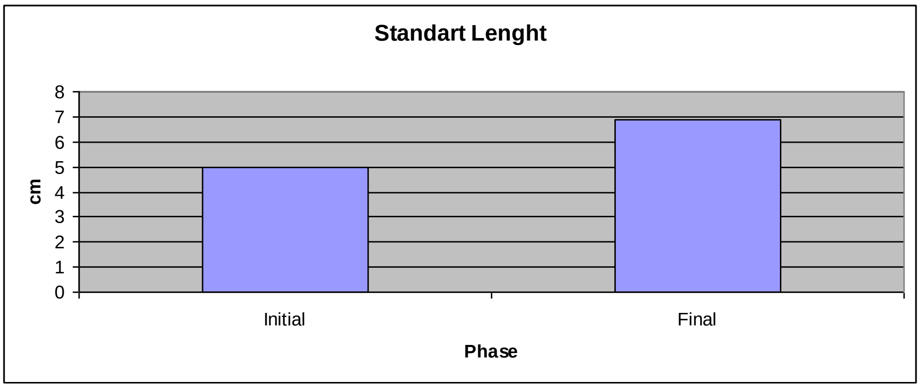

Figure 17. Graph of fish initial and final standard length (cm).

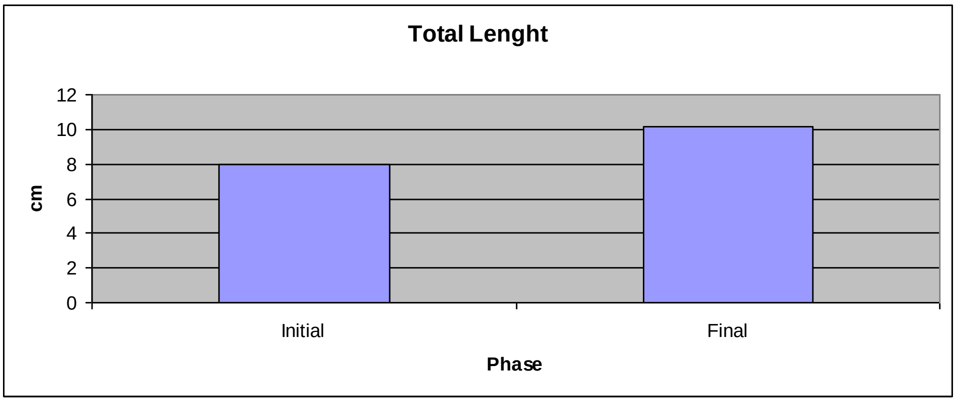

Figure 18. Graph of fish initial and final total length (cm).

4.3.3 *Plants*

Of the four species evaluated, three showed significant growth during the experiment, demonstrated by the statistical differences, trough descriptive analysis, one-way anova test and Tukey test, between the parameters evaluated (Table 3), and the other species, *Origanum vulgare*, showed deficiency results for the parameter of weight (Figure 19) and height. (Figure 20), also occurring mortality of individuals. In the number of leaves parameter, only oregano showed no statistical difference from the initial value (Figure 21).

Table 3. Results of the averages and standart deviation of biometric parameters (weight; height; number of leaves) by plant species.

		Weight (g)		Heigh (cm)		Number of leaves	
Species/Parameter	(n)	Initial	Final	Initial	Final	Initial	Final
Peumus boldus	16	11.56^{a} ± 1.32	1358.75^{b} ± 416.69	18.00^{a} ± 4.47	44.81^{b} ± 5.47	29.06^{a} ± 14.81	135.68^{b} ± 14.89
Mentha piperita	16	8.43^{a} ± 0.90	262.50^{b} ± 96.05	43.75^{a} ± 10.01	63.00^{b} ± 9.79	27.30^{a} ± 9.81	246.54^{b} ± 52.75
Origanum vulgare	16	15.00^{a} ± 1.07	20.00^{a} ± 14.93	33.15^{a} ± 5.15	16.30^{b} ± 3.05	32.12^{a} ± 11.43	40.60^{a} ± 41.93
Alternanthera brasiliana	16	11.56^{a} ± 1.23	105.14^{b} ± 85.38	34.65^{a} ± 4.86	50.57^{ab} ± 22.84	13.06^{a} ± 2.40	42.17^{b} ± 23.60

Means followed by different letters between the columns of each parameter differ at 5% probability by the Tukey test.

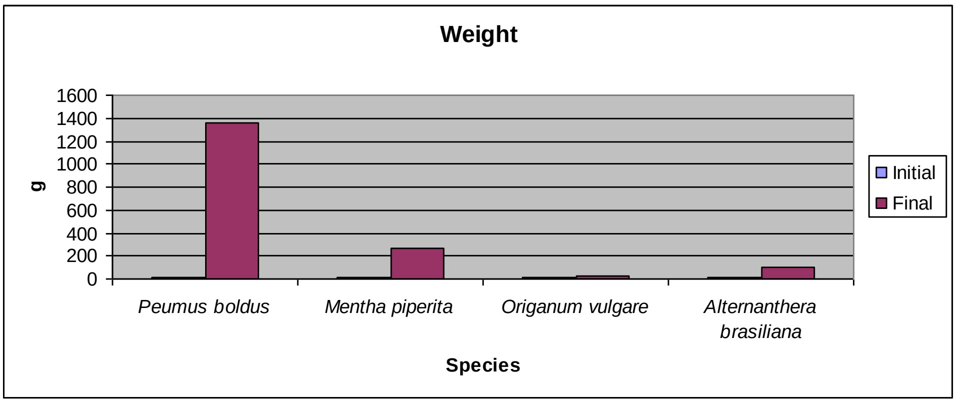

Figure 19. Graph of plants initial and final weight (g).

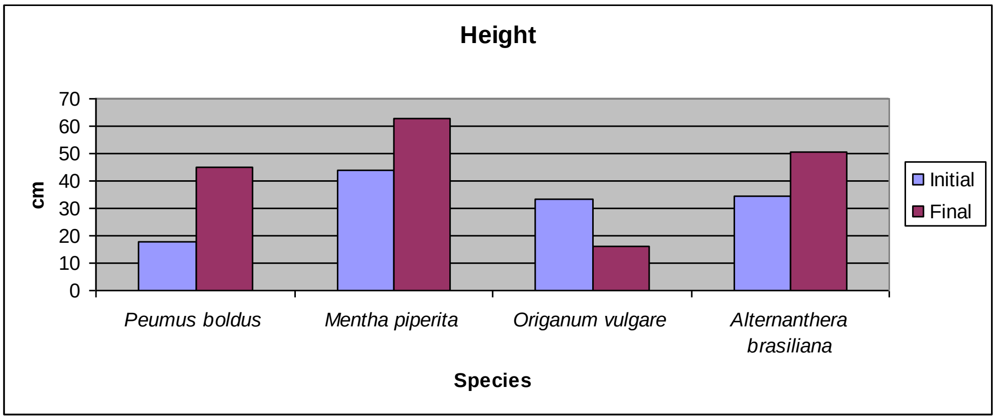

Figure 20. Graph of plants initial and final height (cm) of the plants.

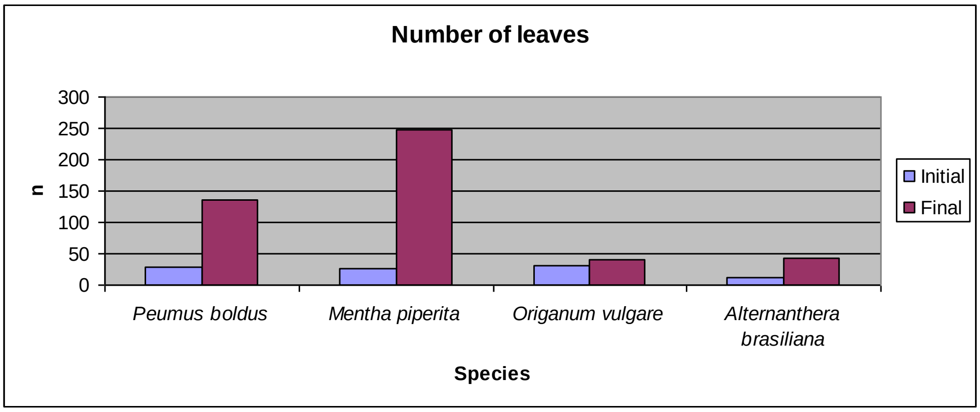

Figure 21. Graph of plants initial and final number of leaves.

The results about the content (g/Kg) of the total nitrogen of the leaves of the species Chilean boldo, terramycin and peppermint were, respectively, 3.13^{a} ± 1.34, 4.31^{ab} ± 1.56 and 5.92^{b} ± 2.54 (Figure 22). Most oregano leaves were naturally dry at the end of the experiment and the specie did not enter in Total Nitrogen analyzes. The results of the experiment showed that the Chilean boldo and peppermint species obtained visibly productive performances in the system (Figures 23 and 24), while the terramycin and oregano species, despite having resisted the period of cultivation in aquaponics, did not develop as expected, although terramycin increased in height, weight and number of leaves (Figures 25 and 26).

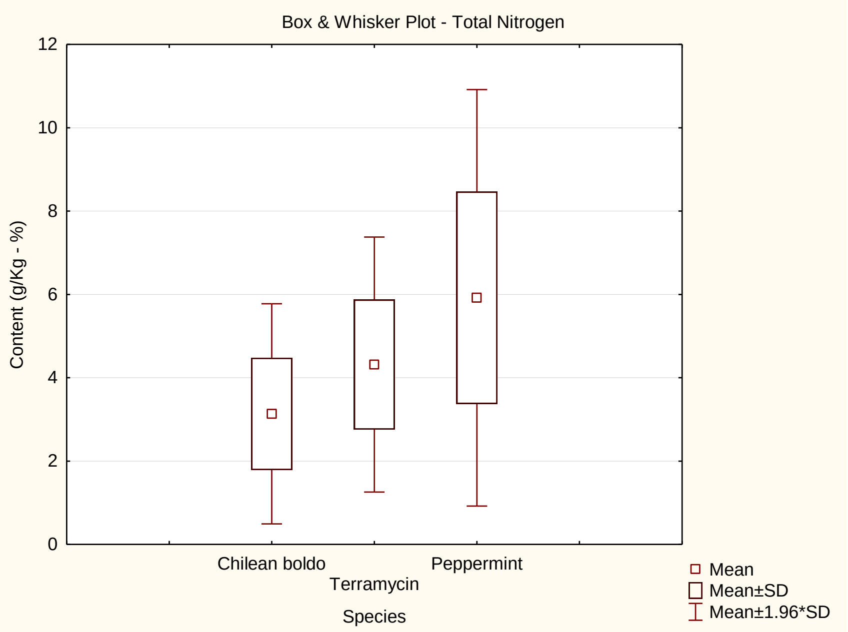

Figure 22. Graph of the content (g/kg - %) of Total Nitrogen in plant leaves.

Figure 23. Chilean boldo at the end of the experiment.

Figure 24. Peppermint at the end of the experiment.

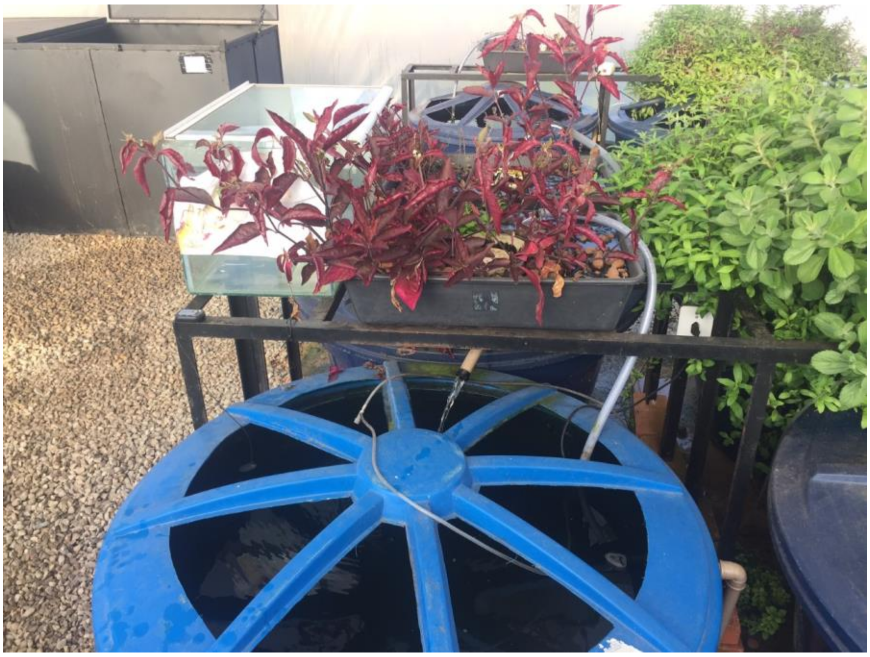

Figure 25. Terramycin at the end of the experiment.

Figure 26. Oregano at the end of the experiment.

4.4 - DISCUSSION

The physical-chemical parameters of water, temperature, dissolved oxygen concentration and pH in our study were within the optimal range for aquaponic systems as recommended by Somerville et al. (2014) and Carneiro et al. (2015). Chemical analysis of ions and cations diluted in aquaponic solution did not show differences between treatments, however low levels of Nitrite are observed, since in aquaponics the nitrification process is favored, converting it into Nitrate, a form of plant absorption of Nitrogen.

For the cultivation of goldfish, in addition to maintaining the species' well-being, the ideal parameters according to the literature (Froese & Pauly, 2009) are in the range of 15 to 24°C, with an average of 19.3 ± 3 .2°C, thus, within the optimal range for the species. Fish showed statistically significant differences between the initial and final biometrics, and Froese & Pauly (2009) indicate that the goldfish reaches an average of up to 15 cm in length and that the larger size is more interesting for commercialization for aquarium hobbyists. The final length mean of the animals was 10.17 ± 1.72 cm, demonstrating the animal growth as expected during the experiment.

The goldfish is commonly used as the aquatic organism in aquaponics systems all over the world (Rakocy et al. 2006; Yildiz et al. 2017). Patil et al. (2019) analyzed three stocking densities of this specie in association with basil in a growing bed aquaponic system, and in this 32 days experiment they observed the growth of the goldfish, which had its initial weight 3.32 ± 0.45 g and different final weights, but at all of them the weight gain (%) were higher than 160%. In our experiment, we found a weight gain of approximately 90%, with the fish having different life stages and staying longer in the system. It should be noted that the production of ornamental fish in aquaponics can differs from the purpose of other fish for human consumption, since the main interest is to reach the stage of maturation for reproduction and possibly for the population of ornamental ponds.

From the analysis of the results (Table 3), it can be observed that the species Chilean boldo and peppermint obtained significant growth results in all parameters and in all implanted individuals, possibly because the are low-nutrient-demand herbs as described by Somerville et al. (2014), being totally viable their cultivation in tropical aquaponic bedding systems of substrate. The Chilean boldo had an average final height of 63.00 ± 9.79 cm in 91 days, while Vogel et al. (2011) found results of 74.5 and 67.6 cm of the same species grown in soil, but of plants already cultivated for four years and in longer sampling periods. The densities of the plants used in the experiment by Vogel et al. (2011) were 8 and 16 plants/m², and the authors did not find significant differences between these two treatments. In the experiment in question, the density used was 16 plants/m² and the results demonstrate a satisfactory development of Chilean boldo, implanted by cuttings, in aquaponics.

For peppermint, the average weight of total biomass per planter was 262.5 ± 96.05, being 65.62 g plant-1, while Costa et al. (2012), who cultivated the same species in pots with prepared soil, shading with shades of different colors and lighting rate of 50%, obtained an average weight of 31g plant-1 in 120 days of experiment. Despite the seedlings in the experiment by Costa et al. (2012) were introduced smaller than that of the experiment in question, the comparison allows identifying that peppermint in aquaponics had excellent performance, demonstrating in the final weight gain its adaptation to the cultivation system.

Among the plant species analyzed in this study, peppermint is one of the best known in aquaponic systems (Moya et al. 2014; Roosta 2014; Shete et al. 2016; Petrea et al. 2016; Nozzi et al. 2018 ; Ogah et al. 2020a; 2020b; Knaus et al. 2020). While Petrea et al. (2016) analyzes the performance in different cropping densities and in different cropping systems, Moya et al. (2014), Shete et al. (2016) and Knaus et al. (2020) analyzed the specie in a cultivation system similar to the experiment carried out, media bed sytems.

Buzby et al. (2016), who evaluated stand establishment and growth performance of 34 cultivars grown in an aquaponic system under three treatments regimes, cultivated Italian oregano (*Origanum* X *majoricum*) in aquaponics, but like in our experiment, the specie couldn’t adapt to the system. Kosakowska et al. (2019), carried out a study to determine differences between the cultivation of oregano in open field and shaded environments cultivated organically, found higher productivity in dry mass of plants cultivated in excess than in open field (76.49 and 49.44g plant^{-1}, respectively). Murillo-Amador et al. (2013), in a similar experiment in Mexico, obtained results for dry mass productivity of 25.52 and 87.19 g plant^{-1}, for plants in open field and shade, respectively.

Studies that consider the production of organic oregano are scarce (Murillo-Amador et al. 2013). The oregano individuals implanted and analyzed in the aquaponic systems in question did not obtain the expected growth, presenting some plants with lower weights than the initial ones and, on average, a decrease in the final height in relation to the initial, in addition to having presented mortality of six plants, representing 37.5% of the individuals of this species. As reported by Juárez-Rosete et al. (2019), the concentration of the nutrient solution in soilless culture systems influences the accumulation of aereal biomass and nutritional contents, also the low performance of the species in the system may have been due to the non-adaptation of the species to the substrate (expanded clay) and/or the water regime in the system, since all systems received the same supply of feed for the fish and, consequently, same supply of nutrients to plants.

Terramycin, like all other species studied in this work, was introduced into the systems by cuttings and developed significantly, producing elongated branches and flowering during the experiment. Despite having presented the mortality of two plants, representing 12.5% of the individuals of this species, and some individuals having a final average height statistically similar to the initial, 50.57 cm, it proved to be in line with the maximum height of the species (30 to 50 cm), according to Lorenzi & Souza (1999).

Menegaes et al. (2014) investigated the performance of terramycin at three different densities (1 plant/pot; 2 plants/pot and 3 plants/pot) and found better growth results in plants grown at higher densities in pots. The density used in the experiment in question was higher than in the aforementioned work, of four plants per 0.25m², respectively 16 plants^{-1}, and presented an average of final height values, 50.57cm, significantly higher than the 19.90cm from the experiment by Menegaes et al. (2014). The results demonstrate the potential of aquaponic production and the development of these plants using seedling propagation by cuttings.

The number of leaves in three of the four species studied, boldo de Chile, peppermint and terramycin, was considerably higher at the end of the experiment and, as this parameter is related to the plant parts used for the production of the drugs, they are the main products of plant production. According to Castro and Albiero (2016), 80% of the raw materials used by the pharmaceutical industry evaluated in their work are actually imported, leaving only 20% of the market for Brazilian producers. It is believed that investment in training small producers, in cultivation techniques, in agrarian technology and, mainly, in infrastructure could generate a higher quality product and, consequently, increase the sector's potential.

Another important aspect to be considered is that studies such as Bochner et al. (2012), Souza et al. (2012) and Castro and Albiero (2016) report on problems associated with the commercialization of medicinal plant species, mainly contamination and misclassifications. These problems were minimized in aquaponics, since from the selection of the correct species and their maintenance in a protected environment they allowed plant health.

4.5 – CONCLUSION

The potential of aquaponics in the production of medicinal plants was analyzed utilizing four plant species, resulting in a significant increase in biomass production for the Chilean boldo, peppermint and terramycin, corroborating the hypothesis of the possibility of using the aquaponic technology in medicinal plants production. Oregano did not showed positive results, suggesting that the concentration of the nutrient solution should be monitored for the cultive of this specie, as well as by the propagation system of this specie, with the root system developed instead of cuttings. In addition, the goldfish juveniles showed significant growth, doubling the value of individual weight, while the water quality parameters remained as recommended for aquaponic systems. As demonstrated in the experiment, the Chilean boldo and peppermint obtained representative growth, being recommended for cultivation and future experiments, including bioactive analysis and mass-grown by aquaponic farmers. New studies that address the issue of medicinal plants and different species of fish should be encouraged, in order to add final value to products from aquaponics.

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5 - Tropical aquaponic production of lemon balm, *Melissa officinalis*, using different *Astyanax bimaculatus* fingerlings stocking densities

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Abstract: The relationship of the constituent organisms of aquaponics, fish, plants and microorganisms need to be in biological harmony to favor the maximum performance of the species. Lemon balm (*Melissa officinalis*), a food and medicinal plant, in addition to *Astyanax bimaculatus* are species that can add value to aquaponic final products. The present experiment tested five treatments differing by stocking densities of *A. bimaculatus* fingerlings (0.0, 0.1, 0.2, 0.3 and 0.4 fish L^{-1}; T1, T2, T3, T4 and T5, respectively) in association of lemon balm, at constant density (24 plants m^{-2}), in media bed aquaponic systems installed in a greenhouse. The experimental design was completely randomized with three replications for each treatment, totalizing 15 aquaponic systems analyzed. The results showed that, for fish growth, T2 was the one that presented the best performance results, followed by T3 and T4, and finally T5, while for plants it was T3, followed by T4 and T5, which did not showed differences between them, followed by T2 and T1, lastly. In all treatments, animal and plant growth were observed. The studied aquaponic systems demonstrated their viability for the production of the species presenting satisfactory results, which can be interesting for further studies and producers.

Keywords: Water recirculation; Nutrient recycling; Aquaculture; Hydroponics; Medicinal plants

5.1. Introduction

One of the main water-related problems that need to be addressed is the production of more food while using less water, and as agriculture faces complex challenges to satisfy an estimated population of nine billion, between now and 2050, more water will be needed to produce the estimated 60% extra food, being necessary studies that focuses on more efficient, equitable and ecological use of water in agriculture (FAO 2020). Aquaponics is a farming technology advancing rapidly from its first exploits in the last years of the twentieth century and the first decades of the twenty-first century (Goddek et al. 2019). But it still is an ‘emerging technology and science topic’ (Junge et al. 2017).

Aquaponic systems are a branch of recirculating aquaculture technology in which plant crops are included to either diversify the production of a business, to provide extra water filtration capacity, or a combination of the two (Espinal & Matulié 2019). In aquaponic systems, the uptake of nutrients should be maximized for the healthy production of plant biomass but without neglecting the best welfare conditions for the fish in terms of water quality (Yildiz et al. 2017).

In essence, both terrestrial plant and aquatic animal production systems share a common resource: water, whereas plants are generally consumptive of water via transpiration and release it to the surrounding gaseous environment, whereas fish are generally less consumptive of water, but their contained culture produces substantial waste water streams due to accumulated metabolic wastes (Maucieri et al. 2019). Therefore, aquaculture may be integrated within the water supply pathway of plant production in non-consumptive ways so that two crops (fish and plants) may be produced from a water source that is generally used to produce one crop (plants) (Lennard & Goddek 2019).

The nutrient concentration and ratio amongst them are the most important variables capable to influence plant uptake (Maucieri et al. 2019). In aquaponic systems fish metabolic wastes contain nutrients for the plants, but it must be taken into account, especially at commercial scales, that the nutrient concentrations supplied by the fish in aquaponics are significantly lower and unbalanced for most nutrients compared to hydroponic systems (Nicoletto et al. 2018).

Microbial communities play a crucial role in the nutrient dynamic of aquaponic systems (Schmautz et al. 2017), converting ammonium to nitrate, but also contributing to the processing of particulate matter and dissolved waste in the system (Bittsanszky et al. 2016). Plant uptake of nitrogen - N and phosphorous - P represents only a fraction of the amount removed from the water (Trang & Brix 2014), indicating that microbial processes in the root zone of the plants, and in the substrate (if present) and throughout the whole system, play a major role (Maucieri et al. 2019).

The composition of fish feeds depends on the type of fish and this influences nutrient release from fish's metabolic output, and typically, fish feed contains an energy source (carbohydrates and/or lipids), essential amino acids, vitamins, as well as other organic molecules that are necessary for normal metabolism but some that the fish's cells cannot synthesize (Maucieri et al. 2019). Furthermore, it must be taken into account that a plant's nutritional requirements vary with species (Nozzi et al. 2018), variety, life cycle stage, day length and weather conditions and that recently (Parent et al. 2013; Baxter 2015), the Liebig's law (plant growth is controlled by the scarcest resource) has been superseded by complex algorithms that consider the interactions between the individual nutrients (Maucieri et al. 2019). Both these aspects do not allow a simple evaluation of the effects of changes in nutrient concentrations in hydroponic or aquaponic systems (Maucieri et al. 2019).

In fact aquaponics is an alternative for the production of food with less impact on the environment through characteristics that refer to sustainability, such as the implementation of small family systems, the cycling of nutrients and the recycling of water resources (Diver 2006; Rakocy et al. 2006; Love et al. 2015). This integration allows plants to use nutrients from fish farming water, improving water quality, which can be reused in fish production (Hundley & Navarro 2013; Hundley et al. 2013; 2018; Kodama et al. 2019; Navarro et al. 2021).

Fish from genus *Astyanax* can be raised by small rural or urban producers in family production systems (Lopes et al. 2013); and can be used as snacks for human consumption and forage fish in aquarium stores and public aquariums, for environmental enrichment and also to feed larger carnivorous species (Silva et al. 2011). It is a source of essential fatty acids for human and animal food (Gonçalves et al. 2014), with great potential to replace canned sardines (*Sardinella brasiliensis*) and anchovies (*Anchoviella lepidentostole*) in the snack market (Porto-Foresti et al. 2005), which can reduce the impact on the natural populations of these species, which are only available from fishing. Other advantages of *Astyanax* sp. production are the standardization of size, greater traceability and regularity in supply (Gonçalves et al. 2017).

In many commercial aquaponic ventures, the vegetable production is more profitable than the fish, however, having exceptions, estimating up to 90 percent of the financial gains coming from plant production, for the reason of the fast turnover rate of vegetables compared with the fish (Somerville et al. 2014). There are two general categories of aquaponic plants based on this demand, low-nutrient-demand plants include the leafy greens and herbs, and plants with high-nutrient demand, sometimes referred to as nutrient hungry, include the botanical fruits and bulbs plants (Somerville et al. 2014).

Aromatic herbs are plants whose fresh, dried or dehydrated leaves are used as essence, spice, for medicinal purposes, processed or as infusions that are in high demand in developed countries, therefore, they have a high potential for the export market (Espinosa-Moya et al. 2018). Globally, aromatic herbs in culinary use are becoming more important because consumers have a desire for healthier foods, with a significant increase in the choice of organic foods and the rise in ethnic foods (Makri & Kintzions 2007). In general, leafy green plants do extremely well in aquaponics along with some of the most popular fruiting vegetables, including tomatoes, cucumbers and peppers (Somerville et al. 2014).. For culture of high-value ornamental fishes or high yield specialty crops like medicinal herbs, the media bed aquaponic systems are usually most suitable (Espinosa-Moya et al. 2018). According to Diver (2006), herbs and specialty greens are well adapted to aquaponic culture systems and have very low to medium nutritional requirements, then, in the present study, lemon balm (*Melissa officinalis* L.) was the selected food and medicinal specie for analyses.

Lemon balm is a perennial aromatic herb that has a lemon-like aroma and belongs to Laminaceae family (Khalid et al. 2008). This herb is traditionally used as medicine for relieving neurogenic disorders, insomnia, and stress due to its spasmolytic and sedative properties (Kennedy et al. 2002), in addition, the anti-bacterial and anti-oxidative effects of its essential oil are well documented (de Assis et al. 2020; Patora and Klimek 2002; Venskutonis et al. 2005). Lemon balm is widely used as a resource for fragrances, phytomedicine, and teas (Carnat et al. 1998); therefore, lemon balm has been cultivated in many countries and there attracts a continued interest for its mass production (Son et al. 2021).

Since there is a range of plant species to be cultivated in aquaponics, the choice for species that adds final value to the aquaponic product must be highlighted. Considering that leafy plants, as some aromatic herbs, that are less demanding in nutrients stand out in aquaponic systems, the present study was conducted to assess the growth performance as well as to optimize the stocking density of *Astyanax bimaculatus* fingerlings in lemon balm (*Melissa officinalis*) media bed tropical aquaponic systems production.

5.2. Materials and Methods

The experiment was carried out between August 24th and October 14th 2020, totalizing 51 days of cultivation, in 15 identical aquaponic systems installed in a greenhouse at the Sustainable Aquaculture Center at Fazenda Água Limpa, FAL, from the University of Brasília - UnB, Brazil. The study has been approved by institutional animal ethics committee of the University of Brasília (CEUA/UnB protocol code 115/2019 of August 20th, 2020) for studies involving animals. The aquaponic systems rely on an ebb-and-flow water pattern, with one loop. The experimental design, completely randomized, consisted of five treatments (one of them being the control) with three repetitions, being differentiated by fish stocking densities, totalizing fifteen aquaponic units.

The aquaponic units are made up of 310L volume polypropylene water tanks for fish production, filled until 300L, and 0.25 m² polypropylene planters filled with expanded clay, in addition to a water pump (Grupo Sario®, Sariobetter SB1000C, Brazil), that transports water from the fish pond to the vegetable crop. Aeration was constant by an air compressor (Group Boyu®, ACQ-003, Guangdong, China). The climate in the region is tropical with a dry season, type Aw in the Köppen-Geiger climate classification, with monthly average temperatures always above 18º C and annual rainfall around 1,540 millimeters, concentrated between October and April.

Astyanax bimaculatus fingerlings were stocked at five different densities, 0.0 fish L^{-1} (T1-Control), 0.1 fish L^{-1} (T2); 0.2 fish L^{-1} (T3); 0.3 fish L^{-1} (T4); 0.4 fish L^{-1} (000, 100, 200, 300 and 400 fish m^{-3}, respectively). The fingerlings were acquired from a reputable supplier and being fed with extruded ration of 42% of crude protein. For the animal growth analysis, initial and final biometrics were performed, considering parameters of weight (g) and total length (cm), using a precision electronic digital scale (SF-400, manufactured in China) and pachymeter. Biweekly biometrics was realized to determine the fish mean weight for each treatment attempting to correct the feed offer, fixed at 4% of the biomass gross weight. Also, growth indexes were calculated to observe the animal performances, the specific growth rate (% d^{-1}), the protein efficiency ratio (PER), and the feed conversion ratio (FCR). Fish were anesthetized with eugenol solution and euthanized according to recommended techniques (Fernandes et al. 2017; Viegas et al. 2020).

The chosen plant specie for the experiment was the lemon balm, *Melissa officinalis*, which is worldly known for its medicinal and consumption as food uses. The seedlings were acquired from planting the specie in the soil and pricked for installation in planters in the aquaponic system. As for plant growth, the parameters of weight (g), height (cm) and number of leaves (nos. plant-¹) were evaluated; using a precision electronic digital scale (B-max® - SF-400, China), pachymeter and manually, respectively. Plants were installed at density of 24 plants m-² and as we use planters of 0.25 m², there were 6 plants for each aquaponic unit. Also, at the end of the experiment lemon balm plants and fishes were dried at 60 ºC for 3 days, in a drying oven, and analyses of total nitrogen of plant parts and fishes were performed using the Kjeldahl (1883) method, with adaptations (Galvani & Gaertner 2006).

In terms of water quality, the parameters of temperature (°C), pH and dissolved oxygen – DO concentration (mg/L) were measured weekly using specific probes for this purpose (Hanna® - HI 9813-6, Italy; Alfakit® - AT – 160, Brazil, respectively). Also, at the end of the experiment, ion analyzes were performed to determine the cations sodium - Na+ (mg/L-¹), potassium - K+ (mg/L-¹), ammonium - NH4+ (mg/L-¹), calcium - Ca2+ (mg/L-¹) and magnesium - Mg2+ (mg/L-¹), and the anions fluoride - F- (mg/L-¹), chloride - Cl- (mg/L-¹), nitrite - NO2- (mg/L-¹), nitrate - NO3- (mg/L-¹), phosphate - PO43- (mg/L-¹), sulfate - SO42- (mg/L-¹) at the treatments water samples, using the Ion Chromatograph, model 761 Compact IC, Methrohm (Herissau, Switzerland). For cation analyses it was used a Metrosep C2 ion exchange solution and as eluent a buffer solution of 4.0 mM Tartaric Acid and 0.75 mM Dipicolinic Acid (2.6-pyridinedicarboxylic acid). For the anions analyses was used Metrosep Asup5 and a buffer solution of 3.2 mM sodium carbonate and 1.0 mM sodium hydrogen carbonate and a suppressor solution of 100 mM sulfuric acid were used in the ion suppression branch, parallel to ultrapure water, with a pre-set gradient of 50% (water/acid).

Comparative statistical analyzes of the biometric performances of animals and plants and of the water quality between treatments were performed using MaxStat® Lite version 3.60 and Statistica version 10 (Statsoft®), and analyzes were carried out by one-way ANOVA test, Tukey test and Dunn's test with a significance fixed at 5%, and multivariate analyses were carried out by Wilks and LSD test. Graphs were created by factorial ANOVA analyses.

5.3. Results

5.3.1. Fishes

Effect of different fish densities was observed on fish growth (length and weight). Fish growth in terms of body weight (g), length (cm), weight gain (%) and length gain (%) of *A. bimaculatus*, through descriptive statistical analysis, one-way anova hypothesis test and Tukey's test varied significantly ($p<0.05$) between treatments (Table 4).

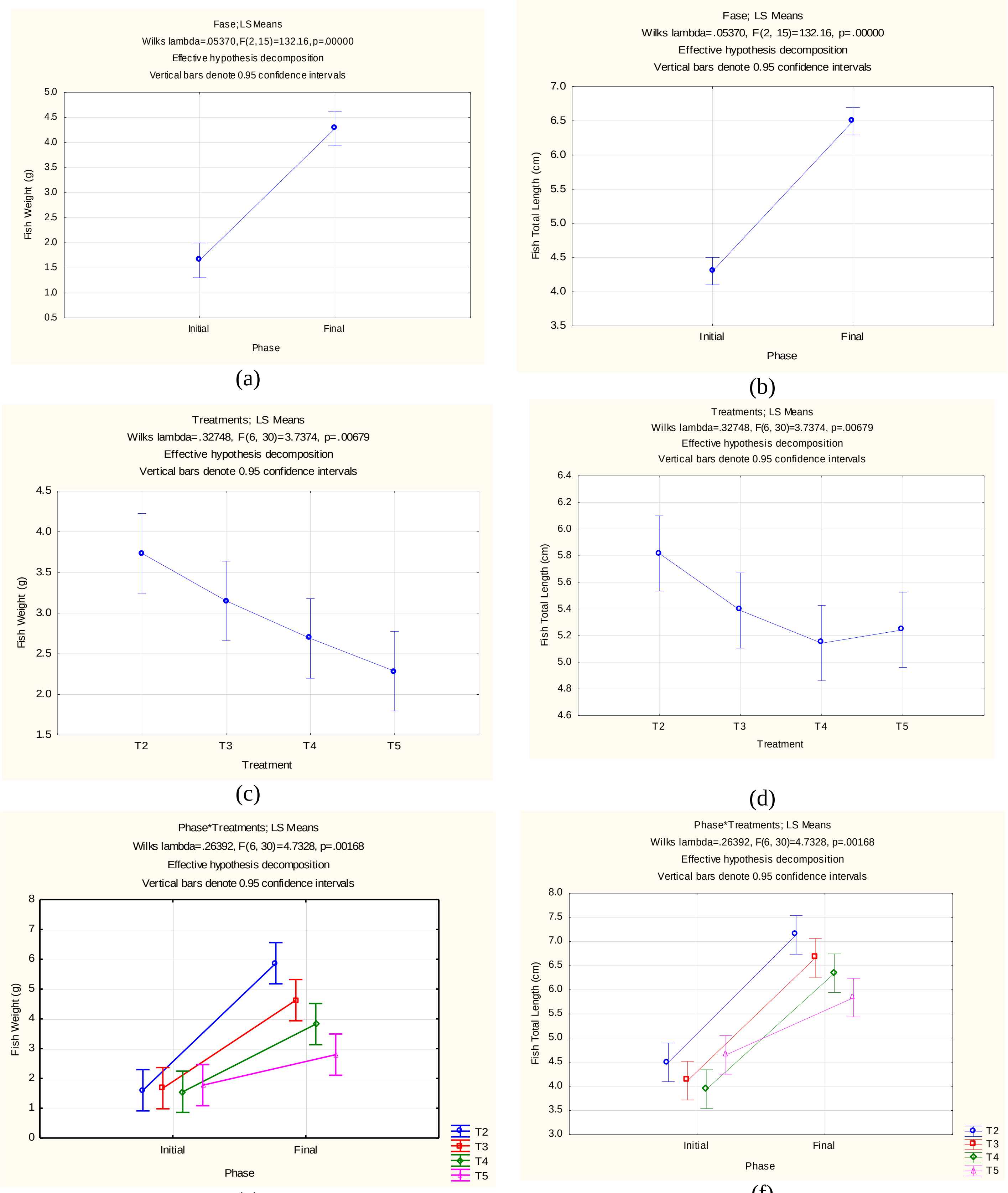
Table 4. Growth parameters and standart deviation of *Astyanax bimaculatus* fingerlings reared in media bed aquaponic system after a period of 51 days (Mean±SE).

Parameters	T2	T3	T4	T5
Initial weight (g)	1.60 ± 0.06^{a}	1.67 ± 0.06^{a}	1.55 ± 0.15^{a}	1.73 ± 0.09^{a}
Final weight (g)	5.86 ± 1.48^{a}	4.62 ± 0.30^{ab}	3.82 ± 0.17^{ab}	2.80 ± 0.36^{b}
Weight gain (%)	266.25	176.64	146.45	61.84
Initial length (cm)	4.49 ± 0.29^{a}	4.11 ± 0.16^{a}	3.94 ± 0.07^{a}	4.65 ± 0.68^{a}
Final length (cm)	7.13 ± 0.45^{a}	6.66 ± 0.11^{ab}	6.34 ± 0.14^{ab}	5.83 ± 0.15^{bc}
Length gain (%)	58.79	62.04	60.91	25.37
Specific growth rate (%d^{-1}) (SGR)	7.89 ± 2.82^{a}	5.46 ± 0.66^{ab}	4.19 ± 0.49^{ab}	1.89 ± 0.60^{b}
Feed conversion ratio (FCR)	1.40 ± 0.58^{a}	1.89 ± 0.30^{ab}	2.22 ± 0.16^{ab}	5.07 ± 1.35^{c}
Protein efficiency ratio (PER)	1.90 ± 0.75^{a}	1.27 ± 0.19^{ab}	1.06 ± 0.08^{ab}	0.49 ± 0.15^{b}

*Values bearing same superscripts do not differ significantly ($p>0.05$)

There were no initial weight and length differences between treatments. For final weight, as for final length, T2 showed better results and, despite being similar to T3 and T4, was different from T5. For all fish performances parameters evaluated T5 was the one that presented the lowest values and, even presenting fish growth, this treatment seems to compromise animal welfare, being desirable the utilization of lower fish stocking densities (Fig 27). There was no mortality during the experiment.

When analyzing the data referring to all treatments as one, both for the weight parameter and for the total length, the initial values were significantly different from the final ones. For the total weight and length between treatments throughout the experiment, significant differences were found through the Wilks test ($p=0.00679$), as well as for the analysis between treatments throughout the experiment, Wilks test ($p=0.00168$). For the multivariate analysis, anova factorial, were 179 degrees of freedom in total.



(a) (b)

(c) (d)

(e) (f)

Fig 27. Graphs of fish performances, weight (g) and length (cm) during the experiment: (a) graph of fish weight means for initial and final phase of the experiment; (b) graph of fish length means for initial and final phase of the experiment; (c) graph of fish weight means for each treatment considering the initial and final measures; (d) graph of fish length means for each treatment considering the initial and final measures; (e) graph of fish weight means for initial and final phase for treatment; (f) graph of fish length means for initial and final phase for treatment.

5.3.2. Plants

Lemon balm growth in terms of mean weight (g), weight gain (%), mean length (cm), length gain (%) and mean leaves yield (nos. plant-^{1}) and leaves gain (%) through descriptive statistical analysis, one-way anova hypothesis test and Tukey's test varied significantly ($p<0.05$) between treatments showed differences (Table 5).

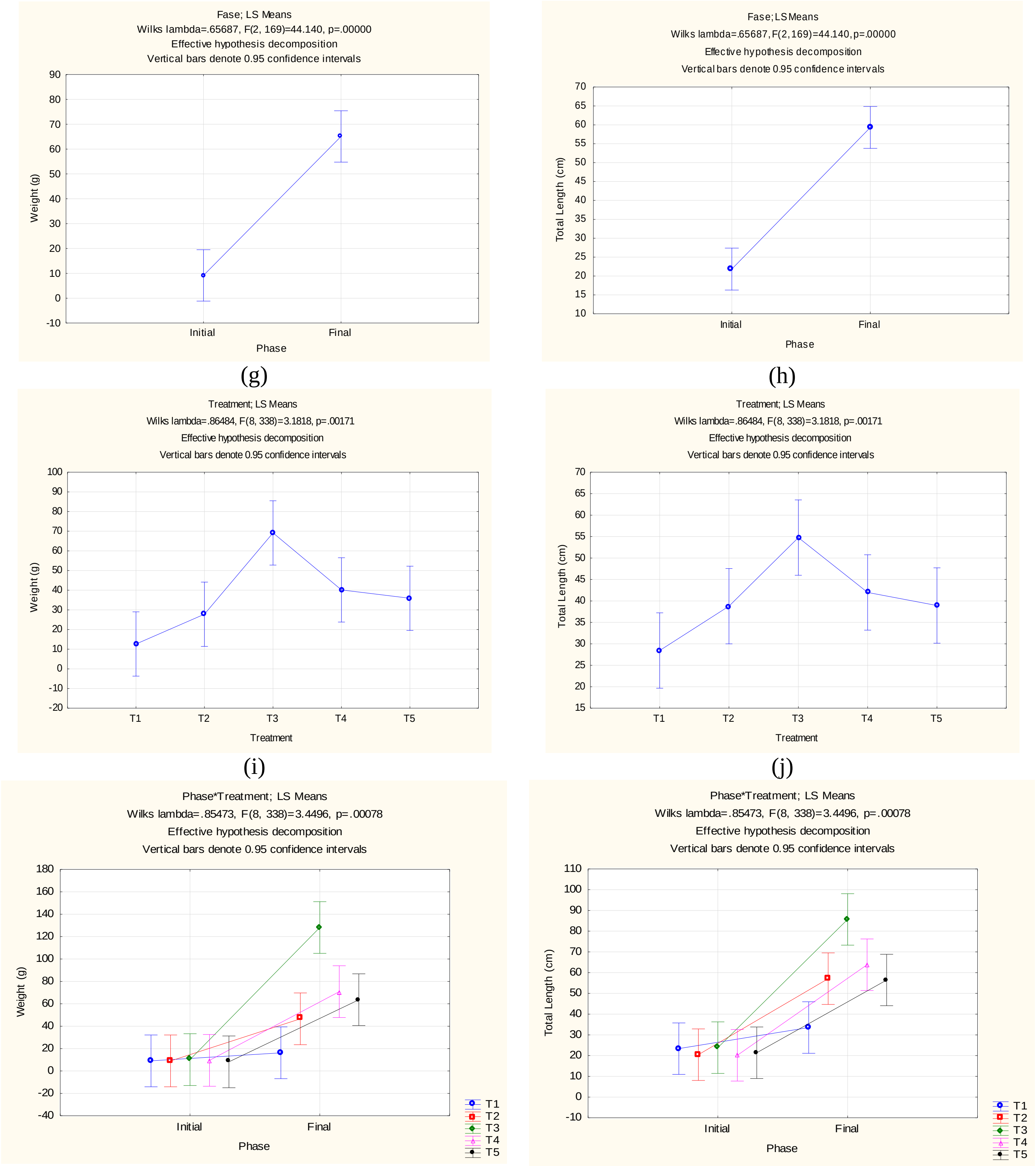
Table 5. Growth parameters and standat deviation of lemon balm plants reared in media bed aquaponic systems after a period of 51 days (Mean±SE).

Parameters	Treatments				
	T1	T2	T3	T4	T5
Initial weight (g/plant-^{1})	9.04 ± 2.81^{a}	9.01 ± 4.98^{a}	10.17 ± 5.56^{a}	9.48 ± 5.73^{a}	8.17 ± 4.95^{a}
Final weight (g/plant-^{1})	17.21 ± 10.42^{ab}	46.57 ± 43.65^{ab}	128.12 ± 116.20^{c}	75.01 ± 61.70^{abc}	63.62 ± 71.67^{abc}
Weight gain (%)	90.37	416.87	1,159.78	691.24	678.7
Initial length (cm)	23.36 ± 8.64^{a}	20.43 ± 7.82^{a}	23.85 ± 11.43^{a}	20.15 ± 10.12^{a}	21.40 ± 9.43^{a}
Final length (cm)	34.02 ± 13.56^{a}	53.67 ± 29.35^{ab}	70.87 ± 37.49^{b}	57.29 ± 25.19^{ab}	55.04 ± 32.23^{ab}
Length gain (%)	45.63	162.7	197.14	184.31	157.19
Initial leaves (nos. plant-^{1})	34.55 ± 13.24^{a}	24.5 ± 10.01^{a}	29.00 ± 18.70^{a}	31.66 ± 15.38^{a}	27.44 ± 13.23^{a}
Final leaves (nos. plant-^{1})	26.41 ± 16.09^{a}	114.72 ± 91.37^{ab}	261.05 ± 254.50^{b}	180.29 ± 181.59^{ab}	177.00 ± 205.68^{ab}
Leaves gain (%)	-23.56	368.24	800.17	469.45	545.04

*Values bearing same superscripts do not differ significantly ($p>0.05$)

For all treatments fed by fish effluent the percentage of gains in number of leaves were above 300%, with the best treatment, T3 being 800%. It should be noted that leaves are the main product of the lemon balm production, being used for manufacture of pharmaceuticals or for using in cooking. Also, the weight and length values of lemon balm plants in all treatments showed growth between the initial and final phase, having the highest values at T3 (Fig 28). Despite the control treatment, T1, which has no fish, showed gains in weight and height, the plants of this treatment demonstrated to be under good nutrition conditions, with yellow colored and negative leaves gain (%), loosing leaves at the end of the experiment.

When analyzing the data referring to all treatments as one, both for the weight parameter and for the total length, the initial values were significantly different from the final ones. For the total weight and length between treatments throughout the experiment, significant differences were found through the Wilks test ($p=0.00171$), as well as for the analysis between treatments throughout the experiment, Wilks test ($p=0.00078$). For the multivariate analysis, anova factorial, were 179 degrees of freedom in total.



(g)

(h)

(i)

(j)

(k)

(l)

Fig 28. Graphs of plant performances, weight (g) and length (cm) during the experiment: (g) graph of plant weight means for initial and final phase of the experiment; (h) graph of plant length means for initial and final phase of the experiment; (i) graph of plant weight means for each treatment considering the initial and final measures; (j) graph of plant length means for each treatment considering the initial and final measures; (k) graph of plant weight means for initial and final phase for treatment; (l) graph of plant length means for initial and final phase for treatment.

5.3.3. Water quality

In the present study the mean variation in average values of water temperature (ºC), pH, dissolved oxygen (mg/L-^{1}), sodium (mg/L-^{1}), ammonium (mg/L-^{1}), potassium (mg/L-^{1}), calcium (mg/L-^{1}), magnesium (mg/L-^{1}), fluoride (mg/L-^{1}), chloride (mg/L-^{1}), nitrite (mg/L-^{1}), nitrate (mg/L-^{1}), phosphate (mg/L-^{1}), sulfate (mg/L-^{1}) observed during the experimental period, respectively (Table 6).

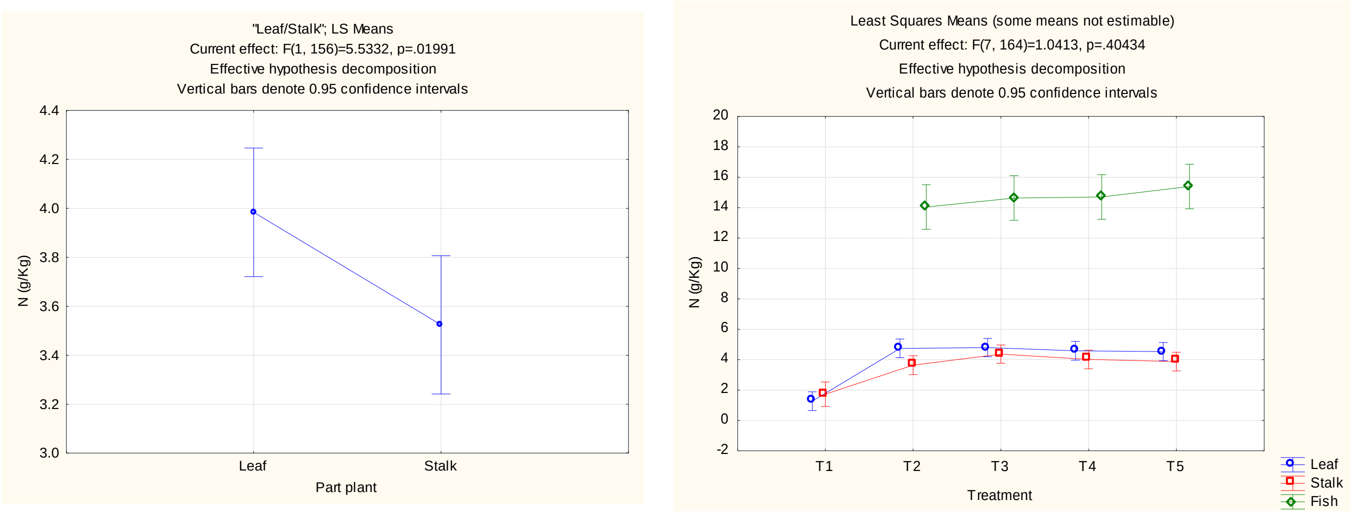
Table 6. Water quality parameters and standart deviation recorded during the experiment (Mean±SE).

Parameters	Treatments				
	T1	T2	T3	T4	T5
Temperature (ºC)	24.56 ± 2.67^{a}	24.78 ± 2.61^{a}	24.84 ± 2.63^{a}	24.20 ± 2.51^{a}	24.21 ± 2.53^{a}
pH	6.1 ± 0.39^{a}	5.95 ± 0.45^{ab}	6.06 ± 0.46^{a}	5.79 ± 0.33^{b}	5.92 ± 0.33^{ab}
DO (MG/L-^{1})	10.73 ± 3.47^{a}	9.91 ± 3.06^{a}	10.10 ± 2.91^{a}	9.65 ± 2.87^{a}	9.91 ± 3.04^{a}
Sodium (mg/L-^{1})	5.47 ± 3.88^{a}	25.11 ± 47.92^{a}	40.16 ± 64.18^{a}	111.64 ± 199.74^{a}	54.76 ± 87.18^{a}
Ammonium (mg/L-^{1})	0.12 ± 0.14^{a}	0.97 ± 0.74^{bc}	0.37 ± 0.31^{ab}	0.55 ± 0.42^{abc}	3.76 ± 3.51^{c}
Potassium (mg/L-^{1})	0.47 ± 0.50^{a}	0.51 ± 0.35^{ab}	1.04 ± 0.37^{bc}	1.47 ± 0.61^{bc}	1.55 ± 1.27^{c}
Calcium (mg/L-^{1})	3.13 ± 1.54^{a}	4.27 ± 1.58^{ab}	5.76 ± 1.52^{b}	6.74 ± 1.71^{b}	6.89 ± 2.24^{b}
Magnesium (mg/L-^{1})	0.25 ± 0.20^{a}	0.27 ± 0.13^{ab}	0.45 ± 0.14^{b}	0.62 ± 0.24^{b}	0.64 ± 0.36^{b}
Fluoride (mg/L-^{1})	0.07 ± 0.04^{a}	0.04 ± 0.01^{a}	0.04 ± 0.01^{a}	0.06 ± 0.05^{a}	0.05 ± 0.03^{a}
Chloride (mg/L-^{1})	10.04 ± 7.74^{a}	38.44 ± 71.50^{a}	60.80 ± 96.01^{a}	168.07 ± 299.24^{a}	83.37 ± 130.07^{a}
Nitrite (MG/L-^{1})	-	-	0.29 ± 0.33^{a}	0.57 ± 0.37^{a}	2.37 ± 3.68^{a}
Nitrate (mg/L-^{1})	0.83 ± 2.03^{a}	5.76 ± 4.99^{b}	5.43 ± 5.08^{b}	3.13 ± 3.31^{ab}	1.63 ± 2.55^{ab}
Phosphate (mg/L-^{1})	2.06 ± 4.42^{a}	2.69 ± 1.80^{ab}	5.55 ± 3.74^{b}	10.37 ± 7.07^{b}	8.82 ± 5.91^{b}
Sulfate (mg/L-^{1})	0.58 ± 1.23^{a}	1.33 ± 0.99^{ab}	2.43 ± 1.17^{b}	3.86 ± 2.44^{b}	3.11 ± 1.71^{b}

*Values bearing same superscripts do not differ significantly ($p>0.05$)

5.3.4. Total nitrogen

Total nitrogen analyses were performed for plants (leaves and stalk) and fishes to determine if there were appears differences between treatments. Differences were observed on nitrogen content between plant parts ($p=0.01991$), and on plant parts between treatments, but not for fish between treatments ($p=0.40434$) (Fig 29).



(m) (n)

Fig 29. Total nitrogen (g/Kg) of plant parts and fishes: (m) graph of the nitrogen content in leaves and stalk; (n) graph of the nitrogen content in the leaf, stalk and fish for treatment.

5.4. Discussion

At the end of the experimental duration, the highest fish growth was observed in the lowest density as compared to other treatment groups. The mean body weight (g), length (cm), weight gain (%) and length gain (%) of *A. bimaculatus* fingerlings were found significantly ($p<0.05$) higher in T2, then came T3 and T4, with no differences between them, and T5 as the lowest one. Specific growth rate (% d-1) followed the similar trend as for growth parameters, showing highest values in T2, followed by T3 and T4, and T5 the lowest values. Specific growth rate (% d-1) in T2 was significantly ($p<0.05$) higher than T3, T4 and T5, as for protein efficiency ratio (PER). For feed conversion ratio (FCR), T2 also presented the highest values, while T3 and T4 were different but with similarity to T2, and no difference between them, and T5 was different from all of the others, presenting the lowest values.

Regarding to protein efficiency ratio (PER) in our experiment, the values of 1.27 and 1.06, related to T3 and T4, respectively, were statistically similar to Hundley et al. (2018) and Patil et al. (2019), which the values fluctuated from 1.25 to 1.50 and from 1.50 and 1.56, respectively, corresponding to tilapia (*Oreochromis niloticus*) growth (0.15, 0.25 and 0.5 fish L-1) for 45 days, and to goldfish (*Carassius auritus*) growth (0.5, 0.6 and 0.7 fish L-1) for 36 days, respectively. The value for PER of the lowest density treatment, T2 was higher than the observed for the cited authors, 1.90, while the highest density treatment, T5 the value of 0.49 demonstrates that the growth of fish was not efficient, despite have demonstrating growth.

For lemon balm performances, Manukyan and Schnitzler (2006) found that 25ºC was the best temperature for increasing lemon balm yield in the greenhouse (total 123.9 g/plant), and fresh weight varied among cultivars, with ranges between 134.0 g/plant and 266.0 g/plant (Szab´o et al., 2016). The yield of lemon balm was also affected by the growth substrate used, including wood fiber (77.1 g/plant) or sand (77.4 g/plant) (Manukyan et al. 2004). Son et al. (2021), in an experiment testing different hydroponic systems found plant yields between 110.3–162.0 and 183.4–277.4 g/plant, similar to those of non-hydroponic cultivated lemon balm plants grown in the same greenhouse conditions. Even though, lemon balm studies using aquaponics are incipient, in our study the best treatment, T3, was 128.12 g/plant, similar to the greenhouse and hydroponic conditions (Son et al. 2021), while the two treatments of highest densities of fishes, T4 and T5, demonstrated values of plant weight (g) similar to substrate conditions, 75.01 and 63.62, respectively, and the lowest density of fishes treatment, T2, the plants, also showed the lowest results of plants weight (g) performance. All treatments showed gains in weight and length.

The temperature and DO values showed no statistic differences between treatments, while pH demonstrated differences between treatments along the experiment. The control treatment, T1, and T3 were similar, above pH 6, while T2 and T5 were intermediate, and T4 was the lower one, 5.79. According to Somerville et al. (2014), the pH level of the water has an impact on the biological activity of the nitrifying bacteria and their ability to convert ammonia and nitrite, and the best way to ensure that plants do not suffer from deficiencies is to maintain the optimum water pH (6–7); feed the fish a balanced and complete diet; and use the feed rate ratio to balance the amount of fish feed to plants.

In general, the tolerance range for most plants is 5.5–7.5, and the lower range is below the tolerance for fish and bacteria, and most plants prefer mildly acidic conditions (Somerville et al. 2014). Even though some values of pH were below the optimum values only T4 demonstrated difference between the control treatment, being the lowest one. Therefore, it is argued broadly that pH represents one of the largest water quality compromises present in aquaponic science (Goddek et al. 2015; Suhl et al. 2016). Maucieri et al. (2019) indicates that potassium, calcium and magnesium are available to plants in a wide range of pH, however, the presence of other ions may interfere in their plant availability due to the formation of compounds with different grades of solubility.

At the end of the experiment, the values of the chemicals parameters, sodium, fluoride and chloride, showed no significant difference between treatments. For potassium, calcium, magnesium and sulfate, the results obtained from T1 were significantly different that the others treatments, showing lowest values. For the first parameter, the mean value for T2 was similar to T1, but also similar to T3 and T4 and different to T5, as also T1. For the others parameters the mean values showed the same dynamic, being lower at T1, which is similar to T2 that is similar to T3, T4 and T5, but all these last three different to T1. Somerville et al. (2014) points that, over time, even an aquaponic system that is perfectly balanced may become deficient in certain nutrients, most often iron, potassium or calcium, but in our study both nutrients, potassium and calcium, demonstrated significant differences between treatments and the control, as written above. Sodium and chloride showed high values and this could be explained from the addiction of sodium chloride - NaCl for preventive treatment when biometrics analyses were realized in intervals of 15 days.

For fish growth, ammonia and nitrite are toxic but nitrate is comparatively harmless and for growing higher plants, nitrate is the most preferred form of nitrogen (Rakocy et al. 2006). Nitrate is the end product of nitrification and commonly the last parameter to be controlled in recirculation systems, due to its relatively low toxicity (Davidson et al. 2014; Schroeder et al. 2011; van Rijn 2013). This is mostly attributed to its low permeability at the fish gill membrane (Camargo & Alonso 2006). The most used nitrogen forms for plant fertilization are nitrate and ammonium, while nitrates are quickly absorbed by the roots, are highly movable inside the plants and can be stored without toxic effects, ammonium can be absorbed by plants only in low quantities and cannot be stored at high quantities because it exerts toxic effects (Maucirei et al. 2019).

The results for the nitrogen compounds diluted in the aquaponics solutions showed significant differences between treatments. The control treatment, T1, presented the lowest values for ammonium and nitrate, also, presenting null value for nitrite, as T2. For ammonium, all treatments showed differences, being T3 similar to T1, presenting the lowest values, then T4, T2 and T5, respectively. The treatment with the highest fish density, T5, showed critical level of ammonium, toxic for fishes. For nitrite, only the three highest densities treatments presented values for this nutrient, showing no significant differences between them. The dynamic of the nitrate results showed T1 as the lowest one, while T4 and T5 were higher but similar to T1, and T2, T3 presented the highest values, having no difference between them, but also having similarity to T4 and T5.

Phosphorus is one of the essential elements for plant growth and can be absorbed under its ionic orthophosphate form (Prabhu et al. 2007; Resh 2013). Little is known about the dynamics of phosphorus in aquaponics (Eck et al. 2019). The solubility of phosphorus depends on the pH, and a higher pH will foster the precipitation of phosphorus, thus rendering it unavailable for the plants (Yildiz et al. 2017). Phosphate values showed significant differences between treatments, T1 having the lowest values followed by T2, which was similar to T1 and the other treatments, T3, T4 and T5, were the highest ones, having no difference between them.

Comparing the values of nitrogen content at plant parts for treatment, only T1 have significant differences from the other treatments, and considering all treatments having proportionally the same feed offer, it is notorious that lemon balm plants converted the same quantity of this nutrient, presenting similar content for this parameter, but presenting different results for other plant growth parameters. Relating plants nitrogen content and nitrogen compounds in the water it is observed that the first one did not correlated to the second, since there were no difference between this parameter at fish fed treatments (T2-T5).

According to Wongkiew et al. (2016), the concentration of nitrogen in both fish and plants, which in aquaponic systems come from fish effluent, allow analyzing the absorption of this nutrient in the system. As fish excrete nitrogen in the form of ammonia, microorganisms (nitrifying bacteria) transform the nutrient so that plants absorb as nitrate. As there are no studies that take into account growth patterns of *Astyanax bimaculatus* and lemon balm in aquaponic systems, it is important that future works consider these data on nitrogen content in each element (fish, plants, microorganisms and the water in the system) in order to calculate the nitrogen utilization efficiency rate using this conformation.

The highest fish growth, observed at T2, was different from the highest plant growth, T3. The observed results for animal growth, which the highest values were found at the treatment with the lowest fish stocking density T2, differs from Hundley et al. (2018), who worked with tilapia densities of 0, 0.15, 0.25 and 0.5 fish L-1 and found better results for fish and plant in the highest fish stocking density. Also, Patil et al. (2019), who worked with goldfish densities of 0.5, 0.6 and 0.7 fish L-1 found better results of plants and fishes at the highest fish stocking density. Both studies were operated in media bed aquaponic systems, like ours, but with production of marjoram (*Origanum majorana*) and sweet basil (*Ocimum basilicum*) in the first and lemon balm in the second.

Aquaponic studies that utilize *Astyanax bimaculatus* are scarce. Recently, Pinho et al. (2021) indicates South American fish species suitable for aquaponics, relating *A. bimaculatus* as one of them, pointing there is no scientific information about its production in aquaponics. Navarro et al. (2021) did not found differences in tilapia fingerlings and sweet basil growth comparing fish stocking densities of 0.072, 0.144 and 0.216 fish L-1. In our study we observed that the values of fish growth were inversely proportional of the highest densities, while the plants growths were better at T3, T4 and T5, respectively. According to Lennard (2017), if water chemistry can be matched to the requirements of the three sets of important life forms (fish, plants and bacteria) efficiency and optimization of growth and health of all may be aspired to. Delaide et al. (2016) reported that interaction between microorganisms and dissolved organic matter present in the recirculating aquaculture system stimulates both root and shoot of the plant resulting in good plant crop.

It was observed that for fish the two systems with the lowest population density, T2 and T3, presented the best performance results, with no differences between them. For the weight between treatments, although T2 presented the best results, the coefficient of variation was 25.22%, while T3, which presented the second best result, presented a coefficient of variation of 6.68%. As for the plants, T3 showed better results and, therefore, we recommend the T3 treatment as ideal for replication in micro aquaponic systems coupled with substrate bed. Also, it was observed that lemon balm plants are selective in the absorption of nitrients, and the increase in the concentration of nutrients in the systems did not favor a greater growth for this species in the studied systems, as observed by Juaréz-Rosete et al. (2018) on the hydroponic production of oregano at different nutrient concentrations.

As the challenges within any aquaponics system are to control inputs – water, fingerlings, feed, plantlets – and their associated microbiota to maximize the benefits of organic matter and its breakdown into bioavailable forms for target organisms (Joyce et al. 2019), the main advantages of coupled aquaponics are in the most efficient use of resources such as feed for nutrient input, phosphorous, water and energy as well as in an increase of fish welfare (Palm et al. 2019). It is believed that the aquaponic systems used and conditions were properly designed to produce *A. bimaculatus* fingerlings and lemon balm, recycling the water and favoring the nutrients cycling, mostly at T2 and T3.

Espinal & Matulié (2019) points that in attached growth systems, solid forms (sand grains, stones, plastic elements) are used as substrates to retain the bacteria inside the reactor and thus, do not need a post-treatment solids capture step. In classical, fully recirculating aquaponic designs, one of the key design drivers is to use the main nutrient input source, the fish feed, as efficiently as possible and therefore fully recirculating designs strive to supply as many of the nutrients required for the plants from the fish feed (Lennard 2017). It was observed the formation of biofilms at all media bed units, which optimizes the water treatment, but despite all fish fed treatments (T2-T5) were feed at 4% of the gross weight of the biomass, at T5 all parameters of fish performance were under satisfaction. The main task of coupled aquaponics is the purification of aquaculture process water through integration of plants which add economic benefits when selecting suitable species like herbs, medicinal plants or ornamentals (Palm et al. 2019).

5.4. Conclusions

Considering aquaponic systems a sustainable manner to produce two high value products at the same time, conformations between aquatic organisms and vegetables are a key to determine economic success to farmers. As observed in our study, the production of *Astyanax bimaculatus* fingerlings and lemon balm in media bed aquaponic system was satisfactory, presenting animal and plant growth; the medium fish stocking density, treatment T3 demonstrated the better results, which can aggregate financial feedback for producers. Considering medicinal leafy plants in aquaponics, we recommend that lemon balm can be excellent chosen specie as *A. bimaculatus* fingerlings, also, which can be transferred to bigger fish tanks or sold to fish farmers and/or to aquarium stores. Experiments that consider medicinal plants in aquaponics are recommended to determine possible growth differences between hydroponical units, and also, mineral contents and bioactive compounds.

5.5. Declarations

5.5.1 Ethical Aprooval and Consent to participate

No applicable.

5.5.2 Human and Animal Ethics

The study has been approved by institutional ethics committee of the University of Brasília for studies involving animals by CEUA/UnB protocol code 115/2019 of August 20th, 2020.

5.5.3 Consent for publication

We, the authors, have approved the manuscript and agree with its submission to Aquaculture International.

5.5.4 Availability of supporting data

No applicable.

5.5.5 Competing interests

No applicable

5.5.6 Funding

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5.5.7 Author's Contribution

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Bernardo Ramos Simões Corrêa. The first draft of the manuscript was written by Bernardo Ramos Simões Corrêa and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

5.5.8 Acknowledgements

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6- CONCLUSÂO

As mudanças climáticas estão mais latentes a cada momento, forçando a reflexão acerca de estratégias para a perpetuação de sistemas agroalimentares já consolidados e que podem ser operados de forma mais eficiente, conciliando a produção de alimentos com a preservação ambiental. A água tem papel primordial na produção agrícola e é foco central de preocupações internacionais, sendo sua poluição e escassez as causas de migrações e impactos de inúmeras naturezas. Além da água, a adição de nutrientes na produção vegetal, principalmente o nitrogênio e fósforo, desempenha um fator importante na produção agrícola, sendo o Brasil grande importador e utilizador desses produtos. Ressalta-se que a além da disponibilidade desses minerais ser finita, sua utilização indiscriminada resulta em impactos ambientais nos ecossistemas.

Diante da necessidade de se estabelecer métodos mais sustentáveis de produção, a aquaponia surge como uma alternativa totalmente viável e que consegue tornar o subproduto da produção aquícola (efluente piscícola) a matéria prima para produção de vegetais em hidroponia (solução nutritiva). Os experimentos realizados demonstraram a viabilidade da produção de diferentes espécies de peixes, o lambari, *Astyanax bimaculatus*, e o kínguio ou goldfish, *Carassius auratus*, além da produção de diferentes espécies de plantas medicinais em sistemas aquapônicos tropicais. Os experimentos foram realizados em escala laboratorial, sendo que a aplicação e reprodução dos modelos estudados por produtores rurais podem e devem ser estimuladas favorecendo o elo entre a ciência e o campo.

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