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THAÍS VILAS BOAS DIAS

Uso da Aquaponia como Ferramenta para o Ensino em Ciências

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Thaís Vilas Boas Dias

Uso da Aquaponia como Ferramenta para o Ensino em Ciências

Dissertação apresentada ao Programa de Pós-Graduação em Ciências Ambientais, da Faculdade UnB Planaltina, Universidade de Brasília (UnB), como requisito para a obtenção do grau de Mestre em Ciências Ambientais.

Orientador: Prof. Dr. Rodrigo Diana Navarro

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Thaís Vilas Boas Dias

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Dissertação apresentada à Universidade de Brasília (UnB) como requisito para a obtenção do título de Mestre em Ciências Ambientais

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Brasília, 29 de junho de 2022

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RESUMO GERAL

A aquaponia desponta como alternativa de produção de alimentos que envolve o cultivo de peixes e plantas em recirculação de água, a qual carreia nutrientes entre suas fases com máximo aproveitamento. Mundialmente esta atividade tem apresentado acentuado crescimento, e, como consequência, há também expansão nos estudos que a analisam sob distintos aspectos. Entretanto, as contribuições da literatura ainda não são capazes de detalhar estes empreendimentos em sua totalidade, restando lacunas sobretudo no panorama educacional. Este trabalho teve por objetivo avaliar a eficácia da inserção da aquaponia como ferramenta pedagógica, visando aumentar o entendimento dos alunos sobre sustentabilidade em seu conceito teleológico, ou seja, como uma meta da sociedade humana como um todo, com propósitos ambientais, sociais e econômicos. Para tanto, no Capítulo 1, foi realizada uma revisão sistemática para determinar se o uso pedagógico dessa ferramenta facilita ou não a compreensão prática da sustentabilidade ambiental de uma forma ampla. Os resultados demonstraram que o uso desta técnica no ensino proporcionou o envolvimento dos alunos com diversos aspectos da produção, favorecendo o trabalho prático colaborativo e amparando sua motivação. No Capítulo 2, foi realizado um estudo de caso mediante a apresentação da aquaponia de forma remota aos alunos do Ensino Superior e aqueles da Educação de Jovens e Adultos (EJA). A finalidade da atividade foi avaliar a capacidade da dinâmica em provocar mudanças nos seus conhecimentos sobre a sustentabilidade após as palestras. Para tanto, os alunos preencheram questionários antes e depois destas, assim como foram realizadas entrevistas com seus professores para obter suas opiniões sobre a atividade realizada e seus efeitos sobre os alunos. Os resultados permitiram observar um aumento de 7,27% no número de acertos às questões no segundo questionário, bem como um maior nível de autoconfiança ao falar dos temas abordados, observados por meio das respostas às questões. Desta forma, os professores e alunos analisados consideraram eficaz o uso da aquaponia como ferramenta pedagógica de ensino, uma vez que houve maior motivação no aprendizado devido ao melhor entendimento sobre sustentabilidade e por prender a atenção do aluno em um aprendizado remoto, reduzindo-se a Zona de Desenvolvimento Proximal (ZDP), além da contribuição relacionada aos Objetivos de Desenvolvimento Sustentável (ODS) das Nações Unidas.

Palavras-chave: aquaponia; produção de alimentos; educação; ensino remoto

ABSTRACT

Aquaponics emerges as a food production alternative that involves the cultivation of fish and plants in recirculating water, which carries nutrients between its phases with maximum utilization. Worldwide, this activity has presented an accentuated growth, and, as a consequence, there is also an expansion in the studies that analyse it under different aspects. However, the contributions of the literature are not yet able to detail these enterprises in their entirety, leaving gaps, especially in the educational panorama. This work aimed to evaluate the effectiveness of the insertion of aquaponics as a pedagogical tool, aiming to increase the students' understanding of sustainability in its teleological concept, that is, as a goal of human society as a whole, with environmental, social, and economic purposes. To this end, in Chapter 1, a systematic review was conducted to determine whether or not the pedagogical use of this tool facilitates the practical understanding of environmental sustainability in a broad way. The results showed that the use of this technique in teaching provided students' involvement with various aspects of production, favouring collaborative practical work, and supporting their motivation. In Chapter 2, a case study was carried out by presenting aquaponics remotely to students of Higher Education and those in Youth and Adult Education (EJA). The purpose of the activity was to evaluate the ability of the dynamics to provoke changes in their knowledge about sustainability after the lectures. To this end, the students filled out questionnaires before and after the lectures, and interviews were held with their professors to obtain their opinions about the activity and its effects on the students. The results showed a 7.27% increase in the number of correct answers to the questions in the second questionnaire, as well as a higher level of self-confidence when talking about the topics discussed, observed through the answers to the questions. Thus, both teachers and students analysed considered the use of aquaponics as a pedagogical teaching tool as being effective, since there was greater motivation in learning due to the better understanding of sustainability and by holding the student's attention in a remote learning, reducing the Zone of Proximal Development (ZPD), in addition to the contribution related to the Sustainable Development Goals (SDGs) stated by the United Nations.

Keywords: aquaponics; food production; education; remote teaching

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1 INTRODUÇÃO

O planeta vem enfrentando grandes desafios no tocante à logística ligada aos meios de produção de alimentos, e a ciência, ante tal cenário, tem buscado a implementação de mecanismos cada vez mais eficientes para sua a produção, distribuição e mitigação do desperdício, um problema cada vez maior (Messner et al., 2021). Nesse âmbito particular, é essencial o aproveitamento mais eficiente de recursos escassos, como águas e solos, fatores primordiais para a produção de alimentos em todo o mundo. Alternativas ecoeficientes trazem em seu cerne a preocupação com as formas e meios utilizados para essa produção, bem como a qualidade dos produtos e maneiras de permitir a redução de custos e recursos.

A pandemia de COVID-19 expôs muitas destas questões e agravou ainda mais os desafios já existentes, ratificando a urgente necessidade de busca por maior investimento em infraestruturas urbanas que viabilizem um sistema de fornecimento de alimentos e outros recursos de forma sustentável. Neste contexto, foi reconhecida uma extensa vulnerabilidade das grandes cidades, majoritariamente dependentes do influxo de insumos de toda natureza. A resiliência de sistemas produtivos passou a tornar-se pivô para as discussões atuais e futuras no que diz respeito ao planejamento urbano, a fim de permitir que as cidades possam buscar novos arranjos para minimizar suas limitações (Pulighe & Lupia, 2020; Boyaci-Gündüz et al., 2021).

Para que seja possível a criação, aplicação de medidas inovadoras e o desenvolvimento de novas tecnologias para sistemas mais eficientes de produção de alimentos torna-se imperioso o envolvimento ou engajamento de toda a sociedade. As escolhas cotidianas de cada cidadão têm influência direta sobre o tipo de sistema produtivo a ser adotado e incentivado pelos tomadores de decisões, e a participação cooperativa favorece a geração de soluções mais efetivas para alguns dos problemas ambientais (Chao et al., 2021). Neste sentido, a educação pode proporcionar maior envolvimento das pessoas com novas tecnologias, permitindo-lhes melhor compreensão sobre seu papel no mundo moderno (Goddard et al., 2020).

Em setembro de 2015 foi adotada a Agenda 2030 para o Desenvolvimento Sustentável, um pacto global participativo adotado por 193 Estados Membros da Organização das Nações Unidas (ONU), incluindo o Brasil. No documento final foram estabelecidos 17 Objetivos de Desenvolvimento Sustentável (ODS) e 169 metas de ações abrangendo aspectos ambientais, econômicos e sociais do desenvolvimento sustentável (Food and Agriculture Organization [FAO], 2020). Dessa forma, os Estados participantes do pacto comprometeram-se a contribuir com a solução de diversos problemas, incluindo a erradicação da pobreza e da fome, mediante incentivo a modalidades sustentáveis de agricultura e com a gestão responsável de recursos naturais, entre outros objetivos de grande importância para a Agenda adotada. Dentre eles, pode-se também destacar a Educação para o Desenvolvimento Sustentável (EDS), que deve atuar de forma holística, buscando atender a todas as áreas da experiência humana (Glaviˇ, 2020).

Em âmbito global, emerge a tendência para uma economia circular, como forma de modificar o modelo linear de produção e consumo baseado no crescimento contínuo e no crescente dispêndio de recursos. O objetivo da economia circular é o aumento da eficiência no uso de recursos, a fim de equilibrar o balanço entre economia, meio ambiente e a sociedade (Ghisellini et al., 2016; Mikkelsen & Bosire, 2019). Seguindo essa nova filosofia, a Ellen MacArthur Foundation (2013) promove novas maneiras de se pensar a economia global com a finalidade de migrar os modelos de negócios, produtos e materiais para uma alternativa que incremente o uso e reuso de recursos, contribuindo com os ODS das Nações Unidas.

É crescente a demanda pela implementação de métodos eficientes de produção de alimentos que considerem o desenvolvimento sustentável como base para seu crescimento levando em consideração a Economia Circular abordada pela Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2013). Um exemplo é a cidade de Bruxelas, na Bélgica, que estabeleceu um programa que apoia a produção local, a otimização do uso da terra e a integração de requisitos de transporte público. Dessa forma, as empresas da cidade reduzem sua pegada ecológica e assim tem uma aceleração na transição para uma economia verdadeiramente circular (Ellen MacArthur Foundation, 2019).

Para alguns autores, o conceito de sustentabilidade pode ser ainda muito amplo, vago e centrado no ponto de vista econômico, e por essa razão ainda não pode ser considerado um paradigma efetivo (Baker, 2016). Entretanto, Salas-Zapata e Ortiz-Muñoz (2019) sugeriram que os pesquisadores utilizassem este termo de acordo com o contexto em que será inserido, reduzindo sua ambiguidade. Tendo em vista os conceitos apresentados por estes autores e o contexto deste trabalho, ao longo desta pesquisa foi adotado o conceito teleológico, o qual considera a sustentabilidade como uma meta da sociedade humana como um todo, com propósitos ambientais, sociais e econômicos.

No Brasil, algumas possibilidades surgem como formas de se buscar uma maior sustentabilidade, sobretudo para o setor produtivo, como a agricultura urbana, o aproveitamento de efluentes de aquicultura e a aquaponia. Esta última é uma atividade que integra sistemas de aquicultura e hidroponia, buscando reduzir o uso de água e possibilitando a produção de alimentos de forma mais sustentável (G. C. Hundley & Navarro, 2013).

Aquaponia é um sistema de produção de animais e plantas em recirculação de água. Desta forma, os nutrientes são transportados para as fases do sistema, maximizando a eficiência no uso de recursos. Entre essas porções, induz-se a formação de um filtro biológico composto principalmente por bactérias nitrificantes, essenciais para o bom funcionamento de todas as reações envolvidas. A fim de manter a qualidade de seus produtos, o bem-estar animal e a viabilidade biológica da produção, é necessário o acompanhamento constante de parâmetros de qualidade da água (Yildiz et al., 2017).

Existem diversas formas de cultivos aquapônicos, sendo essencial a presença do biofiltro, que proporciona grande eficiência no uso do espaço e o aproveitamento dos nutrientes presentes na água, colaborando assim para o significativo aumento da sustentabilidade da produção. O sucesso da produção aquícola depende essencialmente do equilíbrio nutricional entre as fases do sistema, uma incumbência complexa e que exige cautela e avaliação atenta (Eck, Sare, et al., 2019; Joyce, Timmons, et al., 2019).

Os animais em aquaponia são alimentados com rações específicas, e com as fezes e a respiração branquial ocorre o aumento na concentração de íons na água, sobretudo fosfato (PO_4^{3-}) e amônia (NH_3). Em altas concentrações, este composto nitrogenado torna-se tóxico para os peixes, porém as bactérias nitrificantes presentes no biofiltro realizam a transformação da amônia em nitrito (NO_2^-) e, posteriormente, em nitrato (NO_3^-) (Monsees et al., 2017). Este último subproduto torna-se então disponível para as plantas, e será útil na formação de aminoácidos e bases nitrogenadas em seu crescimento (Bredemeier & Mundstock, 2000). O nitrato também pode ser tóxico em altas concentrações, e na presença de oxigênio sua formação é induzida por meio das reações de nitrificação, devendo portanto ter sua dosagem administrada com frequência (Conselho Estadual de Recursos Hídricos, 2019).

Ao contrário do Nitrogênio, o Fósforo não é considerado parâmetro com potencial para impactar a saúde ou bem-estar dos animais presentes no cultivo, já que raramente está associado a toxicidades nestes ambientes. A maior preocupação relacionada a este elemento químico deve-se aos seus efeitos indiretos (Yildiz et al., 2017). Esta substância está diretamente ligada a fenômenos de eutrofização de corpos hídricos, sendo amplamente utilizado na fertilização de solos agricultáveis e exportado pelo Brasil em larga escala (Lun et al., 2022). Entretanto, quantidades adequadas de fósforo nas raízes são associadas a maior crescimento da planta, e são especialmente importantes para plantas frutíferas (Somerville et al., 2014).

Com a retirada dos íons nitrogenados potencialmente tóxicos pelas plantas (NH_3^- e NO_2^-), a água pode retornar ao cultivo de peixes renovada, própria para reuso. Os níveis de Oxigênio Dissolvido (OD) são também importantes para o equilíbrio do sistema, uma vez que influenciam diretamente na ocorrência de todas as reações químicas e podem ser influenciados pela matéria orgânica não decomposta (Maucieri et al., 2018; Eck, Körner, et al., 2019). Da mesma forma, a manutenção do fluxo hídrico no sistema é importante para evitar a deposição de matéria orgânica e o desequilíbrio em alguma de suas porções (Danner et al., 2019). Um sistema bem administrado poderia aumentar a eficiência na absorção de nutrientes, reduzir o consumo de água e a quantidade de efluentes para o meio ambiente, além de aumentar a lucratividade através da produção simultânea de duas espécies de uso comercial (Tyson et al., 2011; Somerville et al., 2014; Hu et al., 2015).

2 REFERENCIAL TEÓRICO

De acordo com a *Food and Agriculture Organization of the United Nations* (FAO-UN), a água está intimamente relacionada à execução de 15 dos 17 ODS pactuados em 2015, sendo determinante para o sucesso de muitos deles. Este recurso está sob crescente estresse e degradação, majoritariamente relacionados ao aumento populacional e o consumo e produção não sustentáveis. Também relacionam-se a este fator as mudanças climáticas, que deverão alterar os regimes hidrológicos do planeta e modificar a disponibilidade de água doce em diversas regiões (FAO, 2020).

Para enfrentar esta escassez em nível global, são necessárias ações para atingir os ODS e garantir sua disponibilidade em quantidade e qualidade adequada para todos seus múltiplos usos a todos os habitantes do planeta, o que sabidamente não é a realidade atual. Cerca de 1,2 bilhão de pessoas vivem, atualmente, em áreas com severas restrições de acesso à água, e nos últimos vinte anos a disponibilidade de água doce disponível *per capita* no mundo sofreu drástica redução, em mais de 20% (FAO, 2020). A melhor estratégia pode ser a gestão de recursos hídricos e de solo, de acordo com boas práticas de manejo de cada região. Isso envolve a adoção de agricultura conservacionista e de precisão, sistemas de irrigação por gotejamento, a gestão integrada de nutrientes e variedades vegetais melhoradas (Lal, 2016). Dessa forma, espera-se maior eficiência agrícola, reduzindo as perdas por erosão, lixiviação e demais processos indesejados, como a eutrofização (Joyce, Goddek, et al., 2019).

Uma forma que tem sido utilizada recentemente para a mitigação dos impactos da produção de alimentos é o uso de técnicas de agricultura conservativa, combinando lavouras de conservação, rotação de culturas e plantio de cobertura (Lal, 2016; Miralles-Wilhelm, 2021). Essas técnicas têm sido cada vez mais adotadas, sobretudo em locais tais como a América do Norte e do Sul, Austrália e Nova Zelândia (Friedrich et al., 2012). Ao se manter a cobertura vegetal sobre o solo, seja pela presença de palha ou por plantas de cobertura verde, ocorre maior infiltração de água, alimentando os lençóis freáticos (Pearson et al., 2011; Gabriel et al., 2021). Dessa forma, a manutenção da cobertura poderia mitigar os impactos relacionados com o desbalanço hídrico, como a ocorrência de erosão e enchentes, e também manter uma maior diversidade faunística (R. A. dos Santos, 2010; Arantes et al., 2017; Cockle et al., 2011; Fitzgerald et al., 2018;).

Com o advento da pandemia por COVID-19, muitas pessoas passaram a se dedicar a atividades domésticas e a buscar alternativas para lidar com a necessidade de isolamento que se observou em todo o mundo. A alta dependência de produtos provindos de regiões rurais ou periurbanas exigiu ampla reflexão no sentido de se gerenciar melhor o fluxo de produtos dentro das cidades, que estiveram em situação de extrema vulnerabilidade no acesso a bens de consumo importantes. Dessa forma, a agricultura urbana ganhou destaque como alternativa para mitigar essas limitações com soluções inovadoras e a execução de cadeias de suprimentos mais curtas, reduzindo as incertezas dos riscos sistêmicos globais (Pulighe & Lupia, 2020; Boyaci-Gündüz et al., 2021).

Além de contribuir para um sistema alimentar mais sustentável e resiliente, estudos têm associado a agricultura urbana à saúde dos cidadãos. Pode ser associada ao bem-estar e relaxamento, o consumo de alimentos mais saudáveis e sem uso de agrotóxicos, além da realização de atividades em ambientes externos e a economia doméstica (Delabre et al., 2021; Ruggeri et al., 2016). Produzindo o próprio alimento, os cidadãos tornam-se menos dependentes dos mercados locais, onde os preços são altamente dependentes de uma grande cadeia produtiva, que se mostrou em colapso no momento da pandemia (Boyaci-Gündüz et al., 2021).

Esta dependência levou os custos com alimentação em residências brasileiras a ter um grande impacto sobre a economia doméstica, seguindo a tendência mundial de inflação sobre os principais produtos de consumo (Departamento Intersindical de Estatística e Estudos Socioeconômicos [DIEESE], 2021; Parente e Lima, 2022). Dessa forma, a produção de alimentos dentro de casa passou a ser uma alternativa interessante como estratégia de mitigar a crise, permitindo resposta mais rápida a eventos extremos (Boyaci-Gündüz et al., 2021). Dentre as alternativas de agricultura urbana ganham destaque as fazendas verticais, hidroponia, aeroponia, aquaponia e os cultivos em telhados verdes, que podem ser menos suscetíveis a intempéries naturais e servir para revitalizar espaços públicos e particulares inutilizados e abandonados (Specht et al., 2019; Pulighe & Lupia, 2020).

Do ponto de vista dos consumidores, novas tecnologias de produção de alimentos trazem principalmente os benefícios de reutilizar espaços nas cidades, o uso eficiente dos recursos, o uso de novas fontes proteicas e o fortalecimento de economias locais (Specht et al., 2016, 2019). Dessa forma, é perceptível a preocupação dos cidadãos frente às adversidades potenciais, e estudos mostram uma propensão dessas populações para implementar a agricultura urbana, com distintas motivações (Ruggeri et al., 2016; Mojtahedi et al., 2021).

Hidroponia é uma metodologia de cultivo de folhagens sem o uso de solos, em estruturas em que a solução nutritiva alaga as raízes e permanece dissolvida em água para que elas possam absorver seus nutrientes. Já na aeroponia, a solução nutritiva é pulverizada diretamente nas raízes por 30 a 60 segundos, a depender do período do cultivo, a etapa de crescimento das plantas, a espécie e o horário do dia (Alshrouf, 2017; Maucieri et al., 2019).

Nas fazendas verticais, são utilizadas estruturas como prédios e outros tipos de edificações para a instalação de cultivos dispostos de maneira vertical, otimizando o espaço e a eficiência do uso de água por meio do controle de saída de água (Al-Kodmany, 2018; Joyce, Goddek, et al., 2019). Todas essas modalidades de produção podem ser realizadas também em estruturas pré-existentes, como telhados de prédios e terrenos abandonados, com a finalidade de maximizar a eficiência no uso de recursos (Joyce, Goddek, et al., 2019).

A aquaponia desponta entre essas modernas tecnologias produtivas devido à combinação entre as técnicas de cultivo de hidroponia com a aquicultura, possibilitando a produção de proteína de qualidade com redução no custo de aquisição de terras e maior proximidade do mercado consumidor (Joyce, Goddek, et al., 2019). Nessa metodologia, distintas técnicas promovem o melhor aproveitamento de espaço físico, água, nutrientes e redução de custos, favorecendo a adaptação à condição pontual do produtor, que pode até mesmo ser uma comunidade urbana (Goddek, Joyce, Kotzen, & Dos-Santos, 2019).

A racionalização quanto ao uso de recursos para fins de produção somada à redução na distância entre os mercados produtor e consumidor favorecem o estabelecimento da agricultura urbana (Gómez et al., 2019; Laidlaw & Magee, 2014a). Do ponto de vista logístico, os problemas relacionados à perda e desperdício de alimentos são um paradoxo diante da insegurança alimentar que afeta milhões de pessoas no planeta (Santeramo & Lamonaca, 2021; Soomro et al., 2021). Para melhor gerenciamento da cadeia de desperdício de alimentos é necessário combater a criação sistêmica de resíduos, por meio do monitoramento transparente dos excedentes de produção em todo o mundo (Messner et al., 2021).

Por outro lado, enquanto muitos sofrem em razão da fome causada por falhas nessa cadeia logística, outros enfrentam a obesidade crônica e problemas relacionados à nutrição. A desnutrição está ligada à falta de nutrientes no organismo, e atualmente aflige bilhões de pessoas em todo o mundo. Esta falta pode ocorrer devido à escassez de alimentos ou à ausência de alimentos adequados, uma vez que muitos indivíduos não consomem diariamente uma dieta composta pelos nutrientes essenciais ([IDEC], 2019).

Uma parte do problema justifica-se pelo privilégio dado pelo mercado internacional a alimentos pobres em nutrientes e ricos em gorduras e carboidratos, desfavorecendo a transação de proteínas de qualidade e macro e micronutrientes. Grande parte dos produtos que compõem o comércio mundial de alimentos é formada por *commodities*, tais como soja, milho, cana-de-açúcar, canola e arroz. Estes alimentos ocupam cerca de 80% da terra dedicada à agricultura em todo o mundo, e urge uma abordagem mais diversificada que permita a inserção de outras fontes de nutrientes (Lima, 2020).

É nesse aspecto que se insere a aquaponia urbana como importante mecanismo de busca por melhores condições aos cidadãos, tanto para obter uma alimentação mais saudável quanto pela melhoria de sua qualidade de vida na interação com a natureza (Mojtahedi et al., 2021; Pulighe & Lupia, 2020; Ruggeri et al., 2016). Esta tecnologia tem potencial contributivo para o aumento da resiliência das cidades diante de desafios e catástrofes inevitáveis, como pandemias, mudanças climáticas e demais riscos potenciais. Entretanto, são ainda necessários esforços de governança na regulação e incentivo deste tipo de atividade (Milliken & Stander, 2019; Pulighe & Lupia, 2020).

2.1 Aquaponia urbana

Nas zonas urbanas o espaço é um fator limitativo, e para que a produção de alimentos nessas regiões seja viável torna-se imperioso estabelecer melhor equilíbrio entre os elevados custos de produção e as vantagens nas áreas de distribuição e marketing (M. J. P. L. dos Santos, 2016). Para um sistema urbano de produção de alimentos, outra vantagem considerável é a redução dos custos operacionais com transporte e armazenamento, já que a distância até o consumidor é sensivelmente menor (Goddek, Joyce, Kotzen, & Burnell, 2019).

Por ser uma tecnologia que demanda um aporte hídrico reduzido, a aquaponia tem sido estudada como parte integrante do planejamento urbanístico em algumas regiões do mundo. O estudo de Murotani (2013) inclui a aquaponia na arquitetura em forma de fazenda vertical, propondo a sua incorporação ao desenho urbanístico das cidades. Desta forma, a tecnologia contribuiria para a produção de alimentos em regiões mais próximas ao mercado consumidor, o que reduz o consumo de combustíveis fósseis e a logística envolvida na produção agrícola. Al-Kodmany (2018) também aponta que, no futuro, as fazendas verticais poderão ser integradas às cidades, que passarão a produzir alimentos para toda a população. Para tanto, são necessários mais estudos para aumentar as escalas de produção e melhorar a viabilidade econômica e comercial dos projetos, como ratifica o trabalho de Armanda *et al*. (2019).

Nesse contexto, também é possível inserir a tecnologia ao planejamento e modernização de cidades, a exemplo das cidades inteligentes. Nestas cidades, as rotinas urbanas são automatizadas, monitoradas, compreendidas e analisadas com a finalidade de melhorar, em tempo real, sua eficiência, equidade e a qualidade de vida dos cidadãos. Dessa forma, a aquaponia é vista como um sistema que integra produtores e consumidores (M. J. P. L. dos Santos, 2016). Fazendas urbanas inovadoras contam com altos níveis de tecnologia para otimizar o processo de crescimento de hortaliças reduzindo manutenção e custos (O'Sullivan et al., 2019).

Um exemplo de projeção desta tecnologia em regiões urbanas é o estudo de Kyaw e Ng (2017), que propôs um sistema inteiramente automatizado em Singapura. No estudo, através da aplicação de tecnologias informatizadas e diversos sensores programados, o uso da aquaponia poderia reduzir os custos operacionais e de mão-de-obra, aumentando a produtividade e a rentabilidade dos negócios. Além disso, por reduzir o consumo hídrico e a ocupação de terras, seria uma interessante alternativa para tornar cidades mais sustentáveis.

Seguindo a mesma filosofia, Silva e Silva (2016) utilizaram a arquitetura de *Internet of Things* (IoT) para promover a incorporação da automação a um sistema de produção de alimentos sem o uso de solo no Sri Lanka. No estudo foi possível observar que o projeto pode ser executado com uma margem significativamente baixa de erros, permitindo intervenções humanas mínimas para regiões rurais ou urbanas.

No Myanmar, um projeto-piloto estudou um sistema de pequena escala com tecnologia acessível de produção aquapônica em uma região urbana com baixo custo, e a lucratividade obtida poderia garantir alimentos e meios de subsistência a localidades com pouco acesso a recursos (Eichhorst, 2014). Segundo Somerville *et al.* (2014), produzindo em pequenas áreas as pessoas em vulnerabilidade social têm a possibilidade de gerar renda e agregar valor ao trabalho doméstico, empoderando sobretudo as mulheres na comunidade.

Pela perspectiva ambiental, a aquaponia também pode trazer benefícios às zonas urbanas além dos fatores relacionados à produção em si. O uso desses sistemas poderia mitigar as ilhas de calor nessas regiões, principalmente nos meses de verão, através do acréscimo à biomassa vegetal e consequente aumento na evapotranspiração (Pearson et al., 2011). Adotando ainda uma gestão inteligente de recursos, seria também possível reduzir o consumo de água e eutrofização, em comparação com uma agricultura industrial (Goddek, Joyce, Kotzen, & Burnell, 2019).

Por outro lado, ao se cogitar cultivos em meios urbanos é importante também analisar a viabilidade técnica e econômica para a sua manutenção. As tarifas de água e energia elétrica são significativamente maiores nessas regiões, o que pode ser um fator limitador para a viabilidade de produções urbanas dependentes destes recursos (Instituto Acende Brasil, 2020). De acordo com a Pesquisa Nacional de Saneamento Básico, realizada pelo Instituto Brasileiro de Geografia e Estatística/IBGE (https://www.ibge.gov.br/ recuperado em 17 de junho de

2022), 100% dos municípios brasileiros tem, desde 2008, algum serviço de saneamento básico. Mas a realidade são dificuldades fundamentais no fornecimento e manutenção desses serviços com qualidade (Instituto Acende Brasil, 2020).

Por depender do suprimento energético de grandes usinas hidrelétricas localizadas em regiões distantes dos principais centros de carga, no Brasil há grande suscetibilidade a blecautes de larga escala (Instituto Acende Brasil, 2014). As interrupções no fornecimento de energia elétrica são frequentes e podem levar à perda dos organismos do cultivo em um sistema produtivo urbano. Entretanto, alternativas de energia cada vez mais atrativas em meio urbano tem ganhado destaque, como a solar e a eólica, que poderiam ser utilizadas ao menos para suprir parte da necessidade do sistema produtivo (Vermeulen & Kamstra, 2013; Goda et al., 2015; He, 2017).

Apesar do maior de custos com essas tarifas, a produção em meio urbano traz os benefícios secundários abordados anteriormente e permite menor dependência dos preços de mercado (Ruggeri et al., 2016; Pulighe & Lupia, 2020). Dessa forma, o custo de oportunidade parece favorecer o cultivo doméstico, uma vez que esta alternativa traz benefícios múltiplos cujos custos não são mensuráveis (bem-estar, qualidade de vida e outros).

2.2 Usos da aquaponia

Nos últimos cinquenta anos a aquaponia tem obtido destaque em várias partes do mundo, e diversos estudos têm apontado diferentes usos desta atividade. Entretanto, este crescente volume de publicações não tem contribuído igualmente com os diferentes aspectos do tema (Greenfeld *et al*., 2019). São ainda necessários estudos mais aprofundados para garantir uma maior compreensão sobre a viabilidade técnica, econômica e comercial do sistema.

Goddek *et al*. (2015) analisaram que o desenvolvimento comercial da atividade enfrenta ainda alguns desafios de ordem técnica, relacionados principalmente a parâmetros de qualidade da produção. Assim, os cultivos em aquaponia somente poderão ser considerados alternativas sustentáveis para a produção alimentos caso sejam observadas as condições locais de desenvolvimento tecnológico, mercados locais e condições climáticas e geográficas.

A publicação de Turnsek *et al*. (2020) corroborou com a hipótese de que são necessários mais estudos para definir se a aplicação comercial da atividade é viável sob diversos aspectos. Comercialmente, a viabilidade econômica tem grande influência na execução de projetos tecnologicamente inovadores, como é o caso da aquaponia para estes autores. Entretanto, eles reconheceram seu potencial para o mercado tanto de produtos oriundos da aquaponia quanto da olericultura, o que torna o tema interessante do ponto de vista científico e comercial.

Outra utilidade apontada em estudos é o uso desses sistemas como ferramentas de ensino para diversos níveis e modalidades educacionais. Utilizando a aquaponia é possível promover o pensamento sistemático e a educação ambiental de uma forma ampla, utilizando esses sistemas para demonstrar ciclos ecológicos da mesma forma como atualmente é realizado em fazendas tradicionais (Proksch et al., 2019; Specht et al., 2019).

Tendo em vista o envolvimento de diversas áreas de estudo para planejamento e execução de todo o projeto, faz-se necessária a colaboração de distintas disciplinas acadêmicas. Dessa forma, Goddek *et al*. (2015) e Proksch *et al*. (2019) avaliaram a aquaponia como atividade multidisciplinar, podendo oferecer ganhos na transmissão de conhecimentos científicos a alunos e até mesmo ao público em geral. Os autores analisaram ainda que essa modalidade de uso da ferramenta poderia contribuir para o desenvolvimento sustentável urbano.

Junge *et al*. (2019) avaliaram diversos estudos de caso utilizando a aquaponia como ferramenta educacional em diferentes níveis de ensino, e muitos benefícios desta abordagem foram apresentados. Através desta, segundo os autores, foi possível desenvolver as competências necessárias para lidar com a complexidade dos problemas ambientais reais, promovendo um senso de responsabilidade perante a humanidade, além de permitir uma oportunidade ímpar de experiências práticas relacionadas à natureza. Os autores de Mikkelsen e Bosire (2019) ratificaram estas conclusões, sugerindo ainda que sejam utilizados equipamentos com maior facilidade de instalação e baixo custo de implantação.

Do ponto de vista social, a aquaponia como ferramenta educacional contribui para a formação de cidadãos mais atentos ao futuro e às suas ações no presente. Existem também projetos demonstrando a importância de seu uso na horticultura terapêutica, para a empregabilidade e o bem-estar de pessoas com deficiências e para a manutenção da segurança alimentar em áreas urbanas (Milliken & Stander, 2019).

Laidlaw e Magee (2014) analisaram dois diferentes projetos aquapônicos com objetivos similares de atender à soberania e segurança alimentar em regiões urbanas. No estudo foi possível concluir que a atividade tem potencial de atingir esses objetivos em um futuro próximo, e poderia ter maior eficácia caso houvesse maior apoio e envolvimento político.

A aquaponia também é objeto de pesquisa em regiões áridas ou com acesso limitado a recursos hídricos, como é o caso da Faixa de Gaza. Na região, a população enfrenta severas restrições alimentares, nutricionais e no acesso a fontes alimentares. A *Food and Agriculture Organization* (FAO) realizou um trabalho focado em contribuir com a segurança alimentar dos moradores desta localidade, e a conclusão do estudo mostra a importância de um acompanhamento técnico apropriado, sobretudo para populações com pouco acesso à educação. O trabalho demonstrou que muitos participantes não possuíam recursos para continuar adicionando os insumos necessários ou o conhecimento e experiência demandados para manter uma performance satisfatória da produção. Assim, os autores sugerem que projetos como este sejam iniciados com famílias que possam receber suporte técnico adequado ou tenham outras fontes de renda, a fim de garantir resiliência com relação à atividade (Food and Agriculture Organization [FAO], 2010). Mesmo não sendo uma solução única capaz de resolver todos os problemas de insegurança alimentar e de dietas pobres em nutrientes, a agricultura urbana poderia contribuir para modelar um sistema alimentar urbano mais resiliente (Pulighe & Lupia, 2020).

No Brasil, o estudo de Silva e Van Passel (2020) demonstrou que a aquaponia tem grande potencial para contribuir com a redução da insegurança alimentar e geração de renda para populações que vivem em regiões semiáridas, apesar das dificuldades técnicas que podem ocorrer devido à falta de experiência e conhecimentos dos beneficiários. Os autores ratificam também a necessidade de um acompanhamento técnico adequado e de mais estudos sobre a aceitação e precificação dos produtos oriundos desses sistemas. Por último, adicionam-se benefícios sociais como a melhoria na nutrição das famílias envolvidas, a educação ambiental e vários aspectos da produção, além do fortalecimento da comunidade e envolvimento dos atores correlacionados.

Um fator determinante no sucesso da implantação de sistemas tecnológicos inovadores é a viabilidade econômica. Para que uma metodologia produtiva seja adotada ela precisa render lucros, assim, os custos da produção e preços de venda dos produtos precisam ser cuidadosamente estudados. Segundo a Companhia Nacional de Abastecimento (Companhia Nacional de Abastecimento, 2010), essa avaliação permite conhecer indicadores de rentabilidade que podem auxiliar na tomada de decisões do negócio, como a escolha do sistema de cultivo, a eficiência econômica e a gestão do empreendimento. Assim, é possível realizar inferências sobre retornos econômicos de sistemas de produção (Guiducci et al., 2012).

Considerando que tecnologias sustentáveis inovadoras trazem grandes riscos e incertezas, com altos investimentos iniciais e retornos tardios (Alkemade & Suurs, 2012), torna-se ainda mais importante a análise da viabilidade econômica desses empreendimentos. A complexidade dos sistemas de aquaponia, somada aos grandes desafios estruturais intrínsecos a atividades ainda incipientes, aumentam significativamente os riscos deste tipo de negócio (König et al., 2018).

Turnsek *et al*. (2019) avaliaram não ser conveniente concluir sobre a viabilidade econômica da atividade de forma generalista devido às distintas condições em várias partes do mundo. Desta forma, generalizar esta análise poderia desconsiderar as particularidades existentes em produções em desenvolvimento, não contribuindo para sua evolução. Seria, portanto, mais prudente realizar avaliações locais, com levantamentos de despesas e precificação dos produtos de forma regionalizada.

Existem ainda muitas lacunas sobre o tema, e ainda são necessários estudos mais profundos para aprimorar a eficiência e sustentabilidade dos sistemas aquapônicos globalmente (Goddek et al., 2015; Love et al., 2015). É também essencial a preocupação com as questões de mercado dos produtos oriundos desses sistemas, avaliando a aceitação dos consumidores, a propensão à adoção da tecnologia por parte dos produtores e os efeitos externos em relação aos meios de produção. A regulamentação e apoio político à implementação desta atividade também devem ser discutidos local e globalmente, a fim de se divulgar informações mais detalhadas acerca da produção aquapônica (Gorcum et al., 2019; Greenfeld et al., 2019). Desta forma, a análise econômica contribui para uma maior compreensão da atividade, reduzindo as lacunas no conhecimento sobre ela.

Kodama (2015) avaliou a viabilidade econômica de um sistema de pequena escala em Brasília, Distrito Federal, considerando custos e receitas do empreendimento. A rentabilidade observada superou os custos do negócio, indicando viabilidade financeira e apontando condições sob as quais o cultivo é exequível. Goda *et al*. (2015) ratificaram estes resultados em um projeto executado no Egito, obtendo superávit em dois desenhos distintos de sistemas de aquaponia e um prazo de retorno de capital investido relativamente curto.

As operações comerciais enfrentam ainda grandes desafios relacionados a condições climáticas, à logística de operações e à cadeia de suprimentos (Tokunaga et al., 2015). Além disso, a competitividade do mercado de produção de alimentos e a necessária especialização da mão de obra contribuem diretamente para o descrédito da aquaponia como atividade comercial (Turnsek et al., 2020).

El-Essawy *et al*. (2019) compararam um cultivo de aquaponia com sistemas de agricultura tradicional, como metodologia mais indicada em Turnsek *et al* (2019), e concluíram que no longo prazo a lucratividade da aquaponia é superior. Além disso, estes sistemas consumem 85% menos água, tornando esta tecnologia mais sustentável. Bich *et al*. (2020) também corroboraram com esta hipótese de viabilidade econômica, acrescentando ainda que o uso de materiais localmente disponíveis e espécies regionais contribuem com a sustentabilidade do negócio.

Na composição dos custos, Tokunaga *et al*. (2015) e Kodama *et al*. (2019) obtiveram resultados similares de viabilidade econômica, sendo os itens com maior impacto no valor global a mão de obra e a energia elétrica, mesmo utilizando metodologias distintas de avaliação. Este último estudo também ratificou a importância da venda de subprodutos do cultivo, os quais contribuem significativamente com o aumento da receita final. Love *et al*. (2015) acrescentaram ainda a oferta de serviços e treinamentos educacionais como formas de aumentar a lucratividade, porém permaneceu a indicação por uma avaliação individualizada.

2.3 Educação

No Brasil, a Educação Ambiental é um direito conferido a todos os cidadãos, e deve ser assegurada pelo Poder Público em todos os níveis de ensino, ao lado da conscientização para a preservação ambiental (Constituição, 1988). Ela se insere também na Política Nacional do Meio Ambiente, como princípio a ser amplamente difundido, inclusive na educação comunitária (Lei 6.938/1981). Da mesma forma, a Organização das Nações Unidas para Educação, Ciência e Cultura/UNESCO (https://pt.unesco.org) considera que a Educação Ambiental deverá ser um componente curricular básico até o ano de 2025, ratificando a necessidade por destaque a este assunto. Pode também ser vista como forma de sensibilizar os indivíduos sobre os problemas ambientais existentes mediante sua difusão entre os estudantes, dando-lhes conhecimento para fundamentar melhores escolhas cotidianas (Kumar et al., 2022).

Introduzir novas ferramentas e metodologias de ensino pode ser um grande desafio para docentes de todos os níveis educacionais (Vujovic et al., 2019). Estudos mostram que os professores relatam limitações de material, tempo e até mesmo apoio institucional, tornando-se um dos gargalos para a execução destes projetos (Martins, 2019; Rosa, 2020). A exigência de alguns países por currículos escolares cumprirem de maneira rígida uma base curricular desfavorece a inserção de formatos diferenciados e inovadores, como é o caso da aquaponia (Junge, Bulc, Anseeuw, Yildiz, & Milliken, 2019). Para lidar com este impasse, gerenciar as expectativas e unir esforços com os principais envolvidos pode beneficiar os alunos e instituições de ensino e pesquisa (Hart et al., 2014).

Mesmo assim, professores de todo o mundo vem enfrentando estas adversidades e buscando formas mais adequadas de conectar as múltiplas disciplinas através da aquaponia (Forchino et al., 2017; Maucieri, Forchino, et al., 2018; Junge, Bulc, Anseeuw, Yildiz, & Milliken, 2019; Greenfeld et al., 2021). Por meio de distintas abordagens e de soluções criativas, o uso da aquaponia no ensino tem contribuído para estudantes compreenderem conceitos didáticos e facilitado a compreensão da natureza multidisciplinar dos principais problemas globais (Dinu et al., 2018; Oliveira, 2019; Rosa, 2020).

O uso de jogos também tem sido uma estratégia interessante, acompanhando a indústria que mais cresce hoje no mundo com conceitos importantes visando à melhoria das condições humanas no nosso planeta (Soma et al., 2020). Uma vez que tem sido crescente o interesse dos estudantes por equipamentos tecnológicos e é notável sua familiaridade com os dispositivos, cada vez mais pesquisadores tem compreendido que utilizá-los como aliados pode ser uma boa estratégia (Ilha & Cruz, 2006; Pimentel et al., 2021). Tais mecanismos são favorecidos por irem ao encontro dos interesses e motivações dos estudantes, que se sentem inseridos no conteúdo programático e assim ficam motivados para continuar aprendendo assuntos dos quais consideram já ter algum domínio (Pimentel et al., 2021).

Da mesma forma, o uso da aquaponia no ensino busca aproximar-se do público, traçando caminhos fundamentados em conhecimentos elementares e presentes no cotidiano. Para isso, a aproximação dos alunos com temas a serem desenvolvidos em sala de aula deve partir de suas vivências e experiências prévias, como forma de envolvê-los na evolução de conhecimento por meio de atividades adequadas. A distância entre o que pode ser aprendido e o que é realmente executado denomina-se Zona de Desenvolvimento Proximal (ZDP), intervalo em que o aluno desenvolve suas habilidades reais (Freire et al., 2017). Assim, ao educador incumbe a função de despertar inquietações e fornecer experiências para favorecer o aprendizado de forma efetiva, como tem sido observado em estudos com uso da aquaponia (Wardlow et al., 2002; Maucieri, Forchino, et al., 2018; M. F. Silva et al., 2018).

A literatura aponta algumas soluções que visam favorecer este processo de ensino-aprendizagem de forma mais efetiva. Primeiro, os professores devem ser continuamente provocados a se manterem atualizados diante de ferramentas inovadoras e disruptivas, bem como precisam receber apoio institucional que permita a execução de ideias e projetos (Souza et al., 2019). Também se faz necessária a inclusão de instituições parceiras, pais e demais professores na busca por alternativas interessantes dirigidas a cada realidade de ensino (Hart et al., 2014; M. F. Silva et al., 2018; Fonsêca et al., 2020; Goddard et al., 2020).

Do ponto de vista dos alunos, a cooperação desponta na literatura como medida mais eficaz para a obtenção de soluções mais efetivas no enfrentamento dos problemas ambientais (Mikkelsen & Bosire, 2019; Glaviˇ, 2020; Chao et al., 2021). Além disso, metodologias de ensino participativas, mesmo que demandem que os alunos elaborem soluções para problemáticas muitas vezes complexas, mostram-se convenientes para facilitar a aprendizagem (Duarte et al., 2015; M. F. Silva et al., 2018).

3 OBJETIVOS

Este trabalho pretende avaliar a eficácia da inserção da aquaponia como ferramenta de ensino.

3.1 Objetivos específicos

3.1.1 Definir se a literatura considera a aquaponia uma ferramenta eficiente de ensino.

3.1.2 Determinar se com o uso da aquaponia no ensino os alunos aprendem conteúdos de ciências.

3.1.3 Determinar se a aquaponia pode ser uma ferramenta eficiente de ensino na modalidade remota.

3.1.4 Determinar se os alunos compreendem melhor os conceitos de sustentabilidade, uso racional de recursos ambientais, aquaponia, hidroponia e aquicultura, após a atividade desenvolvida.

4 HIPÓTESES

A aquaponia pode ser uma ferramenta que acrescenta aos alunos conceitos de sustentabilidade e conscientização sobre o uso de recursos em meios produtivos.

5 JUSTIFICATIVA

Compreender as limitações e aptidões do uso da aquaponia no ensino permitirá embasar futuras iniciativas para sua expansão, identificando entraves e sugerindo modificações para aprimorar esta ferramenta. Difundir tecnologias sustentáveis e aprofundar o conhecimento sobre questões ambientais envolvidas contribui com a construção do pensamento crítico e a preocupação ambiental dos cidadãos, demonstrando a importância de utilizar sistemas que demandam menor aporte hídrico e não utilizam agrotóxicos.

6 REFERÊNCIAS

[IDEC], I. B. de D. do C. (2019). *A sindemia global da obesidade, desnutrição e mudanças climáticas*.

Aalto, S. L., Suurnäkki, S., Ahnen, M. Von, Siljanen, H. M. P., Bovbjerg, P., & Tiirola, M. (2020). Nitrate removal microbiology in woodchip bioreactors : A case-study with full-scale bioreactors treating aquaculture effluents. *Science of the Total Environment*, *723*, 1–9. https://doi.org/10.1016/j.scitotenv.2020.138093

Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, *8*(24). https://doi.org/10.3390/buildings8020024

Alkemade, F., & Suurs, R. A. A. (2012). Patterns of expectations for emerging sustainable technologies. *Technological Forecasting and Social Change*, *79*(3), 448–456. https://doi.org/10.1016/j.techfore.2011.08.014

Alshrouf, A. (2017). Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming. *American Scientific Research Journal for Engineering*, *27*(1), 247–255. http://asrjetsjournal.org/

Amicarelli, V., & Bux, C. (2021). *Food waste measurement toward a fair , healthy and environmental-friendly food system : a critical review*. *123*(8), 2907–2935. https://doi.org/10.1108/BFJ-07-2020-0658

Arantes, C. C., Winemiller, K. O., Petrere, M., Castello, L., Freitas, C. E. C., & Hess, L. L. (2017). Relationships between forest cover and fish diversity in the Amazon River floodplain. *Journal of Applied Ecology*, *55*(1), 42–49. https://doi.org/10.1111/1365-2664.12967

Armanda, D. T., Guinée, J. B., & Tukker, A. (2019). The second green revolution: Innovative urban agriculture's contribution to food security and sustainability – A review. *Global Food Security*, *22*(August 2018), 13–24. https://doi.org/10.1016/j.gfs.2019.08.002

Bertusso, F. R., Terhaag, M. M., & Malacarne, V. (2020). The use of practical classes in science teaching: challenges and possibilities. *Revista Práxis Educational*, *16*(39), 318–336.

Bich, T. T. N., Tri, D. Q., Yi-Ching, C., & Khoa, H. D. (2020). Productivity and economic viability of snakehead Channa striata culture using an aquaponics approach. *Aquacultural Engineering*, *89*(June 2019), 102057. https://doi.org/10.1016/j.aquaeng.2020.102057

Boyaci-Gündüz, C. P., Ibrahim, S. A., Wei, O. C., & Galanakis, C. M. (2021). Transformation of the Food Sector : Security and Resilience during the COVID-19 Pandemic. *Foods*, *10*(497), 1–14. https://doi.org/https://doi.org/10.3390/ foods10030497

Bredemeier, C., & Mundstock, C. M. (2000). Regulação da absorção e assimilação do nitrogênio nas plantas. *Ciência Rural*, *30*(2), 365–372. https://doi.org/10.1590/s0103-84782000000200029

Chang, M., & Lan, S. (2019). Exploring undergraduate EFL students ' perceptions and experiences of a Moodle-based reciprocal teaching application. *Open Learning: The Journal of Open, Distance and e-Learning, 00*(00), 1–16. https://doi.org/10.1080/02680513.2019.1708298

Chao, S., Jiang, J., Wei, K., Ng, E., Hsu, C., Chiang, Y., Fang, & Wei-Ta. (2021). Understanding Pro-Environmental Behavior of Citizen Science : An Exploratory Study of the Bird Survey in Taoyuan ' s Farm Ponds Project. *Sustainability*, *13(9)*(5126), 1–24. https://doi.org/https://doi.org/10.3390/su13095126

Cheng, S. C., Hwang, G. J., & Chen, C. H. (2019). From reflective observation to active learning: A mobile experiential learning approach for environmental science education. *British Journal of Educational Technology*, *50*(5), 2251–2270. https://doi.org/10.1111/bjet.12845

Cockle, K. L., Martin, K., & Wesołowski, T. (2011). Woodpeckers, decay, and the future of cavity-nesting vertebrate communities worldwide. *Frontiers in Ecology and the Environment*, *9*(7), 377–382. https://doi.org/10.1890/110013

Companhia Nacional de Abastecimento. (2010). Custos de Produção Agrícola. In *Custos de Produção Agrícola: a metodologia da Conab*. http://www.conab.gov.br/conabweb/download/safra/custos.pdf

Conselho Estadual de Recursos Hídricos. (2019). *Nitrato nas águas subterrâneas: desafios frente ao panorama atual* (C. Varnier (ed.); 1st ed., Issue 1). SIMA/IG.

Danner, R. I., Mankasingh, U., Anamthawat-Jonsson, K., & Thorarinsdottir, R. I. (2019). Designing aquaponic production systems towards integration into greenhouse farming. *Water (Switzerland)*, *11*(10). https://doi.org/10.3390/w11102123

Delabre, I., Rodriguez, L. O., Smallwood, J. M., Scharlemann, J. P. W., Alcamo, J., Antonarakis, A. S., Rowhani, P., Hazell, R. J., Aksnes, D. L., Balvanera, P., Lundquist, C. J., Gresham, C., Alexander, A. E., & Stenseth, N. C. (2021). Actions on sustainable food production and consumption for the post-2020 global biodiversity framework. *Science Advances*, *7*(eabc8259), 1–17. https://doi.org/10.1126/sciadv.abc8259

Dinu, S., Ladaru, B., Physics, F., & Mg-, P. O. B. O. X. (2018). *Building and monitoring the* *aquaponics experimental lab for students*. *1*(1), 1–5.

Duarte, A. J., Malheiro, B., Ribeiro, C., Silva, M. F., Ferreira, P., & Guedes, P. (2015). Developing an aquaponics system to learn sustainability and social compromise skills. *Journal of Technology and Science Education*, *5*(4), 235–253. https://doi.org/10.3926/jotse.205

Eatmon, T. (2012). Soilless agriculture for Stem Education. *6th International Conference of Technology , Education and Development (INTED)*, 4000.

Eck, M., Körner, O., & Jijakli, M. H. (2019a). Nutrient Cycling in Aquaponics Systems. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 231–246). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_9

Eck, M., Körner, O., & Jijakli, M. H. (2019b). Nutrient Cycling in Aquaponics Systems Chapter 9 Nutrient Cycling in Aquaponics Systems. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., Issue 1, pp. 231–246). Springer. https://doi.org/10.1007/978-3-030-15943-6

Eck, M., Sare, A. R., Massart, S., Schmautz, Z., Junge, R., Smits, T. H. M., & Jijakli, M. H. (2019). Exploring bacterial communities in aquaponic systems. *Water (Switzerland)*, *11*(2), 1–16. https://doi.org/10.3390/w11020260

Ehrlich, P. R., & Harte, J. (2015). Food security requires a new revolution. *International Journal of Environmental Studies*, *72*(6), 908–920. https://doi.org/10.1080/00207233.2015.1067468

Eichhorst, J. (2014). *Distributed aquaponics in urban and peri-urban environments: a white paper on community development and feeding through the creation of local integrated farming clusters* (Issue August).

El-Essawy, H., Nasr, P., & Sewilam, H. (2019). Aquaponics: a sustainable alternative to conventional agriculture in Egypt – a pilot scale investigation. *Environmental Science and Pollution Research*, *26*(16), 15872–15883. https://doi.org/10.1007/s11356-019-04970-0

Ellen MacArthur Foundation. (2013). *Towards the circular economy: economic and business rationale for an accelerated transition* (Vol. 1, Issue 1). Ellen MacArthur Foundation.

Ellen MacArthur Foundation. (2019). Cities and Circular Economy for Food. In *Ellen MacArthur Foundation*. https://www.ellenmacarthurfoundation.org/assets/downloads/Cities-and-Circular-Economy-for-Food_280119.pdf

Fitzgerald, D. B., Sabaj Perez, M. H., Sousa, L. M., Gonçalves, A. P., Rapp Py-Daniel, L., Lujan, N. K., Zuanon, J., Winemiller, K. O., & Lundberg, J. G. (2018). Diversity and community structure of rapids-dwelling fishes of the Xingu River: Implications for conservation amid large-scale hydroelectric development. *Biological Conservation*, *222*(March), 104–112. https://doi.org/10.1016/j.biocon.2018.04.002

Fonsêca, L. B. H. da, Lima, S. M. de S., Costa, M. L. de O., & Almeida, J. D. S. (2020). Perspectivas do ensino remoto na educação brasileira. *Educação Como (Re)Existência: Mudanças, Conscientização e Conheicmentos*, 1–11.

Food and Agriculture Organization [FAO]. (2010). *Implementing aquaponics in the Gaza Strip*. www.fao.org/resilience/home/en/

Food and Agriculture Organization [FAO]. (2020). The State of Food and Agriculture 2020: overcoming water challenges in Agriculture. In *FAO* (1st ed.). FAO. https://doi.org/https://doi.org/10.4060/cb1447en

Forchino, A. A., Lourguioui, H., Brigolin, D., & Pastres, R. (2017). Aquaponics and sustainability: The comparison of two different aquaponic techniques using the Life Cycle Assessment (LCA). *Aquacultural Engineering*, *77*, 80–88. https://doi.org/10.1016/j.aquaeng.2017.03.002

Friedrich, T., Derpsch, R., & Kassam, A. (2012). Sustainable Development of Organic Agriculture. *Field Actions Science Reports*, *Special Issue 6*, 7. https://doi.org/10.1201/9781315365800

Gabriel, J. L., García-González, I., Quemada, M., Martin-Lammerding, D., Alonso-Ayuso, M., & Hontoria, C. (2021). Cover crops reduce soil resistance to penetration by preserving soil surface water content. *Geoderma*, *386*(January). https://doi.org/10.1016/j.geoderma.2020.114911

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Glaviˇ, P. (2020). Identifying Key Issues of Education for Sustainable Development. *Sustainability*, *12*(6500), 1–18. https://doi.org/10.3390/su12166500

Goda, A. M. A.-S., Essa, M. A., Hassan, M. S., & Sharawy, Z. (2015). Bio Economic Features for aquaponics Systems in Egypt. *Turkish Journal of Fisheries and Aquatic Sciences*, *15*, 525–532. https://doi.org/10.4194/1303-2712-v15_2_40

Goddard, J. M., Zurier, H. S., & Nugen, S. R. (2020). *Engaged food science : Connecting K-8 learners to food science while engaging graduate students in science communication*.

November, 31–47. https://doi.org/10.1111/1541-4329.12215

Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K. V., Jijakli, H., & Thorarinsdottir, R. (2015). Challenges of sustainable and commercial aquaponics. *Sustainability (Switzerland)*, *7*(4), 4199–4224. https://doi.org/10.3390/su7044199

Goddek, S., Joyce, A., Kotzen, B., & Burnell, G. M. (2019). Aquaponics Food Production Systems. *Aquaponics Food Production Systems*, *July*. https://doi.org/10.1007/978-3-030-15943-6

Goddek, S., Joyce, A., Kotzen, B., & Dos-Santos, M. (2019). Aquaponics and Global Food Challenges. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 3–17). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_1

Goddek, S., & Keesman, K. J. (2020). Improving nutrient and water use efficiencies in multi-loop aquaponics systems. *Aquaculture International*, *28*(1), 2481–2490. https://doi.org/https://doi.org/10.1007/s10499-020-00600-6

Gómez, C., Currey, C. J., Dickson, R. W., Kim, H. J., Hernández, R., Sabeh, N. C., Raudales, R. E., Brumfield, R. G., Laury-Shaw, A., Wilke, A. K., Lopez, R. G., & Burnett, S. E. (2019). Controlled environment food production for urban agriculture. *HortScience*, *54*(9), 1448–1458. https://doi.org/10.21273/HORTSCI14073-19

Gorcum, B. Van, Goddek, S., & Keesman, K. J. (2019). Gaining market insights for aquaponically produced vegetables in Kenya. *Aquaculture International*, *27*(5), 1231–1237. https://doi.org/10.1007/s10499-019-00379-1

Greenfeld, A., Becker, N., Bornman, J. F., Spatari, S., & Angel, D. L. (2021). Is aquaponics good for the environment ?— evaluation of environmental impact through life cycle assessment studies on aquaponics systems. *Aquaculture International*, *1*, 1–18. https://doi.org/10.1007/s10499-021-00800-8

Greenfeld, A., Becker, N., McIlwain, J., Fotedar, R., & Bornman, J. F. (2019). Economically viable aquaponics? Identifying the gap between potential and current uncertainties. *Reviews in Aquaculture*, *11*(3), 848–862. https://doi.org/10.1111/raq.12269

Guiducci, R. do C. N., Lima Filho, J. R. de, & Mota, M. M. (2012). *Viabilidade econômica de sistemas de produção agropecuários*. Embrapa.

Hart, E. R., Webb, J. B., Hollingsworth, C., & Danylchuk, A. J. (2014). Managing expectations for aquaponics in the classroom: enhancing academic learning and teaching an appreciation for aquatic resources. *Fisheries*, *39*(11), 525–530. https://doi.org/10.1080/03632415.2014.966353

He, J. (2017). Integrated vertical aeroponic farming systems for vegetable production in space limited environments. *Acta Horticulturae*, *1176*, 25–35. https://doi.org/10.17660/ActaHortic.2017.1176.5

Hu, Z., Lee, J. W., Chandran, K., Kim, S., Brotto, A. C., & Khanal, S. K. (2015). Effect of plant species on nitrogen recovery in aquaponics. *Bioresource Technology*, *188*, 92–98. https://doi.org/10.1016/j.biortech.2015.01.013

Hundley, G. C., & Navarro, R. D. (2013). Aquaponia : a Integração Entre Piscicultura E a Hidroponia. *Revista Brasileira de Agropecuária Sustentável (RBAS)*, *3*(2), 52–61.

Hundley, G. M. C., Navarro, R. D., Figueiredo, C. M. G., Navarro, F. K. S. P., Pereira, M. M., Filho, O. P. R., & Filho, J. T. S. (2013). Aproveitamento do efluente da produção de tilápia do Nilo para o crescimento de manjerona (Origanum majorana) e manjericão (Origanum basilicum) em sistemas de Aquaponia. *Revista Brasileira de Agropecuária Sustentável (RBAS)*, *3*(1), 51–55.

Ilha, P. C. A., & Cruz, D. M. (2006). Jogos eletrônicos na educação : uma pesquisa aplicada do uso do Sim City4 no ensino médio. *XXVI Congresso Da SBC*, *Julho*, 1–7.

Instituto Acende Brasil. (2014). *Qualidade do fornecimento de energia elétrica: confiabilidade, conformidade e presteza* (White Pape).

Instituto Acende Brasil. (2020). *Evolução das tarifas de energia elétrica e a formulação de políticas públicas* (White Pape).

Joyce, A., Goddek, S., Kotzen, B., & Wuertz, S. (2019). Aquaponics : Closing the Cycle on Limited Water , Land and Nutrient Resources. In G. M. Goddek, Simon; Joyce, Alyssa; Kotzen, Benz; Burnell (Ed.), *Aquaponics Food Production System* (1st ed., pp. 19–34). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_2

Joyce, A., Timmons, M., Goddek, S., & Pentz, T. (2019). Bacterial Relationships in Aquaponics : New Research Directions. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 145–161). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_6

Junge, R., Bulc, T. G., Anseeuw, D., Yildiz, H. Y., & Miliken, S. (2019). Aquaponics as an Educational Tool. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 561–593). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_22

Junge, R., Bulc, T. G., Anseeuw, D., Yildiz, H. Y., & Milliken, S. (2019). Aquaponics as an educational tool. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 561–595). Springer.

https://doi.org/10.4324/9780203883495

Kirschbaum, M. U. F., Zeng, G., Ximenes, F., Giltrap, D. L., & Zeldis, J. R. (2019). *Towards a more complete quantification of the global carbon cycle*. 831–846.

Kodama, G. (2015). Viabilidade financeira em sistema de aquaponia [Universidade de Brasília]. In *Viabilidade Financeira em sistema de aquaponia* (Vol. 1, Issue 4). https://doi.org/10.1111/j.1540-4781.1969.tb04998.x

Kodama, G., Santos, M. J. dos, Souza, Á. N. De, Hundley, G. C., & Navarro, R. D. (2019). Analysis of the financial viability of the aquaponics (fish farming and hydroponics) system using the Monte Carlo method. *Revista Brasileira de Agropecuária Sustentável (RBAS)*, *9*(4), 20–26.

König, B., Janker, J., Reinhardt, T., Villarroel, M., & Junge, R. (2018). Analysis of aquaponics as an emerging technological innovation system. *Journal of Cleaner Production*, *180*, 232–243. https://doi.org/10.1016/j.jclepro.2018.01.037

Kumar, S., Banerjee, A., Kumar, M., Swaroop, R., & Raj, A. (2022). Environmental education for sustainable development. *Natural Resources Conservation and Advances for Sustainability*, *1*(March), 415–431. https://doi.org/https://doi.org/10.1016/B978-0-12-822976-7.00010-7

Kyaw, T. Y., & Ng, A. K. (2017). Smart Aquaponics System for Urban Farming. *Energy Procedia*, *143*, 342–347. https://doi.org/10.1016/j.egypro.2017.12.694

Laidlaw, J., & Magee, L. (2014a). Towards urban food sovereignty: The trials and tribulations of community-based aquaponics enterprises in Milwaukee and Melbourne. *Local Environment*, *21*(5), 573–590. https://doi.org/10.1080/13549839.2014.986716

Laidlaw, J., & Magee, L. (2014b). Towards urban food sovereignty: The trials and tribulations of community-based aquaponics enterprises in Milwaukee and Melbourne. *Local Environment*, *21*(5), 573–590. https://doi.org/10.1080/13549839.2014.986716

Lal, R. (2016). Feeding 11 billion on 0.5 billion hectare of area under cereal crops. *Food and Energy Security*, *5*(4), 239–251. https://doi.org/10.1002/fes3.99

Lambert, C. G., & Rennie, A. E. W. (2021). Experiences from COVID-19 and Emergency Remote Teaching for Entrepreneurship Education in Engineering Programmes. *Education Sciences*, *11*(282), 1–16. https://doi.org/10.3390/educsci11060282

Lassaletta, L., Billen, G., Grizzetti, B., & Galloway, J. N. (2014). *Food and feed trade as a driver in the global nitrogen cycle : 50-year trends*. 225–241. https://doi.org/10.1007/s10533-013-9923-4

Lennard, W., & Goddek, S. (2019). Aquaponics : The Basics. In S. Goddek, A. Joyce, B.

Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 113–143). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_5

Lima, M. T. (2020). *Por que agricultura na cidade? A importância da Agricultura Urbana em contexto de emergência climática e sanitária*.

Love, D. C., Fry, J. P., Li, X., Hill, E. S., Genello, L., Semmens, K., & Thompson, R. E. (2015). Commercial aquaponics production and profitability: Findings from an international survey. *Aquaculture*, *435*, 67–74. https://doi.org/10.1016/j.aquaculture.2014.09.023

Lun, F., Sardans, J., Sun, D., Xiao, X., Liu, M., Li, Z., Wang, C., Hu, Q., Tang, J., Ciais, P., Janssens, I. A., & Obersteiner, M. (2022). Influences of international agricultural trade on the global phosphorus cycle and its associated issues. *Global Environmental Change*, *69*(102282), 1–13. https://doi.org/10.1016/j.gloenvcha.2021.102282

Lunardi, N. M. S. S., Sousa, J. B. de, Silva, N. R. M. da, Pereira, T. G. N., & Fernandes, J. da S. C. (2021). Aulas Remotas Durante a Pandemia : dificuldades e estratégias utilizadas por pais. *Educação & Realidade2*, *46*(2), 1–22.

Martins, P. (2019). Aquaponia em Educação Ambiental – Perceções de alunos e de professores Escola Profissional de Agricultura e Desenvolvimento Rural de Marco de Canaveses Acuaponia en Educación Ambiental – Percepciones de estudiantes y de maestros Aquaponics in Environmenta. *Revista Eletrônica Do Mestrado Em Educação Ambiental*, *36*(3), 356–369.

Maucieri, C., Forchino, A. A., Nicoletto, C., Junge, R., Pastres, R., Sambo, P., & Borin, M. (2018). Life cycle assessment of a micro aquaponic system for educational purposes built using recovered material. *Journal of Cleaner Production*, *172*, 3119–3127. https://doi.org/10.1016/j.jclepro.2017.11.097

Maucieri, C., Nicoletto, C., Junge, R., Schmautz, Z., Sambo, P., & Borin, M. (2018). Hydroponic systems and water management in aquaponics: A review. *Italian Journal of Agronomy*, *13*(1), 1–11. https://doi.org/10.4081/ija.2017.1012

Maucieri, C., Nicoletto, C., Os, E. Van, Anseeuw, D., Havermaet, R. Van, & Junge, R. (2019). Hydroponic Technologies. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 77–110). Springer. https://link.springer.com/book/10.1007/978-3-030-15943-6

Mercier, V. B., Scholten, U., Baltensperger, R., Gremaud, L., & Dabros, M. (2021). Distance Teaching in Chemistry : Opportunities and Limitations. *CHIMIA*, *75*(1), 58–63. https://doi.org/10.2533/chimia.2021.58

Messner, R., Johnson, H., & Richards, C. (2021). From surplus-to-waste : A study of systemic overproduction, surplus and food waste in horticultural supply chains. *Journal of Cleaner Production*, *278*(123952), 1–11. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123952

Mikkelsen, B. E., & Bosire, C. M. (2019). Food, sustainability, and Science Literacy in One Package? Opportunities and Challenges in Using Aquaponics Among Young People at School, a Danish Perspective. In *Aquaponics Food Production System* (pp. 597–606).

Milliken, S., & Stander, H. (2019). Aquaponics and Social Enterprise. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 607–619). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_24

Miralles-Wilhelm, F. (2021). Nature-based solutions in agriculture - Sustainable management and conservation of land, water and biodiversity. In *Nature-based solutions in agriculture: Sustainable management and conservation of land, water and biodiversity*. FAO and The Nature Conservancy. https://doi.org/10.4060/cb3140en

Mojtahedi, M. R., Alizadeh, K., & Jafari, H. (2021). The Role of Urban Agriculture Approach in Food Supply and Export Ability (Case Study of Neishabour in Iran). *Propósitos y Representaciones*, *9 (SPE1)*(e881), 1–18.

Monsees, H., Kloas, W., & Wuertz, S. (2017). Decoupled systems on trial: Eliminating bottlenecks to improve aquaponic processes. *PLoS ONE*, *12*(9), 1–18. https://doi.org/10.1371/journal.pone.0183056

Morano, L., & Tzouanas, V. (2017). Urban Agricultural and Sustainability Program at Houston's Downtown University: Combining New Curriculum, Hands-on Projects, and a Hurricane. *Journal of Agriculture, Food Systems, and Community Development*, *7*(4), 1–11. https://doi.org/10.5304/jafscd.2017.074.003

Murotani, B. S. (2013). *A fazenda vertical e a cidade: uma reflexão sobre São Paulo* (Vol. 2013). Universidade Presbiteriana Mackenzie.

Oliveira, A. F. F. de. (2019). O uso da aquaponia como instrumento de sensibilização e conscientização ambiental sustentável multidisciplinar desenvolvido em escola privada de Natal, RJ, Brasil. *VI Congresso Nacional Da Educação*, 1–8.

Pantazi, D., Dinu, S., & Voinea, S. (2019). The smart aquaponics greenhouse – an interdisciplinary educational laboratory. *Romanian Reports in Physics*, *71*(3), 1–11.

Paula, C. da S. (2020). *Aquaponia: uma ferramenta didática de ensino no IFPA-Santarém, Brasil*. Universidade Federal do Pará.

Pearson, L. J., Pearson, L., & Pearson, C. J. (2011). Sustainable urban agriculture: Stocktake and opportunities. *Urban Agriculture: Diverse Activities and Benefits for City Society*, *May 2015*, 7–19. https://doi.org/10.3763/ijas.2009.0468

Pimentel, F. S. C., Francisco, D. J., & Ferreira, A. R. (2021). *Jogos digirais, tecnologias e educação: reflexões e propostas no contexto da COVID-19* (1st ed.). Edufal.

Proksch, G., Ianchenko, A., Miller, T., Partnership, H., & Kotzen, B. (2019). Aquaponics Food Production Systems. In *Aquaponics Food Production Systems* (Issue June). https://doi.org/10.1007/978-3-030-15943-6

Pulighe, G., & Lupia, F. (2020). Food first: COVID-19 outbreak and cities lockdown a booster for a wider vision on urban agriculture. *Sustainability (Switzerland)*, *12*(12), 10–13. https://doi.org/10.3390/su12125012

Rosa, L. O. G. C. (2020). *Uma proposta para o uso da aquaponia no ensino de biologia*. Universidade de Brasília.

Ruggeri, G., Mazzocchi, C., & Corsi, S. (2016). Urban Gardeners ' Motivations in a Metropolitan City : The Case of Milan. *Sustainability*, *8*(1099), 1–19. https://doi.org/10.3390/su8111099

Salas-Zapata, W. A., & Ortiz-Muñoz, S. M. (2019). Analysis of meanings of the concept of sustainability. *Sustainable Development*, *27*, 153–161. https://doi.org/10.1002/sd.1885

Santeramo, F. G., & Lamonaca, E. (2021). *Food Loss – Food Waste – Food Security : A New Research Agenda*.

Santos, M. J. P. L. dos. (2016). Smart cities and urban areas—Aquaponics as innovative urban agriculture. *Urban Forestry and Urban Greening*, *20*, 402–406. https://doi.org/10.1016/j.ufug.2016.10.004

Santos, R. A. dos. (2010). *Estudo das variações dos componentes do balanço hídrico e área com solo exposto na bacia hidrográfica do rio Verde , Goiás Ronaldo Antonio dos Santos Ronaldo Antonio dos Santos*. Universidade de São Paulo.

Silva, P. C. P. de, & Silva, P. C. A. de. (2016). Ipanera: An Industry 4.0 based architecture for distributed soil-less food production systems. *1st Manufacturing and Industrial Engineering Symposium*, *October*. https://doi.org/10.1109/MIES.2016.7780266

Silva, M. F. e, & Van Passel, S. (2020). Climate-smart agriculture in the northeast of Brazil: An integrated assessment of the aquaponics technology. *Sustainability (Switzerland)*, *12*(9). https://doi.org/10.3390/su12093734

Silva, M. F., Malheiro, B., Guedes, P., Duarte, A., & Ferreira, P. (2018). Collaborative learning with sustainability-driven projects: A summary of the EPS@ISEP programme.

International Journal of Engineering Pedagogy, *8*(4), 106–130. https://doi.org/10.3991/ijep.v8i4.8260

Sivia, A., MacMath, S., Novakowski, C., & Britton, V. (2019). Examining Student Engagement During a Project-Based Unit in Secondary Science. *Canadian Journal of Science, Mathematics and Technology Education*, *19*(3), 254–269. https://doi.org/10.1007/s42330-019-00053-x

Smith, K., Wells, R., & Hawkes, C. (2022). *How Primary School Curriculums in 11 Countries around the World Deliver Food Education and Address Food Literacy : A Policy Analysis*.

Soma, T., Li, B., & Maclaren, V. (2020). Food Waste Reduction : A Test of Three Consumer Awareness Interventions. *Sustainability*, *12(3)*(907), 1–19. https://doi.org/https://doi.org/10.3390/su12030907

Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2014). Small-scale aquaponic food production. Integrated fish and plant farming. In *FAO Fisheries and Aquaculture* (No. 589).

Soomro, A. H., Shaikh, N., Miano, T. F., Marri, A., Khaskheli, S. G., & Kumar, D. (2021). Food waste management strategies in food supply chain. *International Journal of Ecosystems and Ecology Science (IJEES)*, *11*(4), 759–766. https://doi.org/https://doi.org/10.31407/ijees11.413

Souza, R. T. Y. B. de, Souza, L. de O., Oliveira, S. R. de, & Takahashi, E. L. H. (2019). Formação continuada de professores de ciências utilizando a Aquaponia como ferramenta didática Science teachers ' continuing training using Aquaponics as a didactic tool. *Ciência & Educação*, *25*(2), 395–410. https://doi.org/https://doi.org/10.1590/1516-731320190020008

Specht, K., Weith, T., Swoboda, K., & Siebert, R. (2016). Socially acceptable urban agriculture businesses. *Agronomy for Sustainable Development*, *36*(1), 1–14. https://doi.org/10.1007/s13593-016-0355-0

Specht, K., Zoll, F., Schümann, H., Bela, J., Kachel, J., & Robischon, M. (2019). How will we eat and produce in the cities of the future? From edible insects to vertical farming-A study on the perception and acceptability of new approaches. *Sustainability (Switzerland)*, *11*(16), 1–22. https://doi.org/10.3390/su11164315

Suárez-Cáceres, G. P., Fernández-Cabanás, V. M., Lobillo-Eguíbar, J., & Pérez-Urrestarazu, L. (2021). Characterisation of aquaponic producers and small - scale facilities in Spain and Latin America. *Aquaculture International*, *0123456789*.

https://doi.org/10.1007/s10499-021-00793-4

Tokunaga, K., Tamaru, C., Ako, H., & Leung, P. (2015). Economics of small-scale commercial aquaponics in hawai'i. *Journal of the World Aquaculture Society*, *46*(1), 20–32. https://doi.org/10.1111/jwas.12173

Turnsek, M., Joly, A., Thorarinsdottir, R., & Junge, R. (2020). Challenges of commercial aquaponics in Europe: Beyond the hype. *Water (Switzerland)*, *12*(306), 1–18. https://doi.org/10.3390/w12010306

Turnšek, M., Morgenstern, R., Schröter, I., Mergenthaler, M., Hüttel, S., & Leyer, M. (2019). Commercial Aquaponics: A Long Road Ahead. In S. Goddek (Ed.), *Aquaponics Food Production Systems* (pp. 453–485). Springer.

Tyson, R. V., Treadwel, D. D., & Simonne, E. H. (2011). Opportunities and challenges to sustainability in aquaponic systems. *HortTechnology*, *21*(1), 6–13. https://doi.org/10.21273/horttech.21.1.6

Vermeulen, T., & Kamstra, A. (2013). The need for systems design for robust aquaponic systems in the urban environment. *Acta Horticulturae*, *1004*, 71–78.

Vujovic, A., Todorovic, P., Stefanovic, M., Vukicevic, A., Jovanovic, M. V., Macuzic, I., & Stefanovic, N. (2019). The development and implementation of an aquaponics embedded device for teaching and learning varied engineering concepts. *International Journal of Engineering Education*, *35*(1), 1–11.

Wang, W., Jia, Y., Cai, K., & Yu, W. (2020). An Aquaponics System Design for Computational Intelligence Teaching. *IEEE Access*, *8*, 42364–42371. https://doi.org/10.1109/ACCESS.2020.2976956

Wardlow, G., Johnson, D., & Mueller, C. (2002). Enhancing Student Interest in the Agricultural Sciences through Aquaponics. *Journal of Natural Resources and Life Sciences Education*, *31*(June 2000), 55–58.

Wasieleski, D., Waddock, S., & Fort, T. (2021). *Natural Sciences , Management Theory , and System Transformation for Sustainability*. https://doi.org/10.1177/0007650319898384

Wirza, R., & Nazir, S. (2021). Urban aquaponics farming and cities- a systematic literature review. *Reviews on Environmental Health*, *36*(1), 47–61. https://doi.org/10.1515/reveh-2020-0064

Yildiz, H. Y., Robaina, L., Pirhonen, J., Mente, E., Domínguez, D., & Parisi, G. (2017). Fish welfare in aquaponic systems: Its relation to water quality with an emphasis on feed and faeces-A review. *Water*, *9*(13), 1–17. https://doi.org/10.3390/w9010013

Yuan, Z., Jiang, S., Sheng, H., Liu, X., Hua, H., Liu, X., & Zhang, Y. (2018). *Human*

Perturbation of the Global Phosphorus Cycle : Changes and Consequences. https://doi.org/10.1021/acs.est.7b03910

CAPÍTULO 1

Use of Aquaponics for Teaching: a Systematic Review

(Artigo submetido para publicação na Revista Pesquisa em Educação Ambiental)

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Use of aquaponics for teaching: a systematic review

Uso da aquaponia para o ensino: uma revisão sistemática

Uso de la acuaponía para la enseñanza: una revisión sistemática

Abstract

The growing global demand for food carries to the scientific world a reflection on the productive means used today, raising relevant questions about its sustainability from a broad point of view. In this gap, aquaponics emerged as an alternative for food producing respecting the environment. The educational use of this tool has been studied in recent years, and the union of different areas of study in solving real-world problems seems to be an interesting way for knowledge retention. This is a quantitative study from secondary data recovered from scientific literature and analyzed by a systematic review to assess whether the use of aquaponics in teaching facilitates the practical understanding of environmental sustainability in a broad way. The results obtained corroborate that aquaponic is an adequate teaching tool. This technique allows students to be involved with various aspects of production, facilitating practical teamwork, in addition to generating knowledge and motivation.

Keywords: Aquaponics. Education. Environmental sustainability.

Resumo

A crescente demanda global por alimentos traz ao mundo científico uma reflexão sobre os meios produtivos utilizados atualmente, levantando questões relevantes sobre sua sustentabilidade sob um ponto de vista amplo. Nessa lacuna, a aquaponia surgiu como uma alternativa para a produção de alimentos respeitando o meio ambiente. O uso educacional dessa técnica vem sendo estudado nos últimos anos, e a união de diferentes áreas de estudo na resolução de problemas do mundo real parece ser uma forma interessante de retenção do conhecimento. Este é um estudo quantitativo de dados secundários recuperados da literatura científica e analisados por uma revisão sistemática para avaliar se o uso da aquaponia no ensino facilita a compreensão prática da sustentabilidade ambiental de forma ampla. Os resultados obtidos corroboram que a aquaponia é uma ferramenta de ensino adequada. Esta técnica permite que os alunos se envolvam com diversos aspectos da produção, facilitando o trabalho prático em equipe, além de gerar conhecimento e motivação.

Palavras-chave: Aquaponia. Educação. Sustentabilidade ambiental.

Resumén

La creciente demanda mundial de alimentos trae al mundo científico una reflexión sobre los medios productivos utilizados en la actualidad, planteando preguntas relevantes sobre su sustentabilidad desde un amplio punto de vista. En este vacío surgió la acuaponía como una alternativa para la producción de alimentos respetando el medio ambiente. El uso educativo de esta técnica ha sido objeto de estudio en los últimos años, y la unión de diferentes áreas de estudio en la resolución de problemas del mundo real parece ser una forma interesante de retener el conocimiento. Este es un estudio cuantitativo de los datos secundarios recuperados de la literatura científica y analizado por una revisión sistemática para evaluar si el uso de la acuaponía en la enseñanza facilita la comprensión práctica de la sostenibilidad ambiental de una manera amplia. Los resultados obtenidos corroboran que la acuaponía es una herramienta didáctica adecuada. Esta técnica permite que los estudiantes se involucren en varios aspectos de la producción, facilitando el trabajo práctico en equipo, además de generar conocimiento y motivación.

Palabras clave: Acuaponía. Educación. Sostenibilidad del medio ambiente.

1. INTRODUCTION

The growing global demand for food carries to the scientific world a reflection on the productive means used today, raising relevant questions about its sustainability from a broad point of view (FUKASE; MARTIN, 2020; AMORIM; BARBOSA; SOBRAL, 2022). To involve the world population in the search for solutions to this issue, it is necessary to orient and educate food choices for the population, in addition to including teaching on sustainability in education at all levels might help achieve this goal (AMORIM; BARBOSA; SOBRAL, 2022).

Education for sustainability and education have led to new knowledge in the external world of ecosystems, socioeconomic structures, and governance, but didn't optimize to address current challenges: the individual dimensions. New holistic pedagogies and new methodologies are necessary for sustainable development. This new scenario is already part of the United Nations Sustainable Development Goals (SDGs) (WAMSLER, 2020).

The SDGs' address economic and environmental problems and can generate competitiveness of entrepreneurships and nations in a global, multi dimensioned and participative approach. They integrate science, policies, public and private interventions for management of ecosystems services towards sustainability and well-being (ANDREONI; MIOLA, 2016).

Salas-Zapata and Ortiz-Muñoz (2018) claim that the concept of sustainability is linked to the context in which it is used, and its meaning differs in the academic community. Even so, these authors consider it imperative to connect social and ecological aspects in the issue approached. Understanding education as an important social agent, it could be a relevant means to guide the population on the appropriate and necessary measures to be taken (SALAS-ZAPATA; ORTIZ-MUÑOZ, 2018).

Education for sustainability must use different forms of teaching-learning methods to connect human actions with environmental sciences. The use of practical activities can contribute to the effectiveness of the learning process, and the choice of recycled, reused, or low-cost materials (environmental and even financial) can further expand critical thinking, bringing science closer to students' daily lives (BERTUSSO; TERHAAG; MALACARNE, 2020).

Viable alternatives have emerged and have been increasingly studied and deepened around the world, among them emerges aquaponics (SPECHT *et al*., 2019). This is a productive system that allows the synergistic connection between the production of aquatic organisms by aquaculture and the production of vegetables by hydroponics in a closed system, allowing less water consumption (HUNDLEY; NAVARRO, 2013; KODAMA *et al*., 2019). Through this, it is possible to produce a variety of quality food in different ways, using small spaces and different materials (HUNDLEY, 2013; HUNDLEY *et al*., 2018).

Complexity of aquaponic systems derives not only from their integrated character but also wider economic, institutional, and political structures that impact the delivery of aquaponics and its sustainability potential to advance Science, Technology, Engineering and Mathematics (STEM) connection with educational process and (BUONO, 2014; KÖNIG *et al.*, 2016). Developing solutions towards sustainable aquaponic food systems may well involve contending with diverse realms of understanding from engineering, horticultural, aquacultural, microbiological, ecological, economic, and public health research, to practical and experiential knowledge concerns of practitioners, retailers, and consumers (GOTT; MORGENSTERN; TURNSEK, 2019).

The integrative character and physical plasticity of aquaponic systems means that the technology can be deployed in a wide variety of applications, which is precisely the strength of aquaponic technology (GOTT; MORGENSTERN; TURNSEK, 2019). This, in turn, helps to develop the necessary skills to deal with the complexity and problems of the environment, promoting a sense of responsibility towards humanity. Therefore, this system creates the opportunity for hands-on experience with nature and its natural elements such as water, fish, and plants, developing environmental consciousness, a greater understanding of the potential for practical solutions and a willingness to act on this knowledge (JUNGE *et al.*, 2019).

For the theme 'sustainability' to be fully developed and systematically thought out by the whole society, it is necessary to approach it in a multidisciplinary way, using in all areas of knowledge the fundamental principles of development with respect to future generations. Thus, the objective of this study is to qualify the use of aquaponics systems for education, evaluating whether this tool facilitates the practical understanding of environmental sustainability in a broad way.

2. METHODS AND MATERIALS

This is a quantitative study from secondary data collected from scientific literature and analyzed by a systematic review. To find publications addressing aquaponics and education, we conducted an extensive literature survey according to the PRISMA Protocol (PAGE *et al*., 2021) on the search sites Web of Science and Scientific Electronic Library Online (SciELO). These platforms were selected to find both International and Latin American focuses, translating the state of the art in a higher geographic horizon. Also, they present a friendly environment with robust search tools, resulting in more consistent results within the intended scope.

The search was conducted on march of 2022. We determined the search criteria that refer to "aquaponics and education", translated to retrieve studies in English, Portuguese, and Spanish, finding words like *aquaponics*, *aquaponic*, *aquaponical*, *aquaponia*, *aquaponico*, *aquaponicos*, *acuaponico*, *acuaponicos*, *acuaponia* related to terms such as *education*, *educational*, *educative*, *educação*, *educacional*, *educativo*, or *educación*. In Web of Science platform, we used the keywords *a*uaponic* AND educa** in the field topics, with the maximum time horizon available in the search tool (from 1945), filtering by publication date. We included only those qualified as articles to get only manuscripts that got through judicious peer review processes. In the SciELO search site, the keywords used were *a*uapon* AND educa**, also qualifying for articles.

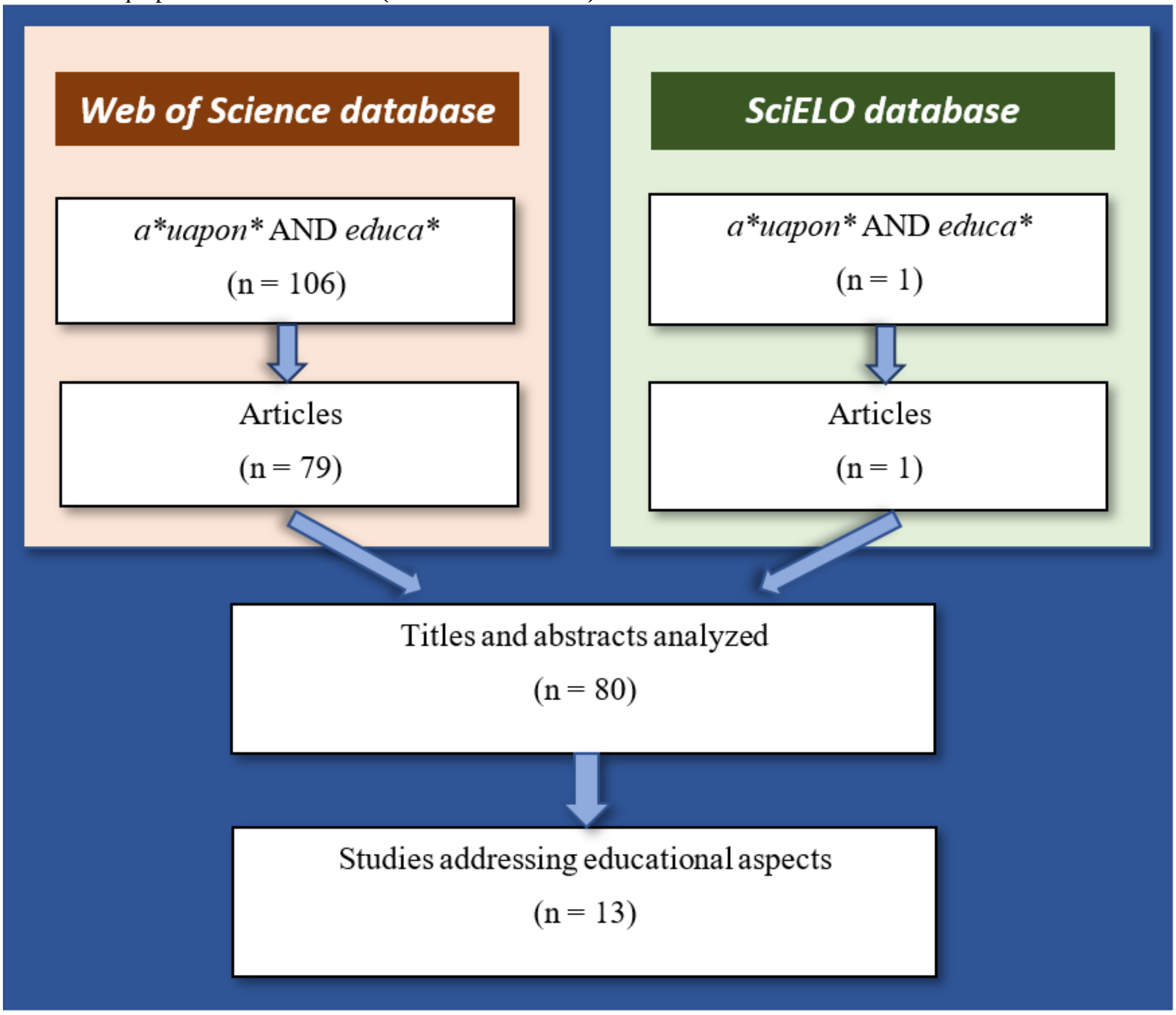
Regarding the criteria for inclusion and exclusion of articles in our online searches, we independently analyzed titles and abstracts to verify their compatibility with the topic, becoming eligible studies that address educational aspects of aquaponics. Based on these criteria, when there was consensus for eliminating a document, it was withdrawn from further analysis. When the consensus was for maintaining the study, it was kept for this review. When there was no absolute consensus, the most voted consensus was used to establish the final verdict for the manuscript.

After the selection steps, the papers were read in full, extracting the following information: (1) Country; (2) Methodology; (3) Education level; and (4) Knowledge area.

3. RESULTS AND DISCUSSION

Following the search criteria, at first, we obtained from Web of Science a total of 106 documents, and after excluding those that were not articles, 79 studies were maintained. On the SciELO platform, we retrieved only one article differing from those already obtained in the other database (Figure 1).

Figure 1 - Flow diagram of the steps executed in each database, *Web of Science* and *SciELO*, to find articles related to aquaponics and education (Source: the authors).



We then analyzed these 80 abstracts, and following the eligibility criteria 13 remained for analysis, eliminating those that did not address educational aspects of aquaponics (Table 1).

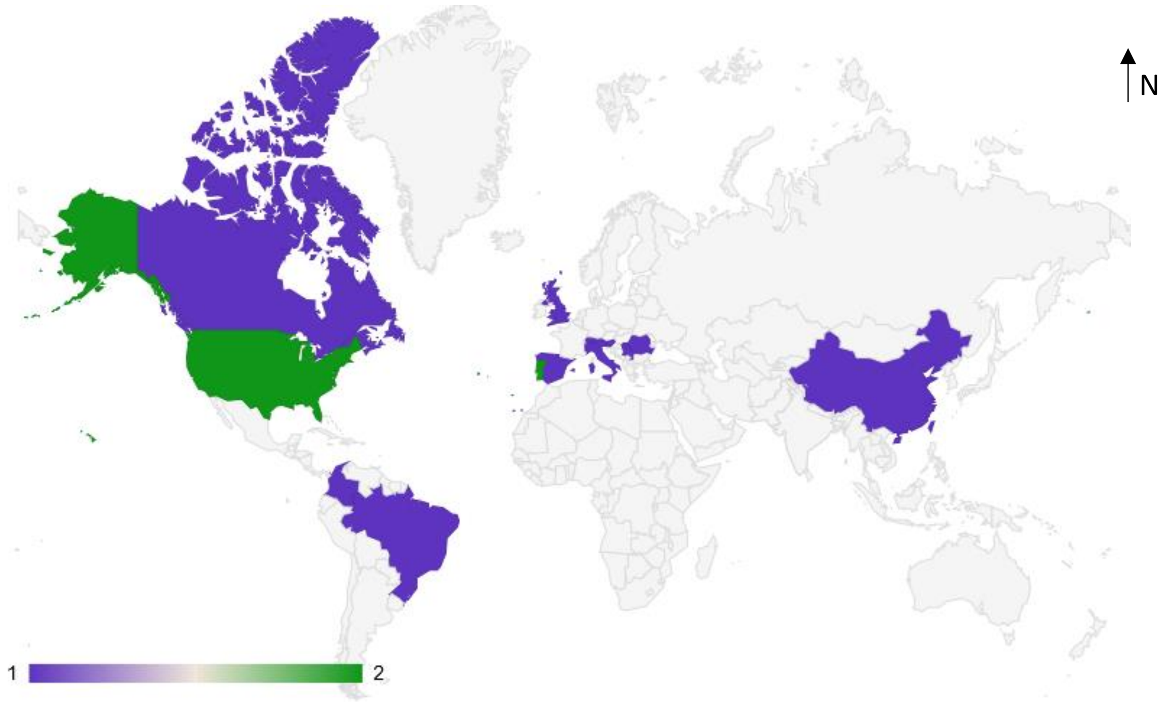
After reading the articles, we analyzed each one and developed Table 1 that shows, for each one: the country where the study was carried out, also shown in Figure 2; type of methodology used; level of education applied; and area of knowledge prevalent in the research.

Table 1 - Results of research on the use of aquaponics in teaching, representing the country where they were carried out, type of methodology applied, educational level and knowledge area (Source: the authors).

Article	Country	Methodology	Education level	Knowledge area
Cheng, Hwang, and Chen, 2019	Taiwan	Case study	Elementary School	Natural Sciences
Garzón *et al*., 2020	Colombia	Case study	General	Natural Sciences
Hart *et al*., 2014	United States of America	Featured article	General	Natural Sciences
Kobayashi, Radovich, and Moreno (2010)	United States of America	Case study	University	Natural Sciences
Martins, 2019	Portugal	Case study	Elementary School	Natural Sciences
Maucieri *et al*., 2018	Italy	Case study	University	Natural Sciences
Milliken *et al*., 2021	United Kingdom, Spain, Switzerland, Slovenia	Case study	University	Natural Sciences
Pantazi, Dinu, and Voinea, 2019	Romania	Case study	University	Exact Sciences
Silva *et al*., 2018	Portugal	Case study	University	Exact Sciences
Sivia et al., 2019	Canada	Case study	High School	Natural Sciences
Souza et al., 2019	Brazil	Case study	High School	Natural and Exact Sciences
Vujovic *et al*., 2019	Serbia	Case study	University	Exact Sciences
Wang *et al*., 2020	China	Case study	University	Exact Sciences

Most of the studies retrieved were carried out in Europe (6 articles), followed by North America (3 articles), and Asia and South America presenting the same number of publications (2 articles each) (Figure 2). These numbers reflect the origins of studies with aquaponics, in Europe. According to Greenfeld *et al*. (2018), the study by Naegel (1977) was the first to talk about aquaponics, whose study proved evidence of the feasibility of combining plant and fish production together in one only system using recirculating water. Some years later, this technique gained space in research groups in the USA and international reach based on the reviews by Tyson, Treadwell, and Simonne (2011) and Goddek *et al*. (2015). Following this trend, studies are mainly concentrated in Europe and North America, with increasing application globally (LOVE *et al*., 2014; LOVE *et al*., 2015).

Figure 2 – Global distribution map of the articles selected for this study. Countries where 1 study was carried out in are represented in purple, and those where 2 were carried out in are represented in green. The scale shows the differentiation of colors (Source: the authors).



Through the methodology used, we did not find publications addressing educational aspects in Oceania and Africa continents, although in recent years a great number of scientific studies on this thematic were carried out in these regions (MCHUNU; LAGERWALL; SENZANJE, 2018; GREENFELD *et al.,* 2020). In Oceania, many articles on the use of aquaponics have been published in recent years, although in different areas of evaluation, despite being an international trend (KHALIL *et al.,* 2021; GREENFELD *et al.,* 2020). Educational aspects are now being studied worldwide, as demonstrated in this review, and the number of publications in this area is expected to rise in the next few years. Also, Africa has increasingly published important findings on aquaponics, especially on technical optimization of production (OBIRIKORANG *et al.,* 2021; MACEDA-VEIGA *et al.,* 2022). By the results of Mchunu, Lagerwall, and Senzanje (2018), it is possible to observe that in this continent the educational use of aquaponics is still incipient, corroborating to our results.

Turnsek *et al*. (2020) found that most facilities used in aquaponics systems in Europe are small-scale research units, with few examples of commercial and educational applications. However, in Spain and Latin America, Suárez-Cáceres *et al*. (2021) described the educational, subsistence and hobby uses as the main purposes for aquaponics. In South Africa, most practitioners have hobby purposes, followed by subsistence and commercial objectives, and evaluating the small number of practitioners and size of the systems, it could be characterized as still incipient in this location (MCHUNU; LAGERWALL; SENZANJE, 2018). In Qatar, its use for food security is considered sustainable, and this purpose is also relevant in the United Arab Emirates (ABUSIN; MANDIKIANA, 2020; DEGEFA; ALBEDWAWI; ALAZEEZIB, 2021). Here, we demonstrate the potential for the educational application of this method but reinforce the importance of further development for other purposes.

A big concern for educational application of aquaponics is the elaboration of adequate curricula in different realities, which might include strategic topics especially for sustainability approaches. The studies of Kobayashi, Radovich, and Moreno (2010), Silva *et al.* (2018) and Milliken *et al*. (2021) use similar methodologies, applying projects for university level students in an environmental-oriented curriculum. In these documents, the authors agree that applied sciences should improve students' interest and autonomy, reflecting their engagement in the learning process.

Martins (2019) also evaluates the application of aquaponics in a technical course, suggesting to interested educators the involvement of community and educational institutions on planning these activities. Hart *et al*. (2014) strongly recommends these mentioned solutions and claim that it is also important to realistically evaluate whether it is more viable to bring the facilities to school, developing small-scale systems, or to program visitations to external systems in the surroundings. For these studies, teachers are expressively mentioned to play a key role for the adequate functioning of these activities. Investing in their formation over time would be a very cost-effective way to improve the effectiveness of practical applications such as these above mentioned (MARTINS, 2019; SIVIA *et al*., 2019; SOUZA *et al*., 2019; SPECHT *et al*., 2019).

The use of project-based methods for teaching abstract concepts using aquaponics, especially for engineering fields, is defended by Cheng, Hwang, and Chen (2019), Pantazi, Dinu, and Voinea (2019), Vujovic *et al*. (2019), Garzón *et al*. (2020) and Wang et al. (2020). These researchers suggest that technology-supported experiential learning can specially benefit students to encounter advanced real-world solutions and improve teamwork, providing them with soft skills in interesting and challenging ways. This way, the future professionals would be able to respond to real problems with creative technical solutions, allowing them to get a better understanding of their positions in the professional market (GARZÓN *et al*., 2020).

Another important finding presented in the studies is the sustainability of the educational process itself, which can also be a source of pollution and resource exploitation. Using Life Cycle Assessment (LCA) analysis, Maucieri *et al*. (2018) conclude that an aquaponics system could be a low-impact structure with a great educational application, being able to prepare students to bigger issues in the world's reality by teaching them to recycle and reuse materials. A great effort is demanded from educators on planning sustainable activities and teaching multidisciplinary aspects of production systems, and aquaponics is suggested to be a sufficiently complex tool to achieve this task (MAUCIERI *et al*., 2018). Through the educational use of aquaponics, these authors agree that it could be possible to combine multidisciplinary themes relevant to productive sustainability, allowing a holistic approach for teaching.

Experiential learning is also cited as an important way for offering the students' the opportunity of building their own knowledge through varied techniques. Cheng, Hwang, and Chen (2019) conclude that environmental attitudes can effectively be enhanced by using this approach, and Pantazi, Dinu, and Voinea (2019) add the importance of *do-it-yourself* experiments to provide them with all the information they need to achieve success. Being closely assisted by the teacher in the entire knowledge-building and learning process, Sivia *et al*. (2019) also conclude that to lead their own apprenticeship could empower these students to actively search for knowledge. Morano and Tzouanas (2017) also suggest the practical use of aquaponics, with a great focus on activities that allow the student to understand the complexity of global challenges in what concerns the search for viable and multidisciplinary solutions to major global challenges, thus developing a more mature decision-making.

Today, food production requires innovations that exceed traditional paradigms, whilst at the same time being able to acknowledge the complexity arising from the sustainability and food security issues that mark our times. Aquaponics is one technological innovation that promises to contribute much towards these imperatives (GOTT; MORGENSTERN; TURNSEK, 2019). These new technologies, including aquaponics, also offer new opportunities as learning tools for people of all ages, but it is particularly appealing for young people at school (MIKKELSEN; BOSIRE, 2019). Only 30,8% of the studies retrieved were developed at an educational level with young people (elementary school and high school). Another 15,4% of the studies aren't specific to an educational level. Aquaponics is a perfect example of a system that can bring nature closer to a classroom and can be used as the starting point for a host of educational activities at both primary and secondary school levels (JUNGE *et al.* 2019).

According to Junge *et al.* (2019), a model system, together with corresponding didactic methods, serves to make natural processes more tangible to pupils, helping to develop the necessary competencies for dealing with the complexity and problems of the environment, and promotes a sense of responsibility toward humanity. Creating the opportunity for hands-on experience with nature and natural elements such as water, fish, and plants also develops environmental consciousness and a greater understanding of the potential for practical solutions and a willingness to act on this knowledge (JUNGE *et al.* 2019).

Mikkelsen and Bosire (2019) also suggest that there appears to be potential for using aquaponics as a keyway of learning about sustainable food production in a wide spectrum of academic disciplines at school. This way, the technique can be readily integrated into the existing educational curriculum, behind the idea of introducing and training students on "systems thinking" by combining fish and plant growing. Junge *et al*. (2014) showed that the students' ability to think in a systematic way improved significantly as a result. The study also suggested that building on social learning in groups the students developed greater teamwork skills.

The use of different technologies as tools to spark students' interests is an important finding in this review. All the retrieved studies use this argument as a bottom line for using different applications, searching for ways of holding their attention (SIVIA *et al*., 2019), developing an emotional attachment to nature (HART *et al*., 2014) or even finding new ways to approach complex contexts and concepts (WANG *et al*., 2020). These factors added to the need for sustainable solutions posted by the Sustainable Development Goals (SDG) and the innovation involved in this methodology suggest that this is an important tool for developing key competences for sustainability such as strategy, collaboration, critical thinking and integrated problem-solving (DEL CERRO VELÁZQUEZ; LOZANO RIVAS, 2020).

Aquaponic systems are related to the SDG 2 (Zero Hunger), particularly the target 2.4 (ensure sustainable food production systems and increased productivity and production) and can also be related to SDG 4 (Quality Education), target 4.7 (ensure that learners acquire the knowledge and skills to promote sustainable development). Körner *et al*. (2021) mention that multi-loop aquaponic systems can enable energy consumption, water use and nutrient supply, called together by GODDEK et al. (2015) as socio-ecological challenges, and promote local vegetable production in urban regions. That also relates aquaponic systems to SDG 11 (Sustainable Cities and Communities), target 11.a (support links between urban, per-urban, and rural areas by regional development planning).

Figure 3 shows the SDGs Wedding Cake, created by Stockholm Resilience Centre in 2016 (partnership between Stockholm University and Beijer Institute of Ecological Economics at the Royal Swedish Academy of Sciences). It shows the interaction of each SDG in three levels that conducts all the actions to food production, combining social, economic, and ecological aspects of the SDG's (STOCKHOLM RESILIENCE CENTRE, 2016). SDG's 2, 4 and 11 are on the level “society”, which allows us to conclude that aquaponic systems approach the ecosystems to the economical level.

Figure 3 - The Sustainable Development Goals wedding cake representing, in the first layer, The Biosphere, in the second layer, The Society and the last layer, The Economy (Source: STOCKHOLM RESILIENCE CENTRE, 2016. Creative Commons license, CC BY 4.0).

Aquaponic systems require greater collaboration between existing academic disciplines to move forward in this new multidisciplinary academic field (GODDEK *et al*., 2015). The collaboration of aquaculture and horticulture specialists, engineers, business strategists, and built environment professionals amongst many others is necessary to turn aquaponics into an important contributor to sustainable development (PROKSCH; IANCHENKO; KOTZEN, 2019).

However, König *et al*. (2018) identified challenges at functional aspects and sustainable parameters of aquaponic systems (particularly SDG 2), considered by these authors a technology in a low technological maturity and still in a formation phase and little economic activity. That means that aquaponic systems still have high risks for entrepreneurs and investors and show the importance of specific funding and public policies for expansion.

4. CONCLUSION

Our results demonstrate the recent increase in studies of aquaponics thematic, and its still incipient growth for educational purposes. Although considered an interesting way for involving students in the learning process, there is still a very low number of publications with this approach. Following this trend and the newly installed facilities worldwide, the next few years might show an increase in papers addressing this issue.

The articles retrieved in our search consider aquaponics a great educational tool for teaching sustainability, abstract concepts involved in STEM and very important soft skills increasingly demanded from today's professionals. Through this methodology, it is possible to improve students' interest and autonomy, reflecting their engagement in the learning process, and also helping them to encounter advanced real-world solutions in a multidisciplinary way for major global challenges with more mature decision-making.

The participation of stakeholders, educational institutions and educators could support the planning process of activities with aquaponics facilities, and together they could find more viable solutions for each educational community. Whether it is more feasible to bring facilities to school or to schedule visitations to external systems should be discussed individually, considering realistic solutions currently available. For this purpose, the key role of teachers must be widely considered, such as investing in their training, which, over time, can improve the effectiveness of practical applications such as those abovementioned.

The need for sustainable solutions posted by the SDGs plus its innovative approach can place aquaponics as a key tool for the future of education in all ages. This can be considered a sufficiently complex tool for teaching multidisciplinary aspects of production systems using a sustainable activity.

Aquaponics technology is increasingly being developed worldwide, being considered by different studies as a sustainable way of producing quality food and involving the society in innovative solutions for environmental issues. Many challenges are still being faced in different areas inside this field, but with the recent rise in studies it might be possible to scale the production and make it technically and economically viable.

Further studies might study the educational use of aquaponics in different regions where it is still sparse, as well as the other areas inside this recent thematic. The collaboration of multidisciplinary specialists is still needed for turning aquaponics into an important contributor to sustainable development.

5. REFERENCES

ABUSIN, S. A. A.; MANDIKIANA, B. W. Towards sustainable food production systems in Qatar: assessment of the viability of aquaponics. *Global Food Security*, Amsterdam, v. 25, p. 1-7, 2020. Available in: http://dx.doi.org/10.1016/j.gfs.2020.100349. Access in: 26 mar. 2022.

AMORIM, A.; BARBOSA, A. de H.; SOBRAL, P. J. do A. Hunger, Obesity, Public Policies, and Food-Based Dietary Guidelines: a reflection considering the socio-environmental world context. *Frontiers In Nutrition*, Lausanne, v. 8, p. 1-12, 2022. Available in: http://dx.doi.org/10.3389/fnut.2021.805569. Access in: 26 mar. 2022.

ANDREONI, V.; MIOLA, A. *Competitiveness and Sustainable Development*. Luxembourg: Publications Office of the European Union, 2016. Available in: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC103576/lb-na-28316-en-n.pdf. Access in: 8 mar. 2022.

BERTUSSO, F. R.; TERHAAG, M. M.; MALACARNE, V. The use of practical classes in science teaching: challenges and possibilities. *Revista Práxis Educacional*, Vitória da Conquista, v. 16, n. 39, p. 318–336, 2020. Available in: https://doi.org/10.22481/praxisedu.v16i39.6380. Access in: 27 set. 2021.

BUONO, E. M. *Aquaponics as a Senior Capstone Design Project.* 2014. 109 f. Dissertation (Master of Arts) – Faculty of the Graduate School of The University of Texas at Austin, Austin, 2014. Available in: https://repositories.lib.utexas.edu/handle/2152/27204. Access in: 27 mar. 2022.

CHENG, S-C.; HWANG, G-J.; CHEN, C-H. From reflective observation to active learning: a mobile experiential learning approach for environmental science education. *British Journal of Educational Technology*, London, v. 50, n. 5, p. 2251-2270, 2019. Wiley. Available in: http://dx.doi.org/10.1111/bjet.12845. Access in: 27 set. 2021..

DEGEFA, B.; ALBEDWAWI, A. M. M.; ALAZEEZIB, M. S. The study of the practice of growing food at home in the UAE: role in household food security & wellbeing and implication for the development of urban agriculture. *Emirates Journal of Food and Agriculture*, Al Ain, p. 465-474, 2021. Available in: http://dx.doi.org/10.9755/ejfa.2021.v33.i6.2712. Access in: 26 mar. 2022.

DEL CERRO VELÁZQUEZ, F.; LOZANO RIVAS, F. Education for Sustainable Development in STEM (Technical Drawing): Learning Approach and Method for SDG 11 in

Classrooms. *Sustainability*, Basel, v. 12, n. 7, e2706, 2020. Available in: https://doi.org/10.3390/su12072706. Access in: 8 mar. 2022.

FUKASE, E.; MARTIN, W. Economic growth, convergence, and world food demand and supply. *World Development*, Amsterdam, v. 132, p. 1-12, 2020. Available in: http://dx.doi.org/10.1016/j.worlddev.2020.104954. Access in: 26 mar. 2022.

GARZÓN, J.; ACEVEDO, J.; PAVÓN, J.; BALDIRIS, S. Promoting eco-agritourism using an augmented reality-based educational resource: a case study of aquaponics. *Interactive Learning Environments*, London, p. 1-15, 2020. Available in: http://dx.doi.org/10.1080/10494820.2020.1712429. Access in: 27 set. 2021.

GODDEK, S.; DELAIDE, B.; MANKASINGH, U.; RAGNARSDOTTIR, K. V.; JIJAKLI, H.; THORARINSDOTTIR, R. Challenges of sustainable and commercial aquaponics. *Sustainability*, Basel, v. 7, n. 4, p. 4199-4224, 2015. Available in: http://dx.doi.org/10.3390/su7044199. Access in: 26 mar. 2022.

GOTT, J.; MORGENSTERN, R.; TURNSEK, M. Aquaponics for the Anthropocene: towards a 'Sustainability First' agenda. In: GODDEK, S.; JOYCE, A.; KOTZEN, B.; BURNELL, G. M. (ed.). *Aquaponics food production systems: combined aquaculture and hydroponic production technologies for the future*. Cham: Springer Nature, 2019. p. 393-432. Available in: https://link.springer.com/content/pdf/10.1007%2F978-3-030-15943-6.pdf. Access in: 27 mar. 2022.

GREENFELD, A.; BECKER, N.; MCILWAIN, J.; FOTEDAR, R.; BORNMAN, J. F. Economically viable aquaponics? Identifying the gap between potential and current uncertainties. *Reviews in Aquaculture*, Hoboken, v. 11, n. 3, p. 848-862, 2018. Available in: http://dx.doi.org/10.1111/raq.12269. Access in: 27 mar. 2022.

GREENFELD, A.; BECKER, N.; BORNMAN, J. F.; SANTOS, M. J. dos; ANGEL, D.. Consumer preferences for aquaponics: a comparative analysis of Australia and Israel. ***Journal of Environmental Management***, Amsterdam, v. 257, p. 1-10, 2020. Available in: http://dx.doi.org/10.1016/j.jenvman.2019.109979. Access in: 27 set. 2021..

HART, E. R.; WEBB, J. B.; HOLLINGSWORTH, C.; DANYLCHUK, A. J. Managing expectations for aquaponics in the classroom: enhancing academic learning and teaching an appreciation for aquatic resources. *Fisheries*, Hoboken, v. 39, n. 11, p. 525–530, 2014. Available in: https://doi.org/10.1080/03632415.2014.966353. Access in: 27 set. 2021..

HUNDLEY, G. C. *Aquaponia, uma experiência com tilápia (Oreochromis niloticus), manjericão (Ocimum basilicum) e manjerona (Origanum majorana) em sistemas de recirculação de água e nutrientes*. 2013. 57 f. Monografia (Graduação em Agronomia) Faculdade de Agronomia e Veterinária, Universidade de Brasília, Brasília, 2013. Available in: https://bdm.unb.br/handle/10483/5977. Access in: 27 set. 2021..

HUNDLEY, G. C.; NAVARRO, F. K. S. P.; RIBEIRO FILHO, O. P.; NAVARRO, R. D. Integration of Nile tilapia (*Oreochromis niloticus* L.) production *Origanum majorana* L. and *Ocimum basilicum* L. using aquaponics technology. *Acta Scientiarum. Technology*, Maringá, v. 40, n. 1, p. 1-7, 2018. Available in: http://dx.doi.org/10.4025/actascitechnol.v40i1.35460. Access in: 27 set. 2021.

HUNDLEY, G. C.; NAVARRO, R. D. Aquaponia: a Integração entre piscicultura e a hidroponia. *Revista Brasileira de Agropecuária Sustentável (RBAS)*, Viçosa, v. 3, n. 2, p. 52–61, 2013. Available in: https://doi.org/10.21206/rbas.v3i2.218. Access in: 27 set. 2021.

JUNGE, R.; WILHELM, S.; HOFSTETTER, U. Aquaponics in classrooms as a tool to promote systems thinking. In: CONFERENCE VIVUS: TRANSMISSION OF INNOVATIONS, KNOWLEDGE AND PRACTICAL EXPERIENCE INTO EVERYDAY PRACTICE, 3., 2014, Strahinj. *Anais*... Strahinj: VIVUS, 2014. p. 234-244. Available in: https://bit.ly/3tGL3rz. Access in: 27 mar. 2022.

JUNGE, R.; BULC, T. G.; ANSEEUW, D.; YILDIZ, H. Y.; MILLIKEN, S. Aquaponics as an educational tool. In: GODDEK, S.; JOYCE, A.; KOTZEN, B.; BURNELL, G. M. (ed.). *Aquaponics food production systems: combined aquaculture and hydroponic production technologies for the future*. Cham: Springer Nature, 2019. p. 561-596. Available in: https://link.springer.com/content/pdf/10.1007%2F978-3-030-15943-6.pdf. Access in: 27 set. 2021.

KHALIL, S.; PANDA, P.; GHADAMGAHI, F.; ROSBERG, A.; VETUKURI, R. R. Comparison of two commercial recirculated aquacultural systems and their microbial potential in plant disease suppression. ***BMC Microbiology***, Cham, v. 21, n. 1, p. 1-19, 2021. Available in: http://dx.doi.org/10.1186/s12866-021-02273-4. Access in: 27 mar. 2022.

KOBAYASHI, K. D.; RADOVICH, T. J. K.; MORENO, B. E. A tropical perspective on environmental sustainability in horticultural education. *HortTechnology*, Alexandria, v. 20, n. 3, p. 503-508, 2010. Available in: http://dx.doi.org/10.21273/horttech.20.3.503. Access in: 27 mar. 2022.

KODAMA, G.; SANTOS, M. J. dos; SOUZA, A. N. de; HUNDLEY, G. C.; NAVARRO, R. D. Analysis of the financial viability of the aquaponics (fish farming and hydroponics) system using the Monte Carlo Method. *Revista Brasileira de Agropecuária Sustentável (RBAS)*, Viçosa, v. 9, n. 4, p. 20–26, 2019. Available in: https://periodicos.ufv.br/rbas/article/view/6315/5328. Access in: 27 set. 2021.

KÖNIG, B.; JANKER, J.; REINHARDT, T.; VILLAROEL, M.; JUNGE, R. Analysis of aquaponics as an emerging technological innovation system. *Journal of Cleaner Production*, Amsterdam, v. 180, p. 232-243, 2018. https://doi.org/10.1016/j.jclepro.2018.01.037. Access in: 8 mar. 2022.

KÖNIG, B.; JUNGE, R.; BITTSANSZKY, A.; VILLARROEL, M.; KOMIVES, T. On the sustainability of aquaponics. *Ecocycles*, Gyöngyösv. 2, n. 1, p. 26–32, 2016. Available in: https://www.ecocycles.net/ojs/index.php/ecocycles/article/view/50. Access in: 8 mar. 2022.

KÖRNER, O.; BISBIS, M. B.; BAGANZ, G. F. M.; BAGANZ, D.; STAAKS, G. B. O.; MONSEES, H.; GODDEK, S.; KEESMAN, K. J. Environmental impact assessment of local decoupled multi-loop aquaponics in an urban context. *Journal of Cleaner Production*, Amsterdam, v. 313, e127735, 2021. Available in: https://doi.org/10.1016/j.jclepro.2021.127735. Access in: 8 mar. 2022.

LOVE, D. C.; FRY, J. P.; GENELLO, L.; HILL, E. S.; FREDERICK, A.; LI, X.; SEMMENS, K. An international survey of aquaponics practitioners. *Plos One*, San Francisco, v. 9, n. 7, p. 1-10, 2014. Available in: http://dx.doi.org/10.1371/journal.pone.0102662. Access in: 27 set. 2021.

LOVE, D. C.; FRY, J. P.; HILL, E. S.; GENELLO, L.; SEMMENS, K.; THOMPSON, R. E. Commercial aquaponics production and profitability: findings from an international survey. *Aquaculture*, Amsterdam, v. 435, p. 67-74, 2015. Available in: http://dx.doi.org/10.1016/j.aquaculture.2014.09.023. Access in: 27 set. 2021.

MACEDA-VEIGA, A.; MACNALLY, R.; RODRÍGUEZ, S.; SZABO, S.; PEETERS, E. T. H. M.; RUFF, T.; SALVADÓ, H. Effects of two submerged macrophyte species on microbes and metazoans in rooftop water-storage ponds with different labile carbon loadings. ***Water Research***, Amsterdam, v. 211, p. 1-10, 2022. Available in: http://dx.doi.org/10.1016/j.watres.2021.117999. Access in: 27 mar. 2022.

MARTINS, P. Aquaponia em Educação Ambiental: percepções de alunos e de professores. *Revista Eletrônica do Mestrado em Educação Ambiental*, Rio Grande, v. 36, n. 3, p. 356-369, 2019. Available in: https://doi.org/10.14295/remea.v36i3.9717. Access in: 8 mar. 2022.

MAUCIERI, C.; FORCHINO, A. A.; NICOLETTO, C.; JUNGE, R.; PASTRES, R.; SAMBO, P.; BORIN, M. Life cycle assessment of a micro aquaponic system for educational purposes built using recovered material. *Journal of Cleaner Production*, Amsterdam, v. 172, p. 3119-3127, 2018. Available in: http://dx.doi.org/10.1016/j.jclepro.2017.11.097. Access in: 8 mar. 2022.

MCHUNU, N.; LAGERWALL, G.; SENZANJE, A. Aquaponics in South Africa: results of a national survey. *Aquaculture Reports*, Amsterdam, v. 12, p. 12-19, 2018. Available in: http://dx.doi.org/10.1016/j.aqrep.2018.08.001. Access in: 8 mar. 2022.

MIKKELSEN, B. E.; BOSIRE, C. M. Food, sustainability, and science literacy in one package? opportunities and challenges in using aquaponics among young people at school, a Danish perspective. In: GODDEK, S.; JOYCE, A.; KOTZEN, B.; BURNELL, G. M. (ed.). *Aquaponics food production systems: combined aquaculture and hydroponic production technologies for the future*. Cham: Springer Nature, 2019. p. 597-606. Available in: https://link.springer.com/content/pdf/10.1007%2F978-3-030-15943-6.pdf. Access in: 8 mar. 2022.

MILLIKEN, S.; OVCA, A.; ANTENEN, N.; VILLAROEL, M.; BULC, T. G.; KOTZEN, B.; JUNGE, R. Aqu@teach—The First Aquaponics Curriculum to Be Developed Specifically for University Students. *Horticulturae*, Basel, v. 7, n. 18, p. 1-9, 2021. Available in: http://dx.doi.org/10.3390/horticulturae7020018. Access in: 8 mar. 2022.

MORANO, L.; TZOUANAS, V. Urban Agricultural and Sustainability Program at Houston's Downtown University: combining new curriculum, hands-on projects, and a hurricane. *Journal of Agriculture, Food Systems, and Community Development*, Houston, v. 7, n. 4, p. 23-33, 2017. Available in: http://dx.doi.org/10.5304/jafscd.2017.074.003. Access in: 8 mar. 2022.

NAEGEL, L. C. A. Combined production of fish and plants in recirculating water. *Aquaculture*, Amsterdam, v. 10, n. 1, p. 17–24, 1977. Available in: https://doi.org/10.1016/0044-8486(77)90029-1. Access in: 27 set. 2021.

OBIRIKORANG, K. A.; SEKEY, W.; GYAMPOH, B. A.; ASHIAGBOR, G.; ASANTE, W. Aquaponics for Improved Food Security in Africa: a review. ***Frontiers in Sustainable Food Systems***, Lausanne, v. 5, n. 1, p. 1-10, 2021. Available in: http://dx.doi.org/10.3389/fsufs.2021.705549. Access in: 25 mar. 2022.

PAGE, M. J.; MCKENZIE, J. E.; BOSSUYT, P. M.; BOUTRON, I.; HOFFMANN, T. C.; MULROW, C. D. SHAMSEER, L.; TETZLAFF, J. M.; AKL, E. A.; BRENNAN, S. E.; CHOU, R.; GLANVILLE, J.; GRIMSHAW, J. M.; HRÓBJARTSSON, A.; LALU, M. M.; LODER, E. W.; MAYO-WILSON, E.; MCDONALD, S.; MCGUINNESS, L. A.; STEWART, L. A.; THOMAS, J.; TRICCO, A. C.; WELCH, V. A.; WHITING, P.; MOHER, D. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic Reviews*, New York, v. 10, e89 2021. Available in: https://doi.org/10.1186/s13643-021-01626-4. Access in: 27 set. 2021.

PANTAZI, D.; DINU, S.; VOINEA, S. The smart aquaponics greenhouse: an interdisciplinary educational laboratory. *Romanian Reports in Physics*, Bucuresti, v. 3, n. 71, p. 1-11, 2019. Available in: http://www.rrp.infim.ro/IP/A396.pdf. Access in: 8 mar. 2022.

PROKSCH G., IANCHENKO A., KOTZEN B. Aquaponics in the Built Environment. In: GODDEK, S.; JOYCE, A.; KOTZEN, B.; BURNELL, G. M. (ed.). *Aquaponics food production systems: combined aquaculture and hydroponic production technologies for the future*. Cham: Springer Nature, 2019.. p. 523-558. Available in: https://link.springer.com/content/pdf/10.1007%2F978-3-030-15943-6.pdf. Access in: 8 mar. 2022.

SALAS-ZAPATA, W. A.; ORTIZ-MUÑOZ, S. M. Analysis of meanings of the concept of sustainability. *Sustainable Development*, Hoboken, v. 27, n. 1, p. 153-161, 2018. Available in: http://dx.doi.org/10.1002/sd.1885. Access in: 8 mar. 2022.

SILVA, M. F.; MALHEIRO, B.; GUEDES, P.; DUARTE, A.; FERREIRA, P. Collaborative learning with sustainability-driven projects: a summary of the EPS@ISEP programme. *International Journal of Engineering Pedagogy (iJEP)*, Vienna, v. 8, n. 4, p. 106-130, 2018. International Association of Online Engineering (IAOE). Available in: https://doi.org/10.3991/ijep.v8i4.8260. Access in: 8 mar. 2022.

SIVIA, A.; MACMATH, S.; NOVAKOWSKI, C.; BRITTON, V. Examining Student Engagement During a Project-Based Unit in Secondary Science. *Canadian Journal of Science,* *Mathematics and Technology Education*, Ontario, v. 19, n. 3, p. 254-269, 2019. Available in: http://dx.doi.org/10.1007/s42330-019-00053-x. Access in: 8 mar. 2022.

SOUZA, R. T. Y. B. de; SOUZA, L. de O.; OLIVEIRA, S. R. de; TAKAHASHI, E. L. H. Formação continuada de professores de ciências utilizando a Aquaponia como ferramenta didática. *Ciência & Educação (Bauru)*, Bauru, v. 25, n. 2, p. 395-410, 2019. Available in: http://dx.doi.org/10.1590/1516-731320190020008. Access in: 8 mar. 2022.

SPECHT, K.; ZOLL, F.; SCHÜMANN, H.; BELA, J.; KACHEL, J.; ROBISCHON, M. How will we eat and produce in the cities of the future? From edible insects to vertical farming — A study on the perception and acceptability of new approaches. **Sustainability**, Basel, v. 11, n. 16, p. 1-22, 2019. Available in: http://dx.doi.org/10.3390/su11164315. Access in: 27 set. 2021.

STOCKHOLM RESILIENCE CENTRE. *The SDGs wedding cake*. 2016. Available in: https://www.stockholmresilience.org/research/research-news/2016-06-14-how-food-connects-all-the-sdgs.html. Access in: 28 fev. 2022.

SUÁREZ-CÁCERES, G. P.; FÉRNANDEZ-CABANÁS, V. M.; LOBILLO-EGUIBÁR, J.; PÉREZ-URRESTARAZU, L. Characterisation of aquaponic producers and small-scale facilities in Spain and Latin America. *Aquaculture International*, Cham, p. 1-16, 2021. Available in: http://dx.doi.org/10.1007/s10499-021-00793-4. Access in: 8 mar. 2022.

TURNSEK, M.; JOLY, A.; THORARINSDOTTIR, R.; JUNGE, R. Challenges of commercial aquaponics in Europe: beyond the hype. *Water*, Basel, v. 12, n. 1, p. 1-18, 2020. Available in: http://dx.doi.org/10.3390/w12010306. Access in: 27 set. 2021.

TYSON, R. V.; TREADWELL, D. D.; SIMONNE, E. H. Opportunities and challenges to sustainability in aquaponic systems. *HortTechnology*, Alexandria, v. 21, n. 1, p. 6–13, 2011. Available in: https://journals.ashs.org/horttech/view/journals/horttech/21/1/article-p6.xml. Access in: 27 set. 2021.

VUJOVIC, A.; TODOROVIC, P.; STEFANOVIC, M.; VUKICEVIC, A.; JOVANOVIC, M. V.; MACUZIC, I.; STEFANOVIC, N. The development and implementation of an aquaponics embedded device for teaching and learning varied engineering concepts. *International Journal of Engineering Education*, Cork, v. 35, n. 1, p. 1-11, 2018.

WANG, W.; JIA, Y.; CAI, K.; YU, W. An aquaponics system design for computational intelligence teaching. *IEEE Access*, Piscataway, v. 8, p. 42364-42371, 2020. Available in: https://ieeexplore.ieee.org/document/9017935. Access in: 8 mar. 2022.

WAMSLER, C. Education for sustainability: Fostering a more conscious society and transformation towards sustainability. *International Journal of Sustainability in Higher Education*, Bingley, v. 21, n. 1, p. 112-130, 2020. Available in: https://doi.org/10.1108/IJSHE-04-2019-0152. Access in: 27 fev. 2022.

CAPÍTULO 2

Aquaponics in Science Education: a Case Study

(Artigo a ser submetido para o Journal of Education for Sustainable Development)

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Aquaponics in Science Education: a Case Study

ABSTRACT

The world population is facing major challenges regarding the issue of access to food, and to face them, intelligent management of the supply chain in all nations is essential. One of the outlets that has been used with the purpose of engaging global citizens for smart solutions in broad aspect is education. One possibility for mitigating the productive sector environmental impacts is aquaponics, integrating aquaculture and hydroponics systems in order to reduce water use and enable food production in a more sustainable way. In education, it could favour the inclusion of students in the solution of everyday problems related to the sustainability of current production methods. This work intends to evaluate if aquaponics is an effective teaching tool in distance learning through a remote activity about aquaponics for students and teachers of Undergraduation Institutions and Youth and Adult Education (YAE). First, students completed an online questionnaire, and we then performed a lecture about aquaponics. Later, they fill in the same questionnaire to compare their results. A question about participants' expectations were asked in the first questionnaire, and in the second we asked if we achieved them. Teachers' opinions about the activity were obtained through a semi-structured interview. Five presentations were held, with the participation of 86 students and 4 teachers. Results show that the number of correct answers after the lecture was much higher than before, showing a change in the students' response patterns at this second moment. Also, there has been an increase in students' self-confidence levels, along with an increase in their propensity for organic, aquaponic and hydroponic food consumption. The cluster analysis demonstrates an approximation in their response pattern, which, combined with the observed increase in the marking of correct answers after the activity, it can be considered that the effect of this research was positive on the students' knowledge about the topics addressed. Teachers understand the importance of carrying out practical activities with different approaches and didactic tools, and also relate motivational factors. With our results, we can conclude that the use of aquaponics as a teaching tool motivates students to learn more by making the subjects more interesting

Keywords: teaching tool; education; motivation; remote teaching

1 INTRODUCTION

The world population is facing major challenges regarding the issue of access to food, and to face them, intelligent management of the supply chain in all nations is essential. An important mechanism to be fought in the meantime is the paradox of hunger, in which it is possible to have three different aspects of an unhealthy diet within the same society: hunger, malnutrition and overweight. The rebalancing of current models of production, consumption and disposal of food must resume the goal of reducing food insecurity and allowing wider access to healthy, nutritious and sustainable food (Amicarelli & Bux, 2021).

Nowadays, a pattern of specialization and simplification of global agricultural systems is identified, and investment in actions to mitigate the environmental impacts caused by the current production models could be an auxiliary tool to solve this issue. There has been a disruption in the main global biogeochemical cycles, and the literature suggests that the whole society should change their consumption patterns and food production models (Lassaleta et al., 2014; Yuan et al., 2018; Kirschbaum et al., 2019; Lun et al., 2022). Thus, initiatives for a more efficient use of scarce resources such as water and soil, which are primordial factors to produce food, have been highlighted. Eco-efficient alternatives bring at their core the concern with the biophysical limits of production, as well as with demographic issues of a world population that has been growing uninterruptedly since its beginnings (Ehrlich & Harte, 2015; Armanda et al., 2019).

To address these challenges, one of the outlets that has been used with the purpose of engaging global citizens for smart solutions in broad aspect is education (Smith et al., 2022). Through a multidisciplinary approach, it is possible to spread knowledge regarding the sustainability of production systems, demonstrating the relevance of small daily choices for the future of the planet (Smith et al., 2022; Goddard et al., 2020; Wasieleski et al., 2021). Education models should also improve their resources consumption thinking, reducing the take-off of newly acquired materials and involving teachers and students in the choice for reused and recycled gadgets (Maucieri et al., 2018; Greenfeld et al., 2021).

From the point of view of the productive sector, some possibilities emerge as ways of mitigating its environmental impacts, such as urban agriculture, the use of aquaculture effluents and aquaponics (Aalto et al., 2020; Armanda et al., 2019; Goddek & Keesman, 2020). The latter is an activity that integrates aquaculture and hydroponics systems, in order to reduce water use and enable food production in a sustainable way (G. C. Hundley & Navarro, 2013; Joyce, Goddek, et al., 2019). This is a system that involves the cultivation of fish and plants in recirculating water, which carries nutrients between its phases with maximum utilization.

Between these portions, it induces the formation of a biological filter composed mainly of nitrifying bacteria, essential for the proper functioning of all the reactions involved (Eck, Sare, et al., 2019). In order to maintain the quality of its products, animal welfare and biological viability of production, it is necessary to constantly monitor water quality parameters (Yildiz et al., 2017).

For all possible designs of aquaponic cultures, the presence of the biofilter is essential, which enables great efficiency in the use of space and the nutrients present in the water, collaborating to increase the sustainability of production (Joyce, Timmons, et al., 2019). Most of the farms around the world produce fish as part of the system, although it is also possible to introduce other types of animals like crustaceans and amphibians (Hundley et al., 2013; Rosa, 2020; Suárez-Cáceres et al., 2021; Wirza & Nazir, 2021). These fish are fed with specific feeds, and with the faeces and gill breathing there is an increase in the concentration of ammonia (NH_3) in the water. In high concentrations, this substance becomes toxic to fish, but the nitrifying bacteria present in the biofilter perform the transformation of ammonia into nitrite (NO_2^-) and subsequently into nitrate (NO_3^-) (Monsees et al., 2017). Then NO_3^- becomes available to plants, and will be useful in the formation of amino acids and nitrogenous bases (Bredemeier & Mundstock, 2000), as explained by Figure 1.

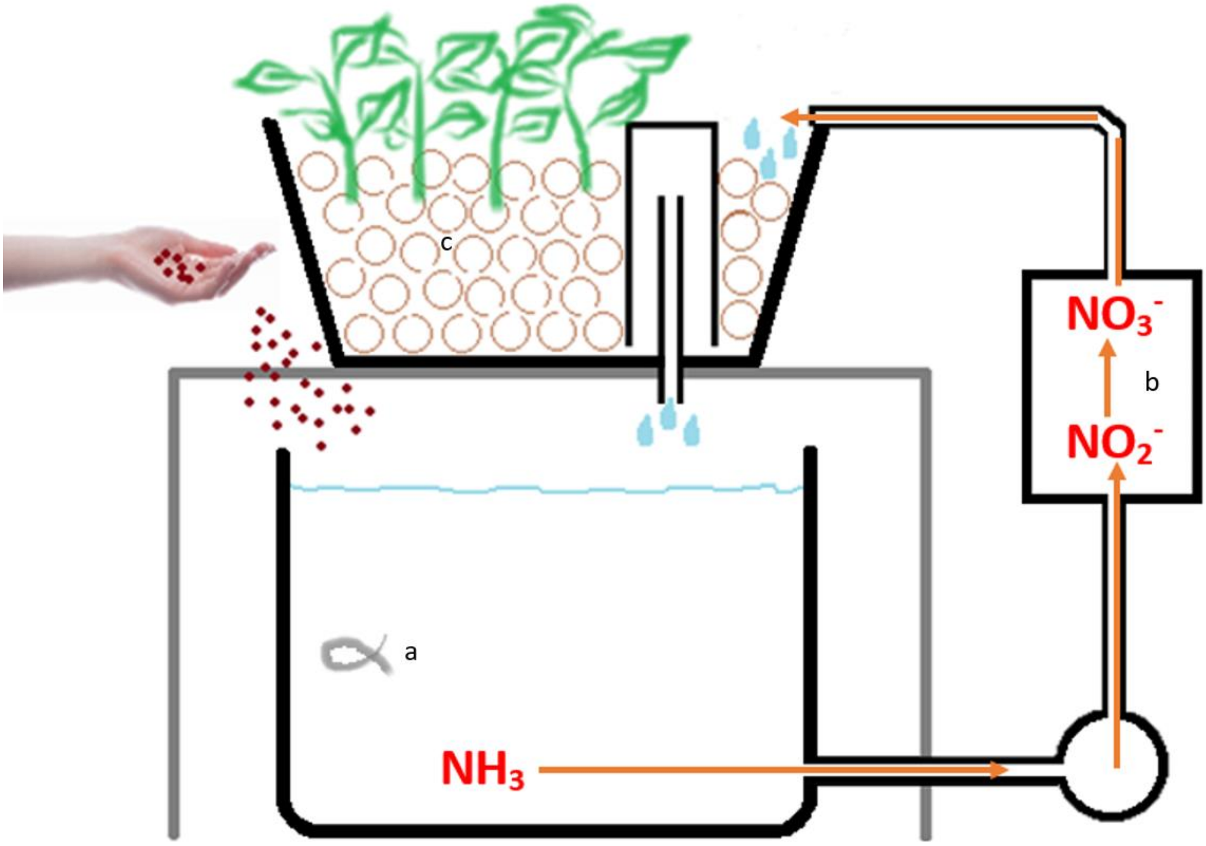

Figure 1. Diagram of the Nitrogen flow in an aquaponics system, indicating the different chemical forms of this compound, according to the sequence: (a) gill breathing and faeces from animal release ammonia (NH_3) in the water; (b) nitrifying bacteria perform the transformation of ammonia into nitrite (NO_2^-) and subsequently into nitrate (NO_3^-); (c) nitrate (NO_3^-) becomes available to plants.
Source: adapted from "Aquaponics: the Basics", from Lennard & Goddek, 2019, in "Aquaponics Food Production Systems", from S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), 1st ed., pp. 113-143. https://link.springer.com/book/10.1007/978-3-030-15943-6.

Another important chemical process is the formation of ionic orthophosphate molecules ($H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}), which are crucial for feeding plants in the hydroponics portion of aquaponics. Fish release inorganic phosphate in the water, acquired through feed, and the pH must remain close to 7,0 to avoid possible binding with other chemicals and increasing the formation of sludge (Eck, Körner, et al., 2019a; Joyce, Timmons, et al., 2019). With the removal of these potentially toxic ions by the plants, if quality parameters are controlled the water can return to the fish farm renewed, suitable for reuse. A well-managed system could increase the efficiency of nutrient uptake, reduce water consumption and the amount of effluent and sludge into the environment, besides increasing profitability through the simultaneous production of two species of commercial use (Tyson et al., 2011; Somerville et al., 2014; Hu et al., 2015; Joyce, Goddek, et al., 2019; Kodama et al., 2019; Turnsek et al., 2020).

The development of farming techniques that enable food production in areas with limited availability of natural resources such as water and soils, and that enable the production of quality protein sources, such as aquaponics, is beneficial to all societies (Greenfeld et al., 2021). In order to unify efforts towards better living conditions and global development, in 2015 all United Nations Member States adopted 17 Sustainable Development Goals (SDG), with a 15-year Agenda of actions in this regard. Aquaponics meet directly the SDG 2, that predicts zero hunger with key solutions for agricultural productivity and sustainable food production, and SDG 11, that aims to make cities inclusive, safe, resilient and sustainable (United Nations, 2022). As a key to escaping poverty and improving life quality possibilities, aquaponics for education could favour the inclusion of students in the solution of everyday problems related to the sustainability of current production methods (Junge, Bulc, Anseeuw, Yildiz, & Miliken, 2019). This way, it could also involve SDG 4, leading pupils to relevant and effective learning outcomes.

Practical activities, as experiential learning approaches or project-based teaching models, can improve student engagement and motivation in different areas of knowledge (Cheng et al., 2019; Sivia et al., 2019; Bertusso et al., 2020). Also, collaborative projects can enhance students' capability to involve multiple scenario thinking, finding better solutions for complex global issues (M. F. Silva et al., 2018).

The use of aquaponics in teaching is still very recent, and some studies have developed this theme to point out possible directions and important observations in the choice of this tool (Hart et al., 2014; Maucieri, Forchino, et al., 2018; Wang et al., 2020). However, the impacts of the use of aquaponics in remote teaching are not yet known, which makes it not possible to assess the benefits of this approach so far. In this way, this work intends to evaluate if aquaponics is an effective teaching tool in distance learning.

2 METHODS

Between March and October of 2021, our team performed a remote activity about aquaponics for students and teachers of Undergraduation Institutions and Youth and Adult Education (YAE)[1] interested in participating in the research. Participants were recruited through their Educational Institutions, which were invited to contribute after a brief

[1]Youth and Adult Education – YAE (*Educação de Jovens e Adultos* in Portuguese, or EJA) is an education level created in Brazil by the Law # 9.394 of 1996, known as the Law of Directives and Bases of National Education. This Law provides the duty of the State to ensure the provision of regular school education for youth and adult workers, maintaining for these public appropriate conditions of access and permanence in regular education, with both elementary and high school levels. The system is intended for those who did not have access or continuity of studies at the proper age, constituting an instrument of lifelong education without fees, stimulating the articulation with vocational education.

presentation of the project individually to coordinators of courses related to Natural Sciences. This research was approved by the Ethics Committee on Research with Human Beings of the Faculty of Health Sciences of the University of Brasilia, receiving the Certificate of Ethics Appreciation Presentation number 34097920.0.0000.0030. It involved four stages: 1) students completed an online questionnaire; 2) a lecture was held for teachers and students; 3) students completed another online questionnaire; 4) an online interview was developed with the teachers of these classes.

First, participants completed an online questionnaire through the Google Forms platform, which consisted of 14 questions on the topic that would be detailed later in the presentations. We then performed a lecture about the main aspects of aquaponics, involving the main themes of sustainability, aquaponics systems and nutrient cycling. After this, a video was shown demonstrating the activities carried out at the Sustainable Aquaculture Centre (SAC) of the University of Brasilia, in which other students had the opportunity to get to know the systems and handle the materials at the facilities. Afterwards a dynamic was carried out to answer questions from the students and teachers and to register their impressions and opinions about the aquaponics system. Two days after these activities, the students were invited to fill in the same questionnaire as at the beginning, with the purpose of comparing the learning obtained through the activity.

A question about participants' expectations on the activity were included in the first questionnaire, and in the second one they were asked if we achieved them. Also, this was a moment for enabling them to express their opinion about how the dynamic could be improved, as well as if they missed something in the study performed. The teachers' opinions were collected through a semi-structured interview carried out after the lecture, according to their availability. This stage sought to obtain their impressions about the contribution of the activity to science teaching and the possibility of changes in students' attitudes towards the environment. All interviews and lectures were recorded and transcribed for further analysis.

2.1 Presentations

Each presentation lasted 35 minutes in average, and explained, basically: global food challenges and food-related SDGs; what aquaponics is and its usefulness in the face of global food access challenges; concepts and gaps related to the sustainability of food production systems; the importance of each component of an aquaponics system; how to choose the species that should compose the system in the animal and vegetal portions; bacteria and possibilities of use in the biological filter; why to choose aquaponics; main benefits and disadvantages of this type of system; the options of cultivation techniques; the necessary quality control; the possible formats of installations and their main objectives; and the possible approaches in education.

After the lecture, a demonstrative video sought to connect the theoretical learning of the presentation with the visualization of the system in a dynamic way. It presented and excursion carried out as part of the project "*Se eu fosse um peixinho*", developed at *Fazenda Água Limpa*, University of Brasilia, Brazil. This project aims environmental education, with a focus on sustainable aquatic systems, animal welfare and rational use of natural resources, serving as a basis to demonstrate to society the possibilities of sustainable food production systems. In the video, students from schools of Brasilia get to know the SAC facilities and dialogue with researchers about animals, plants, water and other structures and components of the systems they see. Sustainable water usage, aquaponics and water recirculation systems are highly emphasized in the project and also in the video, reinforcing the lecture and giving participants a different perspective of the aspects worked on.

2.2 Questionnaires

The questionnaires were developed to test students' knowledge before and after the activity, allowing our team to compare the results and assess the learning obtained through the dynamics carried out. Participants were instructed to fill in their answers based on their current knowledge and feelings, and not to perform searches in any search engine while filling in the questionnaires. There were three types of questions: multiple choice, in which the student can mark only one answer from five possibilities; checkbox, which allows the student to mark more than one possible answer; or subjective, where respondents could write as much as they desire. Questions involved the topics: sustainability, aquaculture, hydroponics and aquaponics, as well as probing their eating patterns. The second questionnaires had the same identical content, differing only in the question about their expectations with the activity, since in the second one the intention was to gauge whether or not these had been met. The subjective responses were separated, and key sentences were retrieved from each to make up the list of possible responses, recording the number of participants who agreed. Answers with incomplete or incomprehensible words were discarded, as well as those without any content.

The questionnaires are presented in Table 1, with the questions and the options that the participants could tick. Questions were structured in six different Groups: (*A*) participant expectations with the activity (*B*) testing the students' knowledge about each subtheme (aquaponics, hydroponics, aquaculture and sustainability); (*C*) their position regarding their own wastage of water; (*D*) their position regarding other people's attitudes to water wastage; (*E*) their position regarding the use of pesticides in food; and (*F*) their eating habits.

The *Group A* (GA) intended to understand the participants' expectations with the activity before and after the presentation and consisted in one question before (question 1) and one question after the lecture (question 2). *Group B* (GB) was used so that students expressed their level of confidence in talking about each subtheme by marking their answer according to a Likert scale of five levels, and then their knowledge about that theme was tested by means of a multiple-choice question with correct or incorrect items. This group is composed by 7 multiple-choice questions, three of them with subitems for students to decide whether they are Right or Wrong and then mark the item with the correct order (Questions with Value Judgement, or QVJ). The other four questions tested their self-confidence about the topics covered, indicating at what level they felt confident about each sub-topic. For the statistical analyses, when a student marked the item was Right, the number one was marked, and when the student marked it Wrong, the number two was marked.

Group C (GC) involved a multiple-choice question about how the participant felt when seeing another person throwing water on the pavement to clean it, and for *Group D* (GD) the student was asked whether he would use water to clean a pavement, by a multiple-choice question. In *Group E* (GE), the multiple-choice question was how the student feels about the use of pesticides in food. Finally, *Group F* (GF) involved two checkbox questions about products that the participant would consume (*organics*, *aquaponics*, *hydroponics*, *fish from natural fisheries*, *aquaculture fish*, *none of the above* or *don't know what these words mean*) and their self-classification regarding eating habits (*vegetarian*, *vegan*, *omnivore* or *crudivore*).

For all statistical analysis, data were standardized, and when the student did not answer the item, the field remained blank. After this step, the values found from all the questions were submitted to an exploratory data analysis to verify the hierarchy of answers by comparing the questions and also comparing the students' answers.

Data obtained through the questionnaires were entered into a Microsoft Office Excel spreadsheet for comparisons, inferences and correlations. For the cluster analysis by hierarchical method the data were standardized, adopting the Euclidean distance coefficient. The clustering strategy was the single linkage (Cooley & Lohnes, 1971), and for these processes the software Statistica (2007) was used.

Table 1
Questions asked in the questionnaires

Group	Type	Questions		Possible answers
A	Subjective	1. What are your expectations of this activity? Try to describe very clearly		-
A	Subjective	2. Do you think this activity met your expectations? How could it be improved? Did you miss anything?		-
B	Multiple-choice	3. Do you know what aquaponics are?		Yes A little bit Maybe No Not interested
B	Multiple-choice	4. Mark W (Wrong) or R (Right) for the statements about aquaponics:	4.1. Aquaponics is the production of animals and plants using the same water;	R, W, W, R, R
			4.2. It is the production of animals using drinking water;	R, R, W, R, W
			4.3. Aquaponics produces food with little water exchange and is an example of an aquatic community;	W, R, R, W, W
			4.4. Aquaponics is a system that preserves the sustainability of the planet;	R, R, R, R, R
			4.5. Having good water quality is very important for aquaponics.	W, R, R, R, W
B	Multiple-choice	5. Do you know what hydroponic foods are?		Yes A little bit Maybe No Not interested
B	Multiple-choice	6. Now about hydroponics, mark W (Wrong) or R (Right):	6.1. In hydroponics the quality of water does not matter much;	W, W, W, R, R
			6.2. It is the production of animals using potable water	W, W, W, W, R
			6.3. The use of agrochemicals does not diminish the quality of the water	R, W, R, W, W
			6.4. It is possible to produce hydroponic food with little water exchange	R, R, R, W, W
			6.5. Hydroponics is one part of aquaponics	
B	Multiple-choice	7. Do you know what aquaculture is?		Yes A little bit Maybe No Not interested
B	Multiple-choice	8. And about aquaculture, mark W (Wrong) or R (Right):	8.1. In aquaculture, aquatic animals are produced;	R, W, W, W, R
			8.2. Aquaculture produces plants;	W, R, R, R, W
			8.3. Fish from aquaculture are of lower quality than fish from fisheries;	R, W, R, W, R
			8.4. To produce food in aquaculture it is required constant water exchange	R, W, R, R, R

		8.5. Aquaculture can bring many benefits to people	R, R, W, W, W
	Multiple-choice	9. Do you know what sustainability is?	Yes A little bit Maybe No Not interested
C	Multiple-choice	10. Would you clean your pavement with water?	Yes A little bit Maybe No Not interested
D	Multiple-choice	11. How do you feel when you see a person throwing water on the pavement to clean it?	Excited Happy Indifferent Sad Angry
E	Multiple-choice	12. How do you feel about the use of agrochemicals in food?	Excited Happy Indifferent Sad Angry
F	Multiple-choice	13. About your eating habits, how would you classify yourself?	Crudivore: only consumes raw food; Omnivore: consumes all types of food; Vegetarian: does not eat any kind of meat; Vegan: does not eat any animal product.
	Checkbox	14. If you know the meaning of these words, tick which of these products you would consume	Organic; Aquaponics; Hydroponics; Fish from natural fisheries; Aquaculture fish; None of the above; Don't know what these words mean.

Note. Table presents questions asked in the questionnaires. For those that have a correct answer, these are marked in grey.

2.3 Interviews

After the lecture and at the most appropriate time for teachers that used the activity as part of their classes, a semi-structured interview was conducted by online video chat. To obtain their opinions about the contribution of the activity developed for science teaching and the possibility of changes in students' attitudes towards the environment. This method was selected to give each participant the opportunity to expand subjects as they consider important. The interviewer was instructed to speak only as much as necessary, with the aim of allowing the interviewee to develop their answers as they see fit.

These interviews were recorded, transcribed and classified as to their content, and key statements were retrieved from each answer, considering how many of the teachers agreed with them. These sentences were used to build a mind map on the contribution of the activity and other perspectives obtained from the answers.

The interviewees answered the 5 questions presented in Table 2, according to their personal opinions and experiences.

Table 2
Questions asked in the semi-structured interviews for teachers

Nº	QUESTION
1	Did the activity contribute to science teaching?
2	Do you think that this activity allowed a change in students’ attitudes towards the sustainable use of water and the consumption of healthy food? In what, in the students’ reality, do you believe this change will happen?
3	Have students shown any change in behaviour related to the environment after the presentation?
4	How do you evaluate the activity developed? Any criticism or suggestions?
5	What other science subjects and multidisciplinary areas do you think it is possible to work on with the knowledge gained from the activity?

3 RESULTS

Five presentations were held, with the participation of 86 students and 4 teachers. All students answered the first questionnaire (n=86), and 41,8% of these answered the second, two days after the dynamic (n=36).

For the question on participants' expectations in the first questionnaire (*GA*), 15 answers were discarded for being incomplete or incomprehensible, leaving 71 for analysis. Of these, 24 possible responses were obtained, which were divided into 7 categories, and as they are subjective answers each one could present more than one key sentence, as shown in Table 3. The percentage of the analysed students' answers that agreed with each of them is also represented in the table (n=71).

Table 3
Key statements from questionnaires before the lecture

Category	Key statement	Agree (%)
General replies	*I hope to learn a lot/understand the subject*	61,97
	Good expectations	15,49
	I hope to test my knowledge on the subject	5,63
	I don't know	4,22
	I think I will be surprised	1,40
Taken a position on the thematic	*I know nothing about it*	14,08
	Don't know much about the subject	7,04
	I would like to deepen my knowledge on the subject	4,22
About the lecture	*I think the lecture will address sustainability*	5,63
	I think the lecture will be enriching and will add a lot	1,40
About the project	*I find the subject interesting*	4,22
	I hope to understand the aim of the project	2,81
The future	*I think the lecture will help me to discover my professional future*	12,67
	It is a very important subject for the future	1,40
	I hope to reflect on agro[2] *and sustainability*	1,40
About Aquaponics	*I hope to learn the advantages and disadvantages of the technique, and also the basics for practicing*	1,40
	I hope to learn about the integrated use of water in an optimal way	1,40
	I hope to develop new knowledge about sustainable techniques for plant and animal production	1,40
	I find it interesting to present conservation and preservation	1,40
	I hope to learn more about sustainable ways of producing food	1,40
	I hope to explore aquaponics functionalities	1,40
Emotional	*I hope it's nice*	1,40
	I look forward to it	1,40
	I'm excited	1,40

[2]In Brazil, the term "agro" is used colloquially to refer to various terms such as agribusiness, farming, agriculture and livestock.

Note. Table displays the key statements retrieved from questionnaires before the lecture and the percentage of participants who agreed with them, divided in categories.

All answers from the 36 respondents to the second questionnaire were considered, retrieving 12 possible statements divided into 4 categories, according to Table 4.

Table 4

Key statements from questionnaires after the lecture

Category	Key statement	Agree (%)
About the lecture	*The lecture was explained simply and accurately*	11,11
	It was an enlightening activity	8,33
	The didactics were good	8,33
	The topic is very important	2,77
	It reminded me of important information about the use of water	2,77
About their expectations	*It met my expectations*	66,66
	I really liked the activity	8,33
	Exceeded my expectations	8,33
Suggestions	*It would be better if it was presential*	5,55
	It should introduce ways to build the system in residences	2,77
	The Project could encourage producers to join aquaponics	2,77
Criticism	*I found it complicated to apply on a large scale*	2,77

Note. Table presents the key statements retrieved from questionnaires after the lecture and the percentage of participants who agreed with them, divided in categories.

In order to compare the answers to the QVJ (questions 4, 6 and 8), we calculated the percentage of correct answers for the questions and also for the individual items, comparing these in questionnaires before and after the activity, shown in Table 5. The table also represents the average correct answers for each whole question and item, and finally the average correct answers considering all these questions before and after the lecture. Differences between answers before and after were calculated by subtracting the percentage of correct items and questions before the lecture from the percentage of correct items after the lecture (correct items after the lecture – correct items before the lecture), also presented in the table. The average correct answers for these questions increased by 7.27% after the presentations, showing that there was an influence on their knowledge.

Table 5
Percentage of correct answers to QVJ and items before and after the activity

Question	Item	Before		After		Difference item	Difference question
4	1	89,53	37,21	97,22	47,22	7.69	10,01
	2	37,21		47,22		10,01	
	3	46,51		50,00		3,49	
	4	97,67		100,0		2,33	
	5	70,23		94,44		24,21	
	Avg.	70,23		77,78		7,55	
6	1	93,02	76,74	91,67	77,78	-1,35	1,04
	2	96,51		100,0		3,49	
	3	93,02		91,67		-1,35	
	4	76,74		77,78		1,04	
	5	93,02		91,67		-1,35	
	Avg.	90,47		90,56		0,09	
8	1	94,19	58,14	100,0	86,11	5,81	27,97
	2	83,72		94,44		10,72	
	3	68,6		91,67		23,07	
	4	76,74		97,22		20,48	
	5	83,72		94,44		10,72	
	Avg.	81,4		95,56		14,16	
TOTAL		80,7	57,36	87,96	70,37	7,26	13,01

Note. Table represents the percentage of correct answers to QVJ (questions 4, 6 and 8) and their items before and after the activity. The total average correct answers for these questions in all the questionnaires were calculated, as well as the differences between answers these two moments (difference = correct answers after - correct answers before) for items and questions. Most relevant results are marked in blue.

Figure 2 presents the differences in percentages between the items of the questions that had the greatest changes after the activity (questions 4 and 8), based on Table 5. For all these items, the number of correct answers after the lecture was much higher than before, showing a change in the students' response patterns at this second moment. The average differences were calculated by subtracting the percentage of correct items or questions before the lecture from the percentage of correct items or questions after the lecture.

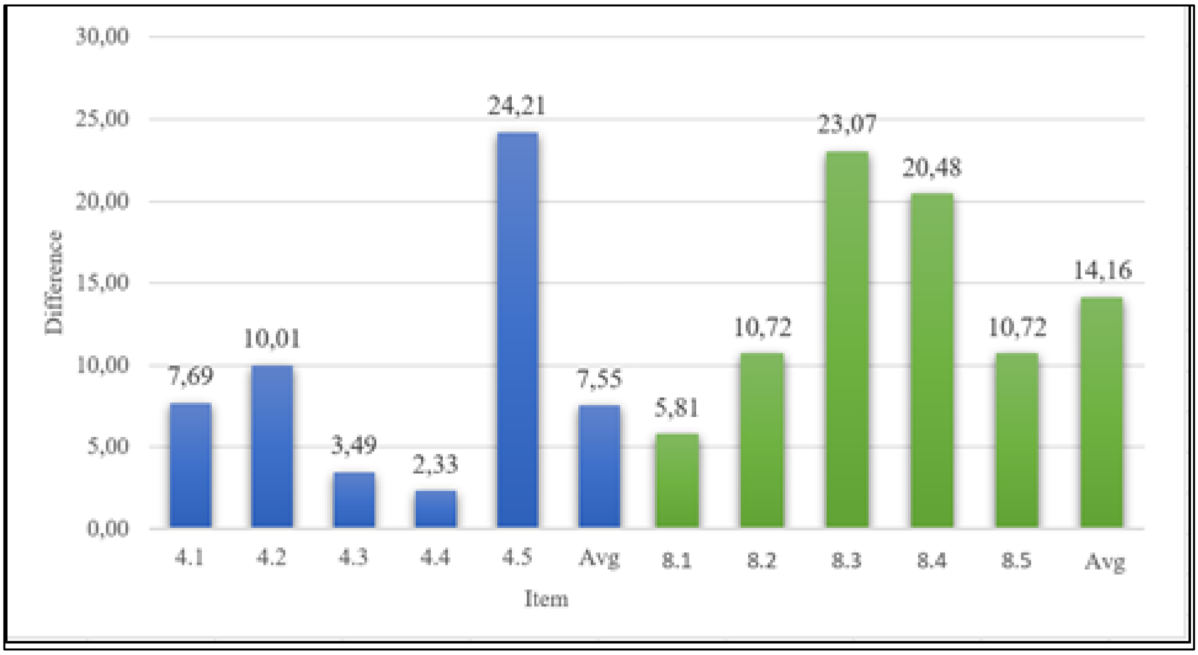

Figure 2. Differences in percentage between questionnaires after and before the lecture for questions 4 and 8.
Note. The Graph represents the differences in percentage for the items of Questions 4 and 8, as well as their average difference. These values were calculated using the formula: correct items or questions after the activity – correct items of questions before the activity. In blue, the differences for question 4, and in green, the differences for question 8.

Questions 3, 5, 7 and 9 (*GB*) evaluated students' self-confidence about each subtopic in five levels, and the results of this analysis are provided by Table 6, showing the percentage of students who scored each level of self-confidence on each subtopic. Level 1 represents the highest level of self-confidence, and 4, the lowest. Item 5 was not considered in the scale because it represents lack of interest of the student in answering. The table also compares results before and after the lecture, as well as their differences by subtracting percentage before the lecture from percentages after the lecture. The markings in blue highlight the most relevant results, which show that there has been an increase in the percentage of students scoring the highest level of self-confidence concurrently with a reduction in the lowest level of confidence scores.

Table 6

Comparative results before and after lecture for questions about students' self-confidence

	Question 3			Question 5			Question 7			Question 9		
Item	Before	After	Dif.	Before	After	Dif.	Before	After	Dif.	Before	After	Dif.
1	12,79	72,22	59,43	33,72	63,89	30,17	22,09	69,44	47,35	10,47	77,78	67,31
2	29,07	25,00	-4,07	23,26	36,11	12,85	25,58	27,78	2,20	22,09	19,44	-2,65
3	20,93	2,78	-18,15	25,58	0,00	-25,58	29,07	2,78	-26,92	22,09	2,78	-19,31
4	37,21	0,00	-37,21	16,28	0,00	-16,28	20,93	0,00	-20,93	44,19	0,00	-44,19
5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,16	0,00	-1,16

Note. Table represents the percentage of students who scored each level of self-confidence on questions 3, 5, 7 and 9, considering 1 the highest level of self-confidence and 5, the lowest. Most relevant results are marked in blue, demonstrating that there was an increase in the percentage of students who marked the highest level of self-confidence after the lecture, as well as a reduction in responses with a low level of self-confidence at this moment.

Representing the highest level of students' self-confidence, the differences between markings for item 1 of questions 3, 5, 7 and 9 before and after the lecture are represented in Figure 3. The values represent that for all questions there was an increase in item 1 markings, i.e., an increase in their self-confidence for the topics addressed.

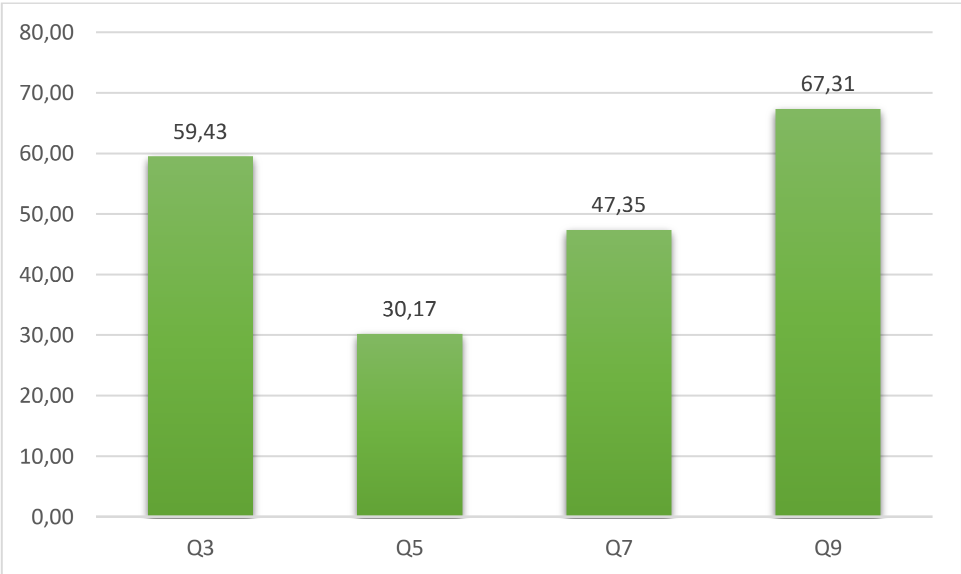

Figure 3. Differences in percentage of markings of item 1 of questions 3, 5, 7 and 9.
Note. The Graph represents the differences between markings of item 1 of questions 3, 5, 7 and 9 before and after the lecture (percentage of markings after lecture – percentage of markings before lecture).

Differences between percentages of markings for item 4 of questions 3, 5, 7 and 9 are presented by Figure 4, representing the lowest level of students' self-confidence. These results show that there was, for all these questions, a reduction in the markings for item 4. This means that fewer students reported having low self-confidence in the topics, being inversely proportional to the increase in markings for item 1. It can also be considered that there was a clear difference in markings before and after lecture.

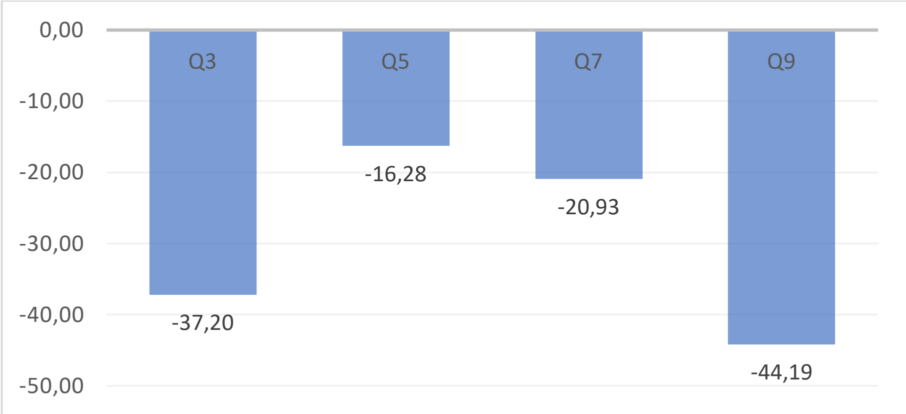

Figure 4. Differences in percentage of markings of item 4 of questions 3, 5, 7 and 9.
Note. The Graph represents the differences between markings of item 4 of questions 3, 5, 7 and 9 before and after the lecture (percentage of markings after lecture – percentage of markings before lecture).

The comparison of percentage markings before and after lecture of Question 10 (*GC*) is presented by Table 7, also showing the average answer for each item and for the question, considering 1 the most concerned and 5 the least concerned. The table also presents the difference of percentages between each item and for the question.

Table 7
Comparative results before and after lecture for question 10

Group	Question	Item	Before		After		Difference	Difference
			%	Average	%	Average	item	question
C	10	1	10,47	**3,03**	5,56	**3,25**	-4,91	0,22
		2	22,09		25,00		2,91	
		3	22,09		13,89		-8,20	
		4	44,19		50,00		5,81	
		5	1,16		5,56		4,40	

Note. The table presents percentage of markings in the items of Question 10 before and after the lecture, the average answer for both moments and the comparison of items and the whole question, considering 1 the most concerned and 5 the least concerned.

Questions 11 and 12 (*GD* and *GE*) were grouped in Table 8, comparing percentage results before and after lecture for each one. The average answer for each question was also calculated, considering 1 the strongest positive response (= excited) and 5 the strongest negative response (= angry).

Table 8
Comparative results before and after lecture for questions of groups D and E

Group	Question	Item	Before		After		Difference item	Difference question
			%	Average	%	Average		
D	11	1	0,00	**3,80**	0,00	**3,78**	0,00	-0,02
		2	1,16		0,00		-1,16	
		3	46,51		44,44		-2,07	
		4	22,09		33,33		11,24	
		5	29,07		22,22		-6,85	
E	12	1	0,00	**3,83**	0,00	**3,75**	0,00	-0,08
		2	3,49		5,56		2,07	
		3	32,56		33,33		0,77	
		4	41,86		41,67		-0,19	
		5	22,09		19,44		-2,65	

Note. The table presents percentage of markings in the items of Question 11 and 12 before and after the lecture, the average answer for both moments and the comparison of items and the whole question, considering 1 the strongest positive response (excited) and 5 the strongest negative response (angry).

For *GF* questions, we also compared results before and after the activity. Percentage of answers for each feeding habit on question 13 are shown in Table 9, comparing results before and after the activity. No students changed their marking about their eating habits after the lecture.

Table 9
Percentage of feeding habitat of participants

Feeding habit	Before	After
Crudivore	0,00	0,00
Omnivore	93,02	94,44
Vegetarian	4,65	5,56
Vegan	3,49	2,78

Note. The table presents the percentage of answers of students for each feeding habitat before and after the lecture, considering that none of them changed their marking.

Table 10 demonstrates differences in answers for question 14 before and after the activity, which presents percentage of answers for each item. Considering that these are checkbox answers, each item can be selected cumulatively with others.

Table 10

Percentage of answers for each product presented in Question 14

Product	Before	After	Difference
Organic	94,19	100,0	**5,81**
Aquaponics	44,19	80,56	**36,37**
Hydroponics	69,77	88,89	**19,12**
Fish from natural fisheries	65,12	63,89	**-1,23**
Aquaculture fish	62,79	80,56	**17,77**
None of the above	0,00	0,00	**0,00**
Don't know what these words mean	1,16	0,00	**-1,16**

Note: Table presents the percentage of students that ticked each product provided in question 14, being possible the marking of more than one item per student.

The hierarchical method of clustering for the multiple-choice answers in questionnaires before presentation is shown in Figure 5, considering the Euclidean distances between the answers provided to the questions and their correlations. For this analysis, we considered only multiple-choice questions (questions 3 to 13) and the subitems of questions 4, 6 and 8, which tested respondent knowledge on subthemes. For all analyses it was possible to unite the responses into proximity units, representing more similar answers. The shorter the linkage distance, the more similar the answers in the questionnaires.

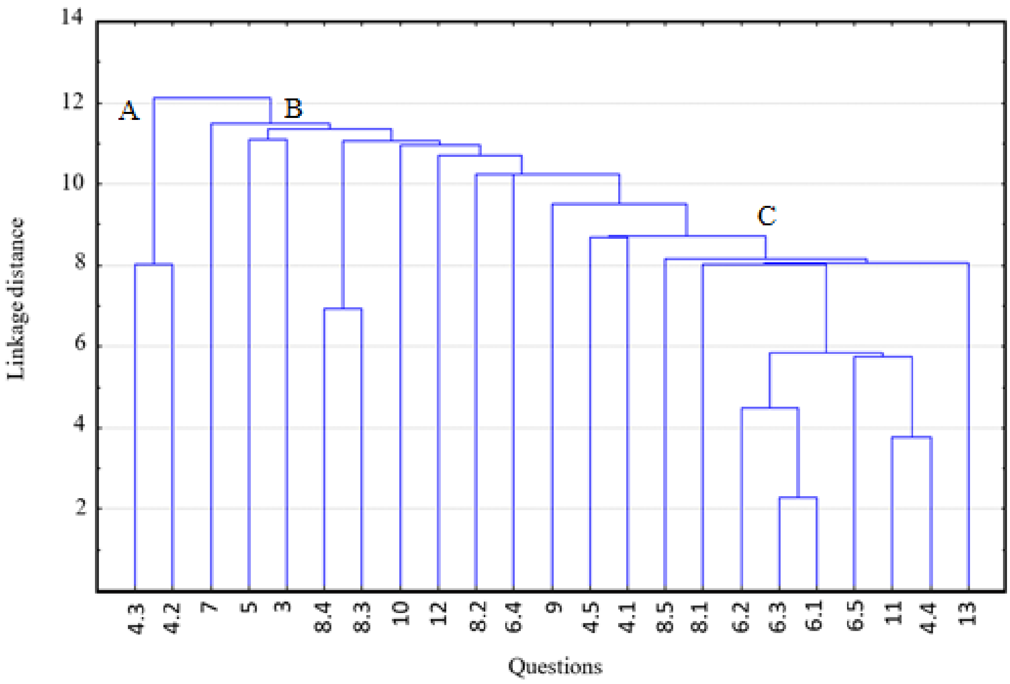

Figure 5. Tree Diagram of answers before lecture

Note. Diagram represents Single Linkage Euclidean distances showing the correlations for the answers of the 23 questions analysed, retrieved from the questionnaires before the lecture. Unit A is composed by questions 4.3 and 4.2, Unit B by questions 7, 5, 3, 8.4, 8.3, 10, 12, 8.2, 6.4, 9, 4.5 and 4.1, and Unit C by questions 8.5, 8.1, 6.2, 6.3, 6.1, 6.5, 11, 4.4 and 13.

The clustering for the answers of multiple-choice questions in the moment after the lecture is represented by Figure 6, correlating students answers in general.

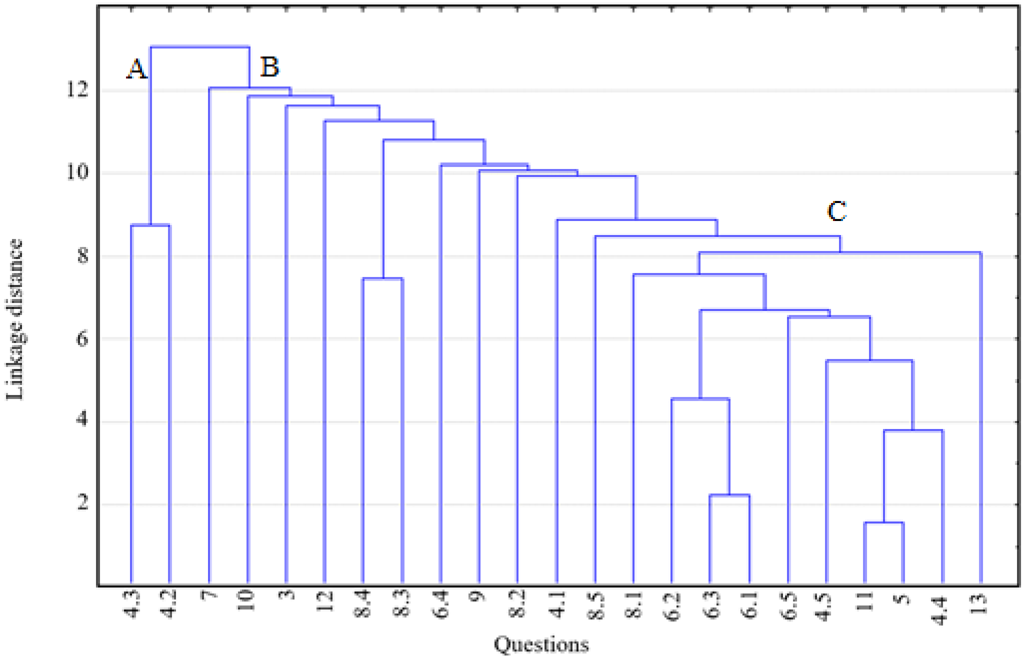

Figure 6. Tree Diagram of answers after lecture.

Note. Diagram represents Single Linkage Euclidean distances showing the correlations for the answers of the 23 questions analysed, retrieved from the questionnaires after the lecture. Unit A is composed by questions 4.3 and 4.2, Unit B by questions 7, 10, 3, 12, 8.4, 8.3, 6.4, 9, 8.2, 4.1 and 8.5, and Unit C by questions 8.1, 6.2, 6.3, 6.1, 4.5, 11, 5, 4.4 and 13.

After these analyses, we developed Figure 7, which represents clusters comparing questionnaires before and after presentation only for students that responded to both, which represented 41,8% of the total of students (n=36).

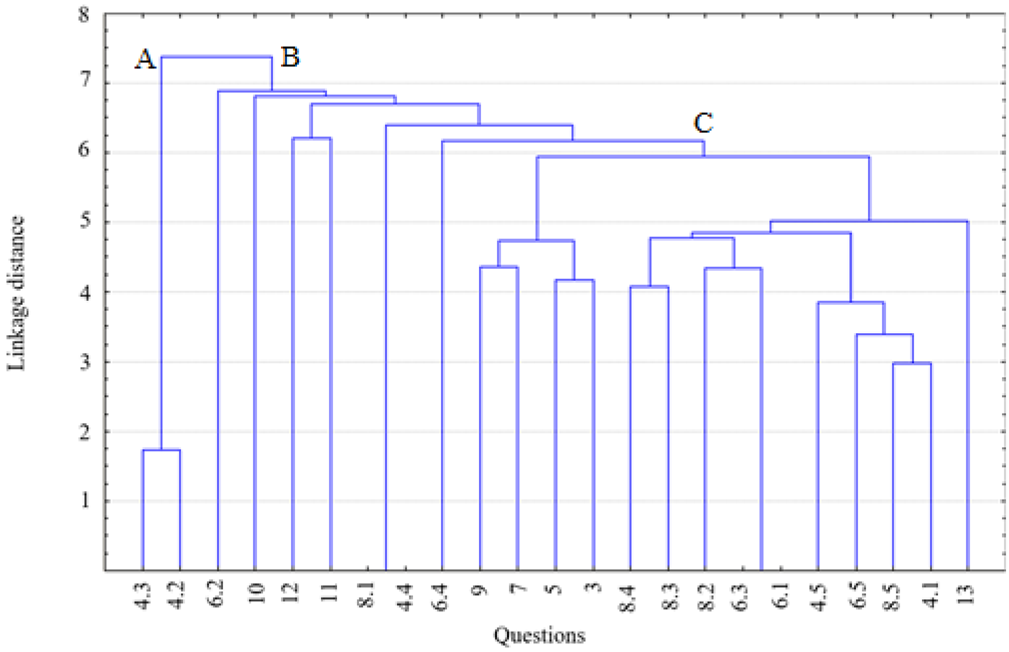

Figure 7. Tree Diagram of evolution of students before and after lecture.

Note. Diagram represents Single Linkage Euclidean distances showing the correlations for the answers of the 23 questions comparing questionnaires before and after the lecture. Unit A is composed by questions

4.3 and 4.2, Unit B by questions 6.2, 10, 12, 10, 12, 11, 8.1, 4.4 and 6.4, and Unit C by questions 9, 7, 5, 3, 8.4, 8.3, 8.2, 6.3, 6.1, 4.5, 6.5, 8.5, 4.1 and 13.

3.1 Interviews

All 4 teachers were interviewed after the activity, and their main statements were retrieved, represented in Table 11 (n=34). Because it allowed the development of themes according to the will of the participants, each interview could present more than one statement, and the number of people who agreed with each one is represented in the table.

Table 11
Key Statements from interviews

N	**Key Statement**	Agree
Question 1. Did the activity contribute to science teaching?		
1	*Yes*	4
2	*It helped to complement the subject that was already being taught*	3
3	*It showed the application of basic science and interesting points that caught their attention*	3
4	*It showed the practical, applied field of sciences*	3
5	*It helped to motivate students*	2
6	*It gave another view on the subject*	1
7	*It consolidated knowledge*	1
8	*It helped them to improve or increase integration between production systems*	1
9	*It allowed the connection of several themes linked to production and care of the environment*	1
10	*The didactics allowed diversifying the rhythm of the subject, bringing novelties*	1
Question 2. Do you think this activity has changed students' attitudes towards sustainable water use and healthy food consumption? In what way, in the reality of the student, do you believe this change will happen?		
11	*I'm not sure, but I believe it can help raise awareness*	4
12	*The presentation contributed to the dialogue we have with them, arousing curiosity*	2
13	*I find it difficult to isolate the activity from the discipline as a whole*	1
Question 3. Have the students shown any changes in their behaviour related to the environment after the presentation?		
14	*I can't say*	1
15	*Many already have a conscious thought, but it can be a trigger for those who intend to awaken this awareness*	1
16	*I believe that the questionnaires will tell us better*	1
17	*It was important to introduce the subject of sustainability in human activity, in food production*	1
18	*The activity was a tool to motivate students to search for solutions involving the knowledge base they are forming*	1
19	*The students reported that they liked to learn about this subject*	1
20	*I think that it takes a little longer to see a change in behaviour*	1
Question 4. How do you evaluate the activity developed? Any criticism or suggestions?		
21	*I think it awakened their interest in the theme*	4
22	*I found it interesting and I really liked what was presented*	2
23	*It demonstrated in a practical way how they can apply aquaponics in their lives*	2
24	*I think that the interview with the teacher should be done closer to the activity*	1
25	*The language of the presentation was accessible*	1
26	*I found it interesting to connect the different levels of education in different activities*	1
27	*I think that the activity being remote makes things a little more difficult*	1
Question 5. What other science and multidisciplinary subjects do you think it is possible to work on with the knowledge acquired through the activity?		
28	*The activity enables students to get closer to the topic*	3
29	*I think it is a comprehensive activity*	2
30	*The activity facilitated the integration of knowledge from various areas in a dynamic way*	2
31	*I think it was a complete activity*	1
32	*The activity helped awaken their interest in aquaponics*	1
33	*The activity motivated students to seek more knowledge*	1
34	*It could explore more the economic and technical sustainability of the aquaponics system*	1

Note. Table shows the key statements obtained from the semi-structured interviews conducted with the teachers of the participating classes, with number of concordances for each.

4 DISCUSSION

In remote activities, the best education practises rely on the use of varied resources with the purpose of conquering students' interest and motivating them to maintain their study rhythms (Mercier et al., 2021). Despite the attempt to carry out an activity with attractive teaching tools, there was a medium response rate to the second questionnaire of this research. One possible explanation for this would be the absence of coercive actions by the participating institutions or even by the researchers, since the students' participation was optional and encouraged only through a discussion about the importance of participating in the work. As the intention of the research was to understand the students' view on the topic and put them at ease in their choices to contribute to the research, we intentionally did not offer extra advantages for their participation, such as gaining grades or lesson hours in curricula or other forms of coercion.

Other studies also point to the lack of interest in remote activities as an important factor for low adherence, possibly influenced by the lack of attractiveness of classes and connection with teachers (Fonsêca et al., 2020; Lambert & Rennie, 2021; Lunardi et al., 2021; Mercier et al., 2021). These studies also display as a difficulty the low preparation of the home environment of students and teachers for carrying out activities solely by means of an electronic device. One possible way to mitigate these effects is to increase flexibility in order to allow the student to choose the best time to carry out the activity, through asynchronous classes (Lambert & Rennie, 2021). Another way to assist in these approaches would be the involvement of the student's family members to create a study environment conducive to their concentration and dedication (Lunardi et al., 2021). Even using creative and innovative ideas for remote teaching, the efficiency of several teaching tools is still doubtful, and students' lack of interest in the proposed activities remains a realistic possibility (Mercier et al., 2021).

The expressively lower number of answers to the second questionnaire could also explain the reduced number of key statements obtained at this point, which represent 50% of the statements given in the first questionnaires. However, the responses obtained were sufficient to assess that students considered that the activity met their expectations in some way, with some students detailing how this was achieved (mentioning the didactics, for example).

For the first questionnaire, there was a large number of generic answers, which could demonstrate some lack of interest in completing the questionnaire or even some anxiety for the beginning of the lecture. This could also explain the concentration of answers in smaller sentences and with less detail or specificity. On the other hand, many students positioned their previous knowledge before the theme to which they would be exposed and their professional insertion in the future, and others also demonstrated curiosity about aquaponics, the project and the lecture, which may come from their interest in the subject and desire to learn. The emotional responses can also be seen as responses of a motivation to carry out the activity, which is ratified with the responses to the second questionnaire.

The differences observed between the *GB* responses demonstrate an increase in the students' self-confidence in relation to the themes. In relation to the aquaponics and aquaculture topics this confidence was ratified with the increase in correct answers for the items in questions 4 and 8 and also for the whole question, according to data presented in Tables 5 and 6 and Figure 2. Considering that many students declared they knew little or nothing about aquaponics, that there was a 10% increase in the number of correct answers for question 4, which dealt with the subject, and that there was a significant increase in the students' confidence level for question 3, it can be inferred that the activity contributed to forming their knowledge base on aquaponics, at least momentarily.

For Question 6, there was no great difference between the answers before and after the lecture, presenting high rates of correct answers in both moments, which could indicate that the students had enough prior knowledge on the subject of hydroponics to fill out the items correctly. The answers to Question 9 also indicate that students considered that they had learned about sustainability throughout the activity, with a significant increase in the number of marks for item 1, which denotes greater self-confidence.

Question 10 was developed with the purpose of checking the student's ability to position their own choices in the face of the current water supply issues, and the answers show a slight increase in the students' concern regarding their own waste of water (0.22% increase in the average marks). This could indicate that the activity could improve the approach to the topic, and also that more time may be needed to carry out the evaluation after the lecture, as Chang and Lan (2019) also indicate in their results. As suggested by two participants in the second questionnaire and also indicated by Morano and Tzouanas (2017), Bertusso et al. (2020) and Mercier et al. (2021), the activity could be more effective if it were conducted face-to-face. The practical work usually enriches classes and allows students to build important concepts, as well as contributing to the formation of more autonomous students (Bertusso et al., 2020).

To answer questions 11 and 12, the students should reflect on the use of water by other people and the use of pesticides in food, and these answers did not show significant differences between the two moments. Possibly, the implementation of the activity had no interference on these issues for students, ratifying the need for a deeper approach on the importance of water and its use for productive systems and suggesting the need for greater depth on the topic of pesticide use in food. The same pattern was identified in Chang and Lan (2019), who pointed out the need for a longer period of student evaluation to verify the effectiveness of teaching tools. As many students verbally reported being agricultural science students, it becomes even more important to raise awareness on the topic of pesticides as this may define their future professional positions.

Only two students who reported being vegetarian filled in both questionnaires and did not change the products they would consume. One of them stated that he consumes only organic and hydroponic products, while the other, who indicated that he was vegetarian and vegan, stated that he would consume organic, aquaponic and hydroponic products. Apparently, for this student, the use of the same water would not change the vegan nature of the products, even after learning more about the functioning of this type of system. However, it would be necessary to further investigate the perceptions of this public for aquaponic products, as one single sample is not enough to infer such information.

One student classified himself as vegetarian and reported consuming organic, aquaponic, hydroponic, fish from natural fisheries and aquaculture fish, which may point out that this student does not consume red meat or that he did not understand the question. It is suggested that future studies add as a food classification option the exclusive consumption of white meats, such as fish and chicken, or even make this question subjective. This paradoxical pattern of answer may also be an indication of a lack of student interest in answering the questionnaire, ratifying the results of the analysis of students' expectations.

After the lecture, 55,55% of the students modified their answers about products they would consume (n=20). Of these, 16 increased the number of options marked, 3 removed some product and 1 maintained the number of markings but changed some product. Only three students did not indicate that they would consume aquaponics, and only one of them had indicated a propensity to consume this type of food in the first questionnaire. Our research points to a clear increase in participants' propensity to consume aquaponic, hydroponic and aquaculture fish, demonstrating the influence of the activity on their choices. This change may indicate that the students had a better understanding of terms that are not very common in the daily lives of the Brazilian population, such as hydroponic and aquaponic, allowing them to make a more informed choice.

The hierarchical cluster analysis indicates an influence of the activity on the students' answer patterns, since there was a reduction in the Euclidean distance between the answers and an approximation between the students’ responses. Combining this information with the increase in the marking of correct answers after the activity, it can be considered that the effect of this research was positive on the students' knowledge about the topics addressed. However, the suggestion remains for further studies with longer time frames to understand if this impact remains over time.

Through the interviews, it is possible to notice that teachers understand the importance of carrying out practical activities with different approaches and didactic tools. All of them agreed that the tool used contributes to science teaching, "planting a seed" in their awareness-raising processes. Furthermore, motivational factors are also related, clearly demonstrated through the following sentences, retrieved from interviews:

> "I am always with them saying the following: this here is like a puzzle game, and the first pieces you are putting now... you still can't have a vision of how the game works, because you have to put more pieces that then as you complete the margin you already start to realize the fit, where things fit, but for this you have to create expectation in you. I believe that your lecture, in this sense, helped to create the expectation then, which is the main thing in this phase of them." (Teacher 2)

It is also notable that teachers mentioned factors such as the students' attention and interest, as well as the application of science fields and consolidation of knowledge provided. The contribution to greater proximity between students and teachers is mentioned by two teachers, ratifying the studies of Souza et al. (2019), Chang and Lan (2019) and Mercier et al. (2021). This connection is determinant for the success of the teaching-learning process, and the use of differentiated tools such as the proposed activity seems to meet this perception. They also suggest that bringing the student closer to the topic could favour their learning, agreeing with studies such as Silva et al. (2018), Cheng et al. (2019), Sivia et al. (2019), Bertusso et al. (2020) and Wang et al. (2020).

Motivation is also mentioned as an important factor for students, as future professionals, to build a solid foundation for more conscious decision-making. The study by Hart et al. (2014) offers important reflections on realistic ways to run educational projects as a way to motivate students to have a taste for the subject, and can serve as a basis for other educators to manage their intentions. The following statement is an example of teachers' view on this subject:

> "They are like a vase that is still to be filled right. Obviously, depending on how they are filled, it will be the professional activity that they will have in the future. So the filling of this vase depends on motivation. The most important thing is to encourage them to dream, and dream big, because then they will feed their ideal and may even arise, then, more ambitious dreams that will create in them a need to know more and then the study is a consequence, the test is a consequence, and not the end." (Teacher 3)

These results are in agreement with the study of (Paula, 2020), in which teachers consider this to be a teaching tool that facilitates the integration between practice and theory, allowing a multifaceted approach. Martins (2019) found similar results, concluding that students and teachers considered aquaponics as a tool able to aggregate theory and practice in an interesting way. In the study, the greatest disadvantages are related to the implementation costs and physical space of the system in the educational environment, as well as teachers' involvement with the activity. However, they suggest as solutions visits to other research sites, inter-institutional collaborative work and the reduction of the scale of the system for schools.

Regarding the effectiveness of the use of aquaponics as a teaching tool, Cheng et al. (2019) obtained similar results to the present study, with successful application to environmental sciences. While in that study the students achieved greater collective self-efficacy, here we observed a great evolution on their knowledge about the topics addressed and a significant level of increase in self-confidence. These results are also aligned with Rosa (2020), where this tool have increased students' interest in the subjects approached and promoted competences for collaborative work. Thus, even though the other authors have not worked remotely, based on our results, we consider this to be an effective teaching tool, capable of adding theoretical and practical knowledge and involving students through active-learning.

The multi-thematic approach of aquaponics allowed the interpellation of several important issues within environmental sciences. Through this activity, it was possible to successfully work, even remotely, on topics such as sustainability, rational use of water and best practices in hydroponics, aquaponics and aquaculture systems, and could be extended to more diverse educational projects. As seen in other studies, complex concepts of technologies, engineering and mathematics can join the practice with great success (Eatmon, 2012; Silva et al., 2018; Junge, Bulc, Anseeuw, Yildiz, & Milliken, 2019; Mercier et al., 2021). Thus, it is suggested the use of this tool in conjunction with other disciplines to allow a better use of knowledge.

The use of aquaponics as a tool in education has great potential to contribute in a significant way to facilitating the teaching-learning process, favouring motivation through practical activities that involve multiple knowledge to be executed, favouring motivation through practical activities and involving multiple knowledge to be executed (Junge, Bulc, Anseeuw, Yildiz, & Miliken, 2019; Pantazi et al., 2019; Vujovic et al., 2019). If well planned, these activities can instigate students to engage in the development and execution of community projects using innovative materials with low impact to the environment (Hart 2014, Maucieri 2018). The results of this research point out that teachers and students consider that the use of aquaponics as a teaching tool motivates students to learn more by making the subjects more interesting.

5 REFERENCES

[IDEC], I. B. de D. do C. (2019). *A sindemia global da obesidade, desnutrição e mudanças climáticas*.

Aalto, S. L., Suurnäkki, S., Ahnen, M. Von, Siljanen, H. M. P., Bovbjerg, P., & Tiirola, M. (2020). Nitrate removal microbiology in woodchip bioreactors : A case-study with full-scale bioreactors treating aquaculture effluents. *Science of the Total Environment*, *723*, 1–9. https://doi.org/10.1016/j.scitotenv.2020.138093

Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, *8*(24). https://doi.org/10.3390/buildings8020024

Alkemade, F., & Suurs, R. A. A. (2012). Patterns of expectations for emerging sustainable technologies. *Technological Forecasting and Social Change*, *79*(3), 448–456. https://doi.org/10.1016/j.techfore.2011.08.014

Alshrouf, A. (2017). Hydroponics, Aeroponic and Aquaponic as Compared with Conventional Farming. *American Scientific Research Journal for Engineering*, *27*(1), 247–255. http://asrjetsjournal.org/

Amicarelli, V., & Bux, C. (2021). *Food waste measurement toward a fair , healthy and environmental-friendly food system : a critical review*. *123*(8), 2907–2935.

https://doi.org/10.1108/BFJ-07-2020-0658

Arantes, C. C., Winemiller, K. O., Petrere, M., Castello, L., Freitas, C. E. C., & Hess, L. L. (2017). Relationships between forest cover and fish diversity in the Amazon River floodplain. *Journal of Applied Ecology*, *55*(1), 42–49. https://doi.org/10.1111/1365-2664.12967

Armanda, D. T., Guinée, J. B., & Tukker, A. (2019). The second green revolution: Innovative urban agriculture's contribution to food security and sustainability – A review. *Global Food Security*, *22*(August 2018), 13–24. https://doi.org/10.1016/j.gfs.2019.08.002

Bertusso, F. R., Terhaag, M. M., & Malacarne, V. (2020). The use of practical classes in science teaching: challenges and possibilities. *Revista Práxis Educational*, *16*(39), 318–336.

Bich, T. T. N., Tri, D. Q., Yi-Ching, C., & Khoa, H. D. (2020). Productivity and economic viability of snakehead Channa striata culture using an aquaponics approach. *Aquacultural Engineering*, *89*(June 2019), 102057. https://doi.org/10.1016/j.aquaeng.2020.102057

Boyaci-Gündüz, C. P., Ibrahim, S. A., Wei, O. C., & Galanakis, C. M. (2021). Transformation of the Food Sector : Security and Resilience during the COVID-19 Pandemic. *Foods*, *10*(497), 1–14. https://doi.org/https://doi.org/10.3390/ foods10030497

Bredemeier, C., & Mundstock, C. M. (2000). Regulação da absorção e assimilação do nitrogênio nas plantas. *Ciência Rural*, *30*(2), 365–372. https://doi.org/10.1590/s0103-84782000000200029

Chang, M., & Lan, S. (2019). Exploring undergraduate EFL students ' perceptions and experiences of a Moodle-based reciprocal teaching application. *Open Learning: The Journal of Open, Distance and e-Learning*, *00*(00), 1–16. https://doi.org/10.1080/02680513.2019.1708298

Chao, S., Jiang, J., Wei, K., Ng, E., Hsu, C., Chiang, Y., Fang, & Wei-Ta. (2021). Understanding Pro-Environmental Behavior of Citizen Science : An Exploratory Study of the Bird Survey in Taoyuan ' s Farm Ponds Project. *Sustainability*, *13(9)*(5126), 1–24. https://doi.org/https://doi.org/10.3390/su13095126

Cheng, S. C., Hwang, G. J., & Chen, C. H. (2019). From reflective observation to active learning: A mobile experiential learning approach for environmental science education. *British Journal of Educational Technology*, *50*(5), 2251–2270.

https://doi.org/10.1111/bjet.12845

Cockle, K. L., Martin, K., & Wesołowski, T. (2011). Woodpeckers, decay, and the future of cavity-nesting vertebrate communities worldwide. *Frontiers in Ecology and the Environment*, *9*(7), 377–382. https://doi.org/10.1890/110013

Companhia Nacional de Abastecimento. (2010). Custos de Produção Agrícola. In *Custos de Produção Agrícola: a metodologia da Conab*. http://www.conab.gov.br/conabweb/download/safra/custos.pdf

Conselho Estadual de Recursos Hídricos. (2019). *Nitrato nas águas subterrâneas: desafios frente ao panorama atual* (C. Varnier (ed.); 1st ed., Issue 1). SIMA/IG.

Danner, R. I., Mankasingh, U., Anamthawat-Jonsson, K., & Thorarinsdottir, R. I. (2019). Designing aquaponic production systems towards integration into greenhouse farming. *Water (Switzerland)*, *11*(10). https://doi.org/10.3390/w11102123

Delabre, I., Rodriguez, L. O., Smallwood, J. M., Scharlemann, J. P. W., Alcamo, J., Antonarakis, A. S., Rowhani, P., Hazell, R. J., Aksnes, D. L., Balvanera, P., Lundquist, C. J., Gresham, C., Alexander, A. E., & Stenseth, N. C. (2021). Actions on sustainable food production and consumption for the post-2020 global biodiversity framework. *Science Advances*, *7*(eabc8259), 1–17. https://doi.org/10.1126/sciadv.abc8259

Dinu, S., Ladaru, B., Physics, F., & Mg-, P. O. B. O. X. (2018). *Building and monitoring the aquaponics experimental lab for students*. *1*(1), 1–5.

Duarte, A. J., Malheiro, B., Ribeiro, C., Silva, M. F., Ferreira, P., & Guedes, P. (2015). Developing an aquaponics system to learn sustainability and social compromise skills. *Journal of Technology and Science Education*, *5*(4), 235–253. https://doi.org/10.3926/jotse.205

Eatmon, T. (2012). Soilless agriculture for Stem Education. *6th International Conference of Technology , Education and Development (INTED)*, 4000.

Eck, M., Körner, O., & Jijakli, M. H. (2019a). Nutrient Cycling in Aquaponics Systems. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 231–246). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_9

Eck, M., Körner, O., & Jijakli, M. H. (2019b). Nutrient Cycling in Aquaponics Systems Chapter 9 Nutrient Cycling in Aquaponics Systems. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., Issue 1, pp. 231–246). Springer. https://doi.org/10.1007/978-3-030-15943-6

Eck, M., Sare, A. R., Massart, S., Schmautz, Z., Junge, R., Smits, T. H. M., & Jijakli, M. H. (2019). Exploring bacterial communities in aquaponic systems. *Water (Switzerland)*, *11*(2), 1–16. https://doi.org/10.3390/w11020260

Ehrlich, P. R., & Harte, J. (2015). Food security requires a new revolution. *International Journal of Environmental Studies*, *72*(6), 908–920. https://doi.org/10.1080/00207233.2015.1067468

Eichhorst, J. (2014). *Distributed aquaponics in urban and peri-urban environments: a white paper on community development and feeding through the creation of local integrated farming clusters* (Issue August).

El-Essawy, H., Nasr, P., & Sewilam, H. (2019). Aquaponics: a sustainable alternative to conventional agriculture in Egypt – a pilot scale investigation. *Environmental Science and Pollution Research*, *26*(16), 15872–15883. https://doi.org/10.1007/s11356-019-04970-0

Ellen MacArthur Foundation. (2013). *Towards the circular economy: economic and business rationale for an accelerated transition* (Vol. 1, Issue 1). Ellen MacArthur Foundation.

Ellen MacArthur Foundation. (2019). Cities and Circular Economy for Food. In *Ellen MacArthur Foundation*. https://www.ellenmacarthurfoundation.org/assets/downloads/Cities-and-Circular-Economy-for-Food_280119.pdf

Fitzgerald, D. B., Sabaj Perez, M. H., Sousa, L. M., Gonçalves, A. P., Rapp Py-Daniel, L., Lujan, N. K., Zuanon, J., Winemiller, K. O., & Lundberg, J. G. (2018). Diversity and community structure of rapids-dwelling fishes of the Xingu River: Implications for conservation amid large-scale hydroelectric development. *Biological Conservation*, *222*(March), 104–112. https://doi.org/10.1016/j.biocon.2018.04.002

Fonsêca, L. B. H. da, Lima, S. M. de S., Costa, M. L. de O., & Almeida, J. D. S. (2020). Perspectivas do ensino remoto na educação brasileira. *Educação Como (Re)Existência: Mudanças, Conscientização e Conheicmentos*, 1–11.

Food and Agriculture Organization [FAO]. (2010). *Implementing aquaponics in the Gaza Strip*. www.fao.org/resilience/home/en/

Food and Agriculture Organization [FAO]. (2020). The State of Food and Agriculture 2020: overcoming water challenges in Agriculture. In *FAO* (1st ed.). FAO.

https://doi.org/https://doi.org/10.4060/cb1447en

Forchino, A. A., Lourguioui, H., Brigolin, D., & Pastres, R. (2017). Aquaponics and sustainability: The comparison of two different aquaponic techniques using the Life Cycle Assessment (LCA). *Aquacultural Engineering*, *77*, 80–88. https://doi.org/10.1016/j.aquaeng.2017.03.002

Friedrich, T., Derpsch, R., & Kassam, A. (2012). Sustainable Development of Organic Agriculture. *Field Actions Science Reports*, *Special Issue 6*, 7. https://doi.org/10.1201/9781315365800

Gabriel, J. L., García-González, I., Quemada, M., Martin-Lammerding, D., Alonso-Ayuso, M., & Hontoria, C. (2021). Cover crops reduce soil resistance to penetration by preserving soil surface water content. *Geoderma*, *386*(January). https://doi.org/10.1016/j.geoderma.2020.114911

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Glaviˇ, P. (2020). Identifying Key Issues of Education for Sustainable Development. *Sustainability*, *12*(6500), 1–18. https://doi.org/10.3390/su12166500

Goda, A. M. A.-S., Essa, M. A., Hassan, M. S., & Sharawy, Z. (2015). Bio Economic Features for aquaponics Systems in Egypt. *Turkish Journal of Fisheries and Aquatic Sciences*, *15*, 525–532. https://doi.org/10.4194/1303-2712-v15_2_40

Goddard, J. M., Zurier, H. S., & Nugen, S. R. (2020). *Engaged food science : Connecting K-8 learners to food science while engaging graduate students in science communication*. *November*, 31–47. https://doi.org/10.1111/1541-4329.12215

Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K. V., Jijakli, H., & Thorarinsdottir, R. (2015). Challenges of sustainable and commercial aquaponics. *Sustainability (Switzerland)*, *7*(4), 4199–4224. https://doi.org/10.3390/su7044199

Goddek, S., Joyce, A., Kotzen, B., & Burnell, G. M. (2019). Aquaponics Food Production Systems. *Aquaponics Food Production Systems*, *July*. https://doi.org/10.1007/978-3-030-15943-6

Goddek, S., Joyce, A., Kotzen, B., & Dos-Santos, M. (2019). Aquaponics and Global Food Challenges. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 3–17). Springer.

https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_1

Goddek, S., & Keesman, K. J. (2020). Improving nutrient and water use efficiencies in multi-loop aquaponics systems. *Aquaculture International*, *28*(1), 2481–2490. https://doi.org/https://doi.org/10.1007/s10499-020-00600-6

Gómez, C., Currey, C. J., Dickson, R. W., Kim, H. J., Hernández, R., Sabeh, N. C., Raudales, R. E., Brumfield, R. G., Laury-Shaw, A., Wilke, A. K., Lopez, R. G., & Burnett, S. E. (2019). Controlled environment food production for urban agriculture. *HortScience*, *54*(9), 1448–1458. https://doi.org/10.21273/HORTSCI14073-19

Gorcum, B. Van, Goddek, S., & Keesman, K. J. (2019). Gaining market insights for aquaponically produced vegetables in Kenya. *Aquaculture International*, *27*(5), 1231–1237. https://doi.org/10.1007/s10499-019-00379-1

Greenfeld, A., Becker, N., Bornman, J. F., Spatari, S., & Angel, D. L. (2021). Is aquaponics good for the environment ?— evaluation of environmental impact through life cycle assessment studies on aquaponics systems. *Aquaculture International*, *1*, 1–18. https://doi.org/10.1007/s10499-021-00800-8

Greenfeld, A., Becker, N., McIlwain, J., Fotedar, R., & Bornman, J. F. (2019). Economically viable aquaponics? Identifying the gap between potential and current uncertainties. *Reviews in Aquaculture*, *11*(3), 848–862. https://doi.org/10.1111/raq.12269

Guiducci, R. do C. N., Lima Filho, J. R. de, & Mota, M. M. (2012). *Viabilidade econômica de sistemas de produção agropecuários*. Embrapa.

Hart, E. R., Webb, J. B., Hollingsworth, C., & Danylchuk, A. J. (2014). Managing expectations for aquaponics in the classroom: enhancing academic learning and teaching an appreciation for aquatic resources. *Fisheries*, *39*(11), 525–530. https://doi.org/10.1080/03632415.2014.966353

He, J. (2017). Integrated vertical aeroponic farming systems for vegetable production in space limited environments. *Acta Horticulturae*, *1176*, 25–35. https://doi.org/10.17660/ActaHortic.2017.1176.5

Hu, Z., Lee, J. W., Chandran, K., Kim, S., Brotto, A. C., & Khanal, S. K. (2015). Effect of plant species on nitrogen recovery in aquaponics. *Bioresource Technology*, *188*, 92–98. https://doi.org/10.1016/j.biortech.2015.01.013

Hundley, G. C., & Navarro, R. D. (2013). Aquaponia : a Integração Entre Piscicultura E a Hidroponia. *Revista Brasileira de Agropecuária Sustentável (RBAS)*, *3*(2), 52–

61.

Hundley, G. M. C., Navarro, R. D., Figueiredo, C. M. G., Navarro, F. K. S. P., Pereira, M. M., Filho, O. P. R., & Filho, J. T. S. (2013). Aproveitamento do efluente da produção de tilápia do Nilo para o crescimento de manjerona (Origanum majorana) e manjericão (Origanum basilicum) em sistemas de Aquaponia. *Revista Brasileira de Agropecuária Sustentável (RBAS)*, *3*(1), 51–55.

Ilha, P. C. A., & Cruz, D. M. (2006). Jogos eletrônicos na educação : uma pesquisa aplicada do uso do Sim City4 no ensino médio. *XXVI Congresso Da SBC*, *Julho*, 1–7.

Instituto Acende Brasil. (2014). *Qualidade do fornecimento de energia elétrica: confiabilidade, conformidade e presteza* (White Pape).

Instituto Acende Brasil. (2020). *Evolução das tarifas de energia elétrica e a formulação de políticas públicas* (White Pape).

Joyce, A., Goddek, S., Kotzen, B., & Wuertz, S. (2019). Aquaponics : Closing the Cycle on Limited Water , Land and Nutrient Resources. In G. M. Goddek, Simon; Joyce, Alyssa; Kotzen, Benz; Burnell (Ed.), *Aquaponics Food Production System* (1st ed., pp. 19–34). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_2

Joyce, A., Timmons, M., Goddek, S., & Pentz, T. (2019). Bacterial Relationships in Aquaponics : New Research Directions. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 145–161). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_6

Junge, R., Bulc, T. G., Anseeuw, D., Yildiz, H. Y., & Miliken, S. (2019). Aquaponics as an Educational Tool. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 561–593). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_22

Junge, R., Bulc, T. G., Anseeuw, D., Yildiz, H. Y., & Milliken, S. (2019). Aquaponics as an educational tool. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 561–595). Springer. https://doi.org/10.4324/9780203883495

Kirschbaum, M. U. F., Zeng, G., Ximenes, F., Giltrap, D. L., & Zeldis, J. R. (2019). *Towards a more complete quantification of the global carbon cycle*. 831–846.

Kodama, G. (2015). Viabilidade financeira em sistema de aquaponia [Universidade de Brasília]. In *Viabilidade Financeira em sistema de aquaponia* (Vol. 1, Issue 4). https://doi.org/10.1111/j.1540-4781.1969.tb04998.x

Kodama, G., Santos, M. J. dos, Souza, Á. N. De, Hundley, G. C., & Navarro, R. D. (2019). Analysis of the financial viability of the aquaponics (fish farming and hydroponics) system using the Monte Carlo method. *Revista Brasileira de Agropecuária Sustentável (RBAS)*, *9*(4), 20–26.

König, B., Janker, J., Reinhardt, T., Villarroel, M., & Junge, R. (2018). Analysis of aquaponics as an emerging technological innovation system. *Journal of Cleaner Production*, *180*, 232–243. https://doi.org/10.1016/j.jclepro.2018.01.037

Kumar, S., Banerjee, A., Kumar, M., Swaroop, R., & Raj, A. (2022). Environmental education for sustainable development. *Natural Resources Conservation and Advances for Sustainability*, *1*(March), 415–431. https://doi.org/https://doi.org/10.1016/B978-0-12-822976-7.00010-7

Kyaw, T. Y., & Ng, A. K. (2017). Smart Aquaponics System for Urban Farming. *Energy Procedia*, *143*, 342–347. https://doi.org/10.1016/j.egypro.2017.12.694

Laidlaw, J., & Magee, L. (2014a). Towards urban food sovereignty: The trials and tribulations of community-based aquaponics enterprises in Milwaukee and Melbourne. *Local Environment*, *21*(5), 573–590. https://doi.org/10.1080/13549839.2014.986716

Laidlaw, J., & Magee, L. (2014b). Towards urban food sovereignty: The trials and tribulations of community-based aquaponics enterprises in Milwaukee and Melbourne. *Local Environment*, *21*(5), 573–590. https://doi.org/10.1080/13549839.2014.986716

Lal, R. (2016). Feeding 11 billion on 0.5 billion hectare of area under cereal crops. *Food and Energy Security*, *5*(4), 239–251. https://doi.org/10.1002/fes3.99

Lambert, C. G., & Rennie, A. E. W. (2021). Experiences from COVID-19 and Emergency Remote Teaching for Entrepreneurship Education in Engineering Programmes. *Education Sciences*, *11*(282), 1–16. https://doi.org/10.3390/educsci11060282

Lassaletta, L., Billen, G., Grizzetti, B., & Galloway, J. N. (2014). *Food and feed trade as a driver in the global nitrogen cycle : 50-year trends*. 225–241. https://doi.org/10.1007/s10533-013-9923-4

Lennard, W., & Goddek, S. (2019). Aquaponics : The Basics. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 113–143). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_5

Lima, M. T. (2020). *Por que agricultura na cidade? A importância da Agricultura Urbana em contexto de emergência climática e sanitária*.

Love, D. C., Fry, J. P., Li, X., Hill, E. S., Genello, L., Semmens, K., & Thompson, R. E. (2015). Commercial aquaponics production and profitability: Findings from an international survey. *Aquaculture*, *435*, 67–74. https://doi.org/10.1016/j.aquaculture.2014.09.023

Lun, F., Sardans, J., Sun, D., Xiao, X., Liu, M., Li, Z., Wang, C., Hu, Q., Tang, J., Ciais, P., Janssens, I. A., & Obersteiner, M. (2022). Influences of international agricultural trade on the global phosphorus cycle and its associated issues. *Global Environmental Change*, *69*(102282), 1–13. https://doi.org/10.1016/j.gloenvcha.2021.102282

Lunardi, N. M. S. S., Sousa, J. B. de, Silva, N. R. M. da, Pereira, T. G. N., & Fernandes, J. da S. C. (2021). Aulas Remotas Durante a Pandemia : dificuldades e estratégias utilizadas por pais. *Educação & Realidade2*, *46*(2), 1–22.

Martins, P. (2019). Aquaponia em Educação Ambiental – Perceções de alunos e de professores Escola Profissional de Agricultura e Desenvolvimento Rural de Marco de Canaveses Acuaponia en Educación Ambiental – Percepciones de estudiantes y de maestros Aquaponics in Environmenta. *Revista Eletrônica Do Mestrado Em Educação Ambiental*, *36*(3), 356–369.

Maucieri, C., Forchino, A. A., Nicoletto, C., Junge, R., Pastres, R., Sambo, P., & Borin, M. (2018). Life cycle assessment of a micro aquaponic system for educational purposes built using recovered material. *Journal of Cleaner Production*, *172*, 3119–3127. https://doi.org/10.1016/j.jclepro.2017.11.097

Maucieri, C., Nicoletto, C., Junge, R., Schmautz, Z., Sambo, P., & Borin, M. (2018). Hydroponic systems and water management in aquaponics: A review. *Italian Journal of Agronomy*, *13*(1), 1–11. https://doi.org/10.4081/ija.2017.1012

Maucieri, C., Nicoletto, C., Os, E. Van, Anseeuw, D., Havermaet, R. Van, & Junge, R. (2019). Hydroponic Technologies. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 77–110). Springer. https://link.springer.com/book/10.1007/978-3-030-15943-6

Mercier, V. B., Scholten, U., Baltensperger, R., Gremaud, L., & Dabros, M. (2021). Distance Teaching in Chemistry : Opportunities and Limitations. *CHIMIA*, *75*(1), 58–63. https://doi.org/10.2533/chimia.2021.58

Messner, R., Johnson, H., & Richards, C. (2021). From surplus-to-waste : A study of systemic overproduction, surplus and food waste in horticultural supply chains. *Journal of Cleaner Production*, *278*(123952), 1–11. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123952

Mikkelsen, B. E., & Bosire, C. M. (2019). Food, sustainability, and Science Literacy in One Package? Opportunities and Challenges in Using Aquaponics Among Young People at School, a Danish Perspective. In *Aquaponics Food Production System* (pp. 597–606).

Milliken, S., & Stander, H. (2019). Aquaponics and Social Enterprise. In S. Goddek, A. Joyce, B. Kotzen, & G. M. Burnell (Eds.), *Aquaponics Food Production Systems* (1st ed., pp. 607–619). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-15943-6_24

Miralles-Wilhelm, F. (2021). Nature-based solutions in agriculture - Sustainable management and conservation of land, water and biodiversity. In *Nature-based solutions in agriculture: Sustainable management and conservation of land, water and biodiversity*. FAO and The Nature Conservancy. https://doi.org/10.4060/cb3140en

Mojtahedi, M. R., Alizadeh, K., & Jafari, H. (2021). The Role of Urban Agriculture Approach in Food Supply and Export Ability (Case Study of Neishabour in Iran). *Propósitos y Representaciones*, *9 (SPE1)*(e881), 1–18.

Monsees, H., Kloas, W., & Wuertz, S. (2017). Decoupled systems on trial: Eliminating bottlenecks to improve aquaponic processes. *PLoS ONE*, *12*(9), 1–18. https://doi.org/10.1371/journal.pone.0183056

Morano, L., & Tzouanas, V. (2017). Urban Agricultural and Sustainability Program at Houston’s Downtown University: Combining New Curriculum, Hands-on Projects, and a Hurricane. *Journal of Agriculture, Food Systems, and Community Development*, *7*(4), 1–11. https://doi.org/10.5304/jafscd.2017.074.003

Murotani, B. S. (2013). *A fazenda vertical e a cidade: uma reflexão sobre São Paulo* (Vol. 2013). Universidade Presbiteriana Mackenzie.

Oliveira, A. F. F. de. (2019). O uso da aquaponia como instrumento de sensibilização e conscientização ambiental sustentável multidisciplinar desenvolvido em escola privada de Natal, RJ, Brasil. *VI Congresso Nacional Da Educação*, 1–8.

Pantazi, D., Dinu, S., & Voinea, S. (2019). The smart aquaponics greenhouse – an interdisciplinary educational laboratory. *Romanian Reports in Physics*, *71*(3), 1–11.

Paula, C. da S. (2020). *Aquaponia: uma ferramenta didática de ensino no IFPA-Santarém, Brasil*. Universidade Federal do Pará.

Pearson, L. J., Pearson, L., & Pearson, C. J. (2011). Sustainable urban agriculture: Stocktake and opportunities. *Urban Agriculture: Diverse Activities and Benefits for City Society*, *May 2015*, 7–19. https://doi.org/10.3763/ijas.2009.0468

Pimentel, F. S. C., Francisco, D. J., & Ferreira, A. R. (2021). *Jogos digirais, tecnologias e educação: reflexões e propostas no contexto da COVID-19* (1st ed.). Edufal.

Proksch, G., Ianchenko, A., Miller, T., Partnership, H., & Kotzen, B. (2019). Aquaponics Food Production Systems. In *Aquaponics Food Production Systems* (Issue June). https://doi.org/10.1007/978-3-030-15943-6

Pulighe, G., & Lupia, F. (2020). Food first: COVID-19 outbreak and cities lockdown a booster for a wider vision on urban agriculture. *Sustainability (Switzerland)*, *12*(12), 10–13. https://doi.org/10.3390/su12125012

Rosa, L. O. G. C. (2020). *Uma proposta para o uso da aquaponia no ensino de biologia*. Universidade de Brasília.

Ruggeri, G., Mazzocchi, C., & Corsi, S. (2016). Urban Gardeners ' Motivations in a Metropolitan City : The Case of Milan. *Sustainability*, *8*(1099), 1–19. https://doi.org/10.3390/su8111099

Salas-Zapata, W. A., & Ortiz-Muñoz, S. M. (2019). Analysis of meanings of the concept of sustainability. *Sustainable Development*, *27*, 153–161. https://doi.org/10.1002/sd.1885

Santeramo, F. G., & Lamonaca, E. (2021). *Food Loss – Food Waste – Food Security : A New Research Agenda*.

Santos, M. J. P. L. dos. (2016). Smart cities and urban areas—Aquaponics as innovative urban agriculture. *Urban Forestry and Urban Greening*, *20*, 402–406. https://doi.org/10.1016/j.ufug.2016.10.004

Santos, R. A. dos. (2010). *Estudo das variações dos componentes do balanço hídrico e área com solo exposto na bacia hidrográfica do rio Verde , Goiás Ronaldo Antonio dos Santos Ronaldo Antonio dos Santos*. Universidade de São Paulo.

Silva, P. C. P. de, & Silva, P. C. A. de. (2016). Ipanera: An Industry 4.0 based architecture for distributed soil-less food production systems. *1st Manufacturing and Industrial Engineering Symposium*, *October*. https://doi.org/10.1109/MIES.2016.7780266

Silva, M. F. e, & Van Passel, S. (2020). Climate-smart agriculture in the northeast of

Brazil: An integrated assessment of the aquaponics technology. *Sustainability (Switzerland)*, *12*(9). https://doi.org/10.3390/su12093734

Silva, M. F., Malheiro, B., Guedes, P., Duarte, A., & Ferreira, P. (2018). Collaborative learning with sustainability-driven projects: A summary of the EPS@ISEP programme. *International Journal of Engineering Pedagogy*, *8*(4), 106–130. https://doi.org/10.3991/ijep.v8i4.8260

Sivia, A., MacMath, S., Novakowski, C., & Britton, V. (2019). Examining Student Engagement During a Project-Based Unit in Secondary Science. *Canadian Journal of Science, Mathematics and Technology Education*, *19*(3), 254–269. https://doi.org/10.1007/s42330-019-00053-x

Smith, K., Wells, R., & Hawkes, C. (2022). *How Primary School Curriculums in 11 Countries around the World Deliver Food Education and Address Food Literacy : A Policy Analysis*.

Soma, T., Li, B., & Maclaren, V. (2020). Food Waste Reduction : A Test of Three Consumer Awareness Interventions. *Sustainability*, *12(3)*(907), 1–19. https://doi.org/https://doi.org/10.3390/su12030907

Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2014). Small-scale aquaponic food production. Integrated fish and plant farming. In *FAO Fisheries and Aquaculture* (No. 589).

Soomro, A. H., Shaikh, N., Miano, T. F., Marri, A., Khaskheli, S. G., & Kumar, D. (2021). Food waste management strategies in food supply chain. *International Journal of Ecosystems and Ecology Science (IJEES)*, *11*(4), 759–766. https://doi.org/https://doi.org/10.31407/ijees11.413

Souza, R. T. Y. B. de, Souza, L. de O., Oliveira, S. R. de, & Takahashi, E. L. H. (2019). Formação continuada de professores de ciências utilizando a Aquaponia como ferramenta didática Science teachers ' continuing training using Aquaponics as a didactic tool. *Ciência & Educação*, *25*(2), 395–410. https://doi.org/https://doi.org/10.1590/1516-731320190020008

Specht, K., Weith, T., Swoboda, K., & Siebert, R. (2016). Socially acceptable urban agriculture businesses. *Agronomy for Sustainable Development*, *36*(1), 1–14. https://doi.org/10.1007/s13593-016-0355-0

Specht, K., Zoll, F., Schümann, H., Bela, J., Kachel, J., & Robischon, M. (2019). How will we eat and produce in the cities of the future? From edible insects to vertical farming-A study on the perception and acceptability of new approaches.

Sustainability (Switzerland), *11*(16), 1–22. https://doi.org/10.3390/su11164315

Suárez-Cáceres, G. P., Fernández-Cabanás, V. M., Lobillo-Eguíbar, J., & Pérez-Urrestarazu, L. (2021). Characterisation of aquaponic producers and small - scale facilities in Spain and Latin America. *Aquaculture International*, *0123456789*. https://doi.org/10.1007/s10499-021-00793-4

Tokunaga, K., Tamaru, C., Ako, H., & Leung, P. (2015). Economics of small-scale commercial aquaponics in hawai'i. *Journal of the World Aquaculture Society*, *46*(1), 20–32. https://doi.org/10.1111/jwas.12173

Turnsek, M., Joly, A., Thorarinsdottir, R., & Junge, R. (2020). Challenges of commercial aquaponics in Europe: Beyond the hype. *Water (Switzerland)*, *12*(306), 1–18. https://doi.org/10.3390/w12010306

Turnšek, M., Morgenstern, R., Schröter, I., Mergenthaler, M., Hüttel, S., & Leyer, M. (2019). Commercial Aquaponics: A Long Road Ahead. In S. Goddek (Ed.), *Aquaponics Food Production Systems* (pp. 453–485). Springer.

Tyson, R. V., Treadwel, D. D., & Simonne, E. H. (2011). Opportunities and challenges to sustainability in aquaponic systems. *HortTechnology*, *21*(1), 6–13. https://doi.org/10.21273/horttech.21.1.6

Vermeulen, T., & Kamstra, A. (2013). The need for systems design for robust aquaponic systems in the urban environment. *Acta Horticulturae*, *1004*, 71–78.

Vujovic, A., Todorovic, P., Stefanovic, M., Vukicevic, A., Jovanovic, M. V., Macuzic, I., & Stefanovic, N. (2019). The development and implementation of an aquaponics embedded device for teaching and learning varied engineering concepts. *International Journal of Engineering Education*, *35*(1), 1–11.

Wang, W., Jia, Y., Cai, K., & Yu, W. (2020). An Aquaponics System Design for Computational Intelligence Teaching. *IEEE Access*, *8*, 42364–42371. https://doi.org/10.1109/ACCESS.2020.2976956

Wardlow, G., Johnson, D., & Mueller, C. (2002). Enhancing Student Interest in the Agricultural Sciences through Aquaponics. *Journal of Natural Resources and Life Sciences Education*, *31*(June 2000), 55–58.

Wasieleski, D., Waddock, S., & Fort, T. (2021). *Natural Sciences , Management Theory , and System Transformation for Sustainability*. https://doi.org/10.1177/0007650319898384

Wirza, R., & Nazir, S. (2021). Urban aquaponics farming and cities- a systematic literature review. *Reviews on Environmental Health*, *36*(1), 47–61.

https://doi.org/10.1515/reveh-2020-0064

Yildiz, H. Y., Robaina, L., Pirhonen, J., Mente, E., Domínguez, D., & Parisi, G. (2017). Fish welfare in aquaponic systems: Its relation to water quality with an emphasis on feed and faeces-A review. *Water*, *9*(13), 1–17. https://doi.org/10.3390/w9010013

Yuan, Z., Jiang, S., Sheng, H., Liu, X., Hua, H., Liu, X., & Zhang, Y. (2018). *Human Perturbation of the Global Phosphorus Cycle : Changes and Consequences*. https://doi.org/10.1021/acs.est.7b03910