Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X

http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

REVISTA AIDIS

de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica.

AQUAPONICS IN BRAZIL: REVIEW AND SURVEY ON WASTE MANAGEMENT PRACTICES

Larissa Bizon [1]
* Marco Aurélio Soares de Castro [1]

Recibido el 2 de agosto de 2022. Aceptado el 17 de abril de 2023

Abstract
Aquaponics is a food production technique that may be applied in the context of urban agriculture to help achieve food security and promote sustainable agriculture and production patterns, among other Sustainable Development Goals. Brazilian population is large and highly concentrated in urban areas and might benefit from this technique. Similar to any other production activity, aquaponic systems generate wastes that must be properly managed, but until now no study focused on waste generated on such systems or on management practices adopted by Brazilian producers; the goal of this article was to address both of these gaps. A systematic review identified waste streams generated on aquaponics, while management practices were seldom mentioned and addressed. A survey on producers located in 17 of the 27 Brazilian federal units helped confirm sludge, packaging waste, dead fish and unusable plant fractions as typical waste streams. It also identified a lack of concern for a more in-depth assessment of such streams to improve management practices, which tended to gravitate toward adequate and inadequate disposal. Finally, the article proposes management practices for each waste stream, drawing from strategies foreseen in Brazilian National Solid Waste Policy.

Keywords: aquaponic sludge; aquaponics; sustainable agriculture; urban agriculture; waste management.

[1] Postgraduate Programa in Technology, School of Technology, University of Campinas, Brazil.
* *Corresponding author:* School of Technology, University of Campinas, Rua Paschoal Marmo, 1888, Zip Code: 13484-332 Limeira, SP, Brazil. Email: marcocastro@ft.unicamp.br

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Introduction

Urban agriculture comprises agricultural activities adapted to economic and ecological systems of urban centers (Mougeot, 2000). Such practices include backyard gardens, community gardens or individual, vegetable gardens on roofs or greenhouses and bee keeping (Hammelman, 2019), as well as hydroponics and aquaponics. Marshall and Randhawa (2017) highlight the importance of urban agriculture in helping urban and peri-urban locations overcome large marginalization and poverty. For instance, of the 17 Sustainable Development Goals established by the 2030 Agenda, such practices may help “end hunger, achieve food security and improve nutrition and promote sustainable agriculture” (Goal 2) and “ensure sustainable consumption and production patterns” (Goal 12) (UN, 2015).

This might be the case with Brazil, the fifth largest country in the world by land area, with approximately 8.5 million km², with a population currently estimated in 214 million people (IBGE, 2022), 84.72% of whom live in urban areas (IBGE Educa, 2022). This large, highly concentrated population makes food security a challenge for Brazil. However, the Brazilian government has favored conventional agricultural systems, based on large-scale production of monocultures for export, with intense use of pesticides and chemical fertilizers, instead of small producers, more focused on organic food production (Nagib and Nakamura, 2020).

At the same time, aquaculture may benefit from high water availability, natural occurrence of species of interest and favorable climate conditions in the country (Brazil, 2013), but factors such as high production costs, low wages for producers, limitations of regional markets and fish mortality due to illnesses have limited its expansion. It also can lead to increased concentrations of nitrogen and phosphorous, causing eutrophication of water bodies, and organic matter on sediments, affecting oxygen availability (Henry-Silva and Camargo, 2008).

Hydroponics is a form of cultivation where plants roots are immersed in nutrient solutions without soil. Some of its benefits are pesticide reduction, less space for implantation and greater growth when compared to conventional cultivation (Santos, 2017). It also requires less water than conventional cultivation methods and presents good results with several vegetables (Cifuentes-Torres, 2020).

Nevertheless, over time, hydroponics revealed negative points as the need for constant maintenance, implying high costs and water consumption (Bontadine *et al.*, 2017). Water recirculation systems allowed lower water consumption per kilogram of fish produced (Azevedo *et al.*, 2014), but still faced difficulties regarding solid removal from water (Braz Filho, 2000).

Aquaponics combines hydroponics with fish production in a water recirculation system (Carneiro *et al.*, 2015). Unlike aquaculture systems, aquaponic effluents are not discarded: bacteria convert toxins such as ammonia from fish excreta into nitrite and then into nitrate,

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

which acts as a nutrient for plants which, in turn, function as filters, returning clean water to the fish tank (Javadzadeh *et al.*, 2019). This recirculation potentially reduces risks of environmental impacts such as soil contamination (Wu *et al.*, 2019), and water consumption is 90% lower than conventional production systems (Carneiro *et al.*, 2015).

Typical aquaponic systems are constituted by a fish farming tank, a mechanical filter for solids retention, a biofilter, a decanter and a hydroponic bed (Goddek *et al.*, 2015). In these systems, filter cleaning is fundamental, because nitrate or excess fish excreta accumulated in the bottom of the tank or in plant roots may prevent nutrient exchange, generating toxic substances (Rakocy *et al.*, 2006). Systems with fish densities greater than 10 kg m^{-3} generate significant amounts of waste (Carneiro *et al.*, 2015).

Such as any other food production technique, operation and maintenance of aquaponic systems generate waste. Poor feed digestion is a key factor for waste generation because it generates leftovers as well as fish excreta, which tend to settle in the tanks, becoming part of the sludge. Other reasons are feeding technique, inappropriate or low-quality food and overfeeding (Braz Filho, 2000). For each kilogram of feed, 0.3 kg of settleable solids are generated (Piper *et al.*, 1982).

In Brazil, Federal Law no. 12350/10 implemented the National Solid Waste Policy (NSWP), which establishes guidelines for integrated solid waste management. The NSWP classifies solid waste in eleven types according to their origin and three types according to their hazard level (Brazil, 2010). Bizon and Castro (2018) proposed classifying aquaponic systems waste as agriculture, forestry and farming waste because they are generated in agriculture and animal breeding. The Environmental Company of the State of São Paulo (CETESB) informs that these systems are not subjected to environmental licensing (CETESB, 2018) therefore their waste might be classified as nonhazardous/noninert (Licença, 2018). However, until now there are no explicit and/or extensive legal provisions about waste generated in aquaponic systems.

In this scenario, the goal of this study was to determine the typical waste streams generated on Brazilian aquaponic systems, as well as the current management practices adopted by local producers.

Materials and methods

Initially, interest in the term ‘aquaponics’ was assessed through Google Trends, a tool that provides a relative number of Google searches for a particular term (Vosen and Schimidt, 2011). It was used to quantify the searches on the term ‘aquaponics’ between January 2004 (earliest date available) and December 2021.

ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

The quantitative evolution of academic studies on the subject 'aquaponics' was then assessed through searches on Scopus, Web of Science and Science Direct databases for the term, considering the same time interval. Afterwards, a systematic review of solid waste generated in aquaponic systems was conducted according to the following protocol:

- Research question: "*Which types of solid waste are generated on aquaponic systems?*"
- Databases used: Scopus, Web of Science, Science Direct
- Language: only articles written in English
- Keywords: "waste AND generation AND aquaponics"
- Publication year: from 2004 to 2022, in order to keep the range close to previous searches
- Publication type: articles and review articles
- Selection procedure: results of the databases searches were exported to the EndNote Web webtool. Afterwards, the articles underwent a three-step selection process: title, abstract and then full text reading.
- Inclusion/exclusion criteria: articles addressing only physicochemical analysis of the process were excluded.

The resulting articles underwent a screening process performed in My EndNote Web. The screening steps were exclusion of duplicates, reading of titles and exclusion of articles not actually related to the topic and reading of the abstract and full text of the remaining articles.

An additional search on the same databases and timespan focused on the Brazilian production in the field by using 'aquaponics Brazil' as keywords. Screening steps excluded duplicates, results that were only indexes or summaries, articles that only mentioned the term 'aquaponics' but were not related to the topic, articles without access to full text, articles where the term 'Brazil' did not refer to the country (appearing as a surname, e.g.) and articles on researches not conducted in Brazil.

Afterwards, a survey was prepared on the basis of researches proposed by Bizon and Castro (2018) and Mchunu *et al.* (2018) and applied to Brazilian owners of aquaponic systems for a diagnosis of waste generation and management practices. Once an official registry of aquaponics producers was not found in the country at the time of the research, the survey was published on a social network page with a national reach, in addition to disclosure via phone contact to a study group related to the topic. The data collection period was from December 23, 2020 to March 5, 2021.

Finally, based on survey answers and strategies mentioned in the reviews and the Brazilian NSWP, the main waste streams generated on aquaponic systems were listed, along with potential management alternatives for each of them.

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica.
ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Results and discussion

According to Google Trends, research interest in 'aquaponics' evolved over time as shown in Fig. 1. Interest on the subject visibly peaked in 2013 and then diminished, albeit to a higher level than the initial years. No explanation was found for the 2013 peak.

The number of articles on aquaponics published in Scopus, Web of Science and Science Direct 164 grew steadily from 2010 until 2021, as Fig. 2 shows.

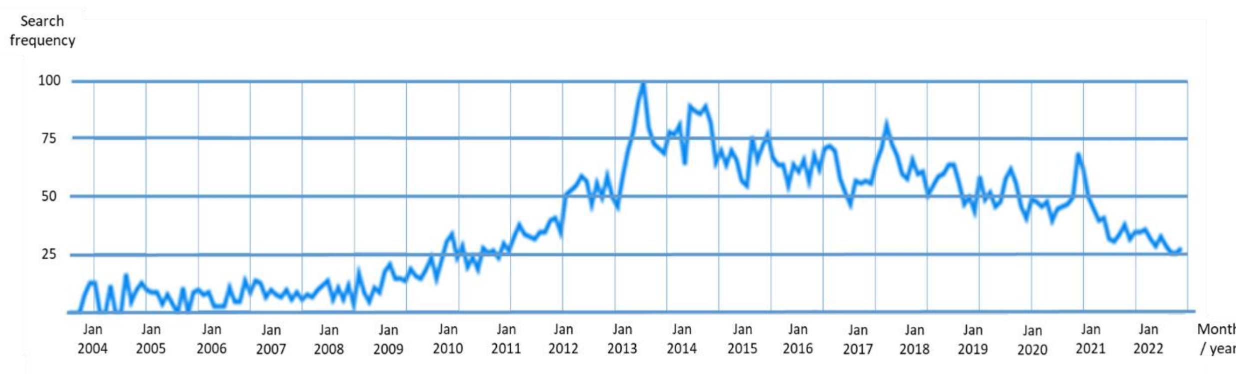

Figure 1. Worldwide research interest in 'aquaponics' (adapted from Google Trends, 2021).

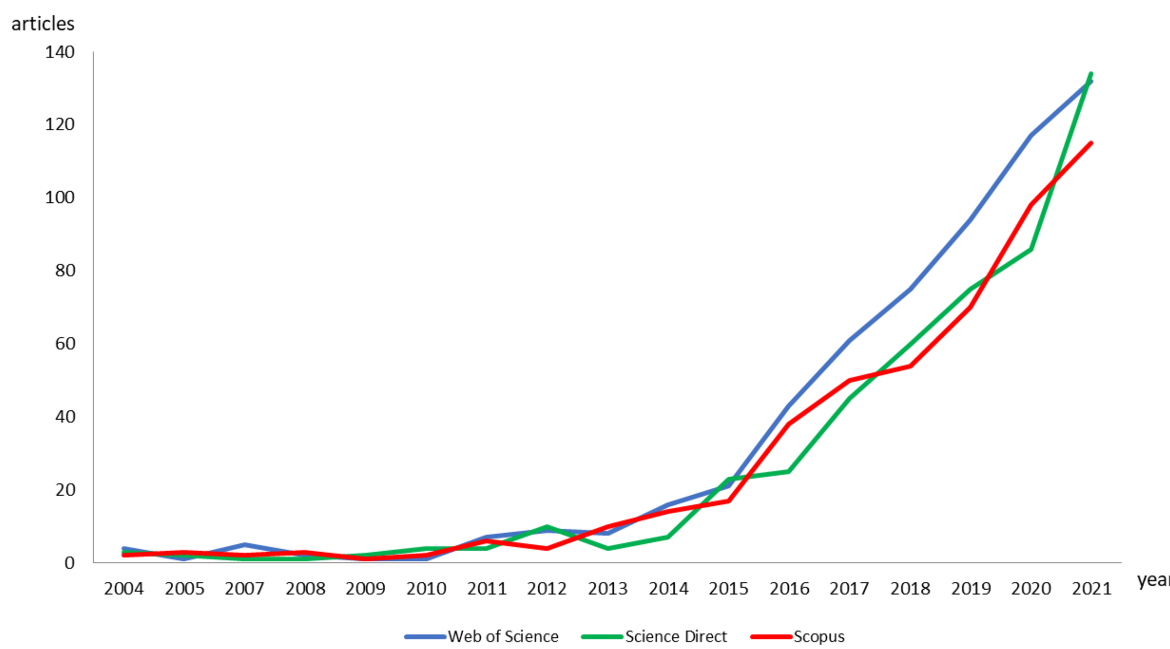

Figure 2. Articles on aquaponics published on Scopus, Science Direct and Web of Science.

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Systematic review

Searches conducted on February 25, 2022 retrieved 213 articles: 11 from Web of Science, 197 from Science Direct and 5 from Scopus. The screening process reduced this set of articles to 13, as shown in Table 1.

Table 1. Steps of the systematic review on aquaponics.

Step	References
Initial searches	213
After exclusion of duplicates	204
Ater title reading	45
After abstract reading	16
After full-text reading	

Among these thirteen articles, Buzby and Lin (2014) and Li *et al.* (2019) discussed water quality in aquaponics, Eck *et al.* (2019) and Estim *et al.* (2019) addressed biofilter bacteria, and Ghamkar *et al.* (2020) and Cohen *et al.* (2018) analysed the life cycle of an aquaponic system. Calone *et al.* (2019) and Endut *et al.* (2010) assessed nutrients present in wastewater, Karimanzira *et al.* (2016) modelled an aquaponic system, König *et al.* (2018) analysed aquaponics as an emerging technological innovation, and David *et al.* (2022) examined the sustainability of urban aquaponics farms. Suárez-Cáceres *et al.* (2020) studied the feasibility of microscale polyculture, and Abusin and Mandikiana (2020) approached what was called 'aquaponics 4.0'.

The articles that specifically addressed some kind of waste stream mentioned fish excreta (Abusin and Mandikiana, 2020), food particles and dust in the filter (Estim *et al.*, 2019), as well as solids and fish or vegetable parts that cannot be consumed or marketed (Ghamkar *et al.*, 2020). A study based on Life Cycle Assesment identified fish feed as one of the largest inputs of the system (Chen *et al.*, 2018). Indeed, Estim *et al.* (2019) mentioned removal of waste feed, fish waste and dead algae when cleaning the bottom of the fish tank, as well as fish mortality. Karimanzira *et al.* (2016) confirmed the types of waste found in aquaponic filters; also, through software simulation, classified the wastes generated in the aquaculture tank as readily biodegradable substrate; not readily biodegradable substrate; inert soluble organic material; inert particulate organic material; particulate products of biomass degradation; active heterotrophic biomass; and active autotrophic biomass.

The review did not find specific discussions on waste management alternatives or possible influences of process parameters on waste generation. An experiment on a 195 m² aquaponic farm revealed that the use of an anaerobic biodigester helped prevent the disposal of 255 liters

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X

http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

of sludge and 16.72 kg of organic matter over a year (David *et al.*, 2022), but the lack of other results prevented generalizations or average calculations.

The articles mentioned fish excreta, leftover feed, dust, algae, dead fish and nonconsumable vegetables as typical waste streams, originated in the fish tank or in the filter, the latter being the only one stemming from vegetable cultivation. Another finding is that these wastes are mostly organic, except for dust, which requires further analysis to determine its origin.

Review of Brazilian production

Searches on Brazilian production on the topic initially returned 139 results, later narrowed down to 27 articles, as shown in Table 2:

Table 2. Steps of the review on Brazilian production on aquaponics.

Step	References
Initial searches	139
Exclusion of duplicates	127
Exclusion of indexes and summaries	115
Exclusion of articles not related to 'aquaponics'	92
Exclusion of articles without access to full text	89
Exclusion of articles where 'Brazil' did not refer to the country	77
Exclusion of articles on studies not conducted on Brazil	27

Brazilian articles on aquaponics address some key points mentioned below:

- evaluation of different systems (Rocha *et al.*, 2017; Pinho *et al.*, 2021a), system scales (David *et al.*, 2022), combinations of vegetable and fish species (Pinho *et al.*, 2015; 2017; 2018; 2021b; Lima *et al.*, 2021), and vegetable and shrimp species (Pinheiro *et al.*, 2017; 2020; Lima *et al.*, 2019; Shardong *et al.*, 2020);
- comparison of 'traditional' and 'alternative' fish species (Pinho *et al.*, 2021c) and multitrophic systems with shrimp and tilapia cultures (Poli *et al.*, 2019);
- influence of parameters such as hydroponic solution concentrations (Sterzelecki *et al.*, 2021), fish densities (Hundley *et al.* 2018), nutrient supplementation techniques (Doncato and Costa, 2021), irrigation regimes (Silva *et al.*, 2022), salinity (Lenz *et al.*, 2017) and levels of crude protein in fish diets (Pinho *et al.*, 2021d) on system performance;
- strategies for preventing mineral deficiency in plants (Cerozi, 2020);
- adoption of aquaponics for familiar food production in urban (Colucci and Sganzetta, 2021) and rural areas (Silva and Van Passel, 2020), including assessment of drivers and barriers (Brewer *et al.*, 2021);
- remote monitoring of water quality (Valero *et al.*, 2020).

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica.
ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Most studies do not address waste streams that stem from aquaponic systems. Also, management alternatives for fish excreta are not addressed; the exceptions are Lenz *et al.* (2021a) and Lenz (2021b), where sludge removed from an aquaponic system was applied to soil to compare vegetable growth in this medium with aquaponic cultivation.

The review did not find investigations on possible influences of process parameters on aquaponic waste generation rates.

Case study

A total of 89 owners of aquaponic systems took part in the survey. They are located in 17 of the 27 Brazilian federal units (26 states and one Federal District), as shown in Fig. 3; the number of participants in each of the 17 units is presented in brackets.

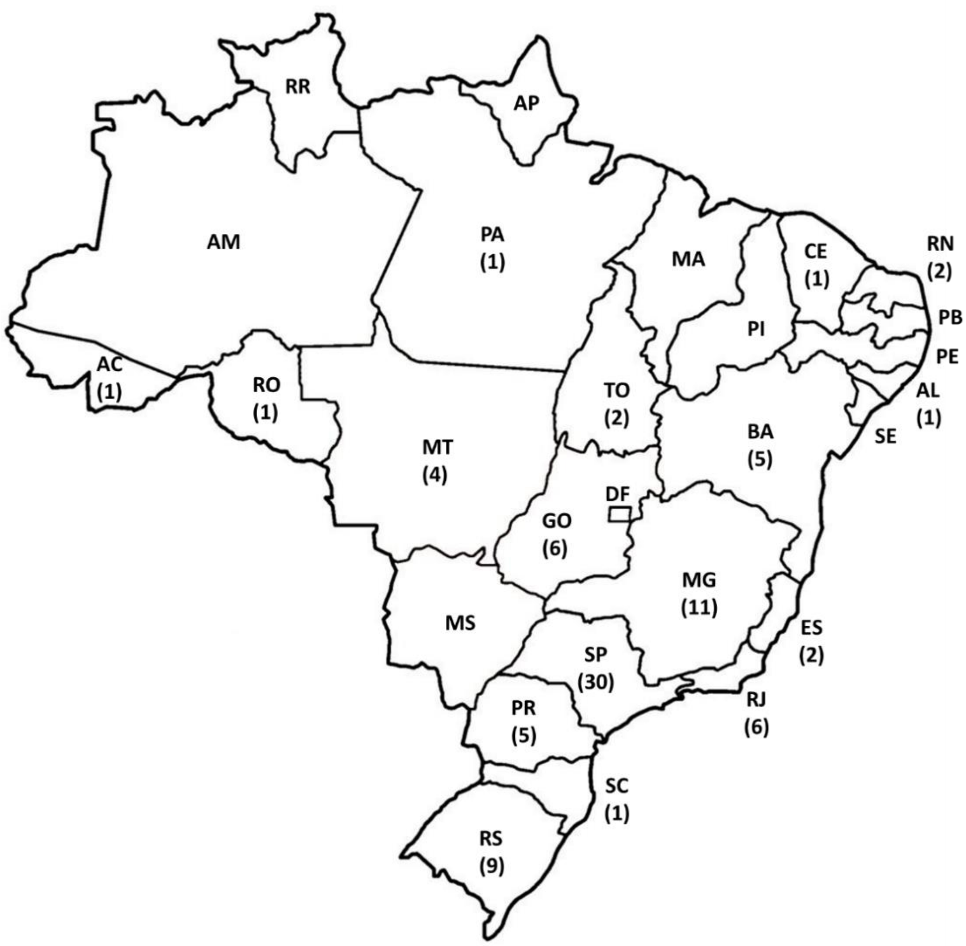

Figure 3. Geographic distribution of survey participants in Brazil (adapted from Depositphotos, 2021)

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Participants' concentration was perceptible: seven Federal Units accounted for over 80% of the answers, and the state of São Paulo (the most populated and rich state of Brazil) alone accounted for one third of them.

Of all the systems, 25 are classifiable as home-based - according Somerville *et al.* (2014), systems that use up to 1000 l of water and a hydroponic space of 3 m² are 'household systems' - and 54 are commercial-scale.

Ten of the 89 producers focus on growing vegetables, while 18 prioritize fish farming, and 61 focus on both. Tilapia was the fish most used (70%), while lettuce was the most grown vegetable (66%).

Regarding the ability in identifying diseases in plants, two producers affirmed to be specialists, while the majority (72%) reported having basic notions. When producers notice signs of deficiency in the plants, the most common measures are adding nutrient solutions (50%) and increasing the amount of feed (28%).

When asked about waste streams, 18 producers mentioned food packaging, but few specified the material, citing plastic, raffia and polyethylene bags. Sludge removed by filter cleaning was also addressed, and its destination is shown in Fig. 4; almost half (47.9%) of responding producers use it for direct fertilization of other cultures, while 9.4% send it to composting areas; disposal, recirculation and biodigestion were also mentioned, in descending order. Approximately 30% of the producers did not answer the question.

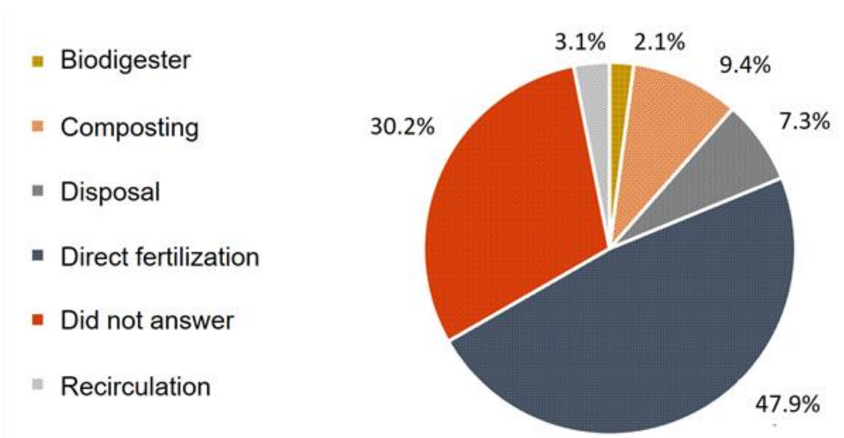

Figure 4. Strategies for sludge disposal adopted by Brazilian aquaponic producers

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

An open question allowed to identify additional types of waste: nylon bags, pruning of wilted plants or leaves, plastic cups (used to grow the seedlings), leftover food, PET bottles, leftover materials such as pipes, silicone tubes and acrylic blankets.

The answers indicated a lack of concern about characterizing waste types and quantities more precisely, regardless of systems scales: none of the responses mentioned the exact amounts of sludge or solid waste generated. Table 3 shows the destinations given by producers to each type of waste.

Table 3. Current strategies for aquaponic waste management adopted by Brazilian producers.

Waste material	Management strategy						
	Reuse	Recycling	Reverse Logistics	Disposal	Composting / vermicomposting	Biodigestion	Fertilization
Unused pipe				x			
Plastic cup				x			
Fish excreta				x	x	x	x
Plastic packaging		x		x			
Withered leaves					x	x	x
Acrylic blanket				x			
Leftover feed				x			X
Feed bags	X	x	x	x			
Silicone tubes				x			

Waste disposal was the most frequent alternative, which indicates that inadequate practices might be very common, despite the mentions to composting, fertilization and recycling.

Survey results confirm that aquaponic systems waste often requires simple management strategies to be diverted from landfills, and that should be made clear to producers. In this sense,

ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

proposals for environmentally adequate destinations for these wastes are summarized in Table 4, according to the hierarchy of strategies adopted by the National Solid Waste Policy:

Table 4. Management alternatives for aquaponics waste.

Waste	Management alternative
Withered leaves, dead vegetables	Composting (Judge et al 2017) Vermicomposting (Forchino et al, 2017)
Plant pruning	Composting (Manríquez-Altamirano et al, 2020)
Sludge	Soil fertilizing (Lenz et al, 2021a; b) Composting (Judge et al 2017; Delaide et al, 2019; Reinhardt et al, 2019) Vermicomposting (Reinhardt et al, 2019) Anaerobic digestion (Delaide et al, 2019)
Dead fish	Landfill disposal (Sitjà-Bobadilla and Oidtmann, 2017)
Packaging/bags	Recycling (Manriquez-Altamirano et al , 2020)
Plastic cups	Recycling (Manriquez-Altamirano et al , 2020)
Feed bags	Recycling (Manriquez-Altamirano et al , 2020)
Raffia sacks	Reuse, recycling (Sayadi-Gmada et al, 2020)
PET bottle	Recycling (Manriquez-Altamirano et al, 2020)
Batting	Recycling and reuse (Sandin and Peters, 2018)
Pipe	Recycling (Manriquez-Altamirano et al, 2020)
Silicone caulk tubes	Disposal, recycling (ASI, 2022; Henkel, 2022)
Dust	*subject to further analysis*

Regarding some of these waste streams, it is worth noting that:

- leftover feed, reported by producers, tends to settle in the tanks and become part of the sludge, as mentioned before;
- disposal of dead fish must be immediate, as they may serve as a disease source to the remaining stock, as well as fouling the water when decomposing, should be removed from the tank and disposed of immediately to avoid attacks of predators (Sitjà-Bobadilla and Oidtmann, 2017);
- raffia can be reused for up to 4 years, and then recycled (Sayadi-Gmada et al, 2020);
- polyester-based batting, pipes and silicone caulk tubes are used to set up structures and therefore are typically generated only in initial stages of the system. Silicone caulk tubes are made of HDPE, but the frequent presence of silicone residues in used cartridges, which cannot be separated with current methods, have prevented their proper recycling (ASI, 2022). A recently considered solution seeks to convert used cartridges into lightweight aggregate for utilization on cementitious based building blocks (Henkel, 2022).

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Conclusion

Brazil, with its large urban population, can benefit from aquaponic systems for food production, given its large urban population. The work reported here identified a crescent but small number of articles addressing aquaponics in the country, but none of them focused on waste management aspects, as this text does.

Survey results indicated that, although most responding producers had installations for commercial purposes, information on waste generation is rarely kept. Additionally, management practices are not well defined, and many wastes are discarded or receive a destination that is not always appropriate.

The review and the survey showed that aquaponics waste is comprised of materials that can be recycled or composted without any special pre-treatment, which eases up management. Aquaponic sludge is the most typical waste stream of these systems, however few studies have assessed proper management alternatives. In this sense, in order to assess and promote adequate practices for managing aquaponic waste in general - and aquaponic sludge in particular -, additional research on its resource recovery potential is much needed.

References

Abusin, S.A.A., Mandikiana, B.W. (2020) Towards sustainable food production systems in Qatar: Assessment of the viability of aquaponics. *Global Food Security*, **25**, 2020, 100349. https://doi.org/10.1016/j.gfs.2020.100349

ASI, Adhesives & Sealants Industry (2022) Recycling Silicone Sealant Cartridges. Accessed 24 March 2023, available at: https://www.adhesivesmag.com/articles/99155-recycling-silicone-sealant-cartridges

Azevedo, V.G., Neto, H.G., Almeida, H.L.P.S., Sanches, E.G. (2014) Sistemas de Recirculação para cultivo de peixes marinhos – Procedimento Operacional Padrão (POP). Accessed 08 February 2020, available at: https://www.researchgate.net/profile/Venancio_Azevedo/publication/267568293_Sistemas_de_Recirculacao_para_Cultivo_de_Peixes_Marinhos_-Procedimento_Operacional_Padrao_POP/links/545296490cf26d5090a37727.pdf *(In Portuguese)*

Bizon, L., Castro, M.A.S. (2018) Caracterização e propostas para gerenciamento de resíduos sólidos gerados em um sistema de aquaponia. *Proceedings of the XV National Congress on the Environment*, Poços de Caldas, Brazil. Accessed 20 January 2019, available at: https://www.meioambientepocos.com.br/Anais2018/Gerenciamento%20de%20Res%C3%ADduos%20S%C3%B3lidos%20e%20L%C3%ADquidos/276.%20CARACTERIZA%C3%87%C3%83O%20E%20PROPOSTAS%20PARA%20GERENCIAMENTO%20DE%20RES%C3%8DDUOS%20S%C3%93LIDOS%20GERADOS%20EM%20SISTEMAS%20DE%20AQUAPONIA.pdf *(In Portuguese)*

Bontadine, A.S., Lima, M.C., Kratz, D., Antunes, G., Hort, H., Martins, J.M., Pinheiro, L., Pontara, M.S., Schalm, M., Rothbarth, C., Bieging, J., Nazario J. (2017) Projeto e construção de um sistema de aquaponia para cultivação de chás e temperos em residências. Accessed 08 February 2020, available at: http://www.labcti.ufsc.br/aquaponia *(In Portuguese)*

Braz Filho, M.S.P. (2000) *Qualidade na produção de peixes em sistemas de recirculação de água.* Dissertation (Postgraduate Program in Quality Control in Companies). Centro Universitário Nove de Julho, São Paulo, 37 f. *(In Portuguese)*

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Brazil (2010) Federal Law No. 12.305/2010. *Política Nacional de Resíduos Sólidos*. Diário Oficial da União, Brasília, DF, 3 ago. 2010 *(In Portuguese)*.

Brazil (2013) Ministry of Fishing and Aquaculture. Boletim estatístico de pesca e aquicultura 2011, Accessed 12 April 2018, available at: https://www.icmbio.gov.br/cepsul/images/stories/biblioteca/download/estatistica/est_2011_bol__bra.pdf *(In Portuguese).*

Brewer, A., Alfaro, J.F., Malheiros, T.F. (2021) Evaluating the capacity of small farmers to adopt aquaponics systems: Empirical evidence from Brazil. *Renewable Agriculture and Food Systems*, **36**(4),1-9. https://doi.org/10.1017/S174217052000040X.

Buzby, K.M., Lin, L. (2014) Scaling aquaponic systems: Balancing plant uptake with fish output. *Aquacultural Engineering*, **63**(2014), 39-44. https://doi.org/10.1016/j.aquaeng.2014.09.002

Calone, R., Pennisi, G., Morgenstern, R., Sanyé-Mengual, E., Lorleberg, W., Dapprich, P., Winkler, P., Orsini, F., Gianquinto, G. (2019) Improving water management in European catfish recirculating aquaculture systems through catfish-lettuce aquaponics. *Science of The Total Environment*, **687**, 759-767. https://doi.org/0.1016/j.scitotenv.2019.06.167

Carneiro, P.C.F., Morais, C.A.R.S., Nunes, M.U.C., Maria, A.N., Fuijmoto, R.Y. (2015) Produção Integrada de Peixes e Vegetais em Aquaponia. *Documentos 189*. Embrapa Tabuleiros Costeiros, 27 p.

Castilho-Barros, L., Almeida, F.H., Henriques, M.B., Seiffert, W.Q. (2018) Economic evaluation of the commercial production between Brazilian samphire and whiteleg shrimp in an aquaponics system. *Aquaculture International*, **26**(5), 1187-1206. https://doi.org/10.1007/s10499-018-0277-8

Cerozi, B.D. (2020) Fulvic acid increases iron bioavailability in aquaponic systems: Theoretical designs and practical considerations to prevent iron deficiency in plants. *Aquacultural Engineering*, **90,** 102091. https://doi.org/10.1016/j.aquaeng.2020.102091

CETESB, Companhia Ambiental do Estado de São Paulo (2018) *Licenciamento ambiental*. Accessed 31 May 2018, available at: http://cetesb.sp.gov.br/licenciamentoambiental/outrosdocumentos/#1505276168403-123f1e6f-7bc3 *(In Portuguese)*

Cifuentes-Torres, L., Mendoza-Espinosa, L.G., Correa-Reyes, G., Daesslé, L.W. (2020) Hydroponics with wastewater: a review of trends and opportunities. *Water and Environment Journal*, **35**, 166-180. https://doi.org/10.1111/wej.12617

Cohen, A., Malone, S., Morris, Z., Weissburg, M., Bras, B. (2018) Combined Fish and Lettuce Cultivation: An Aquaponics Life Cycle Assessment. *Procedia CIRP*, **69**, 551-556. https://doi.org/10.1016/j.procir.2017.11.029

Colucci, A., Sganzetta, L.M. (2021) Chapter Sixteen - PolimiparaRocinha urban regeneration process: The role of “food design” for the sustainability of the Rocinha Favela in Rio de Janeiro. In: Massari S (ed.). *Transdisciplinary Case Studies on Design for Food and Sustainability*. Woodhead Publishing, 263-281. https://doi.org/10.1016/B978-0-12-817821-8.00002-3

Corrêa, R.S., Fonseca, Y.M.F, Corrêa, A.S. (2007) Produção de biossólido agrícola por meio da compostagem e vermicompostagem de lodo de esgoto. *Revista Brasileira de Engenharia Agrícola e Ambiental*, **11**(4), 420-426. https://doi.org/10.1590/S1415-43662007000400012 *(In Portuguese)*

David, L.H., Pinho, S.M., Agostinho, F., Costa, J.I., Portella, M.C., Keesman, K.J., Garcia, F. (2022) Sustainability of urban aquaponics farms: An emergy point of view. *Journal of Cleaner Production*, **331**, 129896. https://doi.org/10.1016/j.jclepro.2021.129896

Delaide, B., Monsees, H., Gross, A., Goddek, S. (2019). Aerobic and Anaerobic Treatments for Aquaponic Sludge Reduction and Mineralisation. In Goddek, S., Joyce, A., Kotzen, B., Burnell, G.M. (Eds.) Aquaponics Food Production Systems. Springer, Cham, 247-266. https://doi.org/10.1007/978-3-030-15943-6_10

Depositphotos. Map of Brazil. Accessed 21 January 2022, available at: https://static8.depositphotos.com/1100878/834/i/600/depositphotos_8347343-stock-photo-map-of-brazil-with-states.jpg

http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Doncato, K.B., Costa, C.S.B. (2021) Micronutrient supplementation needs for halophytes in saline aquaponics with BFT system water. *Aquaculture*, **531,** 735815. https://doi.org/10.1016/j.aquaculture.2020.735815

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*, **11**(2), 260. https://doi.org/10.3390/w11020260

Endut, A., Jusoh, A., Ali, N., Wan Nik, W.B., Hassan, A. (2010) A study on the optimal hydraulic loading rate and plant ratios in recirculation aquaponic system. *Bioresource Technology*, **101**(5), 1511-1517. https://doi.org/10.1016/j.biortech.2009.09.040

Estim, A., Saufie, S., Mustafa, S. (2019) Water quality remediation using aquaponics subsystems as biological and mechanical filters in aquaculture. *Journal of Water Process Engineering*, **30,** 100566. https://doi.org/10.1016/j.jwpe.2018.02.001

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

Ghamkhar, R., Hartleb, C., Wu, F., Hicks, A. (2020) Life cycle assessment of a cold weather aquaponic food production system. *Journal of Cleaner Production*, **244**: 118767. https://doi.org/10.1016/j.jclepro.2019.118767

Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K.V., Jijakli, H., Thorarinsdottir, R. (2019) Challenges of sustainable and commercial aquaponics. *Sustainability*, **7**(4), 4199-4224. https://doi.org/10.3390/su7044199

Google Trends (2021). Research interest in 'aquaponics'. Accessed 16 December 2021, available at https://trends.google.com/trends/explore?q=aquaponics&geo=BR

Hammelman, C. (2019) Challenges to supporting social justice through food system governance: examples from two urban agriculture initiatives in Toronto. *Environment and Urbanization*, **31**(2), 481-496. https://doi.org/10.1177/0956247819860114

Henkel (2022) Henkel named CRDC as winner of unique 'Seal the Cycle' initiative. Accessed 24 March 2023, available at: https://www.henkel.com/press-and-media/press-releases-and-kits/2022-03-18-henkel-named-crdc-as-winner-of-unique-seal-the-cycle-initiative-1633876

Henry-Silva, G.G., Camargo, A.F.M. (2008) Impacto das atividades de aqüicultura e sistemas de tratamento de efluentes com macrófitas aquáticas – relato de caso. *Boletim do Instituto de Pesca*, **34**(1), 163-173. Accessed 20 March, 2022, available at: https://www.pesca.sp.gov.br/boletim/index.php/bip/article/view/782 *(In Portuguese)*

Hundley, G.C., Navarro, F.K.S.P., Ribeiro, O.P., Navarro, R.D. (2018) Integration of Nile tilapia (*Oreochromis niloticus L.*) production *Origanum majorana L.* and *Ocimum basilicum L.* using aquaponics technology. *Acta Scientiarum-Technology*, **40**(1), 7. https://doi.org/10.4025/actascitechnol.v40i1.35460

IBGE, Instituto Brasileiro De Geografia e Estatistica (2022) Information on Brazil. Accessed 20 March, 2022, available at: https://www.ibge.gov.br/

IBGE Educa (2022). População rural e urbana. Accessed March 01 2022, available at https://educa.ibge.gov.br/jovens/conheca-o-brasil/populacao/18313-populacao-rural-e-urbana.html *(In Portuguese)*

Javadzadeh, P., Park, S., Whitworth, C. (2019) *Optimizing the Profit of a Medium Scale Home Aquaponics System*. Accessed 21 January 2022, available at: https://www.researchgate.net/publication/338396878_Optimizing_the_Profit_of_a_Medium_Scale_Home_Aquaponics_System?channel=doi&linkId=5e124b0b92851c8364b26fff&showFulltext=true

Junge, R.; König, B.; Villarroel, M.; Komives, T.; Jijakli, M.H. (2017) Strategic Points in Aquaponics. *Water,* **9**(3), 182. https://doi.org/10.3390/w9030182

Karimanzira, D., Keesman, K.J., Kloas, W., Baganz, D., Rauschenbach, T. (2016) Dynamic modelling of the INAPRO aquaponic system. *Aquacultural Engineering*, **75**, 29-45. https://doi.org/10.1016/j.aquaeng.2016.10.004

http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

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

Lenz, G.L., Loss, A., Lourenzi, C.R., Lopes, D.L.A., Siebeneichler, L.D.M., Brunetto, G. (2021b) Lettuce growth in aquaponic system and soil fertilized with fish sludge. *Aquaculture Research*, **52,** 5008-5021. https://doi.org/10.1111/are.15372

Lenz, G.L., Durigon, E.G., Lapa, K.R., Emerenciano, M.G.C. (2017) Lettuce (*Lactuca sativa*) production with effluent from a tilapia culture maintained in BFT and low salinity. *Boletim Do Instituto De Pesca*, **43**(4), 614-630. https://doi.org/10.20950/1678-2305.2017v43n4p614

Lenz, G.L., Loss, A., Lourenzi, C.R., Lopes, D.L.A., Siebeneichler, L.M., Brunetto, G. (2021a) Common chicory production in aquaponics and in soil fertilized with aquaponic sludge. *Scientia Horticulturae*, **281**, 109946. https://doi.org/10.1016/j.scienta.2021.109946

Li, C., Zhang, B., Luo, P., Shi, H., Li, L., Gao, Y., Lee, C.T., Zhang, Z., Wu, W. (2019) Performance of a pilot-scale aquaponics system using hydroponics and immobilized biofilm treatment for water quality control. *Journal of Cleaner Production*, **208**, 274-284. https://doi.org/10.1016/j.jclepro.2018.10.170

Licença. Instalações de aquaponia. April 12, 2018 (message received by marcocastro@ft.unicamp.br) *(In Portuguese)*

Lima, J.D., Bastos, A.M., Duarte, S.S., Santos, U.R.A. (2021) Are artificial semi-dry wetlands efficient in wastewater treatment from different fish densities and for lettuce production? *International Journal of Environmental Science and Technology*. Epub ahead of print 21 October 2021. https://doi.org/10.1007/s13762-021-03703-6

Lima, J.D., Duarte, S.S., Bastos, A.M., Carvalho, T. (2019) Performance of an aquaponics system using constructed semi-dry wetland with lettuce (*Lactuca sativa L.*) on treating wastewater of culture of Amazon River shrimp (*Macrobrachium amazonicum*). *Environmental Science and Pollution Research*, **26**(13), 13476-13488. https://doi.org/10.1007/s11356-019-04496-5

Manríquez-Altamirano, A., Sierra-Pérez, J.; Muñoz, P., Gabarrell, X. (2020) Analysis of urban agriculture solid waste in the frame of circular economy: Case study of tomato crop in integrated rooftop greenhouse. *Science of The Total Environment*, **734**, 139375. https://doi.org/10.1016/j.scitotenv.2020.139375

Marshall, F., Randhawa, P. (2017) Tackling poverty and food security: lessons from India's peri-urban frontier. *International Institute for Environment and Development*, p. 1-4. Accessed 21 January 2022, available at http://www.jstor.org/stable/resrep02592

Mchunu, N., Lagerwall, G., Senzanje, A. (2018) Aquaponics in South Africa: Results of a national survey. *Aquaculture reports*, **12**, 12-19. https://doi.org/10.1016/j.aqrep.2018.08.001

Mougeot, L.J.A. (2000) Urban agriculture: definition, presence, potential and risks. In: Bakker N, Dubbeling M, Gündel S, Sabel-koschella U and Zeeuw, H. (Ed.). *Growing cities, growing food: urban agriculture on the policy agenda*. Feldafing, Deutsche Stiftung fur Internationale Entwicklung (DSE), 1-42.

Nagib, G., Nakamura, A.C. (2020) Urban agriculture in the city of São Paulo: New spatial transformations and ongoing challenges to guarantee the production and consumption of healthy food. *Global Food Security*, **26**, 1-7. https://doi.org/10.1016/j.gfs.2020.100378

Pinheiro, I., Arantes, R., Espírito Santo, C.M., Vieira, F.N., Lapa, K.R., Gonzaga, L.V., Fett, R., Barcelos-Oliveira, J.L, Seiffert, W.Q. (2017) Production of the halophyte *Sarcocornia ambigua* and Pacific white shrimp in an aquaponic system with biofloc technology. *Ecological Engineering*, **100**, 261-267. https://doi.org/10.1016/j.ecoleng.2016.12.024

Pinheiro, I., Carneiro, R.F.S., Vieira, F.N., Gonzaga, L.V., Fett, R., Costa, A.C.O., Magallón-Barajas, F.J., Seiffert, W.Q. (2020) Aquaponic production of *Sarcocornia ambigua* and Pacific white shrimp in biofloc system at different salinities. *Aquaculture*, **519**, 1183–1184. https://doi.org/10.1016/j.aquaculture.2019.734918

Pinho, S.M., David, L.H.C., Goddek, S., Emerenciano, M.G.C., Portella, M.C. (2021b) Integrated production of Nile tilapia juveniles and lettuce using biofloc technology. *Aquaculture International*, **29**(1), 37-56. https://doi.org/10.1007/s10499-020-00608-y

Revista AIDIS de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica. ISSN 0718-378X
http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Pinho, S.M., David, L.H., Garcia, F., Keesman, K.J., Portella, M.C., Goddek, S. (2021c) South American fish species suitable for aquaponics: a review. *Aquaculture International*, **29**(4), 1427-1449. https://doi.org/10.1007/s10499-021-00674-w

Pinho, S.M., Lima, J.P., David, L.H., Emerenciano, M.G.C., Goddek, S., Verdegem, M.C.J., Keesman, K.J., Portella, M.C. (2021a) FLOCponics: The integration of biofloc technology with plant production. *Reviews in Aquaculture*, **00**, 1-29. https://doi.org/10.1111/raq.12617

Pinho, S.M., de Mello, G.L., Fitzsimmons, K.M., Emerenciano, M.G.C. (2018) Integrated production of fish (pacu *Piaractus mesopotamicus* and red tilapia *Oreochromis* sp.) with two varieties of garnish (scallion and parsley) in aquaponics system. *Aquaculture International*, **26**(1), 99-112. https://doi.org/10.1007/s10499-017-0198-y

Pinho, S.M., Lima, J.P., David, L.H., Oliveira, M.S., Goddek, S., Carneiro, D.J., Keesman, K. J., Portella, M.C. (2021d) Decoupled FLOCponics systems as an alternative approach to reduce the protein level of tilapia juveniles' diet in integrated agri-aquaculture production. *Aquaculture*, **543**(13). https://doi.org/10.1016/j.aquaculture.2021.736932

Pinho, S.M., Molinari, D., de Mello, G.L., Fitzsimmons, K.M., Emerenciano, M.G.C. (2017) Effluent from a biofloc technology (BFT) tilapia culture on the aquaponics production of different lettuce varieties. *Ecological Engineering*, **103**, 146-153. https://doi.org/10.1016/j.ecoleng.2017.03.009

Piper, R.G., Mcelwain, I.B., Orme, L.E., Mccraren, J.P., Folwer, L. G., Leonard, J.R. (1982) Fish hatcheries Management. US Fish and Wildlife Service, Washington DC.

Poli, M.A., Legarda, E.C., de Lorenzo, M.A., Pinheiro, I., Martins, M.A., Seiffert, W.Q., do Nascimento, V.F. (2019) Integrated multitrophic aquaculture applied to shrimp rearing in a biofloc system. *Aquaculture*, **511**, 812-813. https://doi.org/10.1016/j.aquaculture.2019.734274

Rakocy, J.E., Losordo, T.M., Masser, M.P. (2006) Recirculating aquaculture tank production systems: aquaponics: integrating fish and plant culture. *Aquaculture Center Publications*, **454**, 1-7.

Reinhardt, T., Hoevenaars, K., Joyce, A. (2019) Regulatory Frameworks for Aquaponics in the European Union. In Goddek, S., Joyce, A., Kotzen, B., Burnell, G.M. (Eds), *Aquaponics Food Production Systems*, Springer, Cham, 501-522. https://doi.org/10.1007/978-3-030-15943-6_20

Rocha, A.F., Biazzetti, M.L., Stech, M.R., da Silva, R.P. (2017) Lettuce production in aquaponic and biofloc systems with silver catfish *Rhamdia quelen*. *Boletim Do Instituto De Pesca*, **43**, 64-73. https://doi.org/10.20950/1678-2305.2017.64.73

Sandin, G. Peters, G. M. (2018) Environmental impact of textile reuse and recycling – A review, Journal of Cleaner Production, **184,** 353-365. https://doi.org/10.1016/j.jclepro.2018.02.266

Santos, A.A. (2017) Sistema de cultivo hidropônico. *Proceedings of the IV SIMTEC - FATEC Technology Simposium*, Taquaritinga, Brazil. *(In Portuguese)*

Sayadi-Gmada, S.; Torres-Nieto, J.M.; Parra Gómez, S.; García-García, M.C.; Parra-López, C. (2020) Critical point analysis in solid inorganic waste production in the protected cultivation systems in Almeria - approaches to reduce the impact. *Acta Horticulturae*, **1268**, 205-212. https://doi.org/10.17660/ActaHortic.2020.1268.27

Sitjà-Bobadilla, A.; Oidtmann, B. (2017) Integrated Pathogen Management Strategies in Fish Farming. In: Galina Jeney, G (ed.). Fish diseases: Prevention and control strategies, Academic Press, 119-144. https://doi.org/10.1016/B978-0-12-804564-0.00005-3

Schardong, R.M.F., Moro, M.F., Bonilla, O.H. (2020) Aquaponic system with white shrimp *Litopenaeus vannamei* rearing and production of the plants *Batis maritima*, *Sarcocornia neei* and *Sporobolus virginicus*. *Brazilian Archives of Biology and Technology*, **63**, 1-12. https://doi.org/10.1590/1678-4324-2020190118

Silva, H.V., Martins, M.A., Santo, C.M.E., Vieira, F.N., Rezende, P.C., Gonzaga, L.V., Fett, R., Seiffert, W.Q. (2022) Aquaponic production of sea asparagus and Pacific white shrimp using biofloc technology: Different irrigation regimes affect plant production of bioactive compounds and antioxidant capacity. *Aquaculture Research*, **53**(3), 1001-1010. https://doi.org/10.1111/are.15641

http://dx.doi.org/10.22201/iingen.0718378xe.2023.16.2.83120
Vol. 16, No.2, 518-534
6 de agosto de 2023

Silva, M.F.E, Van Passel, S. (2020) Climate-smart agriculture in the northeast of Brazil: an integrated assessment of the aquaponics technology. *Sustainability*, **12**(9),15. https://doi.org/10.3390/su12093734

Somerville, C., Cohen, M., Pantanella, E., Stankus, A., Lovatelli, A. (2014) Small-scale aquaponic food production. Integrated fish and plant farming. *FAO Fisheries and Aquaculture Technical Paper*, 589:262.

Sterzelecki, F.C., Santos, G.R., Gusmão, M.T.A., Carvalho, T.C.C., Reis, A.R., Guimarães. R., Santos, M.L.S., Melo, N.F.A.C., Luz, R.K., Palheta, G.D.A. (2021) Effects of hydroponic supplementation on Amazon river prawn (*Macrobrachium amazonicum Heller*, 1862) and lettuce seedling (*Lactuca sativa L.*) development in aquaponic system. *Aquaculture*, **543**, 1-6. https://doi.org/10.1016/j.aquaculture.2021.736916

Suárez-Cáceres, G.P., Fernández-Cabanás, V.M., Lobillo-Eguíbar, J., Pérez-Urrestarazu, L. (2022) Characterisation of aquaponic producers and small-scale facilities in Spain and Latin America. *Aquaculture International,* **30**, 517–532. https://doi.org/10.1007/s10499-021-00793-4

UN, United Nations (2015) Transforming our world: the 2030 Agenda for Sustainable Development. Accessed 16 June 2020, available at: https://sdgs.un.org/2030agenda

Valero, O.A.O., Trujillo, P.A.R., Valderrama, N.L.M., de Oliveira, M.E., Tech, A.R.B. (2020) Automated remote monitoring of water quality in aquaponic systems in São Paulo, Brazil. *RISTI - Revista Ibérica de Sistemas e Tecnologias de Informação*, **E31**, 223-235.

Vosen, S., Schmidt, T. (2011) Forecasting private consumption: survey-based indicators vs. Google Trends. *Journal of Forecasting*, **30**(6), 565-578. https://doi.org/10.1002/for.1213

Wu, F., Ghamkhar, R., Ashton, W., Hicks, A.L. (2019) Sustainable seafood and vegetable production: aquaponics as a potential opportunity in urban areas. *Integrated Environmental Assessment and Management*, **15**(6), 832-843. https://doi.org/10.1002/ieam.4187