AQUAPONICS IN BRAZIL: REVIEW AND SURVEY ON WASTE MANAGEMENT PRACTICES

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.
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,
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 Schmidt, 2011). It was used to quantify the searches on the term ‘aquaponics’ between January 2004 (earliest date available) and December 2021.
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.
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 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.
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.

<table>
<thead>
<tr>
<th>Step</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial searches</td>
<td>213</td>
</tr>
<tr>
<td>After exclusion of duplicates</td>
<td>204</td>
</tr>
<tr>
<td>After title reading</td>
<td>45</td>
</tr>
<tr>
<td>After abstract reading</td>
<td>16</td>
</tr>
<tr>
<td>After full-text reading</td>
<td></td>
</tr>
</tbody>
</table>

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 Assessment 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
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>
<thead>
<tr>
<th>Step</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial searches</td>
<td>139</td>
</tr>
<tr>
<td>Exclusion of duplicates</td>
<td>127</td>
</tr>
<tr>
<td>Exclusion of indexes and summaries</td>
<td>115</td>
</tr>
<tr>
<td>Exclusion of articles not related to ‘aquaponics’</td>
<td>92</td>
</tr>
<tr>
<td>Exclusion of articles without access to full text</td>
<td>89</td>
</tr>
<tr>
<td>Exclusion of articles where ‘Brazil’ did not refer to the country</td>
<td>77</td>
</tr>
<tr>
<td>Exclusion of articles on studies not conducted on Brazil</td>
<td>27</td>
</tr>
</tbody>
</table>

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).
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)
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
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.

<table>
<thead>
<tr>
<th>Waste material</th>
<th>Management strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reuse</td>
</tr>
<tr>
<td>Unused pipe</td>
<td></td>
</tr>
<tr>
<td>Plastic cup</td>
<td>x</td>
</tr>
<tr>
<td>Fish excreta</td>
<td>x</td>
</tr>
<tr>
<td>Plastic packaging</td>
<td>x</td>
</tr>
<tr>
<td>Withered leaves</td>
<td>x</td>
</tr>
<tr>
<td>Acrylic blanket</td>
<td>x</td>
</tr>
<tr>
<td>Leftover feed</td>
<td>x</td>
</tr>
<tr>
<td>Feed bags</td>
<td>x</td>
</tr>
<tr>
<td>Silicone tubes</td>
<td>x</td>
</tr>
</tbody>
</table>

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

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).
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


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


