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

Characterisation of aquaponic producers and small-scale facilities in Spain and Latin America

Gina Patricia Suárez-Cáceres[1] · Víctor M. Fernández-Cabanás[2] · José Lobillo-Eguíbar[2] · Luis Pérez-Urrestarazu[1]

Received: 8 July 2021 / Accepted: 14 October 2021

Abstract
Aquaponics is a sustainable food production system combining hydroponics and aquaculture. Although the domestic/small-scale aquaponic production has proliferated worldwide, there is scarce knowledge about how it is performed. The objective of this study was to determine the profile and motivations of aquaponic producers, the characteristics of the facilities and the performance of the production. The average aquaponic producer is a middle-aged man, with a certain level of studies and a moderate household income. The main motivations reported were the production of high-quality, healthy food, the concern for the environment and the autonomy gained. These motivations conditioned the purposes of the aquaponic facilities (mainly education, production of food for self-consumption and as a hobby), which, excepting small sales, did not have an economic motive. Due to their characteristics, aquaponic facilities are particularly adapted for urban agriculture (many of them were located on rooftops) and most of those studied were constructed recently. The nutrient film technique was the most used hydroponic subsystem, followed by media beds, where mostly a polyculture of leaf and fruit vegetables and aromatics are produced. Tilapia was the most common fish species used. In general, there is a lack of proper knowledge and expertise about these complex systems in order to efficiently operate them.

Keywords Aquaculture · Hydroponic production · Urban farming

✉ Gina Patricia Suárez-Cáceres
gscaceres@us.es

Víctor M. Fernández-Cabanás
victorf@us.es

José Lobillo-Eguíbar
pepelobillo@yahoo.es

Luis Pérez-Urrestarazu
lperez@us.es

[1] Urban Greening and Biosystems Engineering Research Group, Area of Agro-Forestry Engineering, Universidad de Sevilla, ETSIA, Ctra, Utrera km.1, 41013 Seville, Spain

[2] Urban Greening and Biosystems Engineering Research Group, Dpto. Agronomía, Universidad de Sevilla, ETSIA, Ctra, Utrera km.1, 41013 Seville, Spain

Published online: 20 October 2021

Introduction

Aquaponics is the beneficial integration between hydroponics (production of plants without soil) and aquaculture (production of aquatic animals) (Love et al. 2014). The effluents from aquaculture are used as a nutrient solution for plant growth, thus improving the quality of the water that is then returned to the fish (Hasan et al. 2017) or disposed of.

Aquaponics is considered a model of sustainable food production (Goddek et al. 2015), an innovative farming technique with the potential to produce food to cope with the population growth and the impacts of climate change on food security (Wongkiew et al. 2020).

Aquaponic production can be performed in many different environments and settings, scales and for varied purposes, such as commercial, educational, as entertainment or a hobby, research, or food production for subsistence and domestic use (family self-consumption). Commercial facilities tend to be larger systems as a positive relationship between size and productivity has been described (Tokunaga et al. 2015). Smaller aquaponic systems are common when the aim is non-commercial.

The categorisation of small aquaponic facilities is somewhat variable. Some authors consider small installations those between 50 and 200 m^2, very small between 5 and 50 m^2 and micro systems < 5 m^2 (Maucieri et al. 2018), while others define Small-scale Aquaponic Systems (SAS) as those with a total covered area under 20 m^2 (Palm et al. 2018; Pérez-Urrestarazu et al. 2019).

Although the domestic/small-scale aquaponic production has proliferated worldwide, there are no reliable official censuses. However, there is a wide variety of forums and groups on small-scale aquaponics through social networks that seem to show the expansion of this type of aquaponics. These forums have decisively contributed to expanding and sharing knowledge about aquaponics (Somerville et al. 2014). In Spain for example, the ACUASF network (http://acuaponiasinfronteras.org/) groups together almost 200 aquaponic family producers. In the case of Latin America, there are associations such as 'Asociación de Acuaponía en Colombia' (https://www.adacol.org/), or online groups like 'Acuaponia e Hidroponia Latinoamerica' (https://www.facebook.com/groups/1618976174981253) and 'Acuaponía, alimentación saludable y soberanía alimentaria' (https://www.facebook.com/groups/403903370437106).

There are many different techniques and systems for small-scale aquaponic production which are still not well known. Therefore, characterising this type of production is interesting to evaluate its potential and define strategies for its development. In that sense, it is also important to know the motivations for starting an aquaponic project. Surveys are often employed for this purpose.

There are already some studies based on questionnaires addressed to aquaponic producers. For example, Love et al. (2014, 2015a, b) documented the production methods, experiences, motivations and demographics of aquaponic practitioners through an online survey mainly distributed in the USA and Australia. The vast majority of responses corresponded to commercial facilities, as one of the main focuses of the studies was to determine the profitability of commercial aquaponics.

Villarroel et al. (2016) assessed the state of the art of aquaponic producers and installations in Europe by means of 68 online questionnaires. However, in this study, Spanish participants only represented 5% of the total number of participants. Turnsek et al. (2020) performed two surveys to quantify the experience and expectations of aquaponic entrepreneurs and to assess the commercialisation of aquaponics in Europe in general and in France alone (obtaining 60 and 43 responses, respectively). Mchunu et al. (2018) obtained

44 responses to a questionnaire aimed at collecting information about the types of systems used, the management and distribution of aquaponics in South Africa. However, there are not any studies of these characteristics specifically aimed at small-scale aquaponics, especially in Spanish-speaking countries.

Therefore, the objectives of this study were:

(i) to determine the profile of small-scale aquaponic producers, their characteristics and training, in Spain and Latin America (who?).
(ii) to identify the main motivations for this type of aquaponic production as well as its purpose (i.e. self-supply of food, education, leisure, research) (why?).
(iii) to characterise the aquaponic facilities, the production (i.e. main plant and animal species used, produce obtained, inputs needed) and the challenges observed (how?).

Methodology

Questionnaire design and survey distribution

The questionnaire was prepared in Spanish to be answered online through Google Forms. It was distributed using the snowball method, through links on websites related to aquaponics and hydroponics, social networks (WhatsApp, Facebook, Twitter, LinkedIn) and by e-mail.

The questionnaire was available from May 13 to June 18, 2020 and included a brief introduction to the research group responsible for the study and its objectives. It also informed about the anonymity, confidentiality, handling and use of the collected data.

The questionnaire had both open and closed questions and had 42 questions. The first part of the questionnaire was devoted to acquiring sociodemographic characteristics about the participants. The second part included questions about objectives and reasons for their involvement in aquaponics. The third part concerned the characterisation of the hydroponic and aquaculture facilities. The last section was meant to recover information about the operation and maintenance of the aquaponic installation (Online Resource 1).

Data analysis

Descriptive statistics were used to process the data using Microsoft Office Professional Plus—Excel 2016®.

Results

Technical aspects

Characteristics of the aquaponic facilities

Regarding their location, 26.4% of the respondents had their aquaponic systems in a yard, 22.6% in an agricultural plot, 18.9% on a rooftop, 11.3% inside their house, 9.4% in a garden and the remaining 13.3% in educational centres, sheds, greenhouses, terraces or periurban parks.

As to the weather protection methods used, 34.0% of the respondents reported having the aquaponic systems inside plastic greenhouses, 18.9% used a greenhouse with shade screens, and only two respondents used a glass greenhouse. 13.2% had them inside a shed, garage or small room and 5.7% only installed a small roof as a cover. 26.4% used no protection at all.

Most producers (88.7%) used coupled systems (the water returns to the fish tank after circulating through the hydroponic subsystem), while 9.4% of them had decoupled systems (the water does not return to the fish tank) and 1.9% did not respond.

According to the hydroponic system installed, 54.7% of respondents used the nutrient film technique (NFT), 45.3% deep water culture (DWC), 39.6% media beds and 5.7% had other types of systems. In Fig. 1, the percentage of producers in relation to the objective of their installations and the type of hybrid system used is shown.

Most respondents (69.8%) had their facilities connected to the electricity grid, while the rest had solar panels.

The participants were asked about the total volume of water that they had in their systems' fish tanks. 13.2% reported having more than 5000 L, 17% had between 2000 and 5000 L, 22.6% had between1000 and 1999 L, while 18.9% reported having between 500 and 999 L and 28.3% less than 500 L.

The water source mainly used was the drinking water network (67.9% of the cases), while 20.8% obtained the water from wells, 13.2% from surface water courses (rivers, streams, lakes, swamps, etc.), 9.4% from rainwater and 1.9% from reverse osmosis.

Plant and aquaculture production

The majority of the respondents (50.9%) dedicated in their facilities less than 10 m^2 to plant production, 13.2% used 11–25 m^2, 7.5% were in the range 26–50 m^2, 13.2% between 51 and 100 m^2 and 13.2% of them devoted more than 100 m^2.

81.1% of the respondents grew different plant species (polyculture) while the rest cultivated only one (monoculture). According to the purpose of the aquaponic facility, those

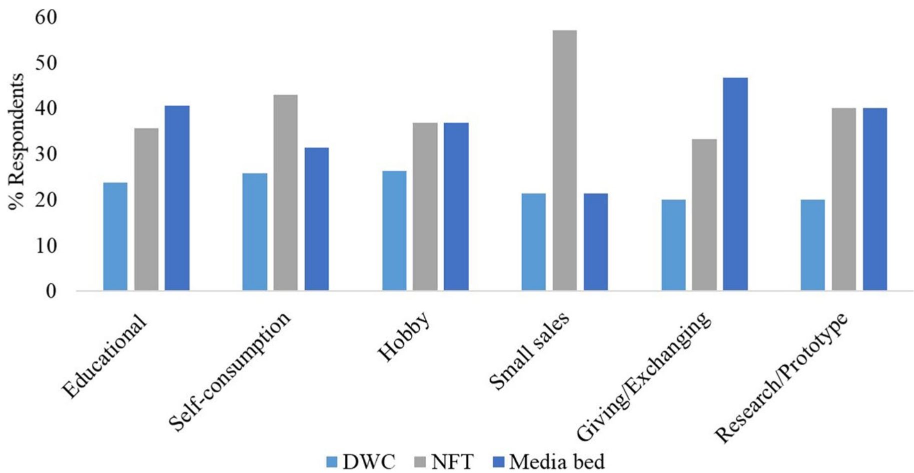

Fig. 1 Hydroponic system used depending on the objective of the facilities. DWC, deep water culture; NFT, nutrient film technique

intended for small sales and self-consumption used mostly polycultures, while only 75% of those with an educational or hobby objective had different species at the same time.

The most usual type of crops produced in the aquaponic systems were leafy greens (lettuce, chard, kale, etc.) (grown by 81.1% of the respondents), fruit vegetables (tomato, cucumber, courgette, etc.) (66.0%), aromatic crops (basil, mint, coriander, etc.) (60.4%) and ornamentals (carnation, gerbera, etc.) or medicinal crops (17.0%).

Most respondents (54.7%) obtained an annual horticultural production between 1 and 10 kg/m^2, 7.5% between 11 and 20 kg/m^2 and 7.6% produced more than 20 kg/m^2. 30.2% did not respond to this question. Table 1 shows the average annual plant production depending on the destination, type of production and hydroponic system used.

Regarding the cultivated species in aquaculture, 69.8% of the respondents produced tilapias, 9.4% crustaceans and 9.4% carps. Other type of animals introduced in these systems were: trout, tench, catfish, gambusia, eels, molluscs, cachama, chame, turtle and others (ornamental fish such as guppies, loricariids, tetras, cichlids, etc.).

Regarding the animal production obtained, most respondents did not know this data or did not respond the question.

Operation and maintenance of the aquaponic facilities

More than half of the respondents (52.8%) did not receive any technical advice regarding the design of aquaponic installations. They obtained information from web pages (69.8%), books (54.7%) and/or asking acquaintances with some expertise in the subject (47.2%). The remaining 47.2% reported having received training courses.

Regardless of the way they acquired their knowledge about aquaponics, 49.1% believed to still need additional training in aquaculture (feeding, management, health, etc.) and 47.2% in plant production (nutrition, management, crop protection, etc.).

Table 1 Annual plant production in relation to destination of productions, type of plant production and hydroponic system used

Variable	Category (% in that category)	Annual plant production (kg/m^2)
Destination of production*	Self-consumption (73.6%)	14.4 ± 25.0
	Small sale (32.1%)	10.0 ± 15.2
	Exchange (26.4%)	22.1 ± 33.6
Type of production	Monoculture (18.9%)	13.4 ± 17.0
	Polyculture (81.1%)	11.6 ± 23.3
Hydroponic system**	Deep water culture (DWC) (45.3%)	9.3 ± 11.6
	Nutrient Film Technique (NFT) (54.7%)	15.7 ± 27.4
	Inert substrate cultivation (media bed) (39.6%)	9.5 ± 13.5

*Multiple selection question. For the categories: 'donation', 'species conservation', 'education' and 'ornamental' no consideration was given to the mean and standard deviation because there were less than three responses.

**Multiple selection question. For the category 'other', no consideration was given to the mean and standard deviation because there were less than three responses.

49.1% of the respondents had their aquaponic facility in operation for less than 1 year, 32.1% between 1 and 2 years, 5.7% between two and three years and 9.4% of the installations had been running for more than three years. A total 83% of the respondents still had their facilities running.

The main problems reported by the respondents were regarding the maintenance of the systems (73.6%), a lack of knowledge or expertise (20.8%), economic issues (9.4%) and difficulties in the construction (7.5%). 1.9% did not state any problems.

67.9% of the respondents spent between 1and 10 h/week on their aquaponic installation, 22.6% between 11and 20 h/week, 3.8% between 21and 30 h/week, 3.8% between 31and 40 h/week and 1.9% did not respond. Additionally, in 50.9% of the cases only one person was operating the facilities, 28.3% of them had 2 people, 7.5% had 3 people, 3.8% had 4 people and 3.8% had 5 or more people.

43.4% of producers did not respond about how much money they spent per month on their aquaponic facilities, 37.7% spent between 1and 50 euros/month, 9.4% spent between 51and 100 euros/month, 5.7% spent more than 100 euros/month and 3.8% did not know. Only 17.0% received external funding for the construction and/or maintenance of the aquaponic facilities.

Maintenance of plant production In relation to the use of additional or corrective nutrients during the growing cycle, 28.3% of the respondents added iron, 26.4% potassium, 24.5% a commercial plant nutrient mix, 22.6% calcium, 11.3% manganese and 9.5% manure, guano, worm leachate and carbon dioxide. 17.0% did not use any additive and 15.1% did not respond. The combination of some of them was also common (e.g. iron + potassium + calcium).

The main pests affecting the crops were aphids (47.2%), white flies (32.1%), mites (red spider…) (15.1%) and caterpillars (11.3%). Other pests reported were grasshoppers/locusts, trips, ants, earwigs, snails, iguanas and birds. 9.4% reported not having any pests and 7.5% did not respond.

Among the respondents who reported pest problems, 37.5% used biological control methods (predators or parasites), 22.9% traps (adhesive films…), 12.5% nettle slurry and 10.4% sulphur. Other less employed methods were potassium soap, kaolin, aromatic plants, neem oil, tobacco or hot chili. 4.2% of the respondents did not use any control method.

The main diseases in their crops were fungal related, 52.8% aerial (powdery mildew, botrytis, mildew, etc.) and 13.2% affected the roots. 5.7% indicated bacterial and virus diseases. Among the respondents reporting diseases, 36.8% treated them with Bio Control Agents (BCA), 26.3% used sulphur and 2.6% applied chemical treatments.

Maintenance of fish production A commercial compound feed was used by most respondents (77.4%) while 22.6% used self-made feed.

The main problems with the animal production were fungal diseases (11.3%), poor water quality (17.0%) and algae (3.8%). 24.5% indicated no problems. These issues were avoided by filtering and renewing the water (40.0%), performing a physical water treatment (28.9%), using antibiotics (15.0%), salt baths against diseases (15.0%), essentials oils, biocompounds, increasing the number of plants in the system or reducing the animal density. Some respondents also reported problems related with septicemia or stressed animals.

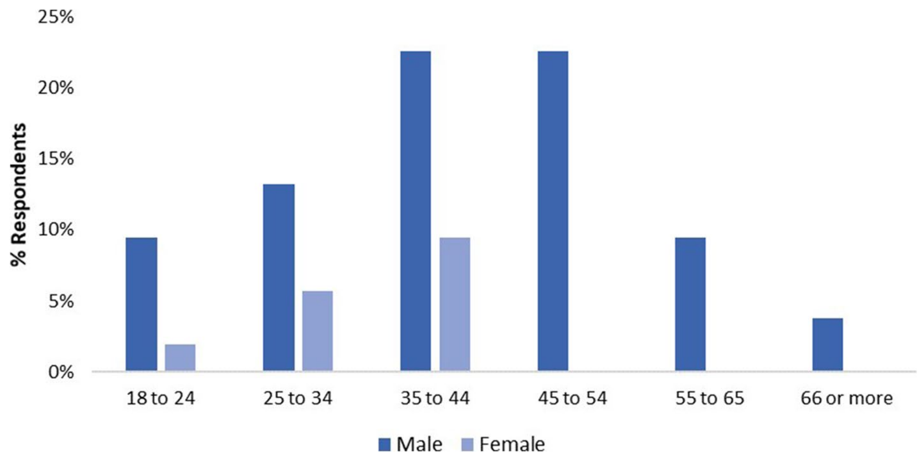

Fig. 2 Respondents' distribution (% over total responses) by gender and age

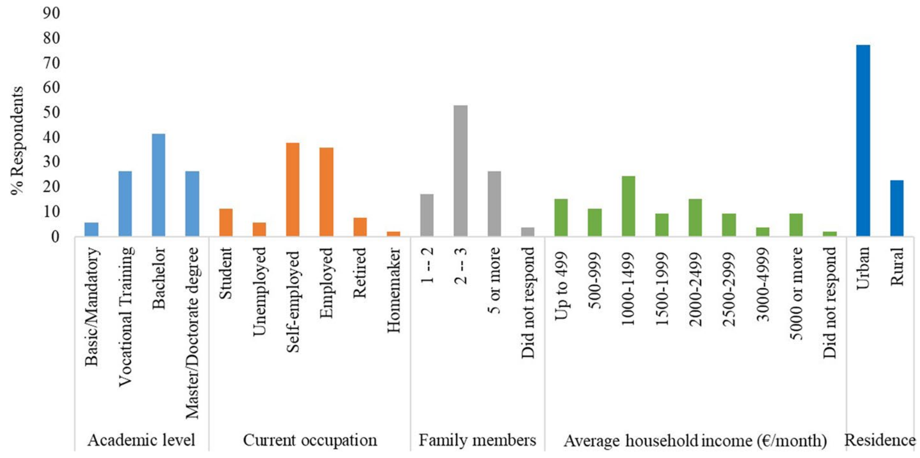

Fig. 3 Sociodemographic characteristics of the participants

Sociological perspective

Demographic data and the participants' characteristics

The total number of participants was 53, 41.5% from Spain and 58.5% from Latin American countries, mainly from Mexico and Colombia. Figure 2 shows the distribution or respondents by gender and age. Their sociodemographic characteristics are shown in Fig. 3.

The majority of the respondents (84.9%) did not belong to any aquaponic production society or group.

Objectives and motivations

The main motivation to start this type of production seems to be obtaining healthy food, free of pesticide residues (food safety), as expressed by 71.7% of the respondents. Other highly selected motivations were the concern for the environment (58.5%), the production of high-quality food (50.9%) and gaining autonomy (i.e. producing part of the food they needed) (49.1%). Some mentioned their wish to continue learning new things (45.3%), to save money on food purchases and have some income (35.8%) or to share knowledge with others (34.0%). 28.3% practiced this production for fun, and 24.5% to feel useful. 18.9% remarked health reasons (i.e. doing a moderate physical activity). 11.3% of respondents selected all the options provided as motivations.

In terms of the objectives intended for the aquaponic facilities, 52.8% of the respondents indicated that they had an educational (schools, farm schools, etc.) purpose. For 49.1% of the participants, the objective was the production of food for self-consumption and 30.2% did it as a hobby. 20.8% reported using the produce for small sales and 20.8% for the exchange of goods. In 13.2% of the cases, the aquaponic facilities had a research objective. It is important to note that this question allowed multiple responses. The combinations of objectives most frequently answered were the following: educational + self-consumption + gift and exchange (7.5%); educational + self-consumption (5.7%); and self-consumption + small sales (5.7%). Figure 4 shows the combination between the purposes of the aquaponic facility and the reasons that motivated starting the aquaponic project.

The products obtained were mainly destined for self-consumption (73.6%), for sale (32.1%) or for exchange (26.4%). The rest (13.3%) reported other uses, such as donation, species conservation, educational or ornamental.

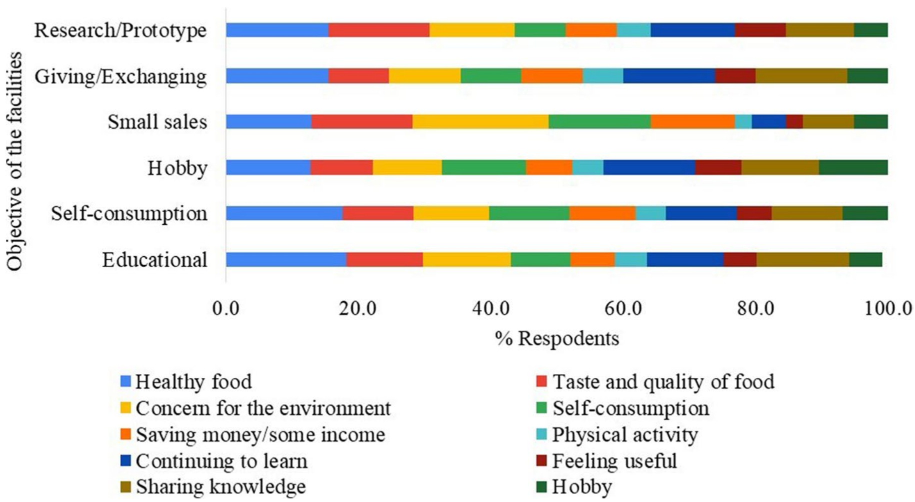

Fig. 4 Relation between the objective of the facilities and the motivations for starting an aquaponic project. The percentage shown in the bars denotes the percentage of producers selecting objective and motivation at the same time

Discussion

Due to the lack of information related to a regional census of aquaponic producers, it was difficult to reach many existing producers in Spain and Latin America to be surveyed. Precisely, this is one of the main constraints of this research, given the low number of responses obtained (which also happened in other similar studies). Despite that, the data acquired was useful to define the main characteristics of small-scale aquaponic producers and their motivations, as well as to characterise their facilities and production operations.

In addition, acquiring information about aquaponic production is complex due to the heterogeneity of system designs, socio-economic and climatic conditions, choice of plant and fish species, etc.

Characteristics and management of small-scale aquaponic facilities

One of the advantages of small-scale aquaponic systems is that they allow a production in small places and do not need special requirements of land. Therefore, they can easily be installed in urban settings. In fact, only 23% of the respondents had their facilities in a non-urbanised location. Surprisingly, a high percentage of the aquaponic facilities included in our study were located on rooftops (nearly 20%), which usually involves using a reduced volume of water to avoid problems due to an overloading of building structures. However, very few of them were inside buildings. Conversely, Love et al. (2014) only reported 3% of the facilities placed on rooftops, while 28% of them were inside buildings. In the study carried out by Villarroel et al. (2016), 7.5% of the aquaponic systems were located on rooftops. This is in line with the increasing trend for the installation of small rooftop food production systems, such as small urban orchards and small-scale hydroponic systems (Orsini et al. 2017).

In our study, more than half of the facilities used the NFT in the hydroponic subsystem to grow plants, followed by DWC and media beds. In contrast, Love et al. (2014) reported that the majority of respondents (86.0%) used media beds, 46% floating rafts and only 19% NFT. Villarroel et al. (2016) also showed floating rafts and media beds as the most commonly used methods while NFT was less employed. Mchunu et al. (2018) also observed that most (96%) aquaponic facilities in South Africa were based on media beds.

These differences in the hydroponic subsystem could be associated with water availability and the type of vegetables produced in the regions studied. Also, while media beds are more advisable when growing larger species, their maintenance is usually more cumbersome (cleaning the substrate). For this reason, it is common to combine hydroponic subsystems in the same aquaponic facility. In our study, for instance, 13.2% of the respondents reported having both an NFT and a media bed, and 11.3% included a DWC, an NFT and a media bed in the same system.

The objective intended for the aquaponic system also seems to have a slight influence on the selection of the hydroponic system (Fig. 1). For instance, the NFT was the one most frequently used to produce food for self-consumption or for small sales, while media beds were more common in educational facilities or for giving and exchanging products.

It is important to note than most aquaponic facilities were coupled systems. In coupled or one-loop aquaponic facilities, the nutrient flow goes from the aquaculture to the hydroponic system and back again to the former (Palm et al. 2019). The abundance of these type of facilities in our study is intrinsically related to their classification as small-scale producers, where it is universally implemented. On the contrary, in modern commercial aquaponic farms, the use of decoupled or multi-loop systems is preferred, where the flow goes just in one direction (from fish tanks to hydroponic beds) and can include mineralisation or distillation/desalination loops that optimise the production process and minimise the use of water and fertiliser (Goddek et al. 2019).

Although most facilities were powered by the electricity network, the number of those including any form of renewable energy source was noteworthy. This was also observed by Love et al. (2014). In their study, 57% of the participants used other sources of energy (solar panels, wood or pellet burning stoves, compost, geothermal and wind energy). This is an important issue, given that a great part of the operation costs of aquaponic systems is due to energy consumption (Ghamkhar et al. 2020; Lobillo-Eguíbar et al. 2020; Maucieri et al. 2018).

It was observed that the users of these aquaponic systems do not usually monitor their production of vegetables and fish (especially the latter). Furthermore, plant diseases control and treatment were barely described. There are two possible explanations for this. On one hand producers, might not have much knowledge about plant diseases and how to control them. On the other hand, it is possible that the incidence of diseases was lower in these productive systems.

In this sense, recent studies raise a hypothesis about a natural protective action of aquaculture or aquaponic effluents against plant pathogens during in vitro tests (Gravel et al. 2015; Sirakov et al. 2016). This phenomenon could be related to the presence of antagonistic microorganisms or inhibitory compounds in fish water. The presence of dissolved or suspended organic matter could also play an important role in the suppressiveness of some diseases, since it can modulate a microbial ecosystem that is less favourable for plant pathogens. This organic matter in the water comes not only from uneaten food debris and fish faeces, but also from organic substrates, root exudates and plant residues (Stouvenakers et al. 2019).

Monoculture producers reported an average annual plant production of 13.4 ± 17.0 kg/m^2 and polyculture producers of 11.6 ± 23.3 kg/m^2. Lobillo-Eguíbar et al. (2020) informed of a considerably higher annual plant production (39.5 kg/m^2) in polyculture, as well as Love et al. (2015b) (in the range of 22–31 kg/m^2). This lower production observed in our study can be due to a lack of proper knowledge and expertise about these complex systems, a low level of automation and little time devoted to the aquaponic production. Also, the productions obtained are not well monitored in some cases, so some producers do not know exactly how much produce they obtain.

The responses obtained regarding the most common plants produced (leaf and fruit vegetables and aromatics) confirm what was reported by Love et al. (2014), Villarroel et al. (2016) and Mchunu et al. (2018), despite the fact that they referred to countries with different climates. They also indicated tilapia as the most common fish species used in aquaponic systems.

In relation to fish feeding, the most commonly used feed was commercial compound feed, followed by feed produced on the farm. Love et al. (2014), Mchunu et al. (2018) and Villarroel et al. (2016) also reported a major use of compound feeds, 94%, 98% and 90%, respectively. Although the use of other alternative animal feed sources was described, there is no information on whether or not they were produced on the farm itself.

Most installations were constructed recently, less than 3 years ago. This was also observed by Love et al. (2014). Conversely, Villarroel et al. (2016) indicated a higher percentage of installations operating for up to 6 years and Turnsek et al. (2020) reported that most facilities had been functioning for 3–9 years.

In addition, 17.0% of the respondents did not have the aquaponic installation in operation any more. Turnsek et al. (2020) also reported 19% of abandoned aquaponic projects in Europe, reaching 35% in France. The main reasons for abandoning them seem to be the difficulties in securing the initial investment or a viable business model, and personal reasons (relocation and family causes).

Although small-scale aquaponic facilities can be constructed with cheap and recycled materials (Lobillo-Eguíbar et al. 2020; Somerville et al. 2014), a certain investment is necessary, especially for their operation and maintenance. In our study, only 17.0% of the respondents received any subsidies or funding. On the other hand, Villarroel et al. (2016) reported a higher percentage of people (35.3%) obtaining funds from the government or other organisations.

Love et al. (2015a) reported that an average aquaponic producer monthly spent from $517 to $833 and Villarroel et al. (2016) indicated that most respondents (53.2%) spent less than 139 € per month. In our study, the respondents indicated spending much less money, 26.5 € per month on average. This is because small producers are not interested in producing on a large scale to sell their products, so they spent less money. This amount is in line with the operating costs of other small-scale aquaponic systems (Asciuto et al. 2019; Lobillo-Eguíbar et al. 2020), around 20–23 € per month.

In commercial aquaponics, personnel represent an important cost. For instance, the most usual number of employees reported by Love et al. (2015a) was 1 or 2 full-time and 1 part-time, and Turnsek et al. (2020) indicated that the majority of installations had between 1 and 3 people working in them. Conversely, small-scale facilities with non-commercial purposes are often self-managed. In fact, most facilities in our study were managed by only one person, spending 8 h/week on average.

This is interesting because this type of aquaponic producer does not spend much time on operating and maintaining the facilities, probably because aquaponics does not represent their main activity. This trend of not devoting much time to the aquaponic production enforces the need for a certain degree of automation.

Profile and motivations of small-scale aquaponic producers

From our results, it can be deduced that the most typical profile for the small-scale aquaponic producer is a man, between 35 and 44 years old, with a Bachelor, self-employed, with an average household income between 1000 and 1499 € and living in an urban setting. This profile is similar to that reported by Love et al. (2014), with the only difference of the average age, closer to the 50-–59-year-old range. Villarroel et al. (2016) also observed a higher prevalence of men over women, mainly distributed in the 30-–34- and 45-–49-year-old groups. However, in their study, the majority of the respondents had a higher level of education than in our study (91.7% had a post-graduate degree which could mean the sample was probably somehow biassed). Turnsek et al. (2020) and Mchunu et al. (2018) also indicated a high participation of men with a higher educational level and aged between 31 and 50 years old.

Aquaponic growers tend to be autodidacts and obtain information online or asking friends or other producers in online forums, which was also highlighted by Villarroel et al. (2016). Therefore, most knowledge seems to be gained from experience (their own or from others). Curiously, few respondents reported belonging to any association of aquaponic producers, which might be not well known. In any case, aquaponic systems are complex and specific training seems to be desired to optimise their operation.

The main objectives declared for the aquaponic facilities were in order of frequency of selection: education, production of food for self-consumption and as a hobby. Love et al. (2014) also pointed to a hobby being the main objective and education as the second. However, they did not report responses related to self-consumption or research. Conversely, their respondents strongly agreed that the motivations for their aquaponic productions were the production of their own food and environmental sustainability. On the other hand, Villarroel et al. (2016) reported research as the most important objective followed by education. This was to be expected since most of their respondents had a post-graduate degree. Once again, they did not report responses related to self-consumption or giving and exchanging. Mchunu et al. (2018) observed that hobby and subsistence were the main objectives while 25% of the aquaponics had a commercial purpose.

The main motivations reported in our study were the production of high-quality, healthy food, the concern for the environment and the autonomy gained (producing part of the food they needed). These motivations are related to the ones reported by Love et al. (2014) and Villarroel et al. (2016): growing their own food, environmental sustainability, improving their health. Those studies also added as motivations the adaptation to climate change and improving their education and training.

Some motivations seem more important, depending on the main objective of the aquaponic facility (Fig. 4). For example, if the purpose was educational, the motivations 'learning new things' and 'sharing knowledge with other people' had more importance. In those for hobby, 'fun and relaxation' and 'learning new things' had more influence. Curiously, 'producing higher quality food' was important in aquaponic systems intended for small sales and for research, while 'producing healthy food' was selected more often when the purpose was educational or for self-consumption.

The economic motivation did not have much importance in the small-scale aquaponic producers. For this reason, they usually do not pay attention to the expenses they have (43% did not know their monthly costs). However, those producing food for self-consumption or for selling the produce showed a higher concern for the economic costs.

In any case, it is clear that other non-economic motivations play a more important role in the existence of small-scale aquaponic systems, such as health, food quality, environmental concern and autonomy. These non-economic motivations are thebasis for maintaining many other types of small-scale family production systems around the world, such as peasant production systems or family urban orchard systems (Maćkiewicz et al. 2019; Schneider and Niederle 2010; van der Ploeg 2010). In one of the few economic studies carried out on small-scale aquaponic systems (Lobillo-Eguíbar et al. 2020) a high degree of autonomy of the system was found thanks to the contribution of the family workforce.

These motivations should not be overlooked among small-scale or family producers, because they are ways of responding to or satisfying (that is why they are called 'satisfactors') the basic human needs defined by Max-Neef (1994) in his 'human-scale development' approach (Table 2).

Conclusions

While aquaponic production has recently been an objective of research, the extent of its use outside of the scientific field is still not well known, especially on a small scale.

The average aquaponic producer is a middle-aged man, with a certain level of studies and a moderate household income. They are usually moved by a wish to sustainably

Table 2 Relation between the motivations for small-scale aquaponic productions, human needs (adapted from Max-Neef (1994)) and the purpose of the facilities

Motivation	Human needs satisfied by the motivation	Purpose of the facility
Producing healthy food	Subsistence, protection, identity (feeling part of the healthy food community), freedom (from markets and products with potentially dangerous chemical residues)	Self-consumption/small sales/exchange of goods/research
Producing higher quality food	Subsistence, protection, identity (feeling part of the community of those who seek quality), freedom (from markets and products with low quality)	Self-consumption/small sales/exchange of goods/research
Concern for the environment	Subsistence, protection, identity (feeling part of the community of those who want to protect the planet)	Educational/research
Autonomy	Subsistence, protection, freedom (from the impositions of the markets)	Self-consumption/exchange of goods
Saving money on food or having some income	Subsistence, freedom (from the impositions of the markets)	Self-consumption/small sales/exchange of goods
Learning new things	Understanding, participation, leisure, creation	Educational/research/hobby
Sharing knowledge with other people	Affection, understanding, participation, creation, identity and freedom	Educational/research
Feeling useful	Affection (feeling useful and appreciated when bringing food to a family or community), participation and identity (when sharing that food as a family or in a community)	Exchange of goods/educational/research
Doing moderate physical activity	Protection (physical health), leisure	Hobby
Fun and relaxation	Affection, participation, leisure, freedom	Hobby

produce high-quality, healthy food that gives them certain autonomy. Acquiring new knowledge and sharing it with others are also important motivations that enforce the educational purpose of many aquaponic facilities.

The economic motivation is not usually of importance and that is why small-scale producers do not pay much attention to the expenses and the production obtained.

The main deficiencies observed are related with little knowledge about plant and fish production (especially about diseases) and proper management of the systems (water quality maintenance). This points out to the need to develop specific formative programmes focusing on these knowledge deficiencies. In this line, it is interesting to promote associationism or thematic networks for sharing both experiences and resources.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10499-021-00793-4.

Acknowledgements We would like to express our gratitude to the respondents who took time and made the effort to answer the survey.

Author contribution Gina Patricia Suárez-Cáceres: conceptualization, methodology, formal analysis, writing—original draft, writing—review & editing. Víctor M. Fernández-Cabanás: conceptualization, methodology, writing—review & editing. José Lobillo-Eguíbar: conceptualization, methodology, writing—review & editing. Luis Pérez-Urrestarazu: conceptualization, methodology, writing—original draft, writing—review & editing.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication According to the publication.

Competing interests The authors declare no competing interests.

References

Asciuto A, Schimmenti E, Cottone C, Borsellino V (2019) A financial feasibility study of an aquaponic system in a Mediterranean urban context. Urban For Urban Green 38:397–402. https://doi.org/10.1016/J.UFUG.2019.02.001

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

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

Goddek S, Joyce A, Wuertz S, Körner O, Bläser I, Reuter M, Keesman KJ (2019) Decoupled Aquaponics Systems. In: Goddek S, Joyce A, Kotzen B, Burnell GM (eds) Aquaponics food production systems: combined aquaculture and hydroponic production technologies for the future. Springer International Publishing, Cham, pp 201–229. https://doi.org/10.1007/978-3-030-15943-6_8

Gravel V, Dorais M, Dey D, Vandenberg G (2015) Fish effluents promote root growth and suppress fungal diseases in tomato transplants. Can J Plant Sci 95:427–436. https://doi.org/10.4141/CJPS-2014-315

Hasan Z, Dhahiyat Y, Andriani Y, Zidni I (2017) Water quality improvement of Nile tilapia and catfish polyculture in aquaponics system. Nusant Biosci 9:83–85

Lobillo-Eguíbar J, Fernández-Cabanás VMVM, Alberto Bermejo L, Pérez-Urrestarazu L, Bermejo LA, Pérez-Urrestarazu L (2020) Economic sustainability of small-scale aquaponic systems for food self-production. Agronomy 10:1468. https://doi.org/10.3390/agronomy10101468

Love DC, Fry JP, Genello L, Hill ES, Frederick JA, Li X, Semmens K (2014) An International Survey of Aquaponics Practitioners. PLoS One 9:e102662

Love DC, Fry JP, Li X, Hill ES, Genello L, Semmens K, Thompson RE (2015a) Commercial aquaponics production and profitability: findings from an international survey. Aquaculture 435:67–74. https://doi.org/10.1016/j.aquaculture.2014.09.023

Love DC, Uhl MS, Genello L (2015b) Energy and water use of a small-scale raft aquaponics system in Baltimore, Maryland, United States. Aquac Eng 68:19–27. https://doi.org/10.1016/J.AQUAENG.2015.07.003

Maćkiewicz B, Asuero RP, Almonacid AG (2019) Urban Agriculture as the path to sustainable city development. insights into allotment gardens in Andalusia. Quaest Geogr 38:121–136. https://doi.org/10.2478/quageo-2019-0020

Maucieri C, Forchino AA, 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. J Clean Prod 172:3119–3127. https://doi.org/10.1016/j.jclepro.2017.11.097

Max-Neef M (1994) Desarrollo a escala humana. Conceptos, aplicaciones y algunas reflexiones. Icaria, Barcelona, Spain

Mchunu N, Lagerwall G, Senzanje A (2018) Aquaponics in South Africa: results of a national survey. Aquac Rep 12:12–19. https://doi.org/10.1016/j.aqrep.2018.08.001

Orsini F, Dubbeling M, de Zeeuw H, Gianquinto G (eds) (2017) Rooftop urban agriculture, urban agriculture. Springer International Publishing, Cham. https://doi.org/10.1007/978-3-319-57720-3

Palm HW, Knaus U, Appelbaum S, Goddek S, Strauch SM, Vermeulen T, HaïssamJijakli M, Kotzen B (2018) Towards commercial aquaponics: a review of systems, designs, scales and nomenclature. Aquac Int 26:813–842. https://doi.org/10.1007/s10499-018-0249-z

Palm HW, Knaus U, Appelbaum S, Strauch SM, Kotzen B (2019) Coupled Aquaponics Systems. In: Goddek S, Joyce A, Kotzen B, Burnell GM (eds) Aquaponics food production systems: combined aquaculture and hydroponic production technologies for the future. Springer International Publishing, Cham, pp 163–199. https://doi.org/10.1007/978-3-030-15943-6_7

Pérez-Urrestarazu L, Lobillo-Eguíbar J, Fernández-Cañero R, Fernández-Cabanás VM (2019) Suitability and optimization of FAO's small-scale aquaponics systems for joint production of lettuce (Lactuca sativa) and fish (Carassius auratus). Aquac Eng 85:129–137. https://doi.org/10.1016/j.aquaeng.2019.04.001

Schneider S, Niederle PA (2010) Resistance strategies and diversification of rural livelihoods: the construction of autonomy among Brazilian family farmers. J Peasant Stud 37:379–405. https://doi.org/10.1080/03066151003595168

Sirakov I, Lutz M, Graber A, Mathis A, Staykov Y, Smits THM, Junge R (2016) Potential for combined biocontrol activity against fungal fish and plant pathogens by bacterial isolates from a model aquaponic system. Water (Switzerland) 8.https://doi.org/10.3390/w8110518

Somerville C, Cohen M, Pantanella E, Stankus A, Lovatelli A, Food and Agriculture Organization of the United Nations (2014) Small-scale aquaponic food production: integrated fish and plant farming. Food and Agriculture Organization of the United Nations

Stouvenakers G, Dapprich P, Massart S, Jijakli MH (2019) Plant Pathogens and control strategies in aquaponics, In: Aquaponics food production systems. Springer International Publishing, pp. 353–378. https://doi.org/10.1007/978-3-030-15943-6_14

Tokunaga K, Tamaru C, Ako H, Leung P (2015) Economics of small-scale commercial aquaponics in Hawai'i. J World Aquac Soc 46:20–32. https://doi.org/10.1111/jwas.12173

Turnsek, Joly, Thorarinsdottir, Junge (2020) Challenges of commercial aquaponics in Europe: beyond the hype. Water 12:306. https://doi.org/10.3390/w12010306

van der Ploeg JD (2010) The peasantries of the twenty-first century: the commoditisation debate revisited. J Peasant Stud 37:1–30. https://doi.org/10.1080/03066150903498721

Villarroel M, Junge R, Komives T, König B, Plaza I, Bittsánszky A, Joly A (2016) Survey of Aquaponics in Europe. Water 8:468. https://doi.org/10.3390/w8100468

Wongkiew S, Hu Z, Nhan HT, Khanal SK (2020) Chapter 20 - Aquaponics for resource recovery and organic food productions. In: Kataki R, Pandey A, Khanal SK, Pant D (eds) Current Developments in Biotechnology and Bioengineering. pp 475–494. https://doi.org/10.1016/B978-0-444-64309-4.00020-9