The Journal of Extension

Volume 60 | Number 4 Article 13

12-19-2022

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Recommended Citation

Pattillo, D. A., Cline, D. J., Hager, J. V., Roy, L. A., & Hanson, T. R. (2022). Challenges Experienced by Aquaponic Hobbyists, Producers, and Educators. *The Journal of Extension, 60*(4), Article 13. https://doi.org/10.34068/joe.60.04.13

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Cover Page Footnote

This project was supported by Agriculture and Food Research Initiative Competitive grant no. 2017-38420-26765 from the USDA National Institute of Food and Agriculture and by the Alabama Agricultural Experiment Station.

JOURNAL OF Extension

Research in Brief

Volume 60, Issue 4, 2022

Challenges Experienced by Aquaponic Hobbyists, Producers, and Educators

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Abstract. We used an online survey to document challenges experienced by aquaponic hobbyists (n = 81), producers (n = 117), and educators (n = 75). Responses were distilled into the following categories: 1) operations and management; 2) facilities, location, and system design; 3) knowledge and educational resources; 4) funding; 5) economic viability; 6) plant culture; 7) marketing and distribution; 8) fish culture; 9) human factors; 10) regulations and certifications. Training and research in these areas are needed to advance the aquaponics industry.

INTRODUCTION

Aquaponics is a system of agriculture that integrates fish and plant production. The process is adaptable to a variety of production methods, climates, and locations (Goddek & Körner, 2019). The United States Department of Agriculture (USDA) Census of Aquaculture did not report any aquaponic operations in 2005, but reported 71 farms by 2012 and 82 farms by 2017 (Engle, 2015; NASS, 2005; 2013; 2018). The approximate average value of aquaculture products sold by these operations grew from $3.2 million in 2012 to $9.0 million in 2017, representing a 181% growth in product sales over five years (NASS, 2018). These farms were concentrated primarily in Florida (n = 11), Wisconsin (n = 9), Hawaii (n = 6), New York (n = 6), Virginia (n = 4), Oregon (n = 4), North Carolina (n = 4), and California (n = 4); these states represented 59% of all reporting farms, and the other farms were spread across 16 additional states (NASS, 2018). According to Love et al. (2014), industry stakeholders include hobbyists, educators, producers, and supporting groups. Most practitioners are relatively new to aquaponics and continuously gathering information, experimenting, and learning (Greenfeld et al., 2020a; Mchunu et al., 2018). The interdisciplinary nature of aquaponics makes the learning curve steep and lowers the likelihood of success (Goddek et al., 2015; Hart et al., 2013; Turnsek et al., 2020). It is important to the success of the industry to identify challenges and document current stakeholder needs (Konig et al., 2018). We surveyed hobbyists, producers, and educators to (a) identify their challenge areas, (b) assess stakeholder needs, and (c) recommend solutions. Results are relevant to researchers, teachers, and Extension educators looking to develop educational resources for newcomers to the aquaponics industry.

MATERIALS AND METHODS

We used an online Qualtrics survey to collect data about challenges experienced by aquaponics stakeholders. The survey instrument included questions adapted from previous research (Love et al., 2014; Villarroel et al., 2016), as well as original questions that were reviewed by peers and pilot tested by the Aquaponics Association membership to establish face validity. The full survey is available from Pattillo (2021). We distributed the survey via email lists to aquaculture Extension networks, professional aquaculture/aquaponic societies, and aquaponics social media groups. Responses were collected from December 2019 to June 2020. Using the snowball advertising method, we encouraged survey recipients to further distribute the survey among peers to extend our response pool (Baltar & Brunet, 2012; Browne, 2005; Love et al., 2014). Respondents identified themselves as hobbyist, producer, or educator; provided their top three challenges; and specified any regulatory or permitting requirements. Two investigators independently reviewed the text responses, assimilated the information into theme areas, and converged on final categories for analysis.

RESULTS

Appendix A shows respondent demographic information, and Appendix B shows information on background, experiences, and system design of each stakeholder group. The typical respondent was middle-aged, male, college educated, from the United States, white, and employed full time outside of aquaponics (Appendix A). Overall, 66% of the respondents had less than five years of experience. Hobbyists were least experienced, as 80% of hobbyists had less than five years of experience compared to 63% of producers and 57% of educators. Most hobbyists (94%) and educators (84%) could complete their aquaponic work in less than 20 hours per week, but more than half (51%) of producers required more than 20 hours per week. Systems were generally self-designed (80%) and were in a coupled configuration (87%), where system water is fully recirculating between the fish and plant components. Most aquaponic operations were in temperate (33%) or subtropical (50%) climates. Operations are established predominantly in rural locations (45%), followed by suburban (27%) and urban (26%). The setting distribution varied by stakeholder group (Figure 2). Only 57 % of respondents were currently operating an aquaponic system, which aligns with their relatively low experience level.

Table 1 provides a summary of respondent challenges, which include (a) operations and management; (b) facilities, location, and system design; (c) knowledge and educational resources; (d) funding; (e) economic viability; (f) plant culture; (g) marketing and distribution; (h) fish culture; (i) human factors; and (j) regulations and certifications. Figure 1 shows the relative proportion of stakeholders reporting these challenges. To approximate the severity of these challenges, we defined primary challenges as those experienced by greater than 50% of respondents and secondary challenges as those experienced by 30–50%. The primary challenges for hobbyists were facilities, location, and system design and

Table 1. Challenge Categories Provided by Aquaponic Survey Respondents

Rank	*N*	Category	Summarized Challenge Responses
1	144	Operations and Management	Labor/staffing; balancing fish and plants; sourcing/availability of inputs; resource management (energy, electricity, etc.); monitoring operations; water quality; nutrient balance; mineralization; algae control; cleaning; power failure; record keeping; system startup/maintenance; optimizing production; marine aquaponics
2	138	Facilities, Location, and System Design	Growing environment/greenhouse; recirculating aquaculture system; plumbing; construction; water filtration; solid waste removal; equipment failure; technology; system efficiency optimization; water access; equipment; heating/cooling; environmental control; automation; location; space; land; climate
3	87	Knowledge and Educational Resources	Knowledge; learning curve; availability of training opportunities; availability, quality, and organization of educational resources; public education; grower networking; research; product development; misinformation; reputable and disreputable suppliers
4	74	Funding	Access to money; capital; financing; funding sources for investment, construction, and operating expenses
5	55	Economic Viability	Production cost; profitability; lack of viable business models; return on investment; startup cost; energy cost; system scale; system cost
6	53	Plant Culture	Species selection; growth rates; production output; nutrient deficiencies; integrated pest management; pests; diseases; processing
7	51	Marketing and Distribution	Market analysis; marketing; sales; price; distribution; consumer acceptance; product and technology promotion; educating others; consumer education; price competition
8	45	Fish Culture	Feed and nutrition; species selection; husbandry; health; growth; processing
9	42	Human Factors	Getting started; time availability and management; personal health; theft and security; motivation; confidence in growing; teacher adoption; community and government support; social views; stakeholder partnerships; food security; environmental sustainability
10	41	Regulations and Certifications	Permits; licenses; regulations; certifications (Global GAP and Organic); food safety

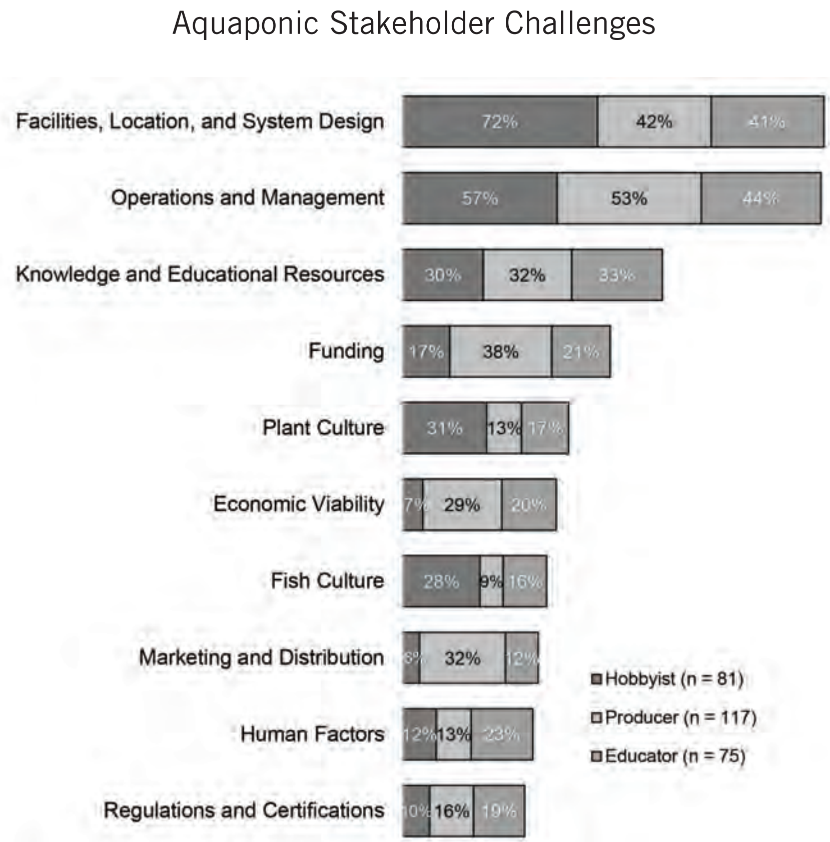

Figure 1. Proportion of aquaponic hobbyists, producers, and educators reporting challenges in various aspects of aquaponic operations. Percentages represent the proportion of each stakeholder group experiencing that specific challenge. Ranking is based on the cumulative percentage of respondents in each group and class.

operations and management, while the primary challenge for producers was just operations and management; educators reported no predominant challenge category. Secondary challenges for hobbyists were plant culture and knowledge and educational resources. For producers, these secondary challenges were funding; facilities, location, and system design; knowledge and educational resources; and marketing and distribution. Secondary challenges for educators were mainly operations and management; facilities, location, and system design; and knowledge and educational resources.

Some challenge categories were experienced at proportionally higher rates when respondents were separated into more and less experienced groups (Figure 2). Respondents with less than five years of aquaponic experience were more commonly challenged by a lack of shared and correct knowledge and educational resources, while respondents with more than five years of experience were often challenged by operations and management, economic viability, and marketing and distribution. These variations seem to indicate that experience solves some challenges and reveals others.

The proportion of respondents that experienced regulatory roadblocks and challenges with permitting/licensing requirements is presented in Figure 3. Overall, 34% of respondents (n = 84) indicated that they encountered regulatory constraints to operating their aquaponics system; many reported multiple constraints. Specific requirements reported as roadblocks include (a) aquaculture and exotic species permitting; (b) zoning, construction, and building permits; (c) organic, processing, and food safety certifications; (d) excessively bureaucratic and unclear policies; (e) institutional or school policies; (f) permitting or certification costs; and (g) effluent discharge permits. The proportion of respondents experiencing these regulatory challenges varied by stakeholder group and background setting (Figure 4). Hobbyists and educators cited aquaculture permitting as a regulatory constraint most frequently, while producers most frequently indicated certifications, food processing, and food safety (Figure 4A). Certifications, food processing, and food safety were the most common challenge in rural areas (37%), whereas aquaculture and exotic species permits were the most common challenge in suburban (30%) and urban (30%) areas (Figure 4B).

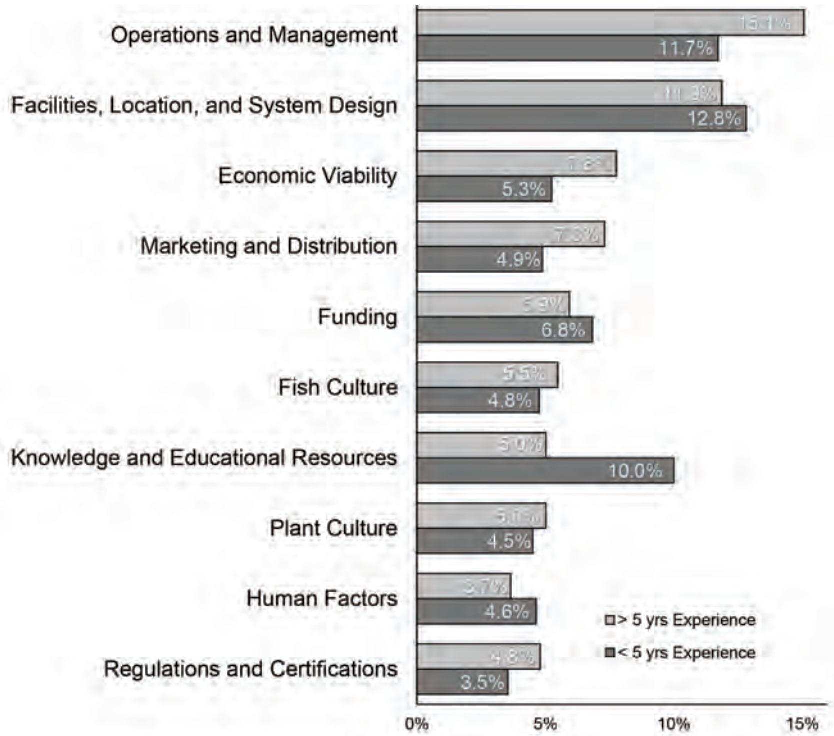

Figure 2. Challenges experienced by aquaponic stakeholders divided by years of growing experience.

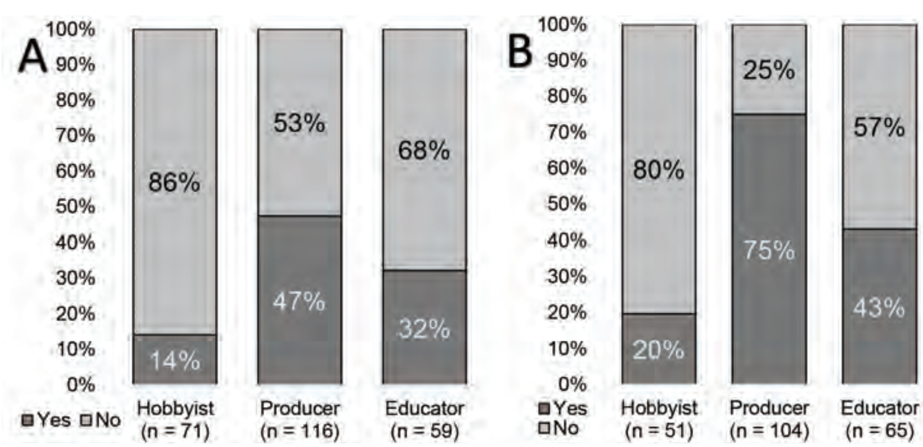

Figure 3. Percentage of aquaponic hobbyists, producers, and educators that experienced (A) regulatory roadblocks and (B) challenges associated with permitting or licensing requirements.

DISCUSSION

OPERATIONS AND MANAGEMENT

Technical proficiency in fish and plant production, environmental control, and legal or business considerations can be difficult, especially for beginners in aquaponics. Several studies (Quagrainie et al., 2017; Turnsek et al., 2020; Tyson et al., 2011) report that daily operational tasks are challenging for newcomers. We found that the majority of respondents experienced operations and management challenges, though respondents with greater than five years of experience encounter more of these issues than those with less experience (Figure 2). Aquaponics takes time and effort to master, particularly for low-tech systems without automation (Kyaw, 2017). As an operator matures their abilities, they inevitably find that careful management of energy, labor, water, plant,

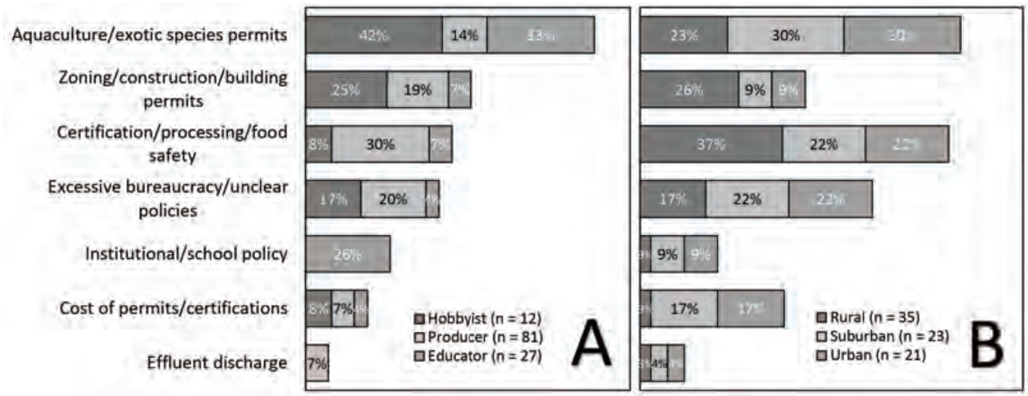

Figure 4. Proportion of respondents experiencing regulatory challenges by (A) stakeholder group and (B) background setting.

and fish inputs are necessary for efficient production and minimized costs (Quagrainie et al., 2017). Physical modifications to the aquaponic system, mentorship from more experienced aquaponics practitioners, and further personal expertise through hands-on experience are all ways to reduce operational challenges (Hart et al., 2013).

The typical time commitment across groups was up to 20 hours per week, but some producers spent over 60 hours per week (Appendix B). Finding skilled labor is a challenge for producers because of the lack of relevant ongoing training opportunities. Expanding the production capacity of the industry will require an increased labor pool and workforce development. Programs to help aquaponic newcomers, especially in the startup phase, would be helpful. Land-grant universities, community colleges, and high school programs are uniquely positioned to train and prepare students for careers in aquaponics. With the appropriate training and support, students can fill needed positions as skilled workers, entrepreneurs, or Extension agents and educators (Lakai et al., 2012).

FACILITIES, LOCATION, AND SYSTEM DESIGN

Local climate effects dictate efficient system design, fish/plant choices, production costs, sales price, and profitability (Goddek & Körner, 2019; Rakocy et al., 2004). Heating and lighting costs associated with out-of-season production in colder climates, especially for warm weather fish and plant species, can be prohibitively expensive (Ghamkhar et al., 2020; Love et al., 2015b). Most respondents operate within temperate and subtropical regions where controlled environments are critical to year-round production (Pickens & Danaher, 2016). Careful system design is critical to the success of these operations, yet many systems were designed by the respondents themselves. Increasing the quality, availability, and cost-effectiveness of professionally engineered systems is necessary to expand industry growth.

KNOWLEDGE AND EDUCATIONAL RESOURCES

Knowledge was a challenge for roughly one-third of all respondents (Figure 1). Knowledge deficiencies tend to vary by topic, stakeholder background, and experience level (Pattillo, 2021; Villarroel et al., 2016). Greenfeld et al. (2020a) reported that even though over half of recent aquaponic adopters had some prior knowledge of the system, 41% still struggled in their first year of operation. This may be due to the overconfidence of inexperienced growers who highly trust their production abilities when in fact their troubleshooting skills are inadequate (Mchunu et al., 2018). In addition, many practitioners get their information from internet sources, which are brimming with misinformation about aquaponics (Pattillo, 2021; Turnsek et al., 2020). Misinformation was a specific challenge highlighted by respondents in this study. Newcomers are particularly susceptible to this misinformation, because they do not have the working knowledge to distinguish between correct and incorrect information. Our results suggest that challenges related to knowledge and educational resources decrease as growers become more experienced (Figure 2). Therefore, it is recommended that growers engage in networking with other growers from various backgrounds and levels of experience to dispel myths and promote the success of new practitioners.

FUNDING

Access to startup capital for construction, land purchases, and operating loans were the most frequent funding challenges for aquaponics practitioners. Lenders see aquaponic operations as high-risk ventures by lenders, making them difficult to finance. This difficulty forces producers to use personal funds and ultimately limits industry growth (Turnsek et al., 2020; Villarroel et al., 2016). Loan opportunities are necessary to propel the growth of commercial aquaponics and may improve when the perceived risk to loan agencies is lowered (König et al., 2018). Most respondents in this study self-financed their operations; however, about 20% of producers reported using loans (Appendix B). This may indicate the beginning of lenders' increased acceptance of aquaponic activities.

ECONOMIC VIABILITY

High production costs, inappropriate production scale, lack of established business models, and lack of overall profitability were the predominant economic challenges to aquaponics operations as reported by survey respondents. Newcomers to the industry are cautioned that aquaponics is in the high-risk formation stage, where markets and prices are not well defined (König et al., 2018). The cost of fish and plant production and realistic selling prices must be researched and addressed during business planning (Engle, 2015; Quagrainie et al., 2017). In this study, even the more experienced growers reported challenges with economic viability (Figure 2). Cash flow becomes more important as startup funds are depleted and the system must generate revenue to be sustainable. System scale directly impacts production costs. Aquaponic systems are often scaled to a size that is too small to be profitable, which is likely a result of improper planning or inadequate capital to build larger facilities (Xie & Rosentrater, 2015). Incorporating alternative income sources such as agritourism, educational opportunities, and the sale of non-food products (e.g., compost, ornamental plants/fish, etc.) could improve viability for some aquaponic producers (Junge et al., 2017; Love et al., 2015a).

PLANT CULTURE

Respondents expressed these primary challenges with plant culture: optimizing production; selecting and maintaining a varied selection of plants; and managing pests, diseases, and nutrient deficiencies. Postproduction challenges included harvesting logistics and processing regulations. Plant varieties, growing environment, and production systems must be compatible to optimize production (Pickens et al., 2016). Coupled systems that recirculate water between fish and plant components were the most popular, but there are limited pest control options for these systems. Decoupled systems effectively separate the fish and plant components, allowing the use of pesticides, nutrient supplements, and temperature/pH modification without endangering the fish or biofilter (Monsees et al., 2017). Newcomers to the aquaponics industry need access to good information on system design to weigh the pros and cons of each system type before investing.

MARKETING AND DISTRIBUTION

Marketing and distribution challenges more commonly afflicted growers with greater experience (Figure 2). This likely relates to a growing appreciation of economically viable marketing as a business matures. The challenges in marketing and distribution included product placement/promotion, understanding consumer preferences, determining appropriate pricing, educating consumers, advertising, making sales, and managing/planning/carrying out distribution. Aquaponic products are market substitutes for conventionally grown products, making price competition a major issue. Many consumers are unaware of the benefits of aquaponic products and unwilling to pay higher prices for them (Greenfeld et al., 2020b; Zugravu et al., 2016). Marketing requires an understanding of customer preferences and a connection to clientele willing to pay a premium for sustainably produced products (Short et al., 2017). Niche ethnic markets are often targeted for live fish sales because prices are generally higher, but this market can be easily saturated (Engle, 2015). Aquaponics practitioners should be careful to develop an effective marketing strategy during the business planning stage.

FISH CULTURE

Fish culture challenges include poor access to fingerlings of the appropriate size and species, feeding efficiency, fish health management, and fish processing. Selecting fish species that are easy-to-grow, sought-after, adaptable to local conditions, available locally, resistant to disease, and worth high market prices is a formidable challenge. Tilapia is the most commonly employed fish species in aquaponics, because it meets many of these selection criteria; however, diversification may be necessary to avoid excessive energy costs and regulatory hurdles while creating opportunities to capture additional revenue (Love et al., 2014). For example, processed food-fish sales are subject to food safety regulations. High-value ornamental fish species, like koi, may be a viable alternative to avoid these regulations. However, other rules may apply when hauling live fish, such as interstate transport laws associated with the Lacey Act (Engle & Stone, 2013).

HUMAN FACTORS

Challenges to aquaponics associated with human factors included personal motivation, theft/security, community/political support, food security, and environmental concerns. Human factors, particularly personal motivation, was most common with educators (Figure 1). Although aquaponics can be an effective teaching tool (Genello et al., 2015; Junge et al., 2014), there are challenges with constructing and maintaining these systems at schools (Hart et al., 2013). The additional workloads or lack of desire to learn new topics can also be barriers to system adoption by educators (Lakai et al., 2012). Connections with social and professional aquaponic groups can provide a support network for new growers and be influential in educating the public and shaping governmental policies.

REGULATIONS AND CERTIFICATIONS

Obtaining and complying with necessary aquaculture and food processing permits, licenses, zoning ordinances, and land use classifications were the predominant issues in this category (Figure 4). Regulatory issues associated with aquaponics are broad, with multiple agencies regulating water quality, interstate transport of fish, food safety/processing, business, land use, and zoning (Engle & Stone, 2013). Not only do farmers need to be able to run their system, but they must also operate in an environment of increasing scrutiny toward agricultural practices and products (Goddek et al., 2015). Zoning codes vary by municipality, many of which have not expanded their definition of urban agriculture to include aquaponics, particularly within warehouse/industrial settings (Tomlinson, 2015). Food safety and seafood processing standards require processing facilities to meet the Hazard Analysis and Critical Control Point (HACCP) certification criteria for sanitation (FDA, 2020; Hollyer et al., 2009; 2012). Additionally, educators encountered institutional policies for ethical animal usage and serving aquaponic produce to students. All these challenges impact newcomers, yet experienced producers reported these challenges more frequently (Figure 2). This is likely because growers become more exposed to regulatory requirements over time.

CONCLUSIONS

This study serves as a needs assessment for training and educational resource development to overcome challenges experienced by aquaponic stakeholders. We recommend developing informational resources and training opportunities to increase the number of growers and qualified trainers. Holistic, hands-on aquaponic Extension training workshops can instill participants with the confidence to perform daily activities and troubleshoot when issues arise (Lakai et al., 2012). Training opportunities ranging from single- or multi-day workshops to full college degree programs and on-farm internships could assist stakeholders at various levels. Traditional delivery methods including workshops, farm tours, and presentations of research-based information can provide solutions to aid participants in addressing the challenges reported in this study. Online instructional opportunities like videos, webinars, and train-the-trainer programs should be incorporated to improve access to aquaponic training (Dittmar et al., 2014; Mathiasen et al., 2012).

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APPENDIX A. DEMOGRAPHIC IDENTIFIERS OF THE AQUAPONICS INDUSTRY SURVEY RESPONDENTS

Demographic Category		Hobbyist		Producer		Educator	
		N	**%**	**N**	**%**	**N**	**%**
Stakeholder Group		105	25	156	37	117	28
Age Group	18–24	1	2	1	1	0	0
	25–34	5	7	12	15	5	9
	35–44	10	15	15	19	11	19
	45–54	15	22	15	19	14	24
	55–64	20	29	25	32	20	34
	65–74	11	16	10	13	7	12
	Over 75	6	9	1	1	1	2
	Total	**68**	**100**	**79**	**100**	**58**	**100**
Gender	Male	53	82	61	81	45	76
	Female	12	18	14	19	14	24
	Total	**65**	**100**	**75**	**100**	**59**	**100**
Education	Less than high school	7	11	7	9	0	0
	Some college	21	32	19	25	6	10
	Bachelors	25	38	31	40	10	16
	Masters	8	12	15	19	26	43
	Doctorate	5	7	5	7	19	31
	Total	**66**	**100**	**77**	**100**	**61**	**100**
Location	United States	58	88	56	76	48	84
	N. America	1	2	8	11	0	0
	S. America	0	0	0	0	2	4
	Europe	2	3	4	5	2	4
	Asia	1	2	2	3	3	5
	Africa	3	5	3	4	1	2
	Australia	1	2	1	1	1	2
	Total	**66**	**100**	**100**	**100**	**57**	**100**
Ethnicity	Asian	4	5	5	5	3	5
	Black	1	2	2	9	6	10
	Hispanic	1	2	2	0	4	7
	Native American	0	0	0	0	0	0
	Pacific Islander	0	0	0	0	1	2
	White	56	82	82	78	38	63
	Other	1	2	2	0	5	8
	Undisclosed	5	7	7	8	3	5
	Total	**68**	**100**	**100**	**100**	**60**	**100**

Demographic Category		**Hobbyist**		**Producer**		**Educator**	
		N	**%**	***N***	**%**	***N***	**%**
Employment Status	Full time	34	50	46	64	42	72
	Part time	3	4	4	6	10	17
	Unemployed	1	2	4	6	2	3
	Retired	24	35	13	18	3	5
	Student	2	3	0	0	2	3
	Disabled	4	6	4	6	0	0
	Total	**68**	**100**	**71**	**100**	**59**	**100**
Primary Income Source	Aquaponics	0	0	21	28	2	3
	Other	68	100	53	72	56	97
	Total	**68**	**100**	**74**	**100**	**58**	**100**

APPENDIX B. BACKGROUND, EXPERIENCES, AND PRODUCTION STRATEGIES OF AQUAPONIC STAKEHOLDERS

		Hobbyist		Producer		Educator	
		N	**%**	***N***	**%**	***N***	**%**
Years of Aquaponic Experience	Less than 1 year	25	24	29	19	16	14
	1–2 years	22	21	31	20	21	18
	3–5 years	35	34	38	25	30	26
	6–10 years	18	18	38	25	31	27
	11–20 years	3	3	15	10	10	9
	More than 20 years	0	0	4	3	9	8
	Total	**103**	**100**	**155**	**100**	**117**	**100**
Weekly Time Spent	0–10 hours	61	71	38	31	47	55
	11–20 hours	20	23	23	19	25	29
	21–30 hours	4	5	18	15	5	6
	31–40 hours	0	0	20	16	5	6
	41–60 hours	1	1	18	15	2	2
	Over 60 hours	0	0	6	5	1	1
	Total	**86**	**100**	**123**	**100**	**85**	**100**
System Design	Self-Designed	93	97	94	73	65	74
	Professional Designed	3	3	35	27	23	26
	Total	96	100	129	100	88	100
System Style	Coupled	85	92	114	84	75	85
	Decoupled	7	8	21	16	13	16
	Total	**92**	**100**	**135**	**100**	**88**	**100**
Climate Zone	Polar	2	3	6	6	1	2
	Temperate	22	31	34	35	19	32
	Subtropical	40	56	48	50	27	45
	Tropical	**7**	**10**	**9**	**9**	**13**	**22**
	N	71		97		60	
Funding Source	Personal Funds	82	96	98	78	36	46
	Private Investment	0	0	35	28	7	9
	Government Grants	0	0	19	15	33	42
	Private Grants	0	0	16	13	17	22
	Loans	0	0	25	20	2	3
	Credit/Financing	5	6	10	8	2	3
	N	85		126		79	
Background Setting	Rural	46	47	79	54	31	31
	Suburban	34	35	25	17	35	35
	Urban	17	17	37	26	34	34
	Industrial	1	1	4	3	1	1
	Total	**98**	**100**	**145**	**100**	**101**	**100**
Development Stage	Researching	16	17	12	9	20	22
	Planning	17	18	38	28	14	16
	Constructed	6	6	8	6	7	8
	Operational	56	59	79	58	48	54
	Total	**95**	**100**	**137**	**100**	**89**	**100**

* N is the number of participants that responded when there was more than one selection option