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Asking the Pros - an assessment of hydroponics professionals' attitudes towards aquaponics food production

Anıl Axel Tellbüscher

atellbuscher@frov.jcu.cz

University of South Bohemia in České Budějovice, FFPW USB, CENAKVA

Christian Rudeloff

Macromedia University of Applied Sciences

Radek Gebauer

University of South Bohemia in České Budějovice, FFPW USB, CENAKVA

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Abstract

Even though integrated aquaculture systems such as aquaponics promise the production of food in a circular and environmentally friendly way, their commercial adoption remains low. This study assessed the attitudes of hydroponic practitioners (= potential investors or adopters) towards aquaponics by investigating the importance of perceptual aspects (expected economic prospects, sustainability in relation to the personal relevance of environmental issues, legislative framework, technical and managerial issues, general attitude). A worldwide survey was conducted between October and December 2023 among hydroponics professionals and Structural Equation Modelling was employed. Perceived sustainability and economic prospects shape the attitude towards aquaponics positively and negatively, respectively. Perceived difficulties in system management, meanwhile, do not have a significant effect. Focusing scientific efforts on solving problems related to the technical aspects of aquaponics management might not result in increased adoption through hydroponics farmers. Instead, targeting improvements regarding the economic situation (legislative framework, consumer knowledge, marketing), or placing technical results into a clear economic context might be more purposeful. A limitation of the study is, however, the small sample size (n = 118).

Introduction

In response to a growing global population and the escalating impacts of climate change, food production systems must become more resilient while simultaneously reducing their environmental footprint. These dual challenges, ensuring food security and mitigating environmental degradation, demand different approaches to how food is produced (Foley et al., 2011; Godfray et al., 2010). These issues have been widely acknowledged by scientists and policymakers, and strategies for the eco-intensification of agriculture and more sustainable and circular food production were developed to mitigate the potentially catastrophic long-term effects of exceeding planet Earth's planetary boundaries for too long (European Union, 2020; Willet et al., 2019).

One promising example of sustainable circular food production is aquaponics, a system that integrates aquaculture, the farming of fish, with plant cultivation. The principle of aquaponics is to reuse nutrient-rich wastewater from aquaculture to irrigate and fertilize plants, thereby reducing the need for external water and fertilizer inputs (Baganz et al., 2021). While the aquaponics principle dates back to ancient times, it gained traction only recently due to the promise of a reduced environmental impact, diversified product portfolio and harvest yields comparable to those of standalone aquaculture or hydroponics systems (Kloas et al., 2015; Monsees et al., 2019). These promises, together with the launch of strategic initiatives such as the EU Green Deal, which promotes circularity and sustainability in food supply chains through targeted funding and innovation programs (European Commission, 2019, 2020), have attracted considerable interest from the scientific community, as evidenced by the growing number of publications on the topic (Fig. 1).

Despite this academic interest, aquaponics has seen limited adoption in commercial food production. Several recent surveys found that most aquaponics operations are confined to small and medium-sized enterprises, nonprofit organizations, and educational or research institutions, while large-scale implementation remains rare (Love et al., 2015; Pattillo, Hager, Cline, Roy, & Hanson, 2022; Raulier et al., 2023; Villarroel et al., 2016). The only study that directly examined this phenomenon by identifying the challenges faced by entrepreneurs is subject to a survivorship bias, as it asks those individuals already engaged in aquaponics (Turnšek, Joly, Thorarinsdottir, & Junge, 2020). Meanwhile, it overlooks the perspectives of those who are part of the group of potential adopters but chose not to invest in aquaponics in the first place. However, this is the more relevant information if the goal is to understand why the industry apparently does not accept aquaponics. Is the actual target group not sufficiently informed about the results of scientific studies, which might be solved by improved science communication? Is there a pressing issue that might not be addressed by science yet? Is there another specific reason, such as the legal situation, costs, or economic prospects, that could potentially be addressed by changes in the policy?

To address the depicted knowledge gap, the present study explores the perceptions of hydroponics practitioners, a key group of potential adopters who have thus far shown reluctance toward aquaponics. Specifically, we aim to determine whether the technical concerns commonly discussed in and addressed by aquaponics research align with the actual reservations held by this group. To do so, we

- Identified the main barriers to aquaponics adoption emphasized in the scientific literature on aquaponics,
- Selected hydroponics practitioners as a relevant group of non-adopters, and
- Assessed their attitudes toward aquaponics.

The overarching goal of this study was to enhance the relevance and utility of aquaponics research by aligning it more closely with the concerns of potential adopters. The findings are expected to support more targeted innovation, inform policy development, and help bridge the gap between academic discourse and real-world adoption, ultimately contributing to the advancement of sustainable food production systems.

Literature review and hypothesis derivation

The scientific literature points to a number of key areas in which aquaponics differs from hydroponics and aquaculture. These include systems operation and management, the economic and legislative situation, and sustainability aspects (Yep and Zheng, 2019).

Operation of Aquaponic Systems

The dedicated aquaponics literature has described many technological factors that pose challenges associated with the successful operation of aquaponic systems. These include difficulties in the management of plant nutrients due to chemical constraints or imbalanced nutrient inputs (Bittsánszky et

al., 2016; da Silva Cerozi & Fitzsimmons, 2016; Goddek et al., 2015; Kloas et al., 2015), fish diseases (Yavuzcan Yildiz et al., 2017), and plant pests and diseases (Folorunso, Roy, Gebauer, Bohatá, & Mraz, 2020; Vermeulen & Kamstra, 2013; Yavuzcan Yildiz et al., 2017).

Hydroponic farmers have the advantage of having access to a range of fertilizers tailored to the cultivated plant. This limits the management of nutrients to the replacement of depleted by freshly prepared nutrient solutions according to given protocols. Such an approach is, however, not feasible in aquaponics, as additional input routes have to be considered. Some nutrients are introduced into the system through the fish feed, in addition to the water used. This leads to nutritional imbalances that need to be addressed at a systemic level, as they are site-specific (Anıl Axel Tellbüscher, Gebauer, & Mráz, 2025). This means that it might be necessary to analyze water samples, followed by an adjustment of the standard nutrient solutions' formulations.

Another aspect that complicates the management of aquaponic systems is the treatment of fish and plant pests and diseases. Fish diseases might cause issues in aquaponic systems because common measures such as treating the fish with table salt cannot be used in aquaponics systems due to the sensitivity of plants to chloride (Geilfus, 2018). Meanwhile, other substances such as peracetic acid that can be used for the treatment of fish parasites are safe to use and can also be used in a hydroponic context (Hong et al., 2018; Liu et al., 2024). At the same time, the use of pesticides to combat plant pests or treat plant diseases is prohibited, as these can also harm the fish population. Alternative treatment approaches are based on biocontrol agents, such as predatory insects, that are commercially available and can be used to eradicate plant pests in a safe way (Folorunso et al., 2020).

Additional technical problems might arise from the mere complexity of the systems, leading to an increased proneness for technical failure in comparison with conventional aquaculture or hydroponic systems. It was, for instance, reported that the combination of aquaculture with drip irrigation systems is problematic due to more frequent clogging of irrigation nozzles (Fernández-Cabanás et al., 2025). However, such systems are well established in the hydroponic production of several crops (Resh, 2016). As the outlined approaches deviate from the "hydroponic way" of addressing said issues, we hypothesized that

H1: Perceived management issues of aquaponic systems negatively affect the perceived economic viability of aquaponics.

We furthermore hypothesized that

H2: Perceived management issues of aquaponic systems negatively affect the attitude towards aquaponics.

Aquaponics legislation

Around the world, there are no specific legal frameworks in place for aquaponic systems to the best of the authors' knowledge due to the dual nature of the system. Instead, a potpourri of laws and regulations

can be of relevance, depending on the location. In Europe, these regulations include system planning and construction (planning law, building law, water law), the production process itself (hydroponic production, aquaculture, fish diseases, animal feed, animal welfare, fish slaughter, vocational training of fish farmers, hygiene law), and the commercialization of the produce (business and tax law, labelling law) (Reinhardt, Hoevenaars, & Joyce, 2019).

An additional challenge that comes with the legislative framework in the European Union is that neither fish nor plants produced in aquaponic systems can be certified as organic under the current legislation (Di Gioia & Rosskopf, 2021; Kledal, König, & Matulić, 2019). According to European law, plants must be cultivated in soil to be certified as organic, which is a disadvantage for substrate-free plant cultivation, as practiced in hydroponics and aquaponics. Organically produced fish, meanwhile, must not be produced in closed systems such as tanks. In contrast, the certification of fish grown in aquaculture in the United States depends on the certification of the feed as organic (Cammies, Mytton, & Crichton, 2021; Fruscella, Kotzen, & Milliken, 2021). The described complexity were described as major hurdle for the wider adoption of aquaponics in Europe (Fruscella et al., 2021; Mata & dos-Santos, 2025; Villarroel et al., 2016), and we thus assumed that this would be reflected by the attitude towards aquaponics, thus hypothesizing that

H3: Perceived legislative issues negatively affect the attitude towards aquaponics.

The legislative uncertainties depicted can also be expected to affect the achievable retail price of the food produced and, therefore, the economic prospects of an aquaponics system. We thus hypothesized that

H4: Perceived legislative issues of aquaponic systems negatively affect the perceived economic viability of aquaponics.

Economy of Aquaponics

Economic prospects for aquaponics appear constrained by several factors. As previously discussed, the potential for generating substantial income is limited by the fact that aquaponic products cannot be certified as organic under current regulations (Kledal et al., 2019). Even if organic certification were possible, consumer demand may remain sensitive to the perception of organic products as comparatively expensive (Feldmann & Hamm, 2015). Conversely, emphasizing the proximity of production to consumers, particularly in urban settings, may increase willingness to pay a price premium and could therefore play a role in economic assessments of aquaponics facilities located near cities. Direct marketing may offer higher potential margins, although these opportunities may be impaired by consumers' limited knowledge of aquaponics and its products (Eichhorn & Meixner, 2020; Greenfeld, Becker, McIlwain, Fotedar, & Bornman, 2018).

Despite these potential advantages, the existing literature generally portrays the economic outlook for aquaponics as modest. Simulation-based analyses suggest that profit margins are narrow and that

profitability is not achieved in most modelled scenarios (Lobanov, Pate, Latrille, & Joyce, 2025). Additional studies indicate that key input costs, such as plant nutrients supplied indirectly via fish feed, may exceed the costs of conventional fertilization strategies (Colt & Schuur, 2021). High capital requirements and limited access to start-up funding have also been identified as significant barriers to establishing new commercial-scale systems or expanding existing operations (Quagrainie, Flores, Kim, & McClain, 2017; Turnšek et al., 2020).

Furthermore, when shifting from model-based profitability assessments to empirical evidence from operating aquaponics businesses, the reliability of available data appears low. Research shows that the current level of industry adoption is insufficient to establish robust performance benchmarks, and that influential claims about aquaponics profitability have often been based on weak or unverifiable data (Turnšek et al., 2019). Survey results further indicate that many aquaponics companies do not rely primarily on the sale of fish and vegetables for income; instead, they generate substantial revenue from services, consultancy, education, or related activities. This reliance on additional income streams reinforces the perception that achieving sustainable profits solely through the production of edible crops and fish remains challenging under current market and technological conditions (Love et al., 2015; Turnšek et al., 2020). We therefore hypothesized that

H5: Perceived economic viability negatively affects the attitude towards aquaponics.

Sustainability of aquaponics and personal environmental awareness

In recent times, impact-driven investment has become a trend, with investors trying to support businesses they deem fit to positively affect the future of mankind (De Amicis et al., 2020). Investment decisions might thus not always be based solely on economic considerations, but also on proven environmental benefits. Against the background of some recent Life Cycle Assessment (LCA) studies that suggest a reduced environmental impact of aquaponics in comparison with other food production systems (Chen, Zhu, Kim, Brown, & Huang, 2020; Greenfeld, Becker, Bornman, Spatari, & Angel, 2022), such a claim is substantiated. It can thus be hypothesized that

H6: The perceived higher sustainability of aquaponics might positively affect the overall attitude towards aquaponics.

The importance of sustainability aspects might gain more weight if one's business is susceptible to environmental stressors. While it is disputed whether awareness about environment-related vulnerability results in a higher likelihood of adopting environmentally friendly technologies (see e.g., Ling, Xue, Yang, and Zhang (2022)), it could have an impact on the perception of environmentally friendly technologies and also add further weight to the perceived sustainability of such technologies. We thus hypothesize that

H7: The awareness of the effects of environmental issues on the viability of a firm positively affects the perception of sustainability aspects related to aquaponics.

Methodology

Study design and data collection

A web-based survey was implemented in Microsoft Forms and fielded between October and December 2023. A purposive sampling strategy targeted professionals in the hydroponics industry. Invitations were disseminated via business associations, expert societies, and sector-specific trade publications (see A. A. Tellbüscher (2023)). Additional hydroponics-related companies were identified through trade press reviews and targeted web searches, followed by direct email outreach. To complement organizational recruitment, LinkedIn was used. Using the LinkedIn Business Suite, approximately 2,500 professionals were identified with the search terms "*hydroponic*", "*greenhouse*", "*invernadero*", and "*soilless*". Each of the identified individuals received a standardized direct message inviting them to participate, and a reminder after five working days. In total, 143 valid responses were collected, corresponding to an estimated response rate of 5%.

Survey instrument and questionnaire design

The questionnaire comprised 41 items. Considering the exploratory nature of this study, items were developed by the authors based on the background outlined in the literature review. To enhance accessibility and participation, the questionnaire was developed in English and translated into Spanish, Russian, Czech, and German. The language versions can be found in the data repository (https://doi.org/10.5281/zenodo.11229498).

A filter question identified respondents unfamiliar with the term "aquaponics". Two items captured demographic information (age and gender), and four items captured employment-related characteristics: facility type (production: greenhouse, vertical farm, aquaponics farm; miscellaneous: supplier, consultancy, construction company, research, other), facility size (if production was chosen as facility type), country of company domicile, and job title.

Thirty-four items were assigned to seven latent variables and assessed the perception of how environmental issues affect a hydroponics firm's business activities ("Environment"; 4 items), the perception of aquaponics' sustainability ("Sustainability"; 6 items), the perception of system management challenges in aquaponics compared with hydroponics ("Management"; 7 items), the simplicity of understanding the legislative framework affecting aquaponics ("Legislation"; 3 items), the perceived economic performance of aquaponics ("Economy"; 7 items), and the overall attitude towards aquaponics ("Attitude"; 7 items). Responses to attitudinal items were recorded on a five-point Likert scale (1 = "Strongly disagree", 5 = "Strongly agree"). The questionnaire can be found in the supplementary material.

Ethics and informed consent

Data collection complied with the General Data Protection Regulation (GDPR; EU 2016/679). The survey's introductory page informed participants about the study aims, data handling procedures, and guarantees

of anonymity. No personally identifiable or geolocation data were collected. Given the anonymous and non-sensitive nature of the data, formal ethical approval was not required. Informed consent was obtained implicitly, as continuing to the questionnaire indicated agreement to participate. Participation was voluntary and uncompensated.

Data preparation, model specification, estimation, and evaluation

All analyses were conducted with R version 4.5.0 (R Core Team, 2025) using the *tidyverse* and *seminr* packages (Ray, Danks, & Calero Valdez, 2018; Wickham et al., 2019). The analysis files can be found in the code repository (https://doi.org/10.5281/zenodo.18518069).

Respondents who indicated unfamiliarity with the term “aquaponics” (*n* = 3) or reported employment at an aquaponics facility (*n* = 9) were excluded. To align the sample with an industrial perspective, respondents employed in research institutions were also excluded (*n* = 13). In total, 25 cases were removed, yielding a final sample size of **118**. One missing value for age was imputed using mean replacement.

The used model structure built on the hypotheses that were derived from the literature review. It did not follow a specific theoretical framework, as the purpose of the study was to explore the effect of specific issues on the overall attitude towards aquaponics. Reflective relationships were assumed for all constructs.

The SEM reliability and validity was assessed following standard methods (Hair et al., 2021). Indicator reliability was tested by assessing the loadings, eliminating those with a loading $x < 0.4$ without further testing and those with a loading $0.4 \leq x < 0.7$ after evaluating a potential increase in the construct reliability and convergent validity indicators. Construct reliability was assessed using Cronbach’s alpha, composite reliability (Rho_C) and Rho_A. A threshold of 0.7 was used to assess their respective values. Convergent validity was evaluated by the Average Variance Extracted (AVE) and discriminant validity was evaluated using the heterotrait-monotrait ratio (HTMT). According to literature, all values should be below 0.85 (conservative threshold) and significantly differ from 1. Significance testing relied on non-parametric bootstrapping with a 5% significance level.

Results

Sample characterization

The geographical distribution of the survey participants is shown in Figure 2. 36% of the responses originated from survey participants based in the United States of America (*n* = 23), Australia (*n* = 10), the Czech Republic (*n* = 8), United Arabic Emirates (*n* = 6), and Canada (*n* = 6). No responses were noted from China, Japan, Argentina, or Brazil.

Sociodemographic data of the survey participants is presented in Table 1. Out of the 118 respondents, 83% were male and 17% female. The average age of the respondents was 42 ± 14 years. No significant

difference of the average in relation to the gender was found (two-sample *t*-test: $p = 0.2$). The survey participants can be divided into producers such as farm managers, or other related staff, and vendors of greenhouse supplies or service providers. Of the 62.7% of producers, 77.0% indicated that they worked in greenhouses and the remaining 23% in vertical farms. Of the 37.3% suppliers or service providers, 71.3% indicated that they offer consulting services. 22.7% sold supplies for hydroponic facilities such as fertilizer, while 6.7% were involved in the planning and construction of such facilities. No significant difference in the responses was found between the two groups (Kruskal-Wallis test: $p > 0.05$).

Table 1: Sociodemographic data of the survey participants in comparison with data from the 2022 Census of Agriculture from the United States Department of Agriculture and National Agricultural Statistics Service (2024).

		Survey respondents (n = 118)		USDA Census (n = 3,374,044)	
Variable		**n**	**Percent**	**n**	**Percent**
Gender					
male	male	98	83%	2,149,318	64%
female	female	20	17%	1,224,726	36%
diverse	diverse	0	0%		
Age (years)					
	18-24	7	6%	57,000	2%
	25-34	44	37%	239,480	7%
	35-44	22	19%	426,616	13%
	45-54	20	17%	519,430	15%
	55-64	14	12%	837,525	25%
	Above 64	11	9%	1,293,993	38%
Business					
Producers					
	Conventional	57	48.3%		
	Vertical farm	17	14.4%		
Related					
	Equipment supplier	10	8.5%		
	System construction	3	2.5%		
	Consultancy	31	26.3%		

Model evaluation

Key outcomes of the measurement model evaluation are shown in Table 2. Following the evaluation procedure, the items *Sust4*, *Att4*, and *Man3* were removed from the dataset due to their loadings (<0.4). Construct reliability was given for all constructs except for *Legislation* (Cronbach's alpha = 0.59, Rho_A = 0.60, Rho_C = 0.83), which was thus removed. Construct reliability of the *Management* construct did not

further improve by removing additional items. The AVE was above the threshold value of 0.5 for all constructs and HTMT values were significantly lower than 1 (Bootstrap: n = 5000, 95% CI).

Table 2: Parameters describing construct reliability and convergent validity of the final Partial Least Squares-Structural Equation Model (PLS-SEM). AVE: Average variance extracted.

Construct	Cronbach's alpha	Rho_A	Rho_C	AVE
Environment	0.795	0.899	0.839	0.576
Management	0.807	0.698	0.843	0.526
Sustainability	0.796	0.827	0.865	0.617
Economy	0.835	0.841	0.876	0.502
Attitude	0.906	0.910	0.928	0.682

66.5% of the variance of *Attitude* in the structural model was explained by all independent variables, while 6.4% and 5.5% of the variability of the *Economy* and *Sustainability* constructs were explained, respectively.

The bootstrapping results of the total effects are shown in Table 3. The effects of the *Management* and *Environment* constructs on the *Attitude* were found to be insignificant ($p > 0.05$), leading to the rejection of hypotheses 2 and 8. The *Management* and *Environment* constructs did also not significantly affect the *Economy* and *Sustainability* constructs, respectively, leading to hypotheses 1 and 7 being rejected. Hypotheses 3 and 4 were rejected due to the removal of the *Legislation* construct from the model. Meanwhile, a significant and positive effect of the *Economy* and *Sustainability* constructs on the *Attitude* was found, thus corroborating hypotheses 5 and 6.

Table 3: Total effects, related hypotheses and bootstrapping results. The result is non-significantly different from zero if the bootstrapped 95% confidence interval encloses zero.

Effect			Hypothesis	Bootstrapping results		
				Mean ± SD	95% CI	Signif.
Management	→	Economy	H1	0.28 ± 0.14	[-0.24, 0.48]	n.s.
Management	→	Attitude	H2	0.29 ± 0.10	[-0.12, 0.43]	n.s.
Economy	→	Attitude	H5	0.38 ± 0.07	[0.24, 0.53]	*
Sustainability	→	Attitude	H6	0.50 ± 0.09	[0.32, 0.66]	*
Environment	→	Sustainability	H7	0.23 ± 0.18	[-0.34, 0.43]	n.s.
Environment	→	Attitude	H8	0.09 ± 0.07	[-0.13, 0.17]	n.s.

Conclusion

Economic prospects and the sustainability of aquaponics are the key topics shaping the attitude of hydroponics professionals towards aquaponics. Improving and diversifying the communication strategies for scientific outputs related to those fields in aquaponics and providing additional information stemming from aquaponics companies is a promising way to improve the overall attitude towards aquaponics. Research related to systems management should, meanwhile, address and ideally quantify the economic benefits as well.

Discussion

It can be proposed that perceptions of an innovation will directly influence attitudes towards the innovation and ultimately enable its adoption. The goal of this study was thus to help align aquaponics research more closely with the concerns of potential adopters by examining the aspects that affect their attitude towards aquaponics. We focused on professionals from the hydroponics sector as potential group of adopters.

Interpretation of model outcomes

The results show significant effects of the perceived economic prospects and sustainability on attitudes towards aquaponics. Technical issues affecting the management of aquaponic systems did, meanwhile, not significantly shape the attitude.

A major hurdle in the theoretical interpretation of the obtained results that also affected initial model creation is the focus of technology adoption frameworks, including the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), the Theory of Diffusion of Innovation (DOI), and the Technology, Organization, Environment (TOE) framework, on incremental innovation. The TAM is one of the most widely used frameworks for understanding how individuals accept and use new technologies. According to the TAM, two key factors influence the adoption of

technology, which are its perceived usefulness and ease of use (Davis, 1989). The UTAUT is a further development of the TAM. Besides including the performance expectancy (similar to the perceived usefulness) and the effort expectancy (similar to the perceived ease of use), it also comprises social influence, and facilitating factors as four key constructs and adds several moderator variables to the model (Venkatesh, Morris, Davis, & Davis, 2003). Due to its complexity, it provides a more comprehensive understanding of the factors influencing technology adoption. Both models focus on the adoption of technology through individuals. Same as the TAM and UTAUT, the DOI theory focusses on the individual. However, in contrast to TAM and UTAUT, which are behavioral models and try to estimate the likelihood of technology adoption through individuals, the DOI theory estimates at what rate the technology is adopted within a social system as a result of innovation communication. The TOE framework, meanwhile, targets factors affecting technology adoption at an organizational level and summarizes technology adoption drivers under technological, organizational, and external aspects (Tornatzky & Fleischer, 1990).

The stated models complement each other and can, if combined, provide a comprehensive overview of the factors determining technology adoption and the adoption rate on the individual and organizational level. However, the adoption of technology generally refers to the implementation of novel technology into an existing system. Meanwhile, the adoption of aquaponic food production is better described as a transformative innovation. In this context, adopting aquaponics comes either with the expansion of production or a fundamental repurposing of existing infrastructure. Research on such transformative innovation is generally scarce.

The outcomes of this study could, however, be interpreted against the background of the TAM. First, the TAM proposes that cognitive factors such as perceptions toward a new technology will predominantly impact attitudes toward the technology. This assumption is corroborated by our findings, as 68.8% of the variance of the variable *Attitude* was explained by the independent variables in this study. Thus, it can be concluded that attitudes towards aquaponics are largely influenced by perceptions of the specific aspects that were derived from the literature review in this study. Secondly, the TAM assumes that two cognitive factors, in particular, have a central influence on the formation of attitudes: perceived usefulness and perceived ease of use of a new technology. Perceived usefulness refers to the belief that using the technology will increase performance or productivity, while perceived ease of use refers to the belief that using the technology will require no effort. The independent variables tested in this study can be assigned to each of these factors. For example, the variables *Sustainability* and *Economy* can be assigned to the usefulness factor, as they relate to the perceived added value or benefit of adopting aquaponics. On the other hand, the variables *Management* and *Legislation* could be interpreted as referring to the technology's ease of use. Accordingly, against the background of this study's outcomes, it can be concluded that perceived usefulness in terms of *Sustainability* and *Economy* has a greater influence on attitudes towards aquaponics than its ease of use in terms of managing the new technology. Our findings thus corroborate the results of a qualitative study from Israel on a global scale, where a sensitivity analysis showed that the profit and environmental benefit would have the greatest effect on the adoption of aquaponics (Greenfeld, Becker, Bornman, & Angel, 2021).

Possible implications for science

A great share of research in the field of aquaponics targets technical questions related to systems management. However, while the survey participants generally agreed that those questions pose real issues, these problems do not affect the general attitude towards aquaponics. In terms of practical implications, this means that communication and marketing activities between the interrelated stakeholder groups should emphasize the usefulness aspects, particularly regarding sustainability. Regarding the latter point, aquaponics companies in particular are in demand: studies have highlighted a lack of reliable data (Turnšek et al., 2019), which could result in a distorted picture of reality (in both a positive and negative sense). More transparency within the industry could therefore allow for a more realistic classification of aquaponics. However, this could also be to the detriment of adoption.

Assessing and pointing out possible economic benefits of such improvements and expanding the range of publishing channels (e.g., focusing more on popularization articles etc.) might have a considerable impact on the overall perception of aquaponics' economic performance and should be considered by the scientific community. The same applies to the topic of sustainability. Sustainability aspects of aquaponics such as the environmental footprint have been the topic of several scientific studies (Forchino, Lourguioui, Brigolin, & Pastres, 2017; Greenfeld et al., 2022).

Raising awareness for the benefits of aquaponics not only among hydroponics practitioners but also among legislators might lead to the creation of incentives or the reduction of barriers to aquaponics, as described elsewhere in greater detail (Fruscella et al., 2021; Greenfeld et al., 2021; Greenfeld et al., 2018).

Limitations of the study

The sample size of PLS-SEMs to reach appropriate power depends on the number of items and latent constructs. The model used in this study, with seven latent variables, has insufficient power because the sample population was too small (n = 118). A simplified model with four constructs has thus additionally been fitted to assess whether core findings are affected. In this model, the environmental awareness and sustainability perception of aquaponics, and the perception of the economic and legislative situation were summarized as internal and external factors, respectively, affecting the attitude towards aquaponics, while the technological variable remained unaltered. The model structure was adapted from the TOE framework, which is used to study technology adoption in organizations (Tornatzky & Fleischer, 1990). The model outcomes indicate again that perceived systems management issues exert a negative but low effect on the overall attitude towards aquaponics (results not shown).

Another limitation of this study is that the representativeness of the sample population could not be verified due to the absence of statistics on the hydroponics sector. Hydroponics is usually classified as a sub-field of agriculture by statistical offices, which masks the gender and age distribution of people employed in the hydroponics sector. Assuming that the age and gender structure is comparable to that in agriculture in general, the sample population in this study is too male dominated. While close to 50% of agricultural workforce are women in high-income countries, the share of women is above 50% in the

global south (FAO, 2023). This bias might have been introduced by using LinkedIn. It is known that the proportion of male LinkedIn users is higher than that of females. In addition, the LinkedIn search algorithm and cookies might have affected the search results. Meanwhile, the distribution of survey respondents across countries is plausible, as Australia, the USA, and European countries such as The Netherlands are major players in the hydroponics market (Mordor Intelligence, 2026).

A third issue originates from the translation of the questionnaire into multiple languages, which can introduce considerable deviations between the respective language versions, as described by the Cultural Dimensions Theory (Hofstede, 1984, 2001). A scale to measure cross-cultural measurement consistency has, however, not been included in the questionnaire. Future, theory-driven studies should take this aspect into account.

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contribution

All authors contributed to the study conception and design. Material preparation, data collection, analysis, and visualization were performed by A. T., who wrote the first draft together with C. R.. All authors reviewed and edited the previous versions and approved the final version of the manuscript.

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Data Availability

All relevant data have been uploaded to the Zenodo data repository. There you can find all versions of the questionnaire used in this study (10.5281/zenodo.18670414) and the code (10.5281/zenodo.18518070).

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Statements and Declarations

Figures

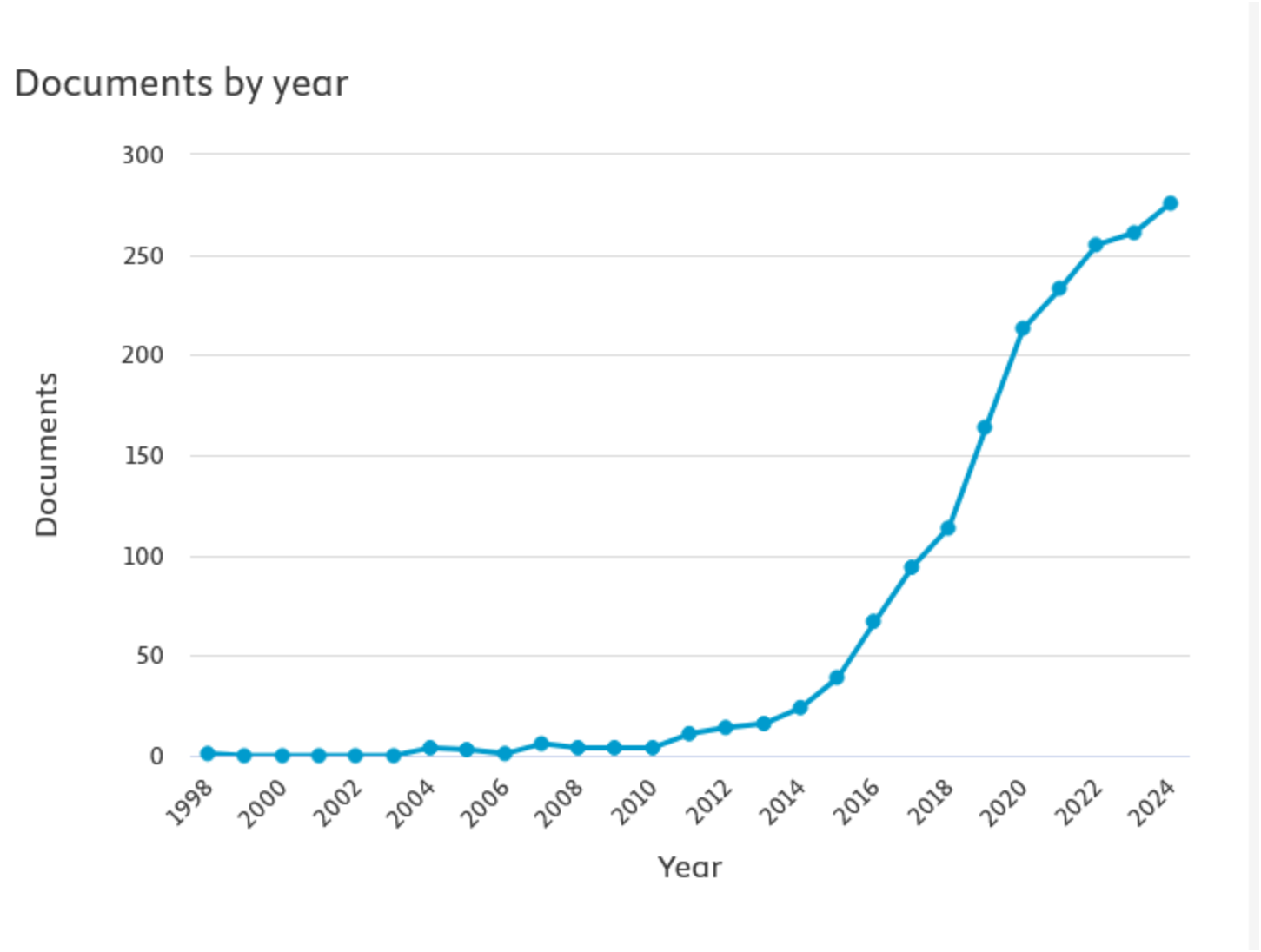


Figure 1

Scientific articles published per year over that contain the search term "aquaponic*" and are indexed by SCOPUS. Data was acquired on January 21, 2025.

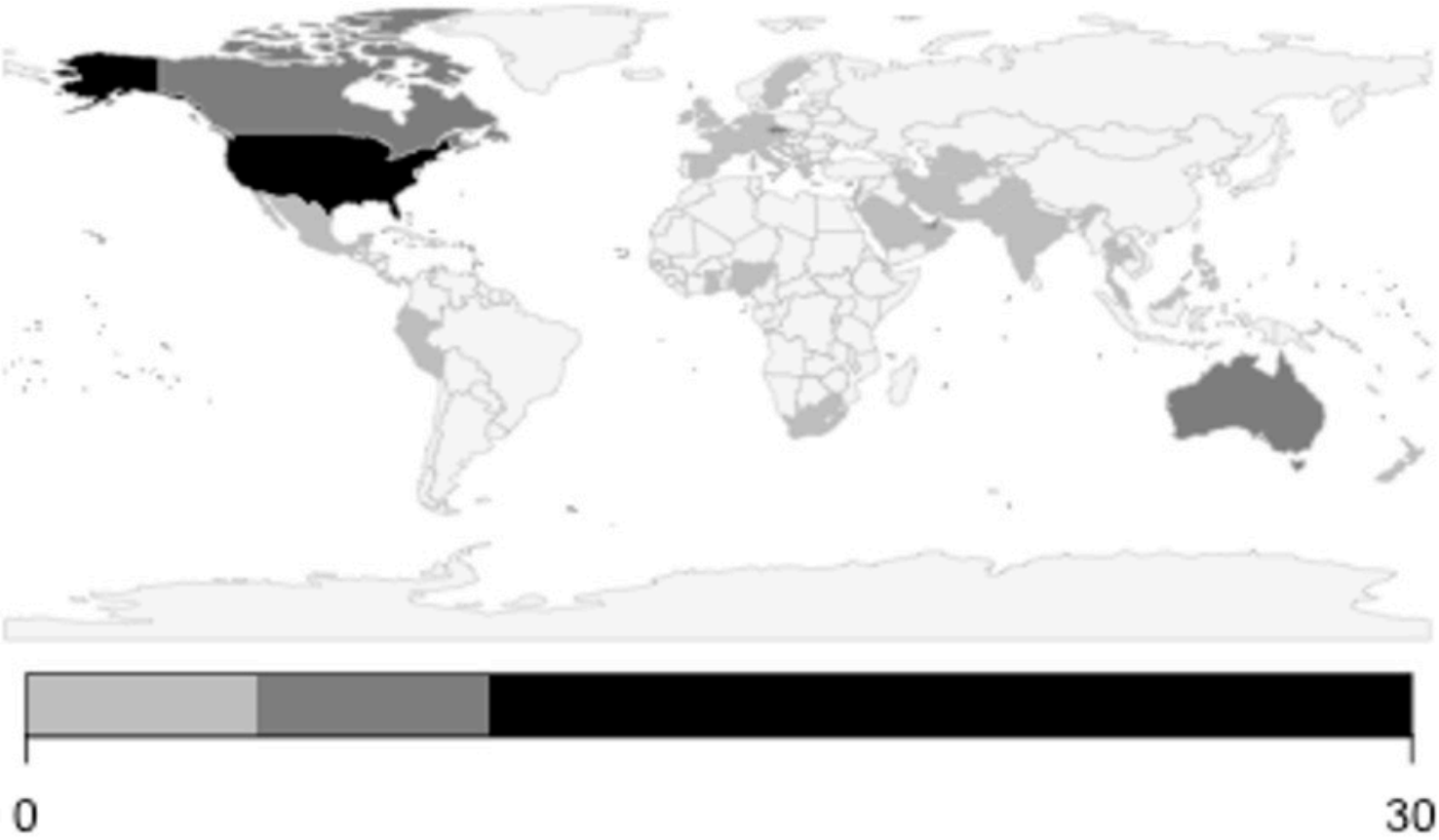


Figure 2

Spatial distribution of the survey participants (n = 118) over their countries of residence (*n* = 38). Main locations: USA (*n* = 23), Australia (*n* = 10), Czech Republic (*n* = 8), United Arabic Emirates (*n* = 6), Canada (*n* = 6).

Supplementary Files

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