Aquaponics as a Potential Sustainable Agri-tech System in Portugal: Stakeholder Attitudes, Perceptions and Perspectives

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Extended Abstract

Abstract

Aquaponics is an Agri-tech frontier in agri-food production systems that synergizes aquaculture and hydroponics in a recirculating, closed system with a low environmental impact. This paper aims to analyze the potential development of commercial aquaponics in Portugal, contributing to sustainable agri-business and food security in the country. The information and data were collected through structured interviews with stakeholders to understand the potential and perspectives of the sector, as well as the regulatory constraints and strategic enablers. The methodology includes univariate methods, a restricted scoping literature review, and mainly qualitative analysis based on interviews with eleven Portuguese stakeholders, including entrepreneurs, academics, policymakers, and practitioners. Based on the information and data, content analysis, key attitudes, perceptions and limitations were identified. The findings reveal a strong perception of administrative and institutional inefficiencies of aquaponics in Portugal, low consumer awareness, and legal inconsistencies and restrictions. Despite these barriers, aquaponics is viewed as a promising and innovative technology with the potential to reduce carbon footprints and agricultural inputs, promote local food systems and short food supply chains, and foster circular economies. The conclusions of this paper highlight the importance of investing in aquaponics and developing research and development schemes to advance the Agri-Teck aquaponics sector, as well as regulatory and institutional reform, certification schemes for aquaponics production, and public engagement to facilitate the scale-up of aquaponics in Portugal.

Keywords: Aquaponics, Artificial Intelligence, Agri-tech, Circular Economy, Food Security, SDGs,

1. Introduction

Increasing worldwide concerns around climate change, water and other resources scarcity, urbanization, and food insecurity call for transformative technologies in agriculture and Agri-tech models of production (Davis et al., 2025; John et al., 2025). Aquaponics, an integrated method that combines aquaculture and hydroponics in a closed-loop system, is increasingly regarded as a solution to future agri-business challenges (Mata & Dos-Santos, 2025; Verma et al., 2023). This technology enables sustainable food production with reduced water use, minimal synthetic input, and the capacity for urban deployment, promoting short supply chains (FAO, 2020; Dos-Santos, 2016; Dos-Santos et al, 2021). It addresses several UN Sustainable Development Goals (SDGs) (Verma et al., 2023; UN, 2025), particularly those related to zero hunger (SDG1), sustainable cities and communities (SDG11), and responsible production and consumption (SD12). Portugal is a country with the highest per capita fish consumption

among European Union consumers (Murthy et al., 2023; Mata & Dos-Santos, 2025), characterized by a strong cultural attachment to fresh and locally produced fish. The country has long been aligned with a "Mediterranean diet" (Rodrigues et al., 2022; Mata & Dos-Santos, 2025), based on plant-fish fresh products. In this case, aquaponics aligns with both environmental and nutritional imperatives, as well as the gastronomic values and culture of Mediterranean countries and the Mediterranean diet (Mata & Dos-Santos, 2025). However, the sector remains underdeveloped, impeded by legal, institutional, and market constraints. This paper aims to assess the perceptions of key stakeholders in Portugal and to identify the barriers and opportunities that define the development path of aquaponics.

2. Methodology

A qualitative approach was based on semi-structured interviews. These interviews take place from March to October 2024. Approximately 15% were completed online via the Zoom platform, and the latest was conducted in person. The interviews were conducted to gather in-depth insights from a sample of eleven stakeholders active in the Portuguese aquaponics ecosystem. The participants in Portugal, including aquaponics entrepreneurs (AQE), hydroponics (HYD) and aquaculture business owners (AQC), academic researchers (ACD), a policymaker (PLM), and a hobbyist (HOB). Data were collected through semi-structured interviews using open questions that explored perceptions of aquaponics by different actors, investment limitations, the impact of these constraints on business decision-making, recommended policy actions, effective marketing strategies, and known legislative challenges. Data were analyzed using univariate analysis, qualitative analysis and complemented by content analysis to identify the main commonalities and divergences in responses.

3. Results and Discussion

3.1. Results

Table 1 presents the results of the socio-economic characteristics of respondents and the recurring statements, along with the number of respondents who supported each, and their corresponding background information.

Table 1: Summary of Thematic Responses and Stakeholder Distribution

Socio-economic characteristics of respondents	**Average**	**Max/Min**
Age	45	57-31
Gender	Male - 85% Female – 15%	
Income per year	31000 euros/year	45000- 14000
Educational level	Bs Science	Mandatory education/ (bachelor's degree/Ms/PhD
Thopic/Statement	**Frequency/Percentage**	**Respondent Type(s)**

General awareness of aquaponics among aquaculture/hydroponic agents	11/100	All
Aquaponics is Agri-tech production that requires a high level of development	11/100	All
Institutional and legal barriers restrict the development of aquaponics	11/100	All
Low consumer awareness of aquaponics	8	AQP, HYD, AQC, ACD, PLM, HOB
Policymakers are unfamiliar with aquaponics	7	AQP, HYD, AQC, HOB
Consumers don't really know the add-value of aquaponics production and are confused with hydroponics and aquaponics	8	AQP, HYD, ACD, PLM, HOB
Entrepreneurs lack technical aquaponics knowledge	6	AQP, ACD, PLM
Aquaponics complexity (RAS management) is a concern	5	AQP, HYD, ACD, PLM, HOB
Lack of organic certification is a key barrier	5	AQP, ACD, PLM
Proposing investment support schemes and CAP measures for aquaponics	6	AQP, ACD, HOB; SM
Recommend marketing and advertising via workshops and forums	6	AQP, ACD, PLM
Licensing the activity is overly complex and fragmented	2	AQP
Exotic species ban (e.g., tilapia) as a barrier	1	AQP
Freshwater fish undervalued in the Portuguese market	3	AQP, HOB; SM
Suggest creating an experimental Research Center for development of aquaponics and new R&D opportunities	3	ACD, PLM; SM

Source: Results from authors, 2025

The total of eleven semi-structured interviews provided qualitative and quantitative information and data. These interviews take place from March to October 2024. Approximately 15% were completed online via the Zoom platform, and the latest was conducted in person. The interviews were conducted to gather in-depth insights from a sample of eleven stakeholders active in the Portuguese aquaponics ecosystem. The participants in Portugal, including 3 aquaponics entrepreneurs (AQE), 1 hydroponics (HYD) and 1 aquaculture business owners (AQC), 2 academic researchers (ACD), a 2 policymaker (PLM), a 1 Science Manager from a IT Research Center (SM) and a 1

hobbyist in aquaponics (HOB). Information and data were collected through semi-structured interviews using open questions that explored perceptions of aquaponics by different actors, investment limitations, the impact of these constraints on business decision-making, recommended policy actions, effective marketing strategies, and known legislative challenges. Data were analyzed using thematic content analysis in order to identify commonalities and divergences in responses.

The results of the socio-economic respondents reveal that the aquaponics practitioners in Portugal are represented by young people (37 years old on average), the majority are male, and the majority are very qualified, with a master's degree related to the area (agricultural sciences, animal sciences and engineering). All of them refer to the fact that aquaponics is taking the first steps in the field, with the commercial level as the target, despite the current restrictions. This situation remains quite similar to the one described in the previous work by Dos-Santos (2019). Other experts and public decisions in the field are indeed highly qualified, as is the complete sample surveyed. The respondents unanimously recognized aquaponics' environmental benefits but pointed out significant operational risks and gaps in institutional support. Many stressed the absence of extension services with aquaponics expertise, and the lack of targeted policy or investment mechanisms. Stakeholders highlighted a range of systemic, technical, and social constraints. Key findings include the unanimous recognition of aquaponics among stakeholders in aquaculture and hydroponics; widespread concern over consumer unawareness of aquaponics; and a shared view that policymakers are largely uninformed about the technology. Technical knowledge gaps, particularly regarding recirculating aquaculture systems (RAS), were cited as barriers to entry. Interviewees referred to the actual complexity of RAS operation, the high dependency on the costs of electricity and oxygenation systems, and the need for constant monitoring, which increases the input and costs associated with qualified labor. They also refer to the fact that organic certification has emerged as a critical restriction within the current EU framework, which excludes aquaponic systems due to their non-soil-based cultivation. Stakeholders suggested creating a new certification scheme, such as "Sustainable Aquaponics" or "Biologic Aquaponics", to add value to this agricultural system. Others recommended increased investment support, promotional activities such as workshops and school exhibitions, and the establishment of an experimental aquaponics station for education and demonstration purposes.

Legal and institutional restrictions were previously described by Miličić et al. (2017). Aquaponics is not officially recognized as a distinct production system and falls under separate legislative umbrellas for aquaculture and agriculture in Portugal and European Member States (EMS). This leads to duplicated bureaucratic processes, which delay licensing and create operational uncertainty. Regulatory fragmentation was especially problematic for start-ups seeking to innovate in this space. The ban on tilapia in Portugal, while ecologically justified, removes a popular species from commercial options. However, other freshwater species such as largemouth bass, pikeperch, and eel were acknowledged as viable alternatives with strong culinary traditions in inland Portuguese regions. These species are suitable for RAS environments and offer economic potential if better integrated into gastronomic culture (Mata & Dos-Santos, 2025).

Market acceptance remains a challenge due to low consumer knowledge and lack of differentiation for aquaponic products (Greenfeld et al., 2020; Miličić et al., 2017). Most Portuguese consumers are unfamiliar with the concept or confuse it with hydroponics or

conventional aquaculture. The same results were previously obtained by Greenfeld et al. (2020) and Miličić et al. (2017). Some interviewees observed that a minority of consumers who are aware of aquaponics associate it with sustainability and local food production, namely, short supply chains of fresh foods. These attitudes present a marketing opportunity that aligns with environmental and ethical values. Strategic actions include public education campaigns, retailer partnerships, and the inclusion of aquaponics in sustainability-focused food policies.

Aquaponics aligns with frontier Agri-tech dimensions by integrating technological innovation, sustainability, and circular economy principles. Despite that, the actual investment in research and development (R&D) in the sector aligned with new technologies (drones, sensors), Internet of Things (IoT) and artificial intelligence (AI) in the sector remains low. This implies the need for R&D that covers not just Portugal but consortia across Europe and other continents, which are imperative to support the progress and lead to the development of the commercial sector. It will support the decentralization of food production, integrate with smart city infrastructure, and reduce dependence on imported food products (Dos-Santos, 2016) from long supply chains. Portugal has a commercial trade deficit in fish (Rodrigues et al., 2022), so Portuguese aquaponic production could offer a high-value and sustainable alternative. Furthermore, consumer trends increasingly favor pesticide-free, ethically produced, and locally sourced foods, positioning aquaponics as a competitive solution. To achieve these level of development the aquaponics sector must address four key priorities: 1) regulatory harmonization to unify and streamline legal frameworks governing aquaponics; 2) To develop and promote innovative certification and to introduce new labels/classification that accurately reflect the real sustainable nature and value of aquaponic products; 3)To promote and develop financial support programs tailored to small and medium-scale producers willing to invest in aquaponic systems; and 4) To promote and develop consumer education campaigns to raise awareness, clarify misconceptions, and foster market acceptance.

Conclusion

Aquaponics stands as a high-potential, low-footprint technology for Portugal's future Agri-tech-food sector. However, its diffusion is limited by outdated legal classifications, technical challenges, insufficient public recognition and low investment in R&D in this sector. There is a critical need for regulatory harmonization to define aquaponics as an independent production category. Certification innovation is necessary to enable market differentiation and consumer trust. Financial support mechanisms and schemes, particularly those implemented through CAP measures and policies, must be tailored to the specific characteristics of aquaponic systems. The urgent need for R&D in new technologies, IoT, and IA that covers not just Portugal but consortia across Europe and continents, involving the production sector, public decision makers, R&D, and the public of consumers, is necessary to support technologies and progress to the commercial sector. Ultimately, widespread public education from a young age, combined with effective marketing strategies, is essential to boost consumer demand. Therefore, if aquaponics production is strategically supported, it will lead to an advancement in Portugal’s leadership in sustainable, high-tech agri-business models of production and consumption.

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Data Availability
Data supporting this study's findings are available upon request.

Appendix A: Questionnaire (English Translation – Part semi-structured questions)

1. How do different actors (entrepreneurs, policymakers, consumers) perceive aquaponics?
2. What are the main limitations for companies investing in aquaponics?
3. How do these limitations affect their decision-making?
4. What actions should be taken by public institutions?
5. What marketing or outreach actions could be effective?
6. Are there specific legal constraints?
7. What are your recommendations for advancing the aquaponics sector?