Accelerating Aquaponics Adoption in Asia: Essential Technical and Policy Considerations

James H. Joo[1,*], Andrew Moses[2], Sanghee Choo[3], and Jinsook Lim[4]

[1] MIT Sandbox Innovation Fund, Massachusetts Institute of Technology, Cambridge, USA
[2] WAM Equity Partners, New York, USA
[3] ESSEC Business School, Cergy, France
[4] Actos Advisory, Boston, USA
Email: jooh@mit.edu (J.H.J.); amoses@pipeline.com (A.M.); choosanghee@yonsei.ac.kr (S.C.); lim_jinsook@brown.edu (J.L.)
*Corresponding author

***Abstract*—The excessive exploitation of natural resources and the rapid industrialization of societies have led to severe ecosystem destruction and exacerbated climate change. Today, the global ecosystem faces significant threats. Consequently, consumer demand for safe and healthy food is steadily increasing while preserving the environment remains a priority. In response, agricultural science has evolved to develop a novel agricultural technology called "aquaponics", which combines aquaculture and hydroponics, surpassing conventional hydroponic systems. However, the adoption of aquaponics remains relatively low compared to traditional farming methods. This study investigates the critical technical aspects that need to be developed in the aquaponics sector and proposes strategies to promote its wider adoption. By identifying key areas for improvement and addressing technical challenges, this research seeks to accelerate the deployment of aquaponics as a sustainable and efficient farming practice.**

***Keywords*—agri-technology, eco-technology, aquaponics, technology, water management, policy, public participation**

I. Introduction

According to the Asian Development Bank, 80% of water resources are used for agricultural irrigation in Asia and the Pacific. However, water scarcity due to climate change and increasing demand for water from other economic sectors threatens to limit agricultural capacity to ensure food security unless water management in agriculture is improved. According to World Resources Institute, about 44 countries, which account for over 30% of the world's population, are already suffering from severe water shortages. The agricultural sector is the largest user of water. Based on the quantity consumed, 70% of all water is consumed in agriculture. However, water use efficiency in the agricultural sector is low enough to exceed 45%, and the loss exceeds 50% [1].

Today, deepening water shortages and mismanagement of available water resources pose a significant threat to sustainable development in clean water supply, industry, and agriculture sectors. Increasing water productivity under climate change is vital for food production, eliminating poverty, easing competition for water use, and water for nature. In aquaponics, which is expected to be commercialized shortly due to technological innovation, research is being actively conducted in Europe and the United States. However, systematic research on aquaponics is relatively lacking in Asia, the region that can benefit most significantly from improving the existing agricultural system [2, 3].

However, water resources and significant improvements in Asia are needed to achieve this goal. Responding to these challenges requires much effort and substantial changes in water management. What needs to be changed? What improvements are required to the deepening water shortage? These issues are described in this report. In other words, through the case of South Korea and Thailand on appropriate technologies and means to save water and increase water productivity using aquaponics technology, we will examine success stories or research trends and critical technologies developed in aquaponics from a short to medium term perspective.

II. Discussion

A. Technical Overview

Aquaponics is a system that creates a symbiotic ecosystem where organic nutrients are naturally produced in water during aquaculture and then supplied to plants. The plants absorb these nutrients, purify the water, and grow simultaneously (Fig. 1). This technology offers several advantages, such as high water use efficiency, no pesticides, and reduced reliance on traditional fertilizers, making it both environmentally friendly and sustainable [4].

Aquaponics has the potential to address many of the challenges faced in traditional agriculture. It enables the direct production and distribution of fresh agricultural products, even in regions with limited arable land. The technology offers a solution for areas struggling with crop cultivation and allows for food production in

Manuscript received May 26, 2023; revised June 21, 2023; accepted December 5, 2023; published May 29, 2024.

locations previously deemed unsuitable for traditional agriculture.

Research has demonstrated that aquaponics offers significant environmental benefits. It helps reduce groundwater pollution caused by fertilizer salts and minimize water and fertilizer usage. Studies have shown that aquaponics can achieve water savings of up to 30% compared to conventional farming methods, while fertilizer usage can be reduced by 30–50% [5]. This contributes to the protection of water resources and promotes the recycling of valuable resources.

There are four widely used aquaponics methods, each with unique characteristics and applications. These methods encompass various approaches to create and maintain the symbiotic relationship between fish and plants, allowing for efficient nutrient cycling and optimal growth.

(1) Deep Water Culture (DWC): DWC is a method that uses foam rafts that float in a channel filled with fish effluent water. The plants are in the raft's punctured holes, allowing their roots to hang freely in the water. It requires little maintenance due to no nozzles, feeder lines, or water pumps and doesn't need fertilizers. However, it requires attentive care for air pump maintenance and has difficulty in temperature maintenance for non-recirculating DWC.

(2) Media-Based Aquaponics: Media-based Aquaponics involves growing plants in inert planting media such as expanded clay pellets or shale. Media-based systems are great for home and hobby scale systems so that you can grow various crops. However, it isn't ideal for commercial purposes due to low productivity and difficulty in large-scale implementation.

(3) Nutrient Film Technique (NFT): NFT works by flowing nutrient-rich water through a narrow trough, such as a PVC pipe. Plants are placed in holes drilled in this pipe, and the roots dangle freely in this stream of water. It is a great way to utilize unused space because it can be hung from ceilings above other growing areas. On the contrary, it has disadvantages, such as significant dependence on electricity and pumping systems for plant survival or the possibility of roots blocking the water from flowing.

(4) Vertical Aquaponics: Vertical Aquaponics is a vertical NFT where plants are stacked on top of each other rather than arranged horizontally. Water flows from top to bottom, feeding the plants water and nutrients. The water then enters the fish tank and repeats the whole process. It possesses the same advantages and disadvantages as NFT methods.

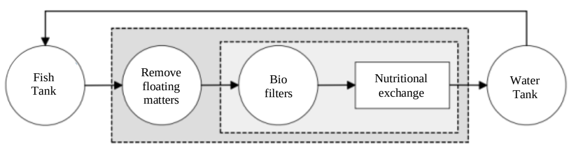

Fig. 1. Aquaponics conceptual map.

One of the significant benefits of aquaponic growing is that minimal water is wasted compared to the traditional growing method, like soil gardening. Although the name implies 'water', aquaponics uses approximately 90% less water than conventional agriculture [6]. In addition, the water is rarely changed or discarded since it's recycled repeatedly throughout the system.

In aquaponics, the water is recycled and used timely. The big reason is that there is no soil to absorb water, and aquaponics continuously uses the same recycled water. So, no extra water is involved unless the water becomes significantly stagnated. The only water lost in aquaponics is through evaporation, which is very little and will require you to replenish the water from time to time.

However, the weaknesses of aquaponics, as described in a United Nations Food and Agriculture report, include: it is knowledge-intensive, expensive to start up, energy/resource demanding, requires daily maintenance, has fewer management choices than agriculture or aquaculture, requires access to fish and plant seed, the fish in the system have narrow temperature ranges, and mistakes or accidents can result in a catastrophic collapse of the system [7].

B. Technological Analysis

Based on the market analysis findings, a Focus Group Interview (FGI) was conducted in July 2022 with nine industry experts. The participants included researchers from academia and industry and individuals responsible for research, development, and finance in relevant companies across Asia, including Korea and India. While the United States currently dominates the aquaponics market, there is growing interest in this emerging technology among Asian companies.

The increasing population in many Asian countries has led to rising demand for food. At the same time, agricultural conditions have become less favorable due to factors such as drought, global warming, the aging of farmers, and urbanization. In response to these challenges, countries are exploring aquaponics as a solution, as it offers a sustainable approach to mass organic food production while minimizing environmental impact [8]. China and India are expected to experience the highest growth rates in the Asia-Pacific aquaponics market. However, Hong Kong, South Korea, Australia, and Japan are also making significant advancements in aquaponics.

Through technology and Intellectual Property (IP) analysis of key players in the Asia-Pacific (APAC) region, such as Manna CEA Co., Ltd, Land craft Agro, and Aquaponics Hardware Asia, as well as the FGI, conducted with major Asian companies, three areas requiring improvement and focused Research and Development (R&D) in the short to medium term have been identified in the aquaponics market.

The identified areas for improvement and R&D focus in the aquaponics market are as follows: pH, electrical conductivity, and introduction of ICT and IoT.

Addressing these areas of improvement through focused R&D efforts will contribute to the advancement and growth of the aquaponics industry in the APAC region, enabling sustainable and efficient food production in response to the evolving challenges faced by Asian countries.

1) pH

In order to supply high-quality organic materials to plants in the first step, it is necessary to create an environment in which aquatic organisms live. In all water systems, the nitrogen concentration of breeding water is controlled by controlling the metabolic activity of fish or microorganisms through the acidity control of water quality. In general, it is known that the {NH}_4^+ and {NO}_2 compound decrease when the pH of the biological oxidation reaction and the activity is less than 6.4 or higher than 9.0 [8]. Therefore, in the aquaponics system, 100–150 mg/L of alkalinity is recommended and used as $CaCO_3$ in the hydroponics system because pH is a buffer degree due to alkalinity. In the case of plants and aquatic organisms that grow under weak base conditions in hydroponics, acidity can be increased through calcium bicarbonate.

2) Electrical conductivity

Electrical conductivity is closely associated with salt levels, making fish populations highly sensitive to fluctuations in conductivity. In aquaponic cultivation systems, it is widely recognized that the optimal range of electrical conductivity falls between 30 to 5,000 μS/cm. When the electrical conductivity is high, there is a tendency to accelerate the reproductive growth rate of plants, leading to shortened harvest times. However, this can also hinder the plant’s ability to absorb moisture, reducing productivity [9, 10].

Conversely, lower electrical conductivity levels promote more vigorous growth of stems and leaves than reproductive growth. To maximize nutrient utilization without excessive fertilizer application, it is essential to maintain consistency in electrical conductivity throughout each crop cycle.

Aquaponic farmers can achieve optimal plant growth and overall system performance by ensuring that electrical conductivity remains within the appropriate range. This involves careful monitoring and control of the electrical conductivity levels, providing an environment that promotes balanced and efficient nutrient uptake by the plants.

Maintaining the recommended electrical conductivity range in aquaponic systems allows for optimizing plant growth and development while avoiding potential imbalances that could negatively impact productivity. Farmers can effectively utilize nutrients, minimize waste, and achieve desirable outcomes in aquaponic cultivation endeavors through this approach.

3) Introduction of ICT and IoT

Integrating Information and Communication Technology (ICT) and Internet of Things (IoT) technologies play a crucial role in enhancing crop productivity. By establishing a data-driven environment, it becomes possible to automate the control of essential factors for plant growth, including temperature, humidity, carbon dioxide levels, and light.

Through the utilization of ICT and IoT, a comprehensive system can be developed to monitor and regulate these environmental variables in real-time. This enables precise adjustments to be made, ensuring optimal crop growing conditions. By leveraging data and advanced analytics, farmers can gain valuable insights into the needs of their plants, leading to improved efficiency and productivity.

ICT and IoT technologies facilitate the collection and analysis of data from various sensors placed throughout the aquaponic system. These sensors monitor crucial parameters, providing valuable information on the overall health and status of the plants. With this data-driven approach, farmers can make informed decisions regarding the application of resources, such as water, nutrients, and energy, optimizing resource allocation and minimizing waste.

Furthermore, the integration of ICT and IoT enables remote monitoring and control, allowing farmers to access real-time data and make necessary adjustments from anywhere at any time. This flexibility enhances operational efficiency and facilitates timely interventions for anomalies or deviations from the desired parameters.

In summary, incorporating ICT and IoT technologies in aquaponics creates a data-driven environment that optimizes essential growth factors’ control. This technological integration empowers farmers to enhance crop productivity by ensuring ideal conditions for plant growth, leading to increased efficiency and improved overall outcomes.

III. Economic Expectation

Aquaponics presents a promising solution for mitigating soil and ocean pollution caused by conventional crop farming and the fish farming industry. Adopting aquaponic systems can substantially reduce the detrimental environmental and economic costs associated with fertilizer usage. This waste-free method ensures that pollution-induced expenses are minimized. Even in cases where a small amount of waste is generated, it can be easily dissolved as sludge, which can then be filtered and repurposed as a beneficial nutrient for the crops.

From an industry-specific perspective, aquaponics offers economic advantages by significantly reducing costs in both greenhouse farming and fish feed production. In the fish farming sector, fish feed is a significant cost contributor, which often contains mycotoxins, contaminating the fish tanks. Implementing aquaponic systems allows for the formulation of environmentally friendly fish feed, enhancing the fish tanks’ overall health and longevity while decreasing feed costs.

Similarly, labor and energy expenses associated with greenhouse operations constitute significant cost factors in crop production. Although aquaponic systems still require intensive labor to operate and maintain, the focus is primarily on monitoring rather than direct production. Consequently, the labor required per production unit is substantially reduced, leading to cost savings in crop cultivation.

By emphasizing both aquaponics’ environmental and economic benefits, its adoption in Asia can be facilitated.

This comprehensive perspective, integrating technology and policy considerations, underscores the potential of aquaponics as a sustainable and economically viable agricultural practice in the region.

IV. Policy Implication

Aquaponics, amalgamating various converging studies, necessitates active Research and Development (R&D) investment support from national and global governments to foster technological advancement [11]. A notable example is South Korea, where the government has demonstrated support for aquaponics by undertaking collaborative research and development projects from 2018 to 2020. Additionally, the government has facilitated the distribution of relevant technologies to three aquaponics start-ups within the province, further promoting the growth of this sustainable agricultural practice.

(1) Yeoju-si farmers have grown to a monthly sale of KRW15 million, growing 1 ton of catfish and 30 tons of vegetables, including red lettuce, on a scale of 1320 m^2.

(2) Pocheon-si farmers are also expanding their markets to Internet sales, direct transactions, and local food with monthly sales of KRW12 million.

Additionally, there has been a significant increase in national project funding for aquaponics research in South Korea, with over $2,000,000 allocated from 2020 to 2022. This represents a more than 200% rise compared to the budget set from 2018 to 2020. Moreover, certain municipalities, such as Gyeonggi-do and Gangwon-do, provide tax benefits to entities adopting aquaponic systems, further encouraging their adoption and growth.

In 2022, the South Korean government enacted the 'Smart Agricultural Promotion Act' to support revitalizing agricultural and livestock ventures. This act aims to establish standards for fostering vertical farms, promote technology development and radicalization, and create a mother fund worth USD 5.5 billion and a subsidiary fund worth USD 15.6 billion through investments over five years (2021–2025). Furthermore, the government plans to invest USD 300 million in smart farm research and development over the next six years to drive the commercialization of smart farm solutions and lead in cutting-edge agricultural technologies.

In Japan, while the market size for aquaponics needs further growth, the Japanese government is committed to aligning aquaponics policies with the 'Sustainable Development Goals' (SDGs) set by the UN. They are introducing the Moonshot R&D system to support world-leading R&D endeavors that can transform future society by achieving the SDGs and addressing the challenges posed by an aging society by 2030.

China and the U.S. are also investing substantially in introducing and developing aquaponics. In China, the National Agricultural Development Fund provides financial support for various agricultural projects, including aquaponics. However, specific subsidy amounts and requirements may vary, and interested parties should refer to the latest guidelines issued by the fund. Similarly, the U.S., the Department of Agriculture (USDA) offers grants through the Specialty Crop Block Grant Program, which supports specialty crop production, including aquaponics. These grants aim to enhance the competitiveness of specialty crops, expand markets, and promote sustainability. Their amounts and eligibility criteria vary annually and are determined by each state's Department of Agriculture.

V. Conclusion & Future Work

In conclusion, this research aimed to broaden the diversity of participants in the survey and interviews conducted. However, it is important to acknowledge that the survey was conducted online and targeted specific communities within a limited range of companies, regions, and colleges. Therefore, further research is warranted to gain a more comprehensive understanding of aquaponics technology and industry.

The successful business cases of aquaponics in Asia provide promising opportunities for its introduction and adoption in the region. However, technical limitations still hinder its further development, emphasizing the importance of global cooperation in technological advancements.

Asian countries should actively support the implementation of aquaponics by offering incentives such as tax benefits and technical assistance. Additionally, governments and international organizations should formulate policies that encourage research and development through technical collaborations, similar to the initiatives undertaken by the South Korean government.

Future research should aim to expand the scope of the study to encompass a broader range of participants and locations. This will provide a more holistic understanding of the challenges and opportunities associated with aquaponics adoption in Asia. Moreover, continued collaboration and knowledge-sharing among stakeholders, both domestically and internationally, will be instrumental in driving the growth and sustainability of the aquaponics industry in the region.

Conflict of Interest

The authors unequivocally declare no conflicts of interest concerning this research. The study was diligently conducted with utmost impartiality, and no financial or personal associations exist that might sway the interpretation of the findings or influence the presentation of the results. The research was undertaken with an unwavering commitment to uphold the highest standards of objectivity and integrity, ensuring the credibility and reliability of the study's outcomes.

Author Contributions

Sanghee Choo and Jinsook Lim were responsible for conducting the research, delving into data collection and analysis intricacies. James H. Joo and Sanghee Choo undertook the comprehensive data analysis and collaborated in drafting the manuscript. Andrew Moses provided expert supervision throughout the research process, ensuring its smooth progression and adherence to rigorous standards. The collective efforts of all authors culminated in the development of the final version of the manuscript, which has been thoroughly reviewed and approved by each author. Their collaborative contributions have been pivotal in shaping this work's scholarly integrity and excellence. All authors had approved the final version.

ACKNOWLEDGMENT

The authors wish to express their heartfelt gratitude to all the esteemed industry participants who generously devoted their time and expertise to enrich this report. Their invaluable insights and contributions have significantly enhanced the findings and analyses presented in this study.

Furthermore, the authors extend their most profound appreciation to the distinguished institutions, namely Massachusetts Institute of Technology (MIT), WAM Equity Partners, and Actos Advisory, a Cogito Company, for their unwavering support and assistance. Their guidance, provision of resources, and facilitation of access to pertinent information have played a pivotal role in successfully completing this report.

The authors feel immense gratitude for the collective, collaborative efforts and contributions of all stakeholders involved, as their steadfast support has been pivotal in shaping the outcomes of this research.

REFERENCES

[1] World Resources Institute. (2019). Aqueduct water risk atlas. [Online]. Available: https://www.wri.org/data/aqueduct-water-risk-atlas

[2] L. Gyuha. A study on aquaponics and hydroponics. *BRIC View 2021-T30*. [Online]. Available: https://m.ibric.org/miniboard/read.php?Board=report&id=3857

[3] X. Luo, A. Rauan, J. Xing, *et al.*, "Influence of dietary Se supplementation on aquaponic system: Focusing on the growth performance, ornamental features and health status of koi carp (Cyprinus carpio var. Koi), production of lettuce (Lactuca sativa) and water quality," *Aquac. Res.*, vol. 52, no. 2, pp. 505–517, 2021.

[4] G. Simon, "Challenges of sustainable and commercial aquaponics," *Sustainability*, vol. 7, no. 4, pp. 4199–4224, April 2015. https://doi.org/10.3390/su7044199

[5] F. Blidariu and A. Grozea, "Increasing the economic efficiency and sustainability of indoor fish farming by means of aquaponics – review," *Anim. Sci. Biotechnol.*, vol. 44, no. 2, pp. 1–8, 2011.

[6] National Agricultural Library. Aquaculture and aquaponics. [Online]. Available: https://www.nal.usda.gov/farms-and-agricultural-production-systems/aquaculture-and-aquaponics

[7] A. Bandi, V. Cristea, S. Petrea, *et al.*, "The review of existing and in-progress technologies of the different subsystems required for the structural and functional elements of the model of multi-purpose aquaponic production system," *Rom. Biotechnol. Lett.*, vol. 21, p. 4, 2016.

[8] J. Hyungsoo. (August 2021). Rural development administration of South Korea. *Agriculture News*. [Online]. Available: https://www.rda.go.kr/board/board.do?boardId=farmlcltinfo&prgId=day_farmlcltinfoEntry&currPage=38&dataNo=100000772911&mode=updateCnt&searchSDate=&searchEDate=

[9] E. Gorbe and A. Calatayud, "Optimization of nutrition in soilless systems: A review," *Adv. Bot. Res.*, vol. 53, pp. 193–245, 2010.

[10] M. J. Haydon, Á. Román, and W. Arshad, "Nutrient homeostasis within the plant circadian network," *Front. Plant. Sci.*, vol. 6, 137112, 2015.

[11] M. Rivera-Ferre, M. Ortega-Cerdà, and J. Baumgärtner, "Rethinking study and management of agricultural systems for policy design," *Sustainability*, vol. 5, pp. 3858–3875, 2015. doi: 10.3390/su5093858