Exploring the Potential of Aquaponics in Addressing Food Security and Future Food Demand in Sweden

A Systematic Literature Review

Ihala Hewage Don Ravindika Sewwandi Dayawansha

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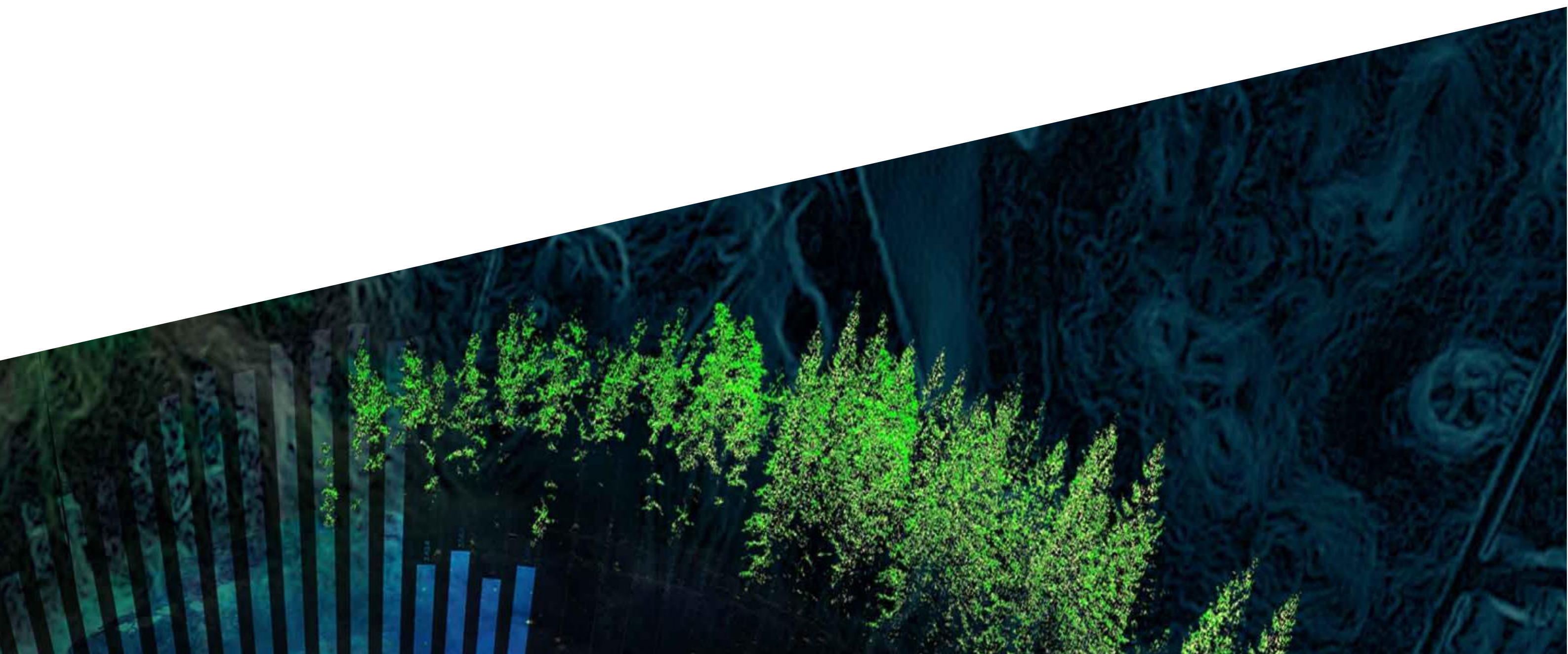

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Supervisor:	Yenitze E. Fimbres Acedo, SLU, Biosystems & Technology
Assistant supervisor:	Annie Drottberger, SLU, Department of Biosystems & Technology
Examiner:	Samar Khalil, SLU, Department of Biosystems & Technology

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Swedish University of Agricultural Sciences
Faculty of Landscape Architecture, Horticulture and Crop Production Sciences
Department of Biosystems & Technology

Abstract

Global food production should be increased by more than 70% to fulfill the food demand in 2050, which is a challenge in prevailing conventional agricultural practices, with limiting resources like land, water, and climatic conditions. Soil degradation, water pollution, greenhouse gas emissions, and biodiversity loss are environmental impacts that have increased in the past few decades due to conventional farming. In Sweden, 87% of residents live in urban areas, and the domestic food production is not enough for the country's food demand. Therefore, Sweden require sustainable food production systems that can reduce the impacts on the environment and enhance food security.

Aquaponics is an innovative, productive agricultural technique integrating fish (aquaculture) with crops (hydroponics- the technique of growing plants without soil) that has garnered global attention for its potential to address food security challenges. Thus this study focused on the viability of aquaponics in addressing food security in Sweden. A systematic literature review was carried out to examine the possibility of aquaponics for addressing food security, its impacts on productivity, energy efficiency, and impacts on the environment, and disadvantages of the system. Based on 32 articles, the results highlight how aquaponics contributes to the availability, access, utilization, stability, agency, and sustainability pillars of food security, providing a holistic solution to food insecurity. Furthermore, through examining the case of Sweden, showing its import-dependent economy, consumption patterns, and how aquaponics could improve local food production. Despite some challenges such as initial investment costs and regulatory barriers to organic products, this innovative, efficient, environmentally friendly, and resilient technique demonstrates the pathway toward a future where nutritious and fresh food is accessible to all, both in Sweden and across the globe, while achieving the Sustainable Development Goals.

Keywords: Aquaponics, Food security, Fish, Plants, Sustainable agriculture

Table of contents

List of tables

List of figures

Abbreviations

AP	Aquaponics
EU	European Union
GHG	Greenhouse Gas
HP	Hydroponics
SDG	Sustainable Development Goal
UN	United Nations

1. Introduction

The earth is shrinking from the population's perspective (Maitima et al. 2014) which means hectares of land per capita are gradually decreasing, and humans are modifying the ecosystem by expanding the power of technology (Vitousek et al. 1997; Díaz et al. 2019). These alterations have the potential to cause long-term ecological harm, which can have severe consequences for both the environment and society as a whole (Harte 2007; Davis et al. 2016; Ripple et al. 2024). According to Ripple et al (2024), the activities of humanity have led to an increase in water and air pollution, resulting in the alteration of Earth's climate. Furthermore, human activities have resulted in soil erosion, fragmentation, and elimination of habitats for plants and animals, as well as the depletion of non-renewable resources. The current rate of consuming natural resources has surpassed the rate at which they are being regenerated, leading to an alarming level of resource degradation on a global scale (Van Vuuren et al. 2010). The quality and quantity of food production depend on the availability of natural resources (Goddek et al. 2019). Planetary boundary (figure 1) refers to the limits within which humanity can safely operate to ensure a stable and sustainable global environment (Rockström et al. 2009). These boundaries represent thresholds for critical Earth system processes essential for maintaining a stable climate and a habitable planet.

Based on the projections by the United Nations (UN), the global population is expected to reach 8.5 billion by 2030 and 9.7 billion by 2050 (UN, 2023). A challenging question is whether the present food system can fulfill future food demands sufficiently with the prevailing transgressed planetary boundaries since currently six boundaries are transgressed (Richardson et al. 2023). According to the United Nations Department of Economic and Social Affairs predictions, global crop production should be increased by more than 70% to fulfill the 2050 food demand (Tian et al. 2021).

Access to an adequate amount of nutritious food, both physically and economically, is a fundamental human need required for basic well-being and health. However, 735 million people faced hunger in 2022 and more than 3 million couldn’t afford a healthy diet (FAO; UNICEF; WHO; WFP; IFAD 2023) it is a challenge to achieve the goal of zero hunger by 2030 while obesity affected over 1 billion people worldwide in the year 2022 (WHO 2024) also the World Health Organization reported that 43% of adults were overweight in 2022 (WHO 2024). As "The State of Food Security and Nutrition 2023" report revealed with rapid urbanization, people tend to consume processed and instant food, and it leads to overweight as well as obesity among urban, peri-urban, and rural areas. Besides earlier self-sufficient rural regions are now becoming increasingly reliant on national and international food markets. This demographic shift and consumer behavior changes need a reconsideration of food systems in order to meet the needs of these new urban populations while also eliminating hunger, food insecurity, and malnutrition.

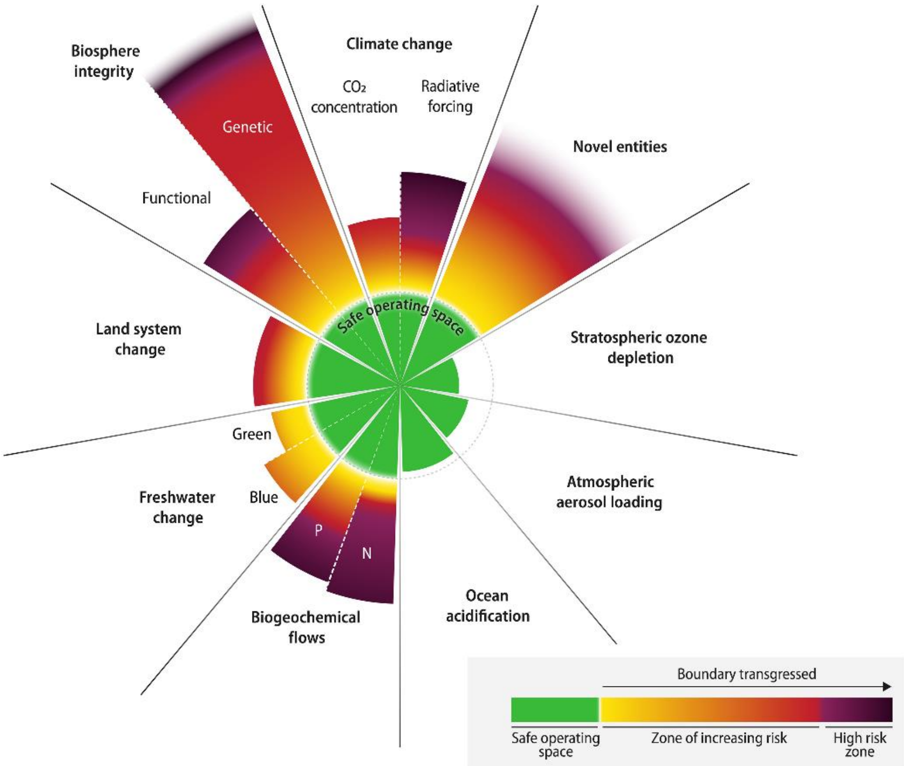

***Figure 1**. The Planetary Boundary Framework. (Richardson et al.2023)*
Control variable status as of right now for each of the nine planetary boundaries.
Six boundaries are transgressed. The green zone is a safe operating space. The zone of increasing risk is shown by yellow to red. Purple indicates the area at high risk.

Tian et al. (2021) have suggested that in order to fulfill the growing demand for food and ensure food security, it would be prudent to update existing agricultural technologies to increase crop productivity. This would require a comprehensive and timely approach, including the adoption of modern agricultural practices and innovative technologies to optimize crop yields. By leveraging the latest advancements in agricultural technology, can facilitate meeting the growing demand for food, while ensuring long-term food security. A sustainable and secure future for agriculture can be achieved through the implementation of these strategies.

Sweden possesses a limited amount of arable land due to its geographic characteristics, with approximately 2.7 million hectares available for agricultural purposes, representing around 7% of the country's total land area and 68% of forests (Statistics Sweden 2023a). Out of the arable lands around 60% of arable lands are located in southern Sweden (Jordbruksverket 2020). However, the economically active population in the agriculture sector is approximately 2% with 74% of farmers being over the age of 50 (Jordbruksverket 2020; Statistics Sweden 2023).

However, cereals such as wheat, rye, barley, and oats, as well as oilseeds, potatoes, and vegetables are grown in Sweden (Figure 2). Livestock production includes dairy farming, poultry, pork, and beef production, with a significant emphasis on animal welfare and environmental sustainability (Jordbruksverket 2020; Statistics Sweden 2023).

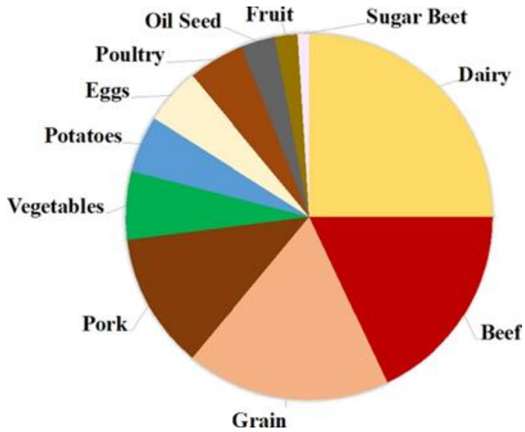

Figure 2. *Food production in Sweden in 2016. (Horn et al. 2022)*

Farms production of livestock (30%), dairy (25%), beef (18%), grains (18%), pork (12%), vegetables (6%), poultry (5%), egg (5%), potato(5%), oil seeds (3%), fruits and berries (2%), and sugar beet (1%)

Over 90% of Swedish agriculture depends on rainfall (Grusson et al. 2021) and many studies revealed that climatic changes affect agricultural production globally including in Europe (Horn et al. 2022). Nevertheless, anticipated climate shifts are set to lengthen the vegetation period by 10–30 days between 2011 and 2040 (Figure 3), with further extensions projected beyond 2100 (Horn et al. 2022; SMHI2022). Sweden can take advantage of this opportunity to cultivate more foods than it currently does.

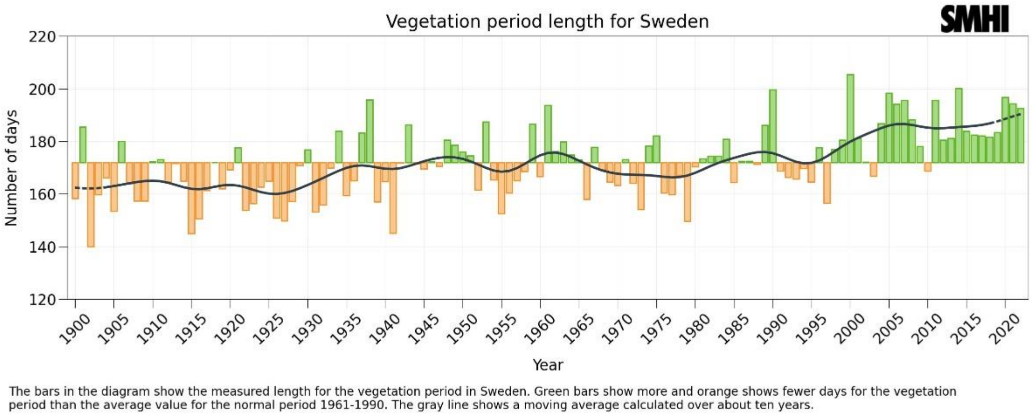

Figure 3. *Vegetation period length for Sweden (SMHI 2022)*

Sweden's population is 10.5 million (Statistics Sweden 2024), and a significant majority of the population, specifically 88.49%, currently inhabits urban areas (Statista 2024). The percent estimated self-sufficiency is around 45-50% (Huyge n.d.) as per the available statistical data, it is evident that Sweden imports a considerable share of food. The figures suggest that the country relies on international trade for a significant portion of its consumption needs. In general, the Circularity Metric of Sweden is 3.4%, which means 96.6% of consumed materials are not back to the country's economy (RE: SOURCE 2022), and this value is below the global level, of 8.6%. As per the above report, the nation consumes 266.7 million tons of materials, and agriculture and livestock require 29.6 million tons per year. If Sweden's population increases in the consumption of fresh vegetables, fruits, and cereals while decreasing meat consumption, it would reduce material consumption by 4.8% and simultaneously enhance the metric by 0.17%. Moreover, reducing "food miles", decreasing fertilizer usage, growing crops organically, and efficiently using electricity when producing food, tend to minimize the material footprint by 0.6% and boost the metric by 0.02% in Sweden (RE: SOURCE 2022).

However, to enhance the sustainable food system in Sweden, the Swedish Government has set the National Food Strategy with the overall objective is;
"A competitive food supply chain that increases overall food production while achieving the relevant national environmental objectives, aiming to generate growth and employment and contribute to sustainable development throughout the country. The increase in production – of both conventional and organic food – should correspond to consumer demands. An increase in the production of food could contribute to a higher level of self-sufficiency. Vulnerability in the food supply chain will be reduced"(Nilsson n.d.; The Government Office of Sweden 2017, p.11)

In the face of increasing global challenges for food production such as unexpected climatic conditions, resource degradation, uneven distribution of food, pandemics, and war-like situations affect food security in Sweden directly and indirectly. Although the availability, accessibility, and consumption of enough safe, nourishing food to support an active and healthy lifestyle are all included in the notion of food security, and to fulfill the increasing population's future food demand, it is a question prevailing agricultural systems can sustainably scale to meet that demand. Thus, it is paramount to explore a sustainable and efficient production system. One possible solution is an aquaponic system, combining hydroponic (growing plants in water) with aquaculture (raising fish) in a symbiotic environment. Within this closed–loop system fish waste provides fertilizer for plants and plants clean water for fish, thus the main aim of this innovative production system is to maximize resource use efficiency, increase production, and minimize environmental impact, for future food production. Sweden presents a unique opportunity to establish this new farming practice with its technological advancements and environmental consciousness. Although the country's current food system is efficient, still faces challenges such as limited arable land, severe climatic conditions, and a heavy reliance on food imports. Therefore, Sweden's agricultural framework can be strengthened, by integrating aquaponics into the country's agricultural framework, the nation can enhance its food security, reduce its carbon footprint, and create a more resilient food production system. Therefore this study aims to investigate the viability and possible advantages of aquaponics as a means of enhancing food security and meeting future food demands in Sweden. This study will investigate the current state of food production systems and the feasibility of aquaponics in the Swedish context. Thus, this study hopes to contribute to the broader discourse on sustainable agriculture and offer practical solutions for securing food production in the face of global challenges.

1.1 Problem statement

From the middle of the twentieth century, arable lands have decreased in Europe by 14% (Lyuri 2008). In Sweden, the total arable area is around 2.7 million hectares and it shows 6.5% of the total land area of the country (Swedish Board of Agriculture). Furthermore, total cultivated lands have decreased by 13% from the year 1982 (Nilsson & Rosenqvist 2018). Moreover, according to the latest data, Sweden's population in 2024 stood at 10,673,669, which indicates a 0.58% increase compared to the previous year, 2023. According to the Eurostat (2023) report, 8.3% of EU citizens could not afford a meal containing meat, fish, or a vegetarian alternative every other day in 2020, which was higher than in 2021**.** In Sweden, food accounts for more than 15% of consumption-based greenhouse gas emissions (Röös et al. 2021.). Furthermore, Röös et al (2021) revealed that Sweden's diets are not sustainable in terms of health because 51% of Swedes are overweight and most common diseases and deaths are occurred due to diet.

Swedish dietary guidelines revealed that eating lots of fruits and vegetables because those are enriched with vitamins and minerals, two or three times a week eat fish and shellfish and thus can get more nutrients very easily (Livsmedelsverket 2015). Therefore aquaculture is regarded as a promising solution to food insecurity (Röcklinsberg 2015) since fish provide adequate nutrients such as protein, micronutrients, and essential fatty acids to people (Beveridge et al. 2013; Chen et al. 2022) and provide several health benefits, such as anti-oxidation, anti-inflammation, wound healing, neuroprotection, cardioprotection, and hepatoprotection properties (Chen et al. 2022). In Sweden, 9500 tons of fish were produced in 2022 (Statistics Sweden 2023) rainbow trout are very popular thus producing 8500 tons. Besides salmons, char, and eel are also consumed (Statistics Sweden 2023). Although there are several benefits of fish, they can cause some challenges, fish farms can cause local eutrophication and damage coastal environments (Livsmedelsverket 2023), and overfishing also affects the natural balance of the ecosystem.

The nation is currently grappling with pressing food security challenges due to a host of factors such as climate change, limited arable land, dependence on imported produce, and food prices due to high inflation. As such, there is a need for innovative and sustainable agricultural methodologies. Aquaponic, as an alternative to traditional farming practices, can significantly reduce resource consumption and environmental impact and is thus well-suited for sustainable food production. In addition to this, it can conserve water by recycling the same water repeatedly, leading to a 90% reduction in water usage (Alberti et al. 2022; Nishanth et al. 2024). To enhance the food security of the country, Sweden should focus on several factors, producing more vegetables is the first factor because market demand for leafy vegetables, herbs, indoor-grown cucumbers, and tomatoes has increased (KTH 2023). Nevertheless, prevailing farming practices in couldn’t be able to supply year-round demand due to limited arable and short growing seasons.

However, the economic feasibility and productivity of employing aquaponics to tackle food security issues, particularly concerning crops like cucumbers, remain ambiguous. Therefore, it is imperative to undertake further research to ascertain the viability of aquaponics in addressing food security issues, in Sweden. Such research will enable us to better understand the potential of aquaponics as a sustainable and economically feasible solution for food security in the country.

1.2 Possible solution

The proposed solution to address food security issues in Sweden is through the use of aquaponics since aquaponics as a sustainable farming method offers several potential solutions to the challenges faced by traditional agriculture (Danish et al. 2021). Regardless of the seasonal changes, aquaponics have the potential to stable and continuously supply fresh, healthy, nutritious vegetables and fish all year round. When increasing the domestic production in the country, Sweden can reduce the dependency on food importation, thereby enhancing food security and economic resilience. Although it needs more energy, Sweden highly consumes renewable energy, the total share of renewable energy is 63% in the year 2021 (CMS 2023), using renewable energy for aquaponics can increase its efficiency simultaneously reducing greenhouse emissions. In addition, no waste disposal in the environment, all are circulating within the system thus reducing the environmental impact of food production. This aligns with Sweden's commitment to sustainability and environmental protection. Furthermore, aquaponics systems can be established in urban areas, making use of unused spaces and bringing food production closer to consumers. This can help reduce food miles with the reduction of transport costs and carbon emissions associated with food distribution.

Aquaponics presents a compelling alternative to conventional farming methods when it comes to cucumber production. Cucumbers are a staple crop with high water demand (Pal 2020; RHS 2024) and susceptibility to pests and diseases making them particularly suitable for aquaponics. By cultivating cucumbers in aquaponic systems, farmers can optimize water usage, mitigate pest pressures, and maintain consistent crop yields throughout the year, regardless of seasonal variations. The controlled environment of aquaponics enables precise monitoring and adjustment of factors such as temperature, pH levels, and nutrient concentrations, further enhancing crop productivity and quality (Pantanella 2018).

The scalability of aquaponics will be examined to assess its potential to contribute significantly to Sweden's food security goals. The study will analyze the scalability of aquaponic production in terms of its capacity to meet increasing demand, optimize resource utilization, and adapt to changing market dynamics. Additionally, consideration will be given to the regulatory frameworks, technological advancements, and investment incentives necessary to facilitate the widespread adoption of aquaponics across diverse agricultural landscapes in Sweden ensuring a resilient and self-sustaining food supply for Sweden's future generations.

1.3 Aim of the study

This thesis examines the feasibility of growing food using an aquaponics system, and how it can address food security issues in Sweden. To fulfill the aim of this study the following detailed objectives were formulated;

a. To compare the productivity of aquaponic with traditional soil-based and greenhouse farming methods.

b. To compare the resource efficiency of aquaponic with other agricultural practices.

c. To compare the economic aspects of aquaponic with other farming methods, considering rural, urban, and household scales.

d. To determine the potential of aquaponics to enhance food security in Sweden.

Ultimately, this study seeks to contribute to the ongoing discourse on sustainable food production and present aquaponics as a practical approach to ensuring a stable and resilient food supply for Sweden in the future.

1.4 Research question

This study focuses on addressing the following research questions:

a. How does aquaponics compare to conventional horticulture in terms of its contribution to food security outcomes, including crop yields, and dietary diversity?

b. What are the environmental sustainability implications of aquaponics for food production and resource use, and how do these factors intersect with food security considerations?

c. How do aquaponics systems contribute to resilience and adaptation in food systems, particularly in the face of climate change, water scarcity, and other environmental stressors?

d. How does the aquaponic system contribute to achieving Sustainable Development Goals?

Identifying knowledge gaps, and generating insights into the potential benefits and challenges of using aquaponics as a strategy to enhance food security can be guided by these research questions.

The present study is based on the following hypotheses:

a. Aquaponic systems can produce higher or comparable yields compared to traditional soil-based and greenhouse farming methods.

b. Aquaponic systems use water and nutrients more efficiently than traditional farming methods, resulting in lower environmental impact.

c. Aquaponic is economically viable and provides significant financial returns compared to other farming methods.

d. Implementing aquaponic can significantly enhance food security in Sweden by providing a stable, sustainable, and resilient food production system.

By addressing these objectives and testing these hypotheses, the study aims to provide a clear understanding of the potential and challenges of adopting aquaponics as a common agricultural practice in Sweden, offering valuable insights and recommendations for future developments in sustainable food production.

2. Literature Review

2.1 Food Security

A major global concern is food security, as millions of people experience hunger, malnutrition, and food insecurity globally, and a sustainable, holistic, and comprehensive approach is needed to manage this complex issue. FAO, WHO, UNICEF, IFAD, and WFP estimated that between 691 million and 783 million people faced hunger in the world in 2022, additionally, 9.2% world population are undernourished (FAO 2023). The FAO states "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 2006). The 1996 World Food Summit focused on four dimensions, availability, access, utilization, and stability, however, Clapp et al. (2022) updated the definition of food security with proposed two new dimensions, agency and sustainability. Therefore, establishing a six-dimensional framework for food security in academic and sustainable policy contexts makes sense given the six pillars taken together (Figure 4).

I. **Food availability** - The availability of sufficient foods, whether it comes from domestic production or imports
II. **Food access** – Physical and economical access to food.
III. **Utilization** – All physiological needs fulfilled, such as sanitation and health care, clean water as well as nutritional well-being.
IV. **Stability** – The stability of its provisions, i.e., the risk of accessing food in sudden shock situations such as crises, wars, or pandemics.
V. **Agency-** improving the rights and capabilities of people to feed themselves with dignity and to relate to and shape their food systems on their terms (HLPE-FSN 2020)
VI. **Sustainability**- strengthening the economic, social, and ecological bases that generate food security and nutrition for future generations (HLPE-FSN 2020)

Figure 4. *Graphical representation of food security with six dimensions (HLPE-FSN 2020)*

2.1.1 Availability

The term "availability" describes the regular presence of enough food, whether imported or produced domestically, to meet the dietary needs of both individuals and communities. It includes elements like food production systems, distribution networks, market mechanisms, and agricultural productivity. The literature on food security generally acknowledges the concept of food availability. Increased food availability is a result of farmers being able to produce higher yields from scarce resources thanks to high agricultural productivity. Crop varieties, soil fertility, irrigation techniques, technological developments, pest control strategies, and climatic conditions are the factors affecting agricultural productivity (Dar & Laxmipathi Gowda 2013). Besides, systems for producing food include all of the different techniques and procedures used to grow, harvest, prepare, and distribute food, and these systems, which can include commercial agriculture, agroecological techniques, industrialized production methods, and traditional subsistence farming, differ greatly amongst regions. The selection of food production systems affects the availability of food in terms of quantity, quality, and diversity as well as its effects on the environment and society (Yiridoe & Anchirinah 2005; Campi et al. 2021).

The infrastructure, supply chains, and logistics involved in moving food from producers to consumers are referred to as distribution networks. By reducing losses and waste along the route, efficient distribution networks guarantee that food reaches its intended destination in a timely and economical manner. Distribution networks include market outlets (supermarkets and food markets), storage facilities (warehouses and cold storage), and modes of transportation (roads, railroads, and waterways). The other thing is pricing, purchasing, and selling of food are regulated by market forces. The dynamics of supply and demand, price formation, market competition, and government interventions (e.g., price controls, and subsidies) are some examples of these mechanisms. Food is exchanged more easily between producers, consumers, and middlemen when markets are in good working order. This guarantees that food is distributed effectively and that prices accurately reflect costs and values (European Union 2020).

2.1.2 Access

The ability of people to physically and financially obtain food is referred to as accessibility. It includes social safety nets, market accessibility, transportation infrastructure, food prices, and income levels. For everyone to have equitable access to nutrition, food must be accessible and affordable, irrespective of socioeconomic status or geographic location (Simon n.d.). Economically, a person's ability to purchase food is a function of their purchasing power in relation to food prices. Access to food is significantly influenced by affordability, especially for low-income households that may find it difficult to meet their basic needs on a tight budget. More than 3.1 billion people were unable to afford a healthy diet in 2021 due to low household income levels and the high price of foods (FAO 2023). FAO estimated that 3.66 dollars per person per day is required for a healthy diet (FAO 2023). Market conditions, interruptions in the food supply chain, and trade and subsidy policies of the government can all have an impact on food prices. Excessive food costs can create major access barriers, which puts vulnerable populations at risk for food insecurity and malnutrition. Physically, having access to food means that food sources must be close to places where people gather, work, and live. The availability of supermarkets, grocery stores, farmers' markets, and food banks within reasonable travel distances may make access easier in urban areas. Urban food systems are less visible than rural ones (Pothukuchi & Kaufman n.d.). Access can be more difficult in rural and isolated areas because there are fewer food establishments and fewer transportation options. Natural obstacles like mountains or bodies of water may also make it difficult for people to physically access a place. These obstacles can isolate communities and make it more difficult for them to get food. Access to food is also shaped by social and cultural factors, which also have an impact on dietary habits, food distribution networks, and personal preferences. People's food choices and access to foods that are appropriate for their culture can be influenced by cultural norms surrounding the purchase, preparation, and consumption of food (Monterrosa et al. 2020). Access to food may be made easier by social networks, neighborhood associations, and unofficial support networks, especially for marginalized populations like immigrants, refugees, and Native Americans. Besides government actions and policies, whether they increase or decrease people's access to food, can have a significant effect on food access (Monterrosa et al. 2020). Agriculture, trade, labour, social welfare, food strategies, and health policies can all have an impact on the availability, cost, and distribution of food in a community. Initiatives like nutrition education, food assistance programs, income support programs, and infrastructure improvements to strengthen food distribution and transportation networks are a few examples of how to improve food access (Monterrosa et al. 2020).

2.1.3 Utilization

The concept of utilization encompasses the effective and efficient utilization of food to meet nutritional needs and promote optimal health outcomes. Despite significant progress in recent years, malnutrition in its various forms remains a persistent global challenge, with far-reaching consequences ranging from stunted growth and micronutrient deficiencies to obesity and diet-related diseases. The FAO reports that nearly 148.1 million (22.3%) children under the age of five are stunted, while over 45 million (6.8%) suffer from waste and 37 million (5.7%) with overweight in 2022 in the world (FAO 2023). Promoting dietary diversity, food fortification, and nutrition education is critical for enhancing food utilization and combating malnutrition.

2.1.4 Stability

In the domain of food security, the term 'stability' denotes the consistency and predictability of accessing and utilizing it over a period of time. However, various factors such as climate change, conflicts, war, and economic shocks can severely disrupt food systems, leading to food shortages and sudden price surges. For instance, Russia and Ukraine are primary global exporters of agricultural commodities, with Russia also holding the position of the primary exporter of fertilizers worldwide (FAO 2023). The ongoing conflict between these two nations has had a significant impact on international food prices. Investing in climate-resilient agriculture, social protection programs, and emergency preparedness measures is essential for building stable food security systems. Nicholson et al. (2021) revealed the conceptual connection between resilience concepts from socio-ecological analyses and the stability component of food security, including the definition of stability measurements that take availability, access, and utilization into account.

2.1.5 Agency

Encouraging people and communities to make decisions about their own food security is what is meant by the agency. Marginalized groups often lack the agency to access nutritious food or participate in decision-making processes that affect their food security. Gender disparities further exacerbate food insecurity, with women and girls being more affected by hunger and malnutrition than men, and also when comparing the rural, urban, and peri-urban areas, food security is higher in urban areas (FAO 2023). The World Food Programme (WFP) estimates that 60% of the world's chronically hungry are women and girls (WFP, 2021). Promoting gender equality, enhancing access to education and resources, and fostering community engagement are critical for empowering individuals and advancing food security.

2.1.6 Sustainability

Sustainability involves ensuring that food systems operate in an environmentally, socially, and economically sustainable manner. Unsustainable agricultural practices, such as deforestation, soil degradation, and excessive water use, threaten food security and exacerbate environmental degradation. According to the United Nations Environment Programme (UNEP), food production is a major driver of biodiversity loss, deforestation, and habitat destruction, these activities leading to the disruption of the ecosystem. Additionally, agriculture accounts for more than 70% of water withdrawals (UNEP 2024), leaching and accumulation of chemicals in water bodies and eutrophication are the other main global issues of current food production systems (Withers et al. 2014). Thus both water scarcity and alteration of water quality affect both human and ecological health. Therefore, an innovative holistic approach is needed for food security to increase productivity, efficient resource use, reduce emissions to the environment, and create habitats for beneficial organisms. Sustainable food systems also depend on reducing food waste. A large amount of food produced worldwide is lost or wasted during the supply chain with lack of infrastructures, technology, and long distances (Yetkin Özbük & Coşkun 2020). Thus increasing the food miles and food waste is a global issue for the greenhouse gas emission. By lowering greenhouse gas emissions linked to food decomposition in landfills and reducing the need for extra agricultural resources, addressing food waste can greatly reduce the environmental footprint of food systems. Improving post-harvest storage, optimizing supply networks, and raising consumer knowledge of the value of reducing food loss are some strategies to reduce food waste. Adopting agroecological practices, promoting sustainable land management, introducing innovative, efficient alternate systems, and reducing food waste are essential for building resilient and sustainable food systems to protect natural resources, support livelihoods, and enhance food security for future generations.

2.2 Food security in Sweden

Food security researchers discussed that developed countries have concentrated on accessibility and utilization (Fusco et al. 2020; Horn et al. 2022). Each domain of food security presents unique challenges and opportunities in the context of Sweden. As per Horn et al. (2022), limited agricultural diversity and insufficient yield are common in most countries located in climate regions. During World War-I and the Cold War Sweden's self-sufficiency remained high, which means all people have had physical and social access to food for their dilatory needs. (Stenberg 2021). Although, in 1985 Sweden had a significant surplus of agricultural food production, they relied on the importation of some parts of food sectors such as fertilizers and and spare parts (Stenberg 2021). However, extreme weather conditions such as unexpected drought in growing seasons and heavy rain or rainstorms in harvesting seasons affect food security (Grusson et al. 2021; Horn et al. 2022). Grusson et al. (2021) show in 2018, 50% of cereal yield was reduced and significant livestock were reduced in Sweden due to the drought in summer. Hence, extreme weather conditions affect the food production and availability of food in Sweden. Thus, Sweden relies on food importation to enhance the country's food security but it makes Sweden vulnerable to global market fluctuations and trade disruptions.

In Sweden, food security is generally high compared to many other countries (Rost & Lundälv 2021). Sweden has a high standard of living and a well-developed social welfare system as well as infrastructure, transportation, and retail network systems that ensure economic and physical access to food. However, low-income households and marginalized communities such as immigrants might struggle to afford nutritious food. According to the FAO statistics, those proportions seem to be rising recently from 4.5% in 2014 to 5.8% in 2019 of the population (Rost & Lundälv 2021; Eurodiaconia 2022). As per the discussion of Eurodiaconia (2022), the nation has experienced its highest rate of inflation in decades, with food prices rising by a record 20 percent. The Swedish government believes that food production and the food supply chain within the country are placed well. As well as they also believe more foods can be produced in Sweden because they have the necessary expertise and innovative capacity and they are more concerned about the environment (GOS, 2017). Therefore, the Swedish government tries to keep the best level of the country's food availability. Although Sweden has opportunities there are some challenges in the food industry such as low profitability, climatic changes, and environmental problems. The Swedish government has implemented various initiatives to promote food security, including subsidies for farmers, food assistance programs for low-income individuals and families, and regulations to maintain food safety and quality standards. Therefore, the Swedish government introduced a national food strategy to find sustainable solutions for the food sector. As a result, "A National Food Strategy for Sweden – More Jobs and Sustainable Growth Throughout the Country" is launched by the government collaborating with many other public and private stakeholders. While challenges related to food security still exist in Sweden (Rost & Lundälv 2021), particularly for marginalized groups or in certain regions, the country's robust agricultural sector, social policies, and commitment to sustainability help ensure a high level of food security for its population.

2.3 Swedish food consumption

In 2021, Swedish households expended 13.6% of their budget on food and non-alcoholic beverages (Statistics Sweden 2024a). Meat products, dairy products and fats, fruit and vegetable products, and bread and cereal products were the primary product groups, accounting for 16%, 18%, 15%, and 14% respectively (Huyge n.d.). Studies reveal that up to 90% of the food consumed in Sweden is canned, frozen, and highly processed a considerably higher percentage than is typical throughout the world (Huyge n.d.). Fresh fruit and vegetables, fresh fish, fresh meat, and eggs make up the remaining portion. About 38% of fresh produce is organic, which is nearly 100% more than it was in previous years since Swedish consumers are increasingly moving to organic foods. Self-sufficiency in Sweden has decreased from 1988 to today from 85% to around 50% (Huyge n.d.; Johansson 2020.) and they further revealed that Sweden imports nearly twice as much food as it exports. Sweden imports not only products that are not produced within the country such as coffee, tea, cocoa, citrus, nuts, and spices but also seasonal products that can be grown within the country such as fresh fruits and vegetables. As an example cucumber is globally ranked as the third most-produced vegetable, following tomatoes and onions (Fernandez et al. 2018) Within Swedish culinary culture, cucumbers hold a significant position, with per capita consumption reaching 6.4 kilograms in 2021 (Statista, 2024a). The annual consumption volume of cucumbers has shown an upward trend, increasing from 1985 to 2022, with an overall consumption rate of 60.3 thousand metric tons in 2022 (Statista, 2024a). Cucumbers are cultivated professionally in open fields and greenhouses, primarily located in southern Sweden (Swedish Board of Agriculture). According to FAOSTAT (2024), Sweden produced 38,520 tons and 43,530 tons of cucumbers in 2020 and 2021, respectively. To meet the growing demand and enhance food security, Sweden imports 51 percent of all cucumbers, (Agtira 2023). In 2020 and 2021, Sweden imported 38,138.00 tons and 36,095.00 tons of cucumbers, respectively (FAOSTAT, 2024). Furthermore, the domestic production of tomatoes is sufficient to fulfill 17% of Swedish consumption (Danevad et al. 2023), which represents a significant amount of tomato importation needed to fulfill country demand. Furthermore, fish and seafood, meat, dairy products, and cereal products are also imported, and an excessive amount of farmed fished imported from Norway (Huyge n.d). A significant portion of Sweden's food, including fruits, vegetables, and cereals, is imported from other EU nations as well as beyond the

EU. Due to its reliance on imports, Sweden's access to food can be greatly impacted by international trade agreements, changes in the price of food, and the political climate of the nations that export.

Sweden boasts a high standard of living and a robust social welfare system that largely ensures economic access to food for the majority of its population (Rost & Lundälv 2021). Nonetheless, disparities persist, particularly among vulnerable groups such as low-income families, immigrants, and the elderly, who encounter challenges in accessing food. With a highly developed infrastructure, encompassing well-maintained roads, efficient transport networks, and established retail distribution, the country ensures widespread physical accessibility of food. However, rural areas may encounter obstacles in accessing a diverse range of food options in comparison to urban centers.

Sweden encourages a diet low in sugar and fats and rich in fruits, vegetables, and whole grains. The goal of public health campaigns and government programs is to inform the public about nutrition and balanced meals. Sweden upholds strict regulations on food safety (Livsmedelsverket 2015). The National Food Agency ensures that safe food handling procedures are followed and that foodborne illnesses are kept to a minimum by regulating and monitoring food safety.

2.4 Aquaponics; an Innovative agricultural method

Aquaponics (AP) is a cutting-edge method that combines two distinct technologies, namely aquaculture, and hydroponics (HP), into a single, integrated system. The term "aqua" refers to the practice of cultivating fish in densely populated tanks, while "ponics" denotes the technique of cultivating plants in a soil-free environment, using water as the primary medium (Masabni & Niu 2022). The combination of these techniques results in a self-sustaining and highly efficient system that utilizes the nutrient-rich wastewater generated by fish farming to grow crops (Figure 5). Aquaponic was initiated by the United States of America in the 1980s (Masabni & Niu 2022).

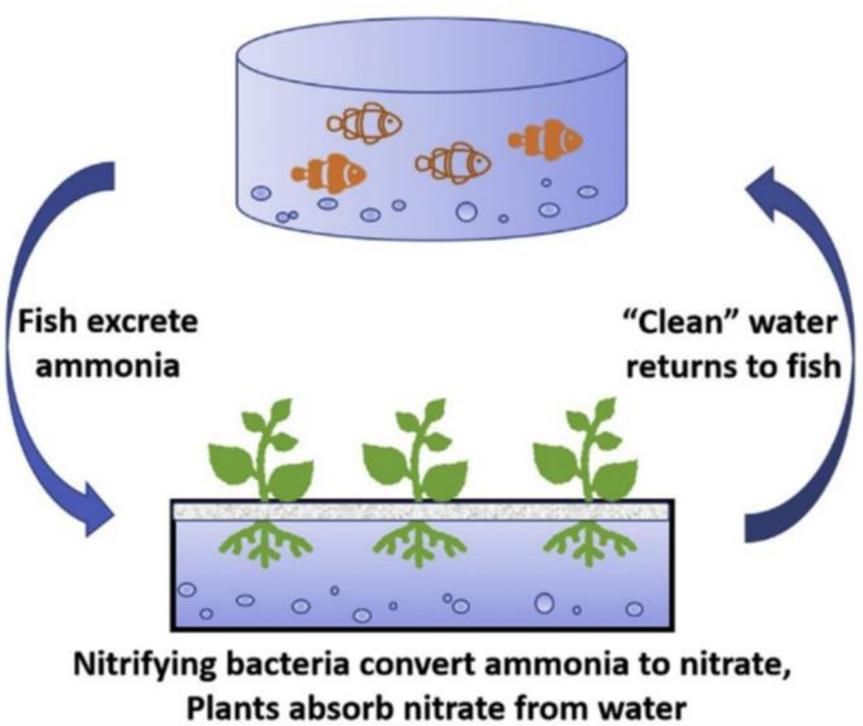

Figure 5. *Representation diagram of AP (Masabni &Niu 2022)*

In hydroponic chemical fertilizers are used according to the plants and their growth rates. So, there are monetary costs and energy costs added to the cost of production of farming because chemical fertilizers are derived from petroleum besides affecting the natural environment. But in aquaponic there is no need to add chemical fertilizers because the fish and the bacteria provide nutrients besides reducing fresh water usage, low wastewater discouragement, and no antibiotic usage it less impact on the ecosystem (Danish et al. 2021; Wei et al. 2019). The interest in aquaponics has increased worldwide, especially in small-scale farming in urban areas. However, it is not very popular among large producers (Masabni & Niu, 2022). A survey conducted by Miličić et al. (2017) revealed that 50% of 16 European countries had never heard of aquaponics, and only 17% of respondents were willing to pay a premium price for aquaponic produce. Aquaponics allows for year-round crop growth and uses 90% less water than traditional farming methods (Danish et al. 2021; H-alo, 2023). This makes it a great option for areas with water scarcity, as well as coastal and arid/semi-arid regions with low rainfall. Moreover, aquaponics can be done in urban areas with limited space for traditional cultivation (Masabni & Niu, 2022). Rooftops, schools, office buildings, abandoned buildings, and even neglected construction sites are ideal locations for aquaponic cultivation.

Furthermore, aquaponic is aligned with all the 17 United Nations' (UN) Sustainable Development Goals (SDG) (Troell et al. 2023) but most obviously aligned with the following SDGs.

- SDG 1 & 2 – No poverty & Zero Hunger:
  AP has the potential to significantly enhance food security and quality. It enables the production of fish and vegetables, which are rich in proteins, vitamins, and minerals, locally and diversely. Additionally, it can provide small farmers and rural communities access to new markets and technologies, thereby increasing their income and employment opportunities.

- SDG 3- Good health & wellbeing:
  AP prides itself on producing fresh and healthy food that is free from the use of chemicals. Such practices not only positively impact human health but also align with the United Nations' Sustainable Development Goal 3, which aims to ensure good health and well-being for all. By adhering to this goal, AP is contributing to the global effort to promote a healthier and more sustainable world.

- SDG 6 & 14- Clean water and sanitation, Life below water:
  Aquaponics is an innovative and eco-friendly farming method that holds significant potential in reducing water consumption and pollution. It is capable of reusing and recycling water, thus contributing significantly to water conservation efforts, with the potential to save up to 90% of water when compared to traditional farming methods. In addition to aiding in water conservation efforts, aquaponics also has the added advantage of improving sanitation by converting fish wastewater into valuable fertilizer for crops. Given its numerous benefits, aquaponics is an approach that holds promise not only for the environment but also for the economy and human health.

- SDG 7- Affordable & Clean Energy:
  AP is an energy-efficient and energy-conserving system. By utilizing recirculating water systems, minimizing chemical inputs, shortening supply chains, integrating renewable energy sources, and fostering innovation, aquaponics contributes to energy conservation and sustainable food production. As a result, it supports SDG 7 objectives for affordable, reliable, and modern energy access.

- SDG 8 & 9- Decent Work & Economic Growth and Industry, Innovation and Infrastructure:
  This innovative technique presents a compelling opportunity for entrepreneurs, as it has the potential to create job opportunities and contribute to economic development.

- SDG 12- Responsible Consumption and Production:
  This innovative closed-loop system is designed to optimize the utilization of resources, requiring significantly less water than traditional farming methods while also eliminating the need for synthetic fertilizers and pesticides. As a result, this system has a significantly lower environmental impact. Aquaponics technology allows for the conversion of fish waste into valuable nutrients for plant growth, which ultimately fosters a circular economy, minimizing waste generation. Furthermore, the system's capacity to facilitate local food production helps to reduce the carbon footprint associated with food transportation, making it an excellent option for those committed to sustainable practices.

- SDG 13 & 15- Climate Action & Life on Land :
  Aquaponics significantly reduces Greenhouse gas (GHG) emissions when comparing conventional farming systems by minimizing the need for chemical fertilizers and pesticides. And conserving water resources through its closed-loop system. This is particularly important in areas that are prone to droughts that are worsened by climate change. Besides it conserves land and soil and simultaneously reduces biodiversity loss. By promoting local food production and reducing the carbon footprint associated with food transportation, aquaponics supports climate resilience and adaptation strategies. These eco-friendly farming practices contribute to the global effort to mitigate climate change and conservation of biodiversity.

2.5 The concept of aquaponics

It is a mutually beneficial symbiosis of plants, fish, and microorganisms and a harmonious existence of ecological balance relationships (Wei et al. 2019). As per Figure 2, fish are usually kept in tanks where they produce waste in the form of ammonia. The beneficial bacteria present in the system then convert this ammonia into nitrites and subsequently, nitrates, which are vital nutrients for plant growth. The nutrient-rich water is then circulated to the hydroponic beds where vegetables and herbs are grown. These plants absorb the nutrients, thus filtering the water and removing toxins for the fish. The clean water is then recirculated back to the fish tanks, completing the closed-loop cycle.

In an aquaponic system, the bacterial community plays a crucial role in the efficient cycling of nutrients. *Nitrosomonas* bacteria are responsible for converting toxic ammonia, which is produced by fish waste, into nitrite. Further, *Nitrobacter* bacteria transform nitrite into nitrate, which serves as a valuable nutrient for the plants grown in the system, thereby completing the essential cycle of nutrient conversion and uptake (Masabni & Niu 2022). By capitalizing on the natural processes facilitated by these bacteria, (Figure 6) aquaponic systems can recycle waste into usable nutrients for plant growth, promoting a sustainable and balanced ecosystem.

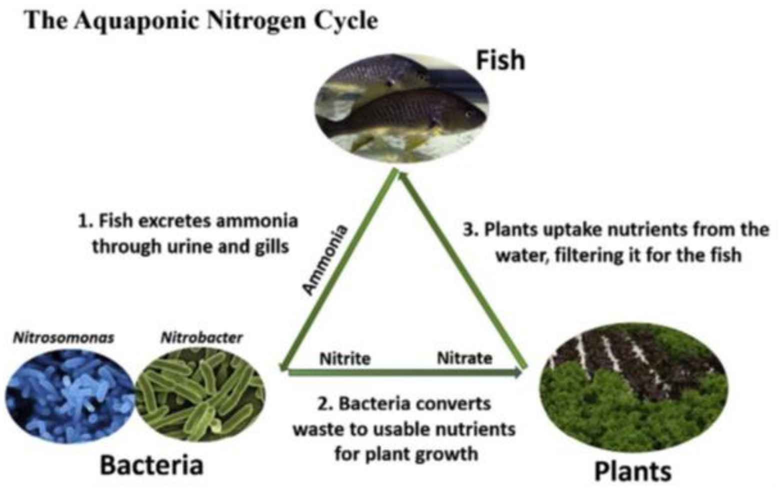

Figure 6. *Symbiosis relationship between plants, fish, and microorganisms in the AP system (Masabni &Niu 2022)*

2.6 Aquaponics and food security

In recent years food security has been a critical challenge globally due to climatic changes, resource limitations, traditional farming systems, and economic conditions (Mchunu et al. 2017). Researchers and different stakeholders suggested that aquaponics is one of the best solutions for enhancing food security and simultaneously reducing malnutrition worldwide (Béné et al. 2015).

Aquaponic is a highly effective agricultural method that enables year-round cultivation of both fish and vegetables, irrespective of the prevailing weather conditions. This consistent production can help mitigate seasonal food shortages and ensure a steady food supply, particularly in regions that are susceptible to extreme weather events or seasonal fluctuations in agricultural output (Yahya et al. 2023). Additionally, the controlled environment of aquaponic systems allows for the cultivation of a diverse range of crops, providing greater dietary diversity and nutritional security for communities (Sunny et al. 2019).

These systems are scalable and adaptable, making them a suitable solution for addressing food security challenges in both rural and urban settings (Flores-Aguilar et al. 2024a). In rural areas, where limited access to arable land and water resources is a common problem, small-scale aquaponic setups offer a viable alternative for sustainable food production (Adeleke et al. 2022). Similarly, in urban environments, aquaponics has the potential to transform underutilized spaces into productive food production hubs (Degefa et al. 2021), reducing the carbon footprint associated with food transportation, Wu et al. (2019) revealed that large-scale AP systems having a small impact on the environment and increasing access to fresh locally grown produce. Furthermore, the integration of aquaponics into community development initiatives and humanitarian aid programs has demonstrated the potential to reduce food insecurity and malnutrition in vulnerable populations (Beebe et al. 2020). By empowering individuals to produce their own food locally, aquaponic systems not only meet immediate food needs but also promote long-term food security and resilience (Kyaw & Ng 2017a). This contributes to poverty reduction and to achieve the sustainable development goals, No poverty (SDG 1), Zero hunger (SDG 2) Responsible consumption and production (SDG 12). Thus, aquaponics is a multifaceted tool that can effectively address the complex interplay of social, economic, and environmental factors underlying global food security challenges. Its benefits are far-reaching and have the potential to create lasting positive impacts on communities worldwide

3. Methodology

The Systematic Literature Review (SLR) was carried out to analyze data based on the articles published in scientific journals focusing on aquaponics and food security. This effective method helped for summarizing and evaluating the existing literature in qualitative and quantitative ways. Besides, it enhances the reliability of the findings with minimized bias in the selection and synthesis of studies with its structured and transparent methodology (Carver et.al 2013; Xiao & Watson 2019). Furthermore, it was used to identify the research gaps in current literature and highlight areas for further research or exploration.

3.1 Systematic Literature Review Process

As per Figure 7, planning, execution, and documentation steps were carried out for my study.

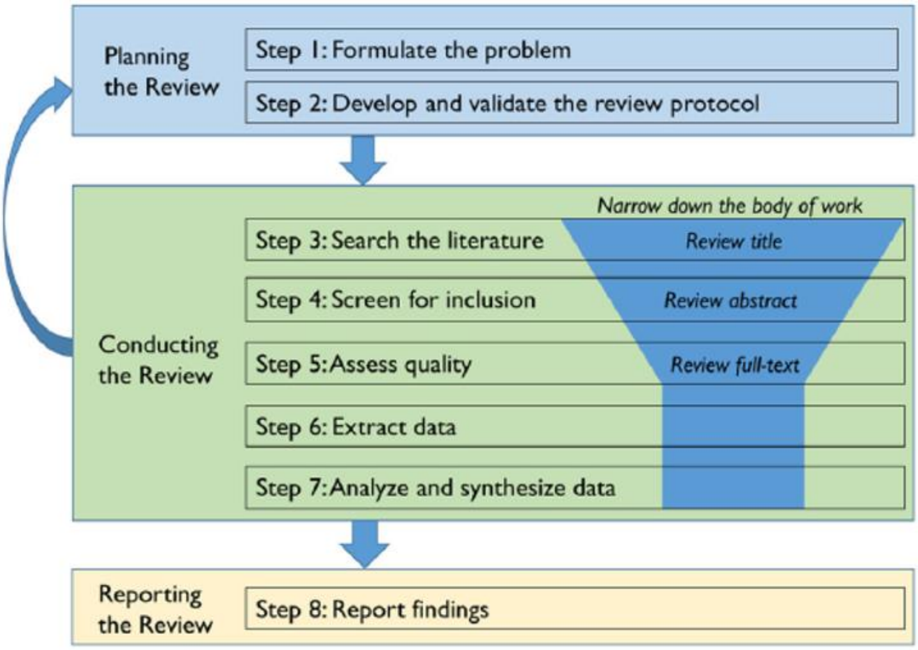

Figure 7. *The process of SLR (Xiao & Watson 2019)*

During the planning stage research protocol was clearly defined to guide the research process and achieve the intended outcomes of the study. In the planning stage, research questions and research objectives were defined (Carver et.al (2013). According to the research question PICO (P- Population, I- Intervention, C- Comparison, and O- Outcome) framework was developed as shown in Table 1, and it helped to define key elements of a systematic review.

Table 1. *PICO Framework.*

Criteria	**Inclusions:**	**Exclusions**
Population (P)	Individuals engaged in AP farming, urban communities, small-scale farmers, and AP companies.	Research unrelated to AP.
Intervention (I)	Studies evaluating the implementation, design, or management of AP systems for food production, including economic, social, and environmental aspects.	Studies unrelated to aquaponic systems. The research focused solely on aquaculture.
Comparison (C)	Comparative studies comparing AP systems with traditional agricultural methods (e.g., soil-based farming, HP). Economic analyses comparing the costs and benefits of AP food production with greenhouse farming practices. Research evaluating the environmental impact of AP systems compared to conventional agriculture.	Investigations focusing solely on the Comparison between different types of AP systems.
Outcomes (O)	Economic outcomes such as profitability, return on investment, or cost-effectiveness of AP food production. Environmental outcomes such as resource use efficiency,	Research focuses solely on crop yield or nutritional value without considering broader outcomes.

	greenhouse gas emissions, or water quality. Social outcomes such as community empowerment, food access, or equity.	

In conducting the review process PubMed, Web of Science, and Scopus, three major databases were used to identify relevant research. The search terms utilized in the query were carefully selected to capture various aspects of aquaponic systems and their implications for food security. Keywords "aquaponics," "food security," "economic viability," "environmental sustainability," "social equity," and "community resilience" were included to ensure comprehensive coverage of relevant articles and searched with “AND/OR” in the databases. The search for articles relevant to the systematic review was fine-tuned by constructing search strings using Boolean operators. The resulting search strings reflected the intersection between aquaponics and food security, ensuring that only relevant articles were included in the refined search results.

As the second step, all the selected records were imported into Covidence, (a web-based software platform (n = 133) (Figure 7). Covidence is a very good platform for screening and data extraction in conducting SLR. Subsequently, duplicates were removed (n = 36) by the Covidence and 97 records were left. The next step was screening, 42 studies were excluded by Title and Abstract screening and 55 records were left. The criteria for selecting articles (as shown in Table 1) included studies published in peer-reviewed journals, written in English, and focusing on the relationship between aquaponics and food security. Studies evaluating the economic viability, environmental sustainability, social equity, or community resilience of aquaponic systems were also considered eligible for inclusion. The aim was to include a diverse range of research studies conducted in various geographic regions and demographic contexts. On the other hand, titles and abstracts that did not meet the above criteria were excluded (n = 42). Then, full-text screenings were carried out, and 23 studies were excluded with the reasons of Out of Scope (n = 11), Irrelevant Topic (n = 6), and Non-Original Research/Reviews (n =6), the final selection was made with 35 (n =32). Based on the process PRISMA (Preferred Reporting Item for Systematic Review and Meta-Analyses) flow diagram was arranged through the Covidance platform (Figure 8). As the final step read the selected studies thoroughly, prepared notes, analyzed, and wrote the review based on the objectives of the study.

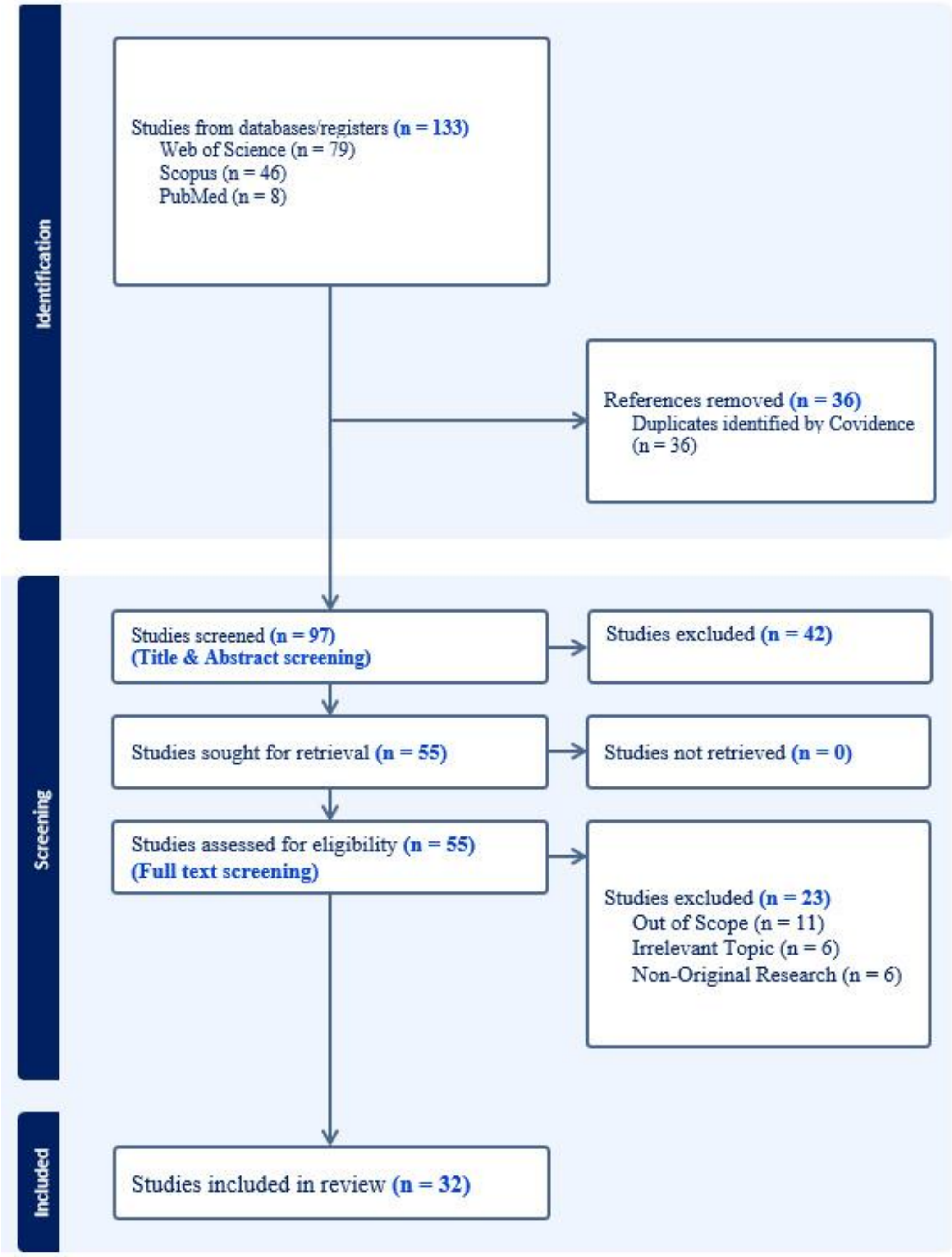

Figure 8. *PRISMA flow diagram (Preferred Reporting Item for Systematic Review and Meta-Analyses) visually summarizes the screening process of SLR*

4. Results

Out of 32 articles, findings relating to food production were summarized in Table 2, consisting of domestic, small-scale, commercial, or large-scale, and the research-level aquaponics in different countries with different climatic, and socio-economic conditions. Other studies consist of energy, profitability, and environmental-related findings of the aquaponic systems in different geographical areas.

Table 2. *General description of the AP systems regarding food security*

Continent	**Country**	**Fish rearing area (m^3)**	**Crop growing area (m^2)**	**Fish**	**Crop**	**Production (F-fish) (C- crop)**
Europe	Germany	7.91	166.6	Tilapia	Tomato	F: 600.1kg C: 1005.6kg
	Germany	*	573	African catfish	Tomato	F: 24ton C: 11ton
	Spain	*	45	Red hybrid tilapia	tomato, lettuce watermelon eggplant, cucumber pepper, onion pumpkin, broccoli cauliflower basil cabbage, strawberry	F: 33.5kg C: 177.7kg
	Netherland	40	1000	Tilapia	Tomato	F: 5ton C: 75tons (annual)
North America	Virgin island	7.8	214	Nile tilapia	Lettuce	F: 77kg/m^3 C:4.35kg/m^2
Asia	China	*	2100	**	**	F: 30 ton C: 360 ton
Africa	South Africa	*	2.5	Tilapia African catfish	Spinach, lettuce, tomatoes, peppers	F: 13 kg C: 3kg

* Fish raring area not mentioned ** Not specified

4.1 Effects of aquaponics on productivity

Eleven articles were focused on the production of aquaponic systems and out of that six studies revealed that the productivity of aquaponics was very high compared to current greenhouse farming (Kloas et al. 2015a; Lastiri et al. 2016; Karimanzira & Rauschenbach 2021a; Fernández-Cabanás et al. 2023; Yuan et al. 2023; Kok et al. 2024) and further, elaborated that within a 573m^2 farm, 11 tons of tomatoes and 24 tonnes of African catfish were produced in Germany. Nevertheless, in 2100m^2 China has produced 30 tonnes of fish and 360 tonnes of vegetables (Kloas et al. 2015). Yuan et al. (2023) investigated that the food production of aquaponic was 1.51 higher than the production of hydroponic. Fernández-Cabanás et al. (2023) found that the micro-scale aquaponic systems in Spain have produced 38.96 kg m^{-2} plants production while producing 33.5kg of Tilapia annually. Moreover, Lastiri et al. (2016) evaluated 5 tons of tilapia and 75 tons of tomato produced within the 40 m^3 fish tanks and 1,000 m^2 growing spaces. However, Love et al. (2015) suggested that commercial aquaponics were appropriate for producing large amounts of food after investigating data from several countries all around the world, such as Australia, Canada, the UK, Brazil, Greece, the Netherlands, Puerto Rico, Saint Martin, South Africa, Sweden, Thailand, Trinidad, & Venezuela.

By using the secondary data from the Swedish Board of Agriculture, calculated the average productivity of cucumbers from the year 2002 to 2022 open-field cucumbers and greenhouse cucumbers. Then those were compared with the productivity of cucumbers on four aquaponic farms in Sweden. Data shows that aquaponic systems have a significantly higher yield per unit area (Figure 9) compared to the other production systems.

AP 1 was located in the middle of Sweden and the other three plantations were located in northern Sweden. Aquaponic plantations produce cucumber, tomato (cherries, plums), herbs (coriander, basil), and grow in or adjacent to grocery stores, by utilizing innovative technologies these farms grow all year round, harvest every day, and sell the same day. Thus, consumers can buy very fresh, good-quality products, and their shelf life also increases due to that reasons food waste can be reduced. Besides, those aquaponic farms can reduce the use of fossil fuel due to zero transportation, which impacts and reduces Green House Gas (GHG) emissions.

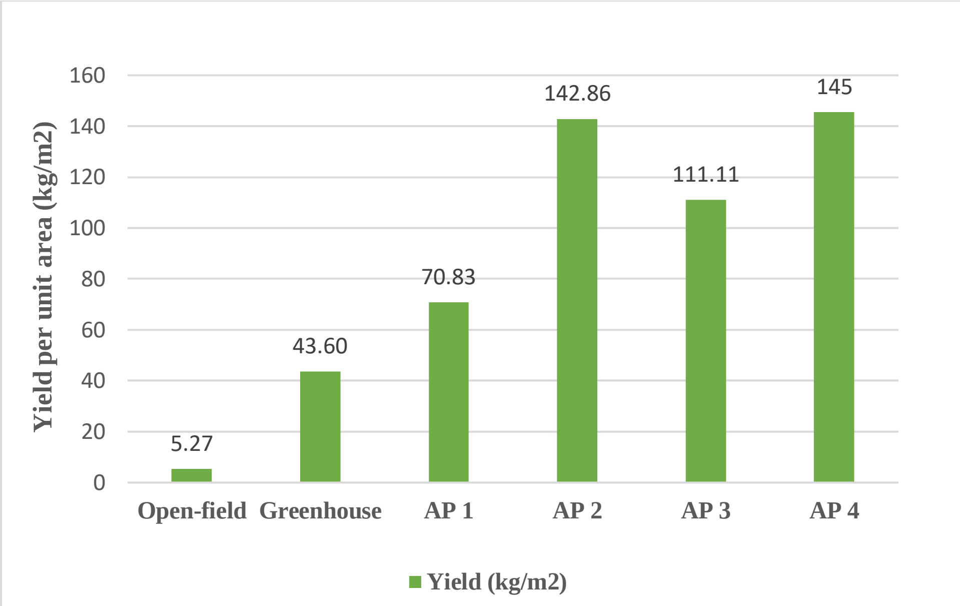

Figure 9. *A visual comparison of the efficiency in terms of yield per unit area across the different cucumber cultivation systems in Sweden. Three alternative systems were displayed (open field, greenhouse, and aquaponics. And four aquaponic farms were displayed as AP1, AP2, AP3, and AP4*

Not only do the crops simultaneously fish production was also significantly high in the above aquaponic systems. Higher crop productivity and fish production in aquaponic systems (Table 3) improve food security in the country (Sunny et al. 2019).

Table 3. *Average production of AP farms (plantations) in Sweden*

Criteria	AP 1	AP 2	AP 3	AP 4
Area (m2)	1,200	70	90	11,000
Cucumber production (ton)	85	10	10	1600
Atlantic salmon (tons)	10	1.4	1.4	*
Tomato (cherries and plums)	11	0	0	
Herbs (coriander, basil) pots	40,000	30,000	25,000	

*The salmon for AP 2 and AP 3 is produced in AP 4

From the analysis of the above secondary data and considering the results of related articles, aquaponics plays a crucial role in food production and simultaneously food security in the country.

4.2 Impacts on economic profitability

Seven studies were discussed regarding the economic profitability of aquaponic, as per the results of growing tomatoes, and lettuce in China, (Yuan et al. 2023) calculated profit of aquaponic is 1.54 times higher than hydroponic, and when considering the profitability it was 68.08% more than hydroponic. In another study in Bangladesh, Sunny et al. (2019) calculated that the benefit-cost ratio of the tilapia, climbing perch, and vegetable growing aquaponic was 2.2 and they found that aquaponic is economically viable. Further revealed that low-cost aquaponics was more economically viable as it has low risk, low capital investment, and can gain 100% Return on Investment (ROI) after 80 days (Sunny et al. 2019). In contrast, the small-scale aquaponic which was growing tomatoes, sweet peppers, and cucumbers in South Africa with a fish plant revenue model of 59% to 41% was not economically viable (Babatunde et al. 2023), but with the 30% to 70% fish-to-plant revenue model was economically viable. Thus Babatunde et al. (2023) suggested that the aquaponic systems are able to enhance food security and local economic development of South Africa. However, according to research in Australia, Greenfeld et al. (2019) revealed that large-scale, commercial AP's economic viability was superior to small ones. In addition, Kyaw & Ng (2017) also proved large-scale aquaponics had fewer labor costs and operating costs while profitability is high. In another study in Africa, the benefit-cost ratio was 1.12, and if aquaponic farms are fabricated with local materials, their economic feasibility can be increased grammatically (Benjamin et al. 2021). Moreover, it revealed that fish wastes can fulfill the total nitrogen requirements of plants, as well as aquaponic has the ability to enhance local nutrition and food security. However, Love et al. (2015) reported that soil-based gardens' yearly costs were higher than the non – commercial aquaponic. Therefore, the economic viability of non-commercial aquaponic systems is under debate.

4.3 Energy uses, water uses, and environmental sustainability of aquaponics.

Several studies discussed water use efficiency, sustainable energy consumption, and environmental sustainability of aquaponics. Six studies were focused on water use and all reported that aquaponic requires less water amounts for food production (Karimanzira & Rauschenbach 2021; Alberti et al. 2022; Nishanth et al. 2024; Calone et al. 2019; Kloas et al. 2015; Sánchez & Gómez 2023). The study in the United Arab Emirates, producing basil, coriander tilapia, and common catfish found that water savings exceeded 90% than to conventional farming methods (Nishanth et al. 2024b). In Germany, a European Catfish farm outputs 555 water liter per day, by converting the above aquaculture farm into an aquaponic farm it was able to decrease water output from 555L/day to 103 L/day (Calone et al. 2019). Thus the efficiency of water usage of aquaponic farms is considerably high.

Energy usage in aquaponics is a critical aspect that warrants attention due to its implications for sustainability and operational costs. Aquaponics requires energy for water circulation, aeration, heating or cooling, lighting, and supplemental feeding.

According to the locations where aquaponics farms are located, system design, the scale of operation, climate conditions, and technology employed, energy requirements, and consumption vary, the research in Saudi Arabia found that the majority of energy was used to create a cooling environment suited for the aquaponics (Memon et al. 2022) in contrast, Parajuli et al. (2023) revealed that 85% of total energy was used for the heating of aquaponics in cooler climatic regions, as this study was done in Nepal. Even though aquaponics is frequently praised for using fewer resources than traditional agriculture, energy usage is still a key factor to take into account when evaluating the system's overall environmental impact (Kloas et al. 2015). Yuan et al. (2023) found that the energy usage of aquaponics was 2.21 times higher than that of hydroponic farming however, the Environmental Loading Ratio (ELR) of aquaponics was 0.83 which is more environmentally friendly than hydroponic farming, a system may be more environmentally friendly if its value is less than 1, which shows that its environmental outputs were less than its environmental inputs.

Every article covered the relationship between aquaponics and environmental sustainability, with eight emphases being covered in detail (Kloas et al. 2015; Yuan et al. 2023; Garzón et al. 2020; Goddek et al. 2015; Fernández-Cabanás et al. 2023; Kyaw & Ng 2017; Laidlaw & Magee 2016; Kok et al. 2024). Promising answers to agriculture's problems with environmental sustainability can be found in aquaponics. Aquaponics lessens its impact on the environment by minimizing resource inputs and waste outputs through the integration of hydroponic and aquaculture in a symbiotic system (Mok et al. 2020). Aquaponic systems use water more efficiently than traditional agriculture; estimates indicate that compared to soil-based farming, they may use up to 90% less water (Nishanth et al. 2024b). Furthermore, aquaponics has reduced the risk of soil and water pollution while preventing eutrophication, by doing away with the need for synthetic fertilizers and pesticides (Yahya et al. 2023). Furthermore, they discovered that aquaponics could be used to grow vegetables and fish all year round in flood-prone and coastal saline-affected soil regions. Additionally, because aquaponic systems were closed-loop, they encouraged nutrient recycling because fish waste was used as an organic fertilizer to support plant growth. This circular resource-use strategy promotes ecosystem resilience and aids in the preservation of natural resources. All things considered, aquaponics represents a sustainable farming paradigm that is in line with environmental stewardship principles, providing a workable route towards more robust and environmentally friendly food production systems.

4.4 Impacts on social sustainability

Ten publications indicated that aquaponic systems foster local food production and decrease reliance on distant food supply chains, enhancing food security and resilience to external shocks like disruptions in global trade or climate change. Through encouraging fair access to healthy meals, empowering communities, and building resilience against food insecurity, aquaponics played a critical role in addressing social sustainability and promoting food security (Goddek et al. 2019; Milliken & Stander 2019; Kloas et al. 2015; Yuan et al. 2023). The ability of aquaponics to supply communities with a consistent supply of fresh fish and produce, irrespective of location or environmental conditions, was closely associated with social sustainability. According to (Fernández-Cabanás et al. 2023) the calculation, a healthy diet with macronutrients, essential nutrients, and minerals can be obtained with a real cost of 3.07 Euro per person per day by having an aquaponic system. Furthermore, they emphasized it was 22% cost saving when comparing the market price of food and aquaponic's food nutrient content contribution exceeded 20%. Aquaponic systems foster local food production and decrease reliance on distant food supply chains, enhancing food security and resilience to external shocks like disruptions in global trade or climate change. Aquaponic can be affected not only nutrient security but also economic prosperity in both urban and rural areas (Adeleke et al. 2022) as well aquaponic contributed toward livable and sustainable cities (Kyaw & Ng 2017b). The results (Beebe et al. 2020) revealed that having a backyard aquaponic system exceeds the families' expectations because they have more benefits, increased access to vegetables, fruits, and fish, and increased family and community connections. Most non-commercial aquaponic growers consume homegrown vegetables and fruits weekly basis, however, they consume their fish rarely (Love et al. 2015). Therefore (Flores-Aguilar et al. 2024b) emphasized aquaponic was a feasible option for small farmers, rural and also urban communities, and women to enhance food security, and aquaponic plays a crucial role in achieving UN SDG 2, Zero hunger. Besides the year-round cultivation and the high nutrient content of aquaponic products (Beebe et al. 2020), it mitigates health hazards and increases food security simultaneously can achieve SDG 1, No Poverty. As a summary Table 4 shows the potential sustainable outcomes of aquaponic.

Table 4. Potential Sustainable Outcomes of AP

Sustainable outcomes	Evidence	Authors
Food security	Optimum productivity of both fish & vegetables 1.51 times higher food production than GH High productivity Crops maintain their nutritional integrity AP Products 20% more rich protein, vitamins, potassium & fiber	(Kloas et al. 2015b) (Yuan et al. 2023) (Karimanzira & Rauschenbach 2021b) (Nishanth et al. 2024a) Fernández-Cabanás et al. 2023
Water efficiency	To produce 1kg Tilapia & 5kg tomato need 1kg feed, & ~200 l of fresh water. Reduction of freshwater consumption	(Kloas et al. 2015b) (Nishanth et al. 2024a) (Karimanzira & Rauschenbach 2021b) (Bibbiani et al. 2016)
Economic efficiency	1.54 times higher profit than GH The benefit-cost ratio 2.2 Return on Investment of 100% after 80 days. Less operating cost	(Yuan et al. 2023) (Sunny et al. 2019) (Kyaw & Ng 2017)
Urban/rural development & social sustainability	Suitable solution for the urban food supply & sustainable urban development. AP contributes towards sustainable and liveable cities. Having AP exceeds their expectations	(Yuan et al. 2023) (Kyaw & Ng 2017) (Beebe et al. 2020)
Nutrient efficiency	AP eliminates the need for chemical fertilizers	(Sánchez & Gómez 2023)
Impact on climate	Low environmental emission The environmental Loading Ratio is lower than the GH Low environmental impact	(Kloas et al. 2015) (Yuan et al. 2023) (Bibbiani et al. 2016)

5. Discussion

This study examined the impacts of aquaponic on food security and the applicability of the aquaponic system in Sweden.

A holistic approach is needed to address food security issues by giving top priority to sustainable farming methods, reducing food miles, and enhancing nutritional education. Societies can work toward ensuring food security for all while reducing the negative effects of environmental degradation and socioeconomic disparities by promoting healthy dietary habits, strengthening access to nutritious food, and fostering resilience in food production. According to the findings of my study, I can suggest that aquaponics is one of the best alternatives for food production, the following information evidences this.

Aquaponic is the symbiotic relationship between plants and fish within the closed loop system, fish like tilapia, trout, catfish, and salmon are raised with vegetables and herbs that are interconnected through a recirculating water system (Table 2). Additionally, filtration systems are integrated to maintain water quality and ensure the health of both aquatic life and vegetation. Fish provide sufficient nutrients to plants and plants help to clean water for fish. The most commonly cultivated fish in aquaponic systems include tilapia, trout, salmon, and catfish (Table 2) with their adaptability to varied environmental conditions, nutrient contents, and rapid growth rates. Vegetables such as lettuce, tomato, cucumbers, and herbs like basil, coriander, and mint, (Table 2) thrive in aquaponic environments, benefiting from the nutrient-rich water provided by the fish waste. Nowadays aquaponic is popular in both developed and developing countries, the United States, Canada, Netherlands, and Australia, developed countries use this production system primarily for commercial food production, supplying local markets with fresh produce and fish while, developing countries such as Kenya, India, Nepal, Bangladesh, and African countries are exploring aquaponic as a means of enhancing food security and livelihoods in rural communities. In addition, aquaponic is becoming more and more popular in education settings, where it is used as a practical teaching tool for biology, ecology, and sustainable agriculture (Junge et al. 2019; Masabni &Niu 2022).

This efficient utilization of resources within the closed-loop ecosystem, maximizes yields while minimizing environmental impact, making aquaponic a viable option for addressing food security concerns. Aquaponic enables year-round cultivation whatever the external factors change such as climatic conditions, and soil or water quality, thus it can contribute to food security by providing a consistent supply of fresh and healthy products (Masabni &Niu 2022). Consequently, aquaponics is a sustainable system for food sovereignty and resilience in communities by encouraging local food production (Beebe et al. 2020) and lowering reliance on imports, especially in areas vulnerable to natural disasters or food shortages. In addition, aquaponic is a feasible solution for food production in water scarcity areas, coastal regions, and flood regions. Furthermore, it empowers farmers to diversify their cultivation as suited to the local conditions, as well as gives some opportunities to cultivate several things by changing the internal environmental conditions within the system. This diversification strengthens the food systems against the market price fluctuations by the steady supply and reduces the reliance on fresh food importation by promoting self-sufficiency. Thus aquaponics promote dietary diversity and nutritional security among consumers. Because aquaponic systems are capable of producing a wide variety of crops such as leafy greens, herbs, fruits, and different kinds of vegetables. Thus consumers can obtain a wide variety of nutrients with vitamins and minerals from various plant sources. This diversity enables consumers to access a broad range of nutrients from different plant sources (Fernández-Cabanás et al. 2023), obtaining all the necessary vitamins and minerals required for optimal health. Furthermore, foods that are grown in aquaponic systems are usually fresher and more nutrient-dense than conventionally grown crops (Fernández-Cabanás et al. 2023) due to avoiding chemical usage and reducing food miles. Moreover, aquaponics is a great source of omega-3 fatty acids, high-quality protein, and important nutrients like vitamin D and selenium from fish (Beveridge et al. 2013; Chen et al. 2022). The inclusion of fish in the diet contributes to nutritional security by providing essential nutrients that are often lacking in plant-based diets. With the year-round production of aquaponic, consumers can benefit from a stable supply of nutritious food throughout the year. Moreover, aquaponic systems can be established in both urban and rural areas, reducing the distance food miles from farm to table. This local production model supports dietary diversity by making a variety of fresh, locally-grown foods more accessible to urban populations.

5.1 Food production, import, and consumption in Sweden

When considering the land area, Sweden is one of the largest countries in Europe dedicating 6.5% to cultivation (Jordbruksverket n.d). Over the past five decades significant decline of farms while increasing the size of the farms could be observed (Jordbruksverket n.d). This shift towards consolidation has seen farms specializing in cereal crops, oilseeds, and animal husbandry, reflecting evolving agricultural practices. Diversified landscapes and climatic conditions cause significant challenges in the production in Southern and Nothern regions and 1.5% are employed in the agricultural sector (Jordbruksverket n.d). Swedish cuisines are characterized by a mix of Nordic dishes and modern, including dairy products, grains, potatoes, vegetables, fruits, and meats such as beef, pork, and poultry. Additionally, seafood, particularly trout and salmon, holds a prominent place in Swedish culinary traditions. Nevertheless, per capita meat consumption is 50-55kg per year (Livsmedelsverket 2023a). Sweden relies on agri-food importation to fulfill the nation's food requirements, and approximately 65% is imported from EU countries, primarily due to climatic constraints and limited agricultural land (Livsmedelsverket 2023a). The most commonly imported food items include fruits, vegetables, and grains, which are difficult to cultivate locally year-round. The products that can be cultivated within the country such as cucumber also imported by 50% Agtira (2023). However, aquaponics has the potential to produce many of these imported products domestically, mitigating the need for reliance on external food sources. Vegetables like tomatoes, cucumbers, lettuce, and peppers, as well as herbs such as basil and mint, can thrive in aquaponic environments. Additionally, fish species like tilapia, salmon, and trout, which are commonly imported, can be successfully raised in aquaponic systems (Table 2). By producing these products locally, aquaponic can reduce dependency on imports and enhance food security in Sweden.

5.2 Aquaponics production in Sweden:

The adoption of aquaponic in Sweden is a preliminary option to strengthen the food system, particularly in urban areas where space constraints and environmental concerns drive interest in alternative farming methods. Aquaponic offers several advantages for Swedish food production, including year-round cultivation, resource efficiency, and minimal environmental impact.

The ability of aquaponic to overcome seasonal constraints imposed by Sweden's northern climate is one of its main advantages. Aquaponic reduces reliance on imported goods during the off-season by allowing year-round cultivation of fresh produce and fish indoors or in controlled environments. Then people can afford fresh, nutritious products at lower prices. Furthermore, the increasing self-life of products can reduce the volume of household food waste. As an example, in the aquaponic farms that I discussed in my results section (Table 3), two farms are situated inside the supermarket, and the other two are situated closer to the supermarket, therefore consumers are able to buy products that are harvested on the same day, fresh, healthy, nutritious, and with long self-life products.

Compared to conventional agriculture, aquaponic systems use resources more effectively by requiring less water and land. By reducing waste and nutrient runoff, the closed-loop ecosystem helps to prevent environmental degradation and protects natural resources for coming generations. Additionally, aquaponic lessens food miles and contributes to the reduction of greenhouse gas emissions. Moreover, it supports Sweden's sustainable quality objectives and self-sufficiency by providing chances for regional food production and community empowerment. Aquaponic builds a sense of ownership over food systems and increases resilience by involving people and communities in food production. Therefore, to enhance food security and achieve the SDGs, AP is one of the best options for Sweden.

However, aquaponic also presents challenges and limitations, it incurs high initial investment costs and needs more education, experience as well as information, by using local materials to construct aquaponic systems can minimize initial costs. In addition to that aquaponic requires more energy for heating and cooling the system (Parajuli et al. 2023) according to the requirements of the products. Additionally, ensuring the welfare of fish and maintaining water quality requires careful monitoring and management. The other main challenge is, that aquaponics have difficulty obtaining organic certification due to strict regulations (Kledal et al. 2019). Overall, aquaponics has the potential to completely transform Sweden's food production system by offering a scalable, resilient, and sustainable substitute for conventional agriculture. Aquaponics can help increase food security, promote environmental sustainability, and strengthen the resilience of Swedish food systems in a world that is changing quickly by utilizing cutting-edge technologies and sustainable practices.

5.3 Productivity, energy efficiency, and environmental sustainability.

When compared to traditional soil-based farming systems, productivity per unit area of the aquaponic systems is very high due to its closed-loop systems efficiently recycling water, nutrients, and waste (Figure 9). The nutrient composition of plants that are grown in aquaponic systems is higher than the plants that were grown in inorganic hydroponic media and unamended loamy soil (Olanrewaju et al. 2022) further, a significant effect on plant height and biomass could be seen in aquaponic herbs (Valdez-Sandoval et al. 2020). With those factors, the quality and productivity of aquaponic products are high, in addition, seasonal changes do not affect production, thus year-round production is a very good strength of this farming system. Several studies have investigated that aquaponic systems are suitable for urban, peri-urban, and urban areas for food production, not only for vegetables and fruits but also for fish production (Stadler et al. 2017). Therefore aquaponic is one of the best solutions for the fulfillment of future food demand for the increasing population. With the year-round production, reduction of food miles, high quality of foods, and the benefits of fish over meat consumption, aquaponic plays a crucial role in food security simultaneously aligning with the zero hunger and the No-poverty SDGs.

The profitability of aquaponic systems is influenced by several factors, such as the scale of operation, the type of crop, market dynamics, and management practices. Larger commercial aquaponic setups generally demonstrate superior economic viability due to economies of scale and higher production volumes (Greenfeld et al. 2019; Love et al. 2015). However, if one can use local materials when constructing aquaponic systems on a small scale and backyard household aquaponic systems it is more economically feasible (Greenfeld et al. 2019; Benjamin et al. 2021; Love et al. 2015) and the return on investment period of non-commercial aquaponic is meager (Sunny et al. 2019). Less freshwater requirement, low fertilizer requirements, and low effluent costs factors are affecting the high profitability of aquaponic systems (Rupasinghe & Kennedy 2010). Despite the variability observed in profitability, aquaponic systems have the potential to enhance food security and contribute to local economic development (Adeleke et al. 2022). Aquaponic offers opportunities for entrepreneurs and individuals with innovative perspectives, while also creating new job prospects. However, there are debates regarding the economic feasibility of non-commercial aquaponic systems, which highlights the need for further research and analysis. Future research should aim to understand the main drivers of profitability, explore innovative business models, and assess scalability and replicability. These insights will inform decision-making and policy interventions aimed at promoting the sustainable integration of aquaponics into food systems. Moreover, aquaponic is one of the best tools to achieve SDG 7,8 and SDG 9.

The primary challenges facing food production to meet future demands include land scarcity, freshwater limitations, and resource constraints. Furthermore, traditional farming systems and some dietary habits such as increased meat consumption are adversely affected by climate change and contribute to high environmental emissions. Around 70% of water withdrawal is used for traditional soil-based agriculture, but water savings exceeded more than 90% in aquaponic farming as the water circulated within the system rather than being lost through runoff or evaporation. Besides, aquaponic significantly reduces freshwater eutrophication due to nutrient (fish waste) circulation (Cohen et al. 2018). Aquaponic eliminates the use of inorganic fertilizers and pesticides, as fish waste can fulfill the nutrient requirement of plants, plants help to clean water for fish, by reducing reliance on chemical inputs, aquaponic minimizes the risk of water pollution and soil degradation, and it promotes environmental health. Compared to conventional farming aquaponic generally emits fewer greenhouse gases, Kalvakaalva et al. (2022) investigated that 40% to 62% reduction of direct greenhouse gas emissions from aquaponic due to carbon sequestration by plants. The other main discussion point is the energy efficiency of the aquaponic s. More than 85% of energy is used for heating or cooling (Parajuli et al. 2023), utilizing energy-efficient equipment and renewable energy sources can boost energy efficiency and reduce emissions.

Given the current challenges of limited land availability and increasing pressure on natural resources, aquaponics offers a viable solution for producing nutritious food resource-efficiently, and aquaponic is more suitable for urban areas due to rapid urbanization and population increment. The method provides a sustainable and eco-friendly alternative to conventional farming practices, enhances food security, and makes it particularly attractive to businesses and organizations seeking to minimize their environmental footprint. Whether there is a possibility to start an aquaponic system in backyards, balconies, and rooftops in urban areas, it will have a huge impact on food security and future food demand in Sweden.

5.4 Aquaponic and food security in Sweden

When it comes to Sweden, aquaponics play a crucial role in producing both fish and vegetables and can significantly bolster the local supply of fresh food. This dual production system offers distinct advantages as it can operate year-round within controlled environments, effectively mitigating the impact of Sweden's harsh winters on food availability. Consequently, it ensures a consistent supply of nutritious food irrespective of the season (Graber & Junge, 2009). The capacity to uphold consistent food production throughout the year confronts a critical challenge in ensuring food security within a country characterized by a cold climate. Furthermore, aquaponic provides the answer for the second parameter of food security, access. To reduce transportation costs and improve access to fresh products, aquaponics farms can be established close to consumers in urban areas. Urban dwellers can easily access locally grown healthy, fresh foods, thus enhancing food security (Love et al., 2015). The nutritional quality of food accessible to Swedish consumers could be greatly improved by the use of aquaponics systems to cultivate nutrient-rich produce. For customers who have access to this premium, fresh meals, this may lead to better health outcomes (Licamele, 2009). Improving the nutritional value of the food that is readily available is a vital component of food security, guaranteeing access to both a sufficient supply of food and food that is health-promoting. Moreover, reducing food miles from farm to table not only improves access but also supports local economies and reduces carbon emissions associated with food transport. In addition to that aquaponics can play a key role in addressing the stability, of food security parameters. Aquaponics systems offer a reliable source of food since they are resistant to outside shocks like market price fluctuations and climate change. In contrast to conventional farming techniques, aquaponics can continue to produce food even in poor market dynamics or weather conditions (Goddek et al., 2015). This resilience guarantees a consistent supply of food despite outside interruptions, which is essential for preserving food security in Sweden.

In Sweden, the implementation of aquaponics can significantly enhance agency aspect of food security, by empowering individuals and communities. Aquaponics systems can be established at various scales, from small community gardens, backyards, and balconies to large commercial operations. This flexibility allows communities to engage in food production directly, increasing their control over the quality and type of food they consume. By enabling urban farming and community-based projects, aquaponics promotes local food sovereignty, where people can grow their own food sustainably and independently (König et al., 2018). Additionally, aquaponics offers a wealth of teaching possibilities that promote healthy eating and sustainable farming methods. Individuals and communities can improve their knowledge and abilities linked to food production by participating in educational programs and seminars that educate them on how to set up and manage aquaponics systems. This promotes more sustainable and health-conscious food choices in addition to developing a stronger bond with the food system (Love et al., 2015). Moreover, aquaponics offers a viable economic model for food production by reducing reliance on imported food and creating local employment opportunities. Aquaponics systems' year-round production capacity guarantees a regular flow of fresh products, which helps stabilize food prices and gives farmers and business owners a reliable source of income (Palm et al., 2018). In addition, aquaponics helps create more environmentally and economically sustainable food systems. Not only the economic sustainability, but it also contributes to the social and ecological sustainability in Sweden, as an example community-based aquaponics projects can strengthen social cohesion by bringing people together around a common goal of sustainable food production. By promoting biodiversity and reducing the ecological footprint of food production, aquaponics helps to preserve natural resources and ensure the long-term sustainability of the food system.

5.4.1 The challenges with scaling up aquaponic at the commercial level

Despite its potential, the scaling up of aquaponics to a commercial level in Sweden is accompanied by several challenges. The initial cost of commercial aquaponics systems is considerably high including expenses for land, infrastructure, and technology (Palm et al., 2018). In addition, it needs expertise in aquaculture, hydroponics, and advanced technologies to succeed in the projects. Thus, the lack of trained professionals can hinder the scalability of these systems (Kloas et al., 2015). The other main challenge in Sweden is regulatory barriers. As an example, organic food consumption has increased in Sweden for the past few decades (Huyge n.d), under the EU organic regulations, there are no regulations and standards for aquaponic products to obtain certificates as organic foods (Kledal et al. 2019) and it is a main barrier to expand the aquaponic products in Sweden. Reinhardt et al. (2019) revealed that "none of the EU policies and guidelines so far explicitly mentions aquaponics", the EU mostly targets research projects of aquaponics thus, in EU very few commercial aquaponic farms are operating (Reinhardt et al. 2019).

5.4.2 Quality parameters of aquaponic in Sweden

High quality standards such as food safety, nutrient density, taste, and freshness are crucial for the success of the aquaponic system. The critical thing of aquaponic is to ensure that both fish and plants are free from contaminants and pathogens. This necessitates stringent monitoring and strict adherence to food safety regulations. The two aquaponic farms that I used for my studies are situated inside supermarkets in Sweden, and they might have some possibilities of contaminating crops. Therefore, regular testing for harmful substances and proper management practices are essential to maintain the integrity of the food produced (Stouvenakers et al. 2019). Implementing robust biosecurity measures and adhering to established guidelines help prevent contamination, ensuring that the products reaching consumers are safe to eat. Stouvenakers et al. (2019) revealed that physical water treatment practices such as filtration, heat, and UV treatments are the most effective practices to eliminate pathogens without harming to fish and plants.

Aquaponics ensures that plants receive the right balance of nutrients to enhance their nutritional content (Licamele, 2009), contributes to superior health benefits for consumers, and sets aquaponics produce apart from conventionally grown alternatives. By focusing on the nutrient-rich quality of their products, aquaponics farms can facilitate health-conscious consumers looking for nutritious food options (Licamele, 2009).

Furthermore, this innovative farming system has the opportunity to reduce food miles between producers and consumers and it ensures that products are as fresh as possible when they reach the market. Thus it affects the superior taste, increases shelf life, and reduces food waste. Maintaining high standards in these areas not only enhances consumer satisfaction but also strengthens the market position of aquaponics farms (Goddek et al., 2015).

5.4.3 Future perspectives for aquaponics and food security in Sweden

Looking ahead, aquaponics holds significant potential for enhancing food security in Sweden through various advancements and strategic initiatives. The technological advancements in automation, monitoring, and control systems hold the potential to considerably decrease labor costs and enhance the efficiency of aquaponics operations. These innovations have the capability to optimize resource utilization, streamline maintenance tasks, and uplift overall productivity, thereby positioning aquaponics as a more sustainable and competitive option for food production (Goddek et al., 2015).
Swedish Government interventions and EU regulations regarding aquaponics are needed for the development and expansion of the aquaponic industry in Sweden. Government initiatives and subsidies can play a crucial role in lowering the financial barriers associated with setting up aquaponics systems. The government can make aquaponics more accessible to farmers and entrepreneurs by providing financial assistance and creating supportive policies. Such support can accelerate the adoption of aquaponics, fostering innovation and expansion in this sector (Palm et al., 2018).

Educational programs and community-based projects are essential for raising awareness about the benefits of aquaponics. Junge et al. (2019) revealed that aquaponic can bring nature into the classroom and can teach from the primary and secondary school levels. As an example, Älandsbro skola, Primary School in Sweden has started an aquaponic unit as an educational program (Junge et al. 2019). By educating the public and engaging communities in aquaponics projects, these initiatives can foster wider adoption and support. Community engagement not only promotes local food production but also enhances social cohesion and collective responsibility towards sustainable food systems (König et al., 2018). By implementing technological advancements, fostering policy support, and engaging communities, Sweden can leverage aquaponics to build a more resilient and sustainable food system for the future

6. Conclusion

In conclusion, aquaponic plays a crucial role in sustainable food production, with its integration of aquaculture and hydroponic offering a multifaceted solution to global food security challenges. From small-scale setups to large commercial operations, aquaponic shows its adaptability and viability, addressing all food security pillars. Not only provide a continuous supply of fresh, nutritious foods aquaponics promotes resilience against environmental shocks and market fluctuations.

In Sweden, where a wide variety of products are preferred in cooking, aquaponics has the potential to enhance food productivity and lower dependency on imported fruits and vegetables. In addition, aquaponic has the potential to improve food production, security, and sustainability, despite obstacles like initial investment costs and regulatory barriers. Through cooperative endeavors among policymakers, researchers, and entrepreneurs, Sweden has the capacity to fully actualize the potential of aquaponic, thereby laying the foundation for a more robust, just, and sustainable food system. Ultimately, this innovative, efficient, environmentally friendly, and resilient technique demonstrates the pathway towards a future where nutritious and fresh food is accessible to all, both in Sweden and across the globe, while achieving sustainable development goals.

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Popular science summary

Can Aquaponics Sustainably Meet Future Food Demand?

We need to produce over 70% more food by 2050 to keep up with the growing population. There is a question, can these food requirements be fulfilled with the prevailing agricultural system, and farming practices that have been causing problems for the environment, like soil degradation, water, and air pollution, decreased natural resources, and loss of habitats of plants and animals? Although Sweden is a developed country, Sweden's population is growing, and most people live in cities. Additionally, Sweden relies on the importation of foods to fulfill the food demand because local production is not enough to satisfy the food demand. Not only does Sweden import the products that are unable to grow in the country with the seasonality and climatic changes, but also imports the products that can be able to grow within the country such as tomato, cucumber, lettuce, basil, mint, and fish such as trouts, salmon, tuna, and cod. Therefore, there is a to find ways to produce food that is good for the environment and make sure we have enough to eat.

Some countries use a new method to cultivate food by growing plants together with fish, and it's called “aquaponics”. In this system, fish waste is used as fertilizer for the plants, and plants can clean water for fish by growing in water, minimizing waste to the environment in this closed system. In many countries, aquaponics practices in both urban and rural areas, and investigated as high-yield, economically feasible, as well as environmentally friendly. So people can obtain fresh, healthy food all year round at lower prices. So it's a good way to make sure there is enough food for everyone. Looking at a bunch of different studies found that aquaponics can help to enough fresh and healthy food for all populations and be good for the environment. Sweden has limited land for agriculture, and with the climatic conditions are not able to cultivate all year round, therefore, Sweden has to import a lot of food, and aquaponics could help to facilitate the production of more food locally. There are some challenges in using aquaponics, like the cost and some regulations, but it could be a good, environmentally friendly way to make sure to have fresh and healthy food to eat.

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