sustainability

Review

Can Aquaponics Be Utilized to Reach Zero Hunger at a Local Level?

Priscila Sarai Flores-Aguilar [1], Julieta Sánchez-Velázquez [1], Humberto Aguirre-Becerra [1], Guillermo Abraham Peña-Herrejón [2], Sergio Aurelio Zamora-Castro [3] and Genaro Martín Soto-Zarazúa [1,*]

[1] Facultad de Ingeniería Campus Amazcala, Universidad Autónoma de Querétaro, El Marqués 76265, Mexico; priscila.flores@uaq.mx (P.S.F.-A.); julieta.sanchez@uaq.mx (J.S.-V.); humberto.aguirreb@uaq.mx (H.A.-B.)
[2] Centro de Investigación y Desarrollo Tecnológico en Materia Agrícola, Pecuaria, Acuícola y Forestal, Campus Concá, Universidad Autónoma de Querétaro, Arroyo Seco 76410, Mexico; guillermo.pena@uaq.mx
[3] Facultad de Ingeniería, Construcción y Hábitat, Universidad Veracruzana, Boca del Río 94294, Mexico; szamora@uv.mx
* Correspondence: soto_zarazua@yahoo.com.mx; Tel.: +52-442-332-9713

Abstract: Meeting the demand for food through sustainable agro-industrial systems has become a concern due to the current state of the planet's natural resources, population growth, and climate change. To address this, the 2030 Agenda has laid out several strategies to enhance human well-being and protect the planet. This paper focuses on Goal 2, which aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. The first three targets of this goal are as follows: 2.1, ending hunger and ensuring access to nutritious food; 2.2, ending all forms of malnutrition; and 2.3, doubling the agricultural productivity of small-scale food producers. The purpose of this manuscript is to demonstrate how aquaponics can positively impact these three targets by guaranteeing food security through the production of high-quality protein. Aquaponic crops are enriched with organic nutrients from the water they grow in. This not only increases their nutrient content but also their bioactive molecule content, making them excellent for fighting hunger and malnutrition. Moreover, these practices can be adjusted to different scales, making them a viable option for small farmers, women, and rural communities to produce their own food. Consequently, aquaponics can play a crucial role in achieving Zero Hunger locally, with appropriate support.

Keywords: sustainable agriculture; aquaponics; zero hunger; agenda 2030; organically-enriched waters; food security

Citation: Flores-Aguilar, P.S.; Sánchez-Velázquez, J.; Aguirre-Becerra, H.; Peña-Herrejón, G.A.; Zamora-Castro, S.A.; Soto-Zarazúa, G.M. Can Aquaponics Be Utilized to Reach Zero Hunger at a Local Level? *Sustainability* **2024**, *16*, 1130. https://doi.org/10.3390/su16031130

Academic Editors: Md Romij Uddin and Uttam Kumer Sarker

Received: 28 October 2023
Revised: 15 January 2024
Accepted: 22 January 2024
Published: 29 January 2024

1. Introduction

The conventional method of food production and consumption, together with the rising population, has caused an imbalance in planetary ecology. This has consequently led to a state where our existing linear economic structure falls short in guaranteeing adequate sustenance for society. Agriculture faces a variety of significant challenges. These include over-utilization of cultivated land and groundwater, which can lead to heavy metal contamination and decreased crop production. To create a regenerative and distributive economy, we must shift our focus toward sustainable food production and consumption, and cultivate a new perspective that prioritizes sustainability and increases Agricultural Development Resilience (ADR). In this way, we can be prepared to respond to national and external challenges and risks, provide stability to regional markets, and affirm the status and position of agriculture [1–3]. Different pathways have emerged to achieve global sustainability, re-establish the biological planetary cycles, and enhance resilience [4]. The most prominent strategy is the Agenda 2030 and its 17 Sustainable Development Goals (SDGs) [5]. The 17 SDGs contain 169 targets, relating to which at least 3823 events, 1344 publications, and 7554 actions were performed by June 2023 [6].

International publications related to agriculture, food safety, aquaculture, and fisheries have established that the current production and consumption trends need to change drastically, starting at the local level. If not, it will take at least another decade to meet most of the SDGs and achieve the common goal of "leaving no one behind" [7,8]. Aquaponics is a sustainable farming technique that combines fish farming and hydroponics and is considered to be sustainable because it takes into account the three pillars of sustainability: environment, economy, and society [9]. This innovative technology has the potential to speed up the adoption of sustainable practices and help tackle the challenges of the 2030 Agenda for Sustainable Development at the local level, such as in Mexico. Its design is inspired by nature to create a sustainable system. Nature provides efficient solutions with minimal energy expenditure, which humans can adapt to their environment. Aquaponics mimics the ecosystem of flowing lakes that transform into rivers, where stones gradually filter sediments, which then flow into wetlands. Eventually, plants growing on the wetland shores and sand absorb all the nutrients [10]. This can be seen in the coupled system with the Recirculating Aquaculture System (RAS) as counterpart of rivers, settler & biofilter as counterpart of stones, and a sump as counterpart of the wetlands (Figure 1). In decoupled systems, water lost through plant evapotranspiration is harvested, comparable to the way clouds capture and return water to lakes.

Mexico has 11,592 km of coastline, a network of rivers, and 633 km of streams, along with systems of lakes and lagoons that can supply aquaculture [11]. Mexico is the fourth-largest aquaculture producer in the Americas, with 82% of fishing and 18% of aquaculture; the practices of marine aquaculture accounted for 69% of the production, while inland aquaculture contributed 31% [7]. The potential for using what is often referred to as "aquaculture wastewater" in aquaponic systems is enormous. Rather than calling it wastewater, it would be more accurate to refer to these waters as organically-enriched waters (OEW), because they contain a diverse range of nutrients, dissolved organic molecules (DOM), and microorganisms [12]. Although aquaponics has not yet been adopted in all areas of Mexico, its beginnings can be traced back to the Aztecs (1150–1350 CE) and their floating islands called Chinampas in the streams of the Mexico Valley [13]. There are many successful cases of small and medium-scale aquaponics globally that can serve as examples to encourage local use. In addition, this country has seven different types of climates, which are: Warm Subhumid, Dry and Semi-Dry, Very Dry or Dry Desert in its majority; Warm Humid, Temperate Subhumid with a smaller surface area, and Temperate Humid and Cold with the minimum surface area. This makes it a place with climates with appropriate growing seasons for a wide variety of both aquatic and horticultural food (https://gisviewer.semarnat.gob.mx/aplicaciones/Atlas2015/atm_climas.html, accessed on 21 January 2024). Furthermore, Mexico has committed since 2017 to collaborate in the establishment of the 17 SDGs [14]. Nowadays, the status of SDG2 is "Greater challenges remain/Stagnating"; the possibilities offered by aquaponic technology in this country could modify the status towards "Moderately increasing" [15]. This paper aims to explore how aquaponics can help achieve SDG2-Zero Hunger locally in Mexican territory. The use of aquaponics in certain areas can increase ADR and have a positive effect on neighboring cities and collaboration among local food producers, government, and universities. We will examine the advantages of aquaponics and its potential to address hunger in the region.

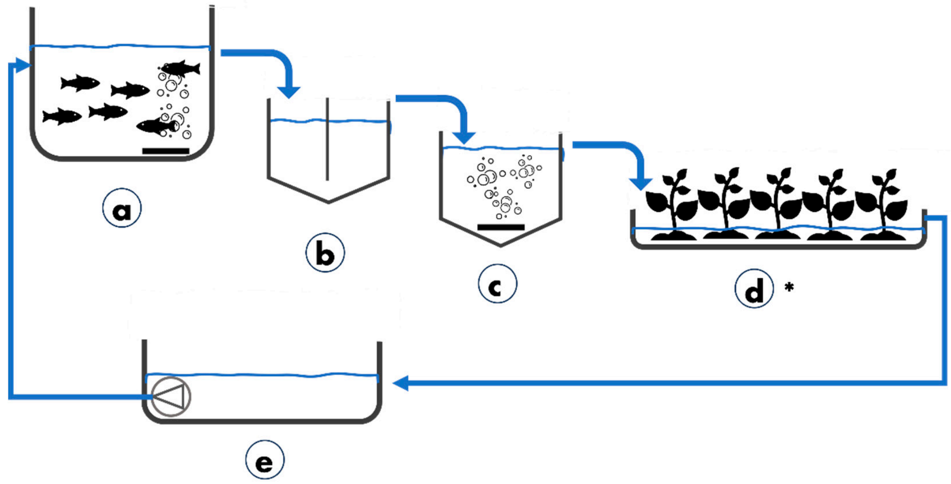

Figure 1. Traditional Coupled Aquaponic System layout. (a) Recirculating Aquaculture System (RAS) tank; (b) Settler for sludges; (c) Biofilter with aeration; (d) Different hydroponic units; (e) Sump and one pump; * The different hydroponic units depend on the crop species, space, and budget. Modified from [16].

2. Aquaponics Can Contribute Significantly to Achieving the Sustainable Development Goal 2 of Zero Hunger at a Local Level

Aquaponics is a technology that integrates the benefits of the two most productive systems, aquaculture and hydroponics [17]. This type of system includes (but is not limited to) the following units: RAS, sludge settler, different hydroponic units, two-stage anaerobic reactor (biodigester), and thermal distillation/desalination technology. This technology recovers fertilizer and clean water for the tank and hydroponic unit (Figure 2). We will delve into its benefits in detail in the following sections while describing its contributions to achieving the SDG2 at local level. This goal aims to eradicate hunger, enhance food security, improve nutrition for all, and promote sustainable agriculture. This goal has eight targets, and in the year 2020, 737 actions were taken globally across 42 events and 42 publications. As of June 2023, at least 1304 actions have been recorded towards achieving this goal https://sdgs.un.org/goals (accessed on 21 January 2024) [6].

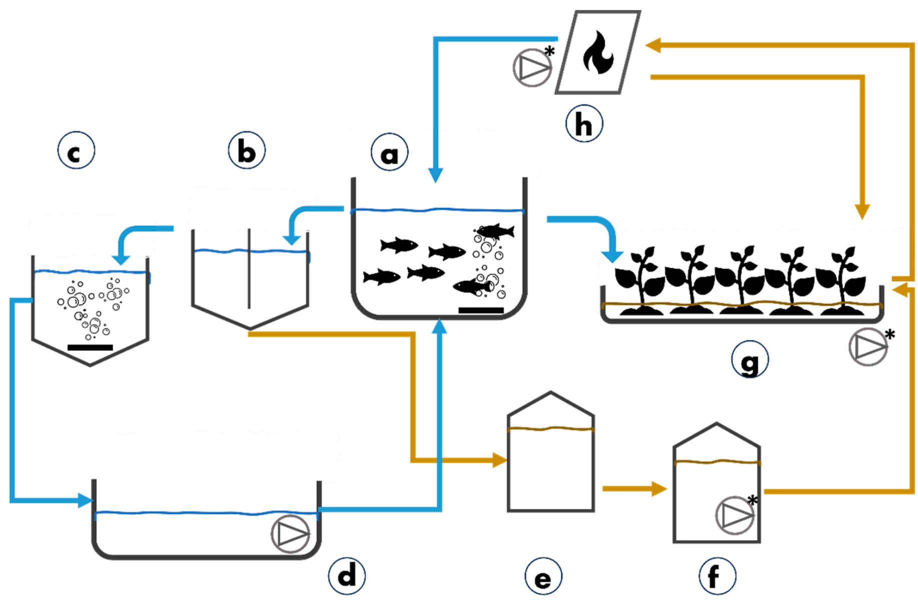

Figure 2. Multi-loop Decoupled Aquaponic System (DAQs). (a) Recirculating Aquaculture System (RAS); (b) Settler for sludges; (c) Biofilter with aeration; (d) Sump and pump; (e) The first stage of the

anaerobic reactor with biogas production (mainly); (f) Second stage of the anaerobic reactor with fertilizer recovery for the hydroponic unit; (g) Hydroponic units; (h) Thermal distillation/desalination technology with recovery of salts and nutrients for crops and demineralized water for RAS. * In DAQs, more than one pump is required for independent recirculation, the amount will depend on the design. The color in the arrows indicates the water loop. Modified from [18,19].

In Mexico, since 2018, five global actions have been initiated with 2 specific national actions, i.e., 2n.1.1 "Percentage of the population under 5 years of age with some type of chronic malnutrition" and 2n.2.1 "Percentage of population with moderate or severe food insecurity" (Appendix A). As shown in Level and Trends of the 2021 Sustainable Development Goals dashboard, there is still work to be done for this goal to be completed in Mexico [15]. The challenge faced in Mexico is not a lack of available food, as Latin America and the Caribbean have over a quarter of the necessary energy food requirement [20]. The actual concern resides in the population's inclination towards unhealthy, inexpensive diets, instead of healthier alternatives.

In Mexico, meals rich in nutrients can cost up to five times more than those that only provide sufficient energy and about 60% more than meals that contain only essential nutrients [8]. Consuming food without proper nutrition causes hidden hunger and chronic diseases such as diabetes and metabolic syndromes [21]. More than 50% of the Mexican population is at some level of food insecurity as they consume only easy-access food like cereal, roots, tubers, and plantains [8]. A healthy diet should consist of at least 400 g of fruits and vegetables daily; however, their consumption has declined [8]. According to Gaona-Pineda et al. [21], 18.5% of preschoolers and 42.3% of adults consume vegetables at least three days a week, while overall fruit consumption is around 39%; also, 60% of people under 20 years old consume snacks, sweets, desserts, and cereals at least three days a week, and 20% of the Mexican population consumes processed meat.

If aquaponics were used more locally, fruits and vegetables could be obtained with the same amount of water and approximately the same yield as hydroponics, which would have a direct and positive impact on target 2.1: "*By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious, and sufficient food all year round*". According to Pantanella et al. [22], 1 kg of fish in 0.3 m^3 can produce 20 heads of romaine lettuce in a coupled aquaponic system, like its hydroponic counterpart, but without the need for synthetic fertilizers and additional energy sources. Furthermore, Suhl et al. [23] described the Freshwater Use Efficiency for a decoupled aquaponic system resulting in 270% greater production for each m^3 of aquaculture water compared to hydroponic control, plus 1.5 kg of tilapia (zero fish produced in control). Also, its Fertilizer Use efficiency results were higher: aquaculture waters were supplemented with only one kilogram of fertilizer compared to control.

Target 2.1. considers food sovereignty, having enough food and access to it, and it also includes food security which demands nutritious food, reflected more specifically in target 2.2 which states: "*By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women, and older persons*". A decoupled aquaponics resulted in a 1.4-fold increase in plant yield. Additionally, the chlorophyll normalized difference index was 17.9% higher, indicating more efficient photosynthesis and greater accumulation of primary metabolites in fruits. This led to a lower rate of fruits being affected by blossom end rot (BER) [23].

Similar results were found by Delgadillo-Díaz et al. [24] where BER on tomatoes was maintained constantly at <0.4% during the whole production cycle. Other research reported a significantly higher antioxidant capacity of tomatoes grown in an aquaponic system (2048.08 μM TEAC/100 g dm) than in organic soil regardless of whether the genotype was commercial or wild. Aquaponically-grown plants exhibit unique behavior and show an increase in the production of bioactive compounds. This phenomenon is attributed to a wide range of dissolved organic molecules produced by fish metabolism, such as feces, urine, and respiration, along with the presence of microorganisms in the water. This leads to the formation of organically-enriched waters (OEW), which act as potent biostimulants and elicitors for crops [25,26]. The Organic Amendment (OEW) is composed of bacteria, fungi, and protozoa. It contains a minimum of 13 nutrients, including NH_4, NO_3, PO_4, SO_4, K, Mg, Ca, Fe, Mn, Zn, Cu, Bo, and Mo, which are present in various proportions. These nutrients can provide at least 50% of the nutrient needs of crops. Consequently, plants and fruits grown with OEW can be more robust and nutritious [27,28].

Incorporating fish consumption into the diet can be a smart nutritional decision that promotes overall well-being. Research has demonstrated that it can also be beneficial in addressing the global concern of overweight and obesity, which currently impacts around 13% of the world's population [8]. There are numerous species suitable to aquaponics, of which tilapia (*Oreochromis niloticus*) is the most frequently used. Consuming fish can help prevent the onset of high blood pressure, coronary heart and inflammatory diseases, specific types of cancer [29], and anemia in women of reproductive age [8], impacting directly and positively on Target 2.2. Likewise, aquaponics is an ideal method for producing leafy greens due to their low nutritional needs and short cultivation cycles. On the other hand, it has been proven that consuming raw fruits and vegetables, as opposed to processed ones, is linked to better mental health and lower rates of depression, stress, and negative mood [30]. Examples of these crops are spinach [31], basil [32], and lettuce [33]; where all of them are rich in nutrients like ascorbic acid, beta-carotene, Ca, Cu, Fe, Mg, Mn, K, and Zn. Other vegetables easily adapted to this system are tomato, kale, cauliflower, Swiss chard, cabbage, broccoli [34], and bell pepper [35]; all of them are also rich in health-promoting bioactive metabolites.

Finally, using aquaponics at a local level can have an indirect positive impact on target 2.3: "*By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists, and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets, and opportunities for value addition and non-farm employment*". According to Suárez-Cáceres et al. [36], a quantity of fresh fish and various vegetable species can be produced in 32 m^2 corresponding to 155% and 129% of fish and vegetable annual requirements, respectively, for a family of four people. In countries where the climate is extreme, aquaponics requires high-technology greenhouses, which raises production costs [37]. In certain areas, using gravity-fed water flow and other adaptations can make farming more cost-effective [38]. In regions with tropical, arid, or semi-arid climates, expensive heating systems and high-tech greenhouses are not necessary. Instead, using alternative energy sources such as solar and gravity flows can be a viable option [39]. In decoupled systems, recovering sludges to produce biogas by bio-digestion is a promising alternative. According to Zhu et al. (2021) [40], the effective digestion of the sludge from fish wastewater can produce biogas composed of ≈59% methane, ≈39% CO_2, and a fraction of hydrogen sulfide.

Aquaponics involves both aquaculture and hydroponics and therefore requires some level of assessment and consultation to manage associated risks. It is possible to implement aquaponics technology in different models, ranging from high-tech to low-tech systems [41]. However, the initial investment required for establishing an aquaponic system can be high, making it financially unfeasible for some individuals or businesses [42]. Therefore, it is important to carefully select the type of system. Before setting up an aquaponic system, it is important to consider all the necessary engineering elements, including pipes, pumps, biofilters, and mechanical filtration.

When engaging in cultivation, it is important to consider various factors such as the availability and affordability of inputs, location, climate, access to water, chemical quality, and others. It is necessary to take into account seasonal variations when selecting aquatic and vegetable species to grow. A proper balance between fish and crops should be maintained [43,44]. According to Iriarte-Rodríguez et al. [45], a Low-Intensity Aquaponic System in a backyard pond of 12 m^3 for fish culture and 9 m^2 for a vegetable crop costs around 800 USD only for infrastructure; after a cultivation period of 178 days, an initial income of 270 USD was recovered, resulting in a total profit of 330 USD. The system was expected to have a useful life of at least 5 years and generates an internal rate of return ranging between 30–40%. This profitability will be realized at the end of the system's useful life. This additional income can be earned by selling food after taking into account the local market's needs and preferences.

There are several manuals available that provide theoretical training on how to cultivate and install aquaponic systems and offer guidance on general aspects. Basic training is sufficient for people to manage small-scale and low-tech aquaponic systems, and maintenance does not require considerable time. Daily tasks such as planting and harvesting are relatively easy and quick, making it possible for people of all genders and ages from rural communities, small-scale farmers, fish farmers, and rural areas to participate in aquaponics [10,46,47].

Lastly, Table 1 provides a summary and enhances the benefits of using needs-focused aquaponic systems to achieve SDG2's Zero Hunger Goals 2.1, 2.2, and 2.3 at the local level. These benefits are based on the potential sustainability outcomes of aquaponics, which König et al. [9] identified in the next areas: water efficiency, nutrient efficiency, energy efficiency, closed cycles, decentralized production and local markets, employment, income, food security, urban development, social cohesion, freshness, diet diversification, food sovereignty, and education.

Table 1. Potential sustainable outcomes of aquaponics have been evidenced in diverse regions over time. Own elaboration based on [9].

Aquaponics' Potential Sustainability Outcomes	Evidence	References
Water efficiency	Aquaponics gives the crops the majority (>50%) of nutrients.	[48]
	The freshwater use efficiency (FWUE) for an aquaponic tilapia-tomato was 13.05 kg plant^{-1} (i.e., 1.55 kg of fish plus 46.1 kg of tomato per m^3 of fresh wastewater used).	[23]
	The production of 1 kg of fish by aquaponics requires only 0.32 m^3 of freshwater.	[49]
	Fish production has the lowest water footprint of animal protein production, with 400 L per kg.	[50]
Nutrient Efficiency	The Fertilizer Use Efficiency (FUE) is higher in tilapia-tomato cultivation as compared to hydroponics.	[23]
	At least 13 nutrients were found in the aquaculture wastewater: NH_4, NO_3, PO_4, SO_4, K, Mg, Ca, Fe, Mn, Zn, Cu, Bo, and Mo.	[27]
	Depending on the species, the fish retains 20–50% of N and 15–65% of P and excretes 30–65% of N and 40% of P.	[51]
	According to research, aquaponics has a higher total biomass assimilation rate of 30–41% compared to hydroponics, which has a rate of 14–24%.	[28]
Energy Efficiency	Easily adapted to use alternative energy supply.	[37]
	The effective digestion of the sludge from fish wastewater can produce biogas composed of ≈59% methane, ≈39% CO_2, and another important fraction of hydrogen sulfide.	[40]
	Aquaponic systems can be designed to work by gravity, reducing energy costs.	[38]

Table 1. *Cont.*

Aquaponics' Potential Sustainability Outcomes	Evidence	References
Closed Cycles	Coupled (one-loop) aquaponic systems are considerably more efficient in water use and protein production.	[52]
	A lifecycle assessment in tilapia-lettuce coupled aquaponic systems use over ten years shows 80–88% less damage associated with human health, 49–75% less damage to ecosystems, and 47–50% less damage to resources compared to conventional growing methods.	[33]
	Decoupled aquaponic systems yield 36% more produce when compared to coupled aquaponic systems.	[53]
Decentralized production & Local Market	It can be applied in tropical climates, arid, semi-arid zones, or during very long cold periods.	[39,44,54]
Employment	Aquaponics is intended to be an extension of aquaculture practices, including 14% of women's participation, 19% in aquaculture, and 12% in fishing practices.	[7]
	The number of Latin American people engaged in fisheries and aquacultural activities is 4%.	
Income	A backyard aquaponic system can generate a profit of 330 USD within 178 days of operation.	[45]
	Culinary herbs are an excellent choice for growth in aquaponics, with profitability depending on the demand.	[38]
	Ornamental fish can be introduced, and traceability in production is guaranteed.	[55]
Food Security	Fish, mainly produced by aquaponics, is rich in B12, Lysine, Leucine, and Valine.	[56]
	Leafy greens are easily produced in aquaponic systems and are rich in ascorbic acid, beta-carotene, Ca, Cu, Fe, Mg, Mn, K, and Zn.	[29]
	Technology, from high-tech to low-tech, is easily adapted to all production levels, and can be managed by people with basic training as well as cultivation experts.	[47]
Urban Development & Social Cohesion	Aquaponics can be implemented on small or commercial scales: in abandoned buildings, rooftops, backyards, or urban gardens, considering the structure's materials and electricity needs.	[57]
	Living walls and other aquaponic designs contribute to thermal and carbon sequestration, microclimate regulation, or landscape improvement.	[58,59]
	In a backyard, fresh fish and various vegetable species can be obtained in 32 m^2, corresponding to 155% and 129% of fish and vegetable annual requirements, respectively, for a family of 4 people.	[36]
	Green Infrastructure, such as aquaponics, increases urban resilience and social welfare and mitigates the post-pandemic impact.	[60,61]
Freshness & Diet diversification & Food Sovereignty	Species best produced by aquaculture: Tilapia, catfish, eel, trout, turbot, sea bass, sole, shrimp, crayfish, prawn, pikeperch, and tench.	[55]
	Vegetable species best adapted to aquaponics are spinach, kale, basil, lettuce, tomato, cauliflower, Swiss chard, cabbage, broccoli, and bell pepper.	[34,62]

Table 1. *Cont.*

Aquaponics' Potential Sustainability Outcomes	Evidence	References
Education	A micro-aquaponic system of 1.5 m^2 can imitate a full-scale system of >50 m^2 and be established in a classroom for 25 students.	[63]
	With an aquaponic system in a classroom, more teachers and students became more interested in sustainability. Math and science teachers engaged their students on the topics, and the students, their families, and friends promoted the use of aquaponics.	[64]

3. Some Cases of the Application of Aquaponics

3.1. Mexico

In Mexico, the research institutions most known for working with Aquaponics are the Autonomous University of Querétaro, the Autonomous University of Guadalajara, the Autonomous Juarez University of Tabasco, the Centre for Higher Studies of the State of Sonora, the Centre for Scientific Research and Higher Education of Ensenada, the Technological Institute of Boca del Río, and the College of Postgraduates in Agricultural Sciences. At a corporate level, the best-known companies are Acuicultura del Desierto in Baja California; South Frontier South School (ECOSUR) with units in Campeche, Chetumal, San Cristobal, Tapachula, and Villahermosa; and BOFISH in Jalisco [65]. Mexico does not have updated statistical aquacultural registers [66,67], and only a few records exist about aquaponics and their current operation. Many marine and coastal institutions developing aquaculture and aquaponics are unreported, along with their research, and therefore cannot be considered in this work.

The Autonomous University of Guadalajara began in 2001 with experimental tests focused on commercial scale-up. Species of tilapia and Australian lobster were tested, along with cucumber, lettuce, and tomato [68]. From this research, BOFISH was established, which is the only company to date dedicated explicitly to producing aquaponic technology for home/ornamental (50 $\times$ 150 cm), orchard (42 m^2), agrotourism (504 m^2), commercial pilots (825 m^2), medium-scale (3300 m^2), and large scale (10,000 m^2) [69].

In La Paz, Baja California Sur, Desert Aquaculture began its research in 2004 with a pilot module that was established for the use and maximum efficiency of salinized water coupled to a unidirectional aquaponics-agriculture system, which was in operation from 2016 to 2017 [70].

In 2008 the Center for Scientific Research and Higher Education of Ensenada (CICESE) established aquaponic cultivation of tilapia-strawberries [71].

The Center for Higher Studies of the State of Sonora signed an agreement in 2016 with the Institute of Aquaculture of the State of Sonora (IAES) to train fish farmers and fishermen on integrated aquaculture production systems [72].

In 2009, the College of Postgraduates established experimental modules for aquaponic production on its different campuses [65,73].

In 2013, Colegio de la Frontera Sur (ECOSUR) Villahermosa Unit, Tabasco "Low Impact Aquaponic System (SABI)" was designed, and financial viability for backyard polyculture was verified [45]. A year later, the system was established in the Tabasco area, and to date, 14 systems are working.

3.2. International

Rakocy et al. (2007) [27], pioneers in aquaponics development, demonstrated the cost-effectiveness of a floating raft with tilapia, basil, and okra (*Abelmoschus esculentus*) in the Virgin Islands. The profits of this system reached 117,700 USD per year with batch production and 110,210 USD with staggered production in a cultivation area of 214 m^2.

Kotzen & Appelbaum et al. (2010) [74] proved some advantages of aquaponics under arid conditions in Israel. They used a brackish water system polyculture on a small scale.

The system showed high conductivity levels (4500 µS/cm) that caused chlorosis in some plants like lettuce, grape, coriander, and spinach. This secondary effect was corrected by adding iron chelate, calcium, and potassium. Other vegetables (celery, chard, chili pepper, chives, and parsley) grew successfully without undesired effects.

An international survey conducted by Love et al. (2015) [75] studied commercial-scale aquaponic systems, including their design, employee count, and the species they grow (69% tilapia and 43% ornamental species). The study also reported on revenue, profitability, and investment, and developed a model to better understand the operation of such facilities. The survey concluded that aquaponics is a technology best suited for local and regional applications, generating local employment and resulting in good profits from locally produced food sold directly to consumers.

Al-Arfan Farms, located in Oman, is a commercial-sized aquaponic facility that has successfully operated in an extremely arid environment. The farm produces around four to five tons of Tilapia fish and various vegetables annually. The farm's slogan is "90% less water and 52% less carbon footprint," reflecting their commitment to sustainability. Additionally, Al-Arfan Farms has made agreements to sell their products to several local companies, including Al Bustan Palace, Ritz Carlton Hotel, InterContinental Muscat, The Chedi Muscat, and The Sultan Centre [76]. Another recent example of sustainable farming practices in the Middle East is Agrico Agricultural Development in Carrefour, located in Qatar's West Bay. The facility, which opened in March of this year, is the first internal aquaponic farm within the city of Doha. The farm is expected to have a capacity of 32,000 tons annually for different plant species [77].

Kloas et al. (2015) [78] also developed a program to implement commercial-scale aquaponic systems in Berlin, Germany. First, in 2015, they created a prototype for improving sustainability, increasing productivity, and reducing environmental impact. The project was named ASTAF-PRO, where the closed loop system of the water to plants forms two loops, one for the fish and the other for the plants. A year after the prototype was successfully tested, they developed the INAPRO technology for an area of ~500 m^2 which is currently in operation [60]. This technology is available worldwide and is financed by the Seventh Framework Program of the European Union within a program for research, technological development, and demonstration with at least 16 partners. Kloas and collaborators pioneered the commercial use of decoupled systems, which are still being studied to verify their economic profitability in different scenarios and scales [79].

4. Conclusions

Aquaponics is an innovative and promising solution to address various sustainability challenges, including hunger and food scarcity. These innovative systems integrate multiple species, allowing them to produce high-quality and nutritious food, which can enhance food security. Consuming vegetables and animal protein that are rich in vitamins, minerals, and healthy fats can promote physical and mental well-being, reduce stress, and prevent illnesses. There are various manuals available that can assist individuals with basic technical knowledge in utilizing this technology. It is essential to recognize the potential risks involved in growing aquatic and plant species. In Mexico, adopting responsible practices in aquaponics can significantly contribute to reducing hunger and malnutrition at the local level. However, achieving this objective requires promoting community involvement and local political support. This will help develop an effective strategy for the proper use and dissemination of technology while improving measurement and accountability mechanisms. A shift in mindset is required at the local level to promote sustainable production and consumption. Aquaponics is a highly effective technique that can provide economic, social, and environmental benefits. To gather data on the use of aquaponics and update the National Aquaculture Registry, it is crucial to promote the implementation of technologies developed both nationally and internationally and test their performance in different environments across Mexico.

Author Contributions: P.S.F.-A.: Writing—original draft, review, editing; J.S.-V.: Writing—reviewing, Investigation; H.A.-B.: Supervision, English editing; G.A.P.-H.: Writing—editing, critical review; S.A.Z.-C.: Resources, Investigation; G.M.S.-Z.: Supervising, Project administration, resources. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: We want to thank CONACYT for the scholarship 2019-000037-02NACF-01190 for P.S.F-A and 2019-000037-02NACF-06572 for J.S.-V. for doctorate studies.

Conflicts of Interest: All authors have reviewed the manuscript and report that they have no competing interests to declare. The sponsors had no role in the design of the study, in the writing of the manuscript, or in the decision to publish the results.

Appendix A

Table A1. Description of the total Targets and Indicators of Goals 2—Zero Hunger—the 2030 Agenda for Sustainable Development. The letter N indicates a national goal. Data extracted from [80,81].

Target	Indicator	Description
		Zero Hunger
2.1		By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round
	2.1.1	Prevalence of undernourishment
	2.1.2	Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)
2N.1		Access to nutritious and quality food
	2N.1.1	Percentage of the population under 5 years of age with some type of chronic malnutrition
2.2		By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women, and older persons
	2.2.1	Prevalence of stunting (height for age <-2 standard deviation from the median of the World Health Organization (WHO) Child Growth Standards) among children under 5 years of age
	2.2.2	Prevalence of malnutrition (weight for height $>+2$ or <-2 standard deviations from the median of the WHO Child Growth Standards) among children under 5 years of age, by type (wasting and overweight)
2N.2		Food Security
	2N.2.1	Percentage of population with moderate or severe food insecurity
2.3		By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists, and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets, and opportunities for value addition and non-farm employment
	2.3.1	The volume of production per labor unit by classes of farming/pastoral/forestry enterprise size
	2.3.2	The average income of small-scale food producers, by sex and indigenous status
2.4		By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding, and other disasters, and that progressively improve land and soil quality
	2.4.1	The proportion of agricultural area under productive and sustainable agriculture

Table A1. *Cont.*

Target	Indicator	Description
2.5		By 2020, maintain the genetic diversity of seeds, cultivated plants, and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional, and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed
	2.5.1	Number of plant and animal genetic resources for food and agriculture secured in either medium or long-term conservation facilities
	2.5.2	The proportion of local breeds classified as being at risk, not-at-risk, or at an unknown level of risk of extinction
2.a		Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development, and plant and livestock gene banks to enhance agricultural productive capacity in developing countries, in particular, the least developed countries
	2.a.1	The agriculture orientation index for government expenditures
	2.a.2	Total official flows (official development assistance plus other official flows) to the agriculture sector
2.b		Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round
	2.b.1	Producer Support Estimate
	2.b.2	Agricultural export subsidies
2.c		Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility
	2.c.1	Indicator of food price anomalies

References

1. Randers, J.; Rockström, J.; Stoknes, P.-E.; Goluke, U.; Collste, D.; Cornell, S.E.; Donges, J. Achieving the 17 Sustainable Development Goals within 9 Planetary Boundaries. *Glob. Sustain.* **2019**, *2*, e24. [CrossRef]
2. Leach, M.; Raworth, K.; Rockström, J. Between Social and Planetary Boundaries: Navigating Pathways in the Safe and Just Space for Humanity. In *World Social Science Report 2013*; OECD: Paris, France, 2013.
3. Chen, D.; Hu, W. Temporal and Spatial Effects of Heavy Metal-Contaminated Cultivated Land Treatment on Agricultural Development Resilience. *Land* **2023**, *12*, 945. [CrossRef]
4. Redek, T.; Domadenik, P.; Koman, M. Sustainable Development Goals in the EU and the Challenges in Their Implementation. In *Challenges on the Path toward Sustainability in Europe*; Emerald Publishing Limited: Leeds, UK, 2020; pp. 11–29. [CrossRef]
5. United Nations. *Equality and Non-Discrimination at the Heart of Sustainable Development Leaving No One Behind: A Shared United Nations System Framework for Action United Nations System Chief Executives Board for Coordination*; United Nations: New York, NY, USA, 2017.
6. United Nations. INEGI Mexico SIODS (Sistema de Información de Los Objetivos de Desarrollo) Sostenible). Available online: https://agenda2030.mx/index.html?lang=en#/home (accessed on 29 August 2021).
7. FAO. *The State of World Fisheries and Aquaculture 2022*; FAO: Rome, Italy, 2022.
8. FAO; IFAD; UNICEF; WFP; WHO. *The State of Food Security and Nutrition in the World 2020*; FAO: Rome, Italy; IFAD: Rome, Italy; UNICEF: Geneva, Switzerland; WFP: Geneva, Switzerland; WHO: Geneva, Switzerland, 2020.
9. König, B.; Janker, J.; Reinhardt, T.; Villarroel, M.; Junge, R. Analysis of Aquaponics as an Emerging Technological Innovation System. *J. Clean. Prod.* **2018**, *180*, 232–243. [CrossRef]
10. Southern, A.; King, W. *The Aquaponic Farmer a Complete Guide to Building and Operating a Commercial Aquaponic System*; New Society Publisher's: Gabriola, BC, Canada, 2017.
11. Zamora, A.V. Análisis y Perspectivas de La Acuaponía en México. Master's Thesis, Universidad Autónoma de Chapingo, Texcoco, Mexico, 2018.
12. Munguia-Fragozo, P.; Alatorre-Jacome, O.; Rico-Garcia, E.; Torres-Pacheco, I.; Cruz-Hernandez, A.; Ocampo-Velazquez, R.V.; Garcia-Trejo, J.F.; Guevara-Gonzalez, R.G. Perspective for Aquaponic Systems: "Omic" Technologies for Microbial Community Analysis. *BioMed. Res. Int.* **2015**, *2015*, 480386. [CrossRef] [PubMed]

13. Espinal, C.A.; Matulić, D. Recirculating Aquaculture Technologies. In *Aquaponics Food Production Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 35–76. [CrossRef]
14. Federal Government. *Voluntary National Review for the High-Level Political Forum on Sustainable Development. (Basis for a Long-Term Sustainable Development Vision in Mexico). Progress on the Implementation of the 2030 Agenda 2018*; Federal Government: Mexico City, Mexico, 2018.
15. Sachs, J.; Schmidt-Traub, G.; Kroll, C.; Lafortune, G.; Fuller, G. *Sustainable Development Report 2020*; Cambridge University Press: Cambridge, UK, 2021.
16. Palm, H.; Knaus, U.; Appelbaum, S.; Strauch, S.M.; Kotzen, B. Coupled Aquaponics Systems. In *Aquaponics Food Production Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 163–199. [CrossRef]
17. Baganz, G.; Junge, R.; Portella, M.C.; Goddek, S.; Keesman, K.J.; Baganz, D.; Staaks, G.; Shaw, C.; Lohrberg, F.; Kloas, W. The Aquaponic Principle—It Is All about Coupling. *Rev. Aquac.* **2021**, *14*, 252–264. [CrossRef]
18. Goddek, S.; Joyce, A.; Wuertz, S.; Körner, O.; Bläser, I.; Reuter, M.; Keesman, K.J. Decoupled Aquaponics Systems. In *Aquaponics Food Production Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 201–229. [CrossRef]
19. Delaide, B.; Monsees, H.; Gross, A.; Goddek, S. Aerobic and Anaerobic Treatments for Aquaponic Sludge Reduction and Mineralisation. In *Aquaponics Food Production Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 247–266. [CrossRef]
20. Rapallo, R.; Rivera, R. *Nuevos Patrones Alimentarios, Más Desafíos Para Los Sistemas Alimentarios*; FAO: Santiago de Chile, Chile, 2019.
21. Gaona-Pineda, E.B.; Martínez-Tapia, B.; Arango-Angarita, A.; Valenzuela-Bravo, D.; Gómez-Acosta, L.M.; Shamah-Levy, T.; Rodríguez-Ramírez, S. Consumo de Grupos de Alimentos y Factores Sociodemográficos en Población Mexicana. *Salud Publica Mex.* **2018**, *60*, 272–282. [CrossRef] [PubMed]
22. Pantanella, E.; Cardarelli, M.; Colla, G.; Rea, E.; Marcucci, A. Aquaponics vs. Hydroponics: Production and Quality of Lettuce Crop. *Acta Hortic.* **2012**, *927*, 887–894. [CrossRef]
23. Suhl, J.; Dannehl, D.; Kloas, W.; Baganz, D.; Jobs, S.; Scheibe, G.; Schmidt, U. Advanced Aquaponics: Evaluation of Intensive Tomato Production in Aquaponics vs. Conventional Hydroponics. *Agric. Water Manag.* **2016**, *178*, 335–344. [CrossRef]
24. Delgadillo-Díaz, M.; Gullian-Klanian, M.; Sosa-Moguel, O.; Sauri-Duch, E.; Cuevas-Glory, L.F. Evaluation of Physico-Chemical Characteristics, Antioxidant Compounds and Antioxidant Capacity in Creole Tomatoes (*Solanum Lycopersicum* L. and *S. Pimpinellifolium* L.) in an Aquaponic System or Organic Soil. *Int. J. Veg. Sci.* **2019**, *25*, 124–137. [CrossRef]
25. Godínez-Mendoza, P.L.; Rico-Chávez, A.K.; Ferrusquía-Jimenez, N.I.; Carbajal-Valenzuela, I.A.; Villagómez-Aranda, A.L.; Torres-Pacheco, I.; Guevara-González, R.G. Plant Hormesis: Revising of the Concepts of Biostimulation, Elicitation and Their Application in a Sustainable Agricultural Production. *Sci. Total Environ.* **2023**, *894*, 164883. [CrossRef]
26. Braglia, R.; Costa, P.; Di Marco, G.; D'Agostino, A.; Redi, E.L.; Scuderi, F.; Gismondi, A.; Canini, A. Phytochemicals and Quality Level of Food Plants Grown in an Aquaponics System. *J. Sci. Food Agric.* **2022**, *102*, 844–850. [CrossRef] [PubMed]
27. Rakocy, J.; Bailey, D.; Shultz, R.; Danaher, J. Preliminary Evaluation of Organic Waste from Two Aquaculture Systems as a Source of Inorganic Nutrients for Hydroponics. In Proceedings of the International Conference and Exhibition on Soilless Culture: ICESC 2005, Singapore, 5–8 September 2005.
28. Yang, T.; Kim, H. Characterizing Nutrient Composition and Concentration in Tomato-, Basil-, and Lettuce-Based Aquaponic and Hydroponic Systems. *Water* **2020**, *12*, 1259. [CrossRef]
29. Moyo, S.M.; Serem, J.C.; Bester, M.J.; Mavumengwana, V.; Kayitesi, E. African Green Leafy Vegetables Health Benefits Beyond Nutrition. *Food Rev. Int.* **2020**, *37*, 601–618. [CrossRef]
30. Brookie, K.L.; Best, G.I.; Conner, T.S. Intake of Raw Fruits and Vegetables Is Associated with Better Mental Health than Intake of Processed Fruits and Vegetables. *Front. Psychol.* **2018**, *9*, 487. [CrossRef] [PubMed]
31. Endut, A.; Jusoh, A.; Ali, N.; Wan Nik, W.N.S.; Hassan, A. Effect of Flow Rate on Water Quality Parameters and Plant Growth of Water Spinach (Ipomoea Aquatica) in an Aquaponic Recirculating System. *Desalination Water Treat.* **2009**, *5*, 19–28. [CrossRef]
32. Fernández-Cabanás, V.M.; Pérez-Urrestarazu, L.; Juárez, A.; Kaufman, N.T.; Gross, J.A. Comparative Analysis of Horizontal and Vertical Decoupled Aquaponic Systems for Basil Production and Effect of Light Supplementation by LED. *Agronomy* **2020**, *10*, 1414. [CrossRef]
33. Cohen, A.; Malone, S.; Morris, Z.; Weissburg, M.; Bras, B. Combined Fish and Lettuce Cultivation: An Aquaponics Life Cycle Assessment. *Proc. CIRP* **2018**, *69*, 551–556. [CrossRef]
34. Lennard, W.; Goddek, S. Aquaponics: The Basics. In *Aquaponics Food Production Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 113–143. [CrossRef]
35. Kanial, S.M. Aquaponic Production of Nile Tilapia (*Oreochromis niloticus*) and Bell Pepper (*Capsicum annum*) in Recirculating Water System. *Egypt. J. Aquat. Biol. Fish.* **2006**, *10*, 85–97. [CrossRef]
36. Suárez-Cáceres, G.P.; Lobillo-Eguíbar, J.; Fernández-Cabanás, V.M.; Quevedo-Ruiz, F.J.; Pérez-Urrestarazu, L. Polyculture Production of Vegetables and Red Hybrid Tilapia for Self-Consumption by Means of Micro-Scale Aquaponic Systems. *Aquac. Eng.* **2021**, *95*, 102181. [CrossRef]
37. Karimanzira, D.; Rauschenbach, T. Optimal Utilization of Renewable Energy in Aquaponic Systems. *Energy Power Eng.* **2018**, *10*, 279–300. [CrossRef]
38. Rakocy, J.; Masser, M.; Losordo, T. *Recirculating Aquaculture Tank Production Systems: Aquaponics-Integrating Fish and Plant Culture*; Oklahoma Cooperative Extension Service: Oklahoma City, OK, USA, 2016.
39. Goddard, S.; Al-Abri, F.S. Integrated Aquaculture in Arid Environments. *J. Agric. Mar. Sci.* **2019**, *23*, 52. [CrossRef]

40. Zhu, Z.; Yogev, U.; Keesman, K.J.; Gross, A. Onsite Anaerobic Treatment of Aquaponics Lettuce Waste: Digestion Efficiency and Nutrient Recovery. *Aquac. Int.* **2021**, *29*, 57–73. [CrossRef]
41. Lobillo-Eguíbar, J.; Fernández-Cabanás, V.M.; Bermejo, L.A.; Pérez-Urrestarazu, L. Economic Sustainability of Small-Scale Aquaponic Systems for Food Self-Production. *Agronomy* **2020**, *10*, 1468. [CrossRef]
42. Pérez-Urrestarazu, L.; Lobillo-Eguíbar, J.; Fernández-Cañero, R.; Fernández-Cabanás, V.M. Suitability and Optimization of FAO's Small-Scale Aquaponics Systems for Joint Production of Lettuce (*Lactuca sativa*) and Fish (*Carassius Auratus*). *Aquac. Eng.* **2019**, *85*, 129–137. [CrossRef]
43. Palm, H.; Seidemann, R.; Wehofsky, S.; Knaus, U. Significant Factors Affecting the Economic Sustainability of Closed Aquaponic Systems. Part I: System Design, Chemo-Physical Parameters and General Aspects. *AACL Bioflux Int. J. Bioflux Soc.* **2014**, *7*, 20–32.
44. Knaus, U.; Palm, H. Effects of the Fish Species Choice on Vegetables in Aquaponics under Spring-Summer Conditions in Northern Germany (Mecklenburg Western Pomerania). *Aquaculture* **2017**, *473*, 62–73. [CrossRef]
45. Iriarte-Rodríguez, F.; Mendoza-Carranza, M.; Gómez Álvarez, R.; Cornelis Van Der Wal, J.; Alicia, M.; García, P. Viabilidad Técnica-Financiera de Un Sistema Acuapónico de Baja Intensidad (SABI) Para La Seguridad Alimentaria Familiar. In *Aplicación del Saber: Casos y Experiencias*; Academia Journals: Tabasco, Mexico, 2017; pp. 1429–1434. ISBN 9781939982285.
46. Lunda, R.; Roy, K.; Másílko, J.; Mráz, J. Understanding Nutrient Throughput of Operational RAS Farm Effluents to Support Semi-Commercial Aquaponics: Easy Upgrade Possible beyond Controversies. *J. Environ. Manag.* **2019**, *245*, 255–263. [CrossRef]
47. Somerville, C. *Small-Scale Aquaponic Food Production Integrated Fish and Plant Farming*; FAO: Rome, Italy, 2014.
48. Palm, H.; Knaus, U.; Appelbaum, S.; Goddek, S.; Strauch, S.M.; Vermeulen, T.; Haïssam Jijakli, M.; Kotzen, B. Towards Commercial Aquaponics: A Review of Systems, Designs, Scales and Nomenclature. *Aquac. Int.* **2018**, *26*, 813–842. [CrossRef]
49. Al-Hafedh, Y.S.; Alam, A.; Beltagi, M.S. Food Production and Water Conservation in a Recirculating Aquaponic System in Saudi Arabia at Different Ratios of Fish Feed to Plants. *J. World Aquac. Soc.* **2008**, *39*, 510–520. [CrossRef]
50. Joyce, A.; Goddek, S.; Kotzen, B.; Wuertz, S. Aquaponics: Closing the Cycle on Limited Water, Land and Nutrient Resources. In *Aquaponics Food Production Systems*; Springer: Berlin/Heidelberg, Germany, 2019; pp. 19–34. [CrossRef]
51. Schneider, O.; Sereti, V.; Eding, E.H.; Verreth, J.A.J. Analysis of Nutrient Flows in Integrated Intensive Aquaculture Systems. *Aquac. Eng.* **2005**, *32*, 379–401. [CrossRef]
52. Graber, A.; Junge, R. Aquaponic Systems: Nutrient Recycling from Fish Wastewater by Vegetable Production. *Desalination* **2009**, *246*, 147–156. [CrossRef]
53. Kloas, W.; Wuertz, S.; Monsees, H. Comparisson of Coupled and Decoupled Aquaponics-Implications for Future System Design. In Proceedings of the Aquaculture Europe (EAS), Edinburgh, Scotland, 20–23 September 2016.
54. Rakocy, J.; Shultz, R.; Bailey, D.; Thoman, E. Aquaponic Production of Tilapia and Basil: Comparing a Batch and Staggered Cropping System. In Proceedings of the South Pacific Soilless Culture Conference-SPSCC 648, Palmerston North, New Zealand, 10–13 February 2003.
55. Oniga, C.; Jurcoane, Ș.; Mocuta, D.; Rahoveanu, A. Studies about the Fish Farming Development in Aquaponic Systems: A Review. *Sci. Bull. Ser. F Biotechnol.* **2018**, *22*, 237–246.
56. Watanabe, F. Vitamin B12 Sources and Bioavailability. *Exp. Biol. Med.* **2016**, *232*, 1266–1274. [CrossRef]
57. David, L.H.; Pinho, S.M.; Agostinho, F.; Costa, J.I.; Portella, M.C.; Keesman, K.J.; Garcia, F. Sustainability of Urban Aquaponics Farms: An Emergy Point of View. *J. Clean. Prod.* **2022**, *331*, 129896. [CrossRef]
58. Charoenkit, S.; Yiemwattana, S. Role of Specific Plant Characteristics on Thermal and Carbon Sequestration Properties of Living Walls in Tropical Climate. *Build. Environ.* **2017**, *115*, 67–79. [CrossRef]
59. Khandaker, M.; Kotzen, B. The Potential for Combining Living Wall and Vertical Farming Systems with Aquaponics with Special Emphasis on Substrates. *Aquac. Res.* **2018**, *49*, 1454–1468. [CrossRef]
60. Baganz, G.; Baganz, D.; Kloas, W.; Lohrberg, F. Urban Planning and Corona Spaces–Scales, Walls and COVID-19 Coincidences. In Proceedings of the REAL CORP REAL CORP 2020: Shaping Urban Change Livable City Regions for the 21st Century, Virtual, 15–18 September 2020.
61. Ugolini, F.; Massetti, L.; Calaza-Martínez, P.; Cariñanos, P.; Dobbs, C.; Ostoić, S.K.; Marin, A.M.; Pearlmutter, D.; Saaroni, H.; Šaulienė, I. Effects of the COVID-19 Pandemic on the Use and Perceptions of Urban Green Space: An International Exploratory Study. *Urban For. Urban Green.* **2020**, *56*, 126888. [CrossRef] [PubMed]
62. Yang, T.; Kim, H.J. Nutrient Management Regime Affects Water Quality, Crop Growth, and Nitrogen Use Efficiency of Aquaponic Systems. *Sci. Hortic.* **2019**, *256*, 108619. [CrossRef]
63. Maucieri, C.; Forchino, A.A.; Nicoletto, C.; Junge, R.; Pastres, R.; Sambo, P.; Borin, M. Life Cycle Assessment of a Micro Aquaponic System for Educational Purposes Built Using Recovered Material. *J. Clean. Prod.* **2018**, *172*, 3119–3127. [CrossRef]
64. Clayborn, J.; Medina, M.; O'Brien, G. School Gardening with a Twist Using Fish: Encouraging Educators to Adopt Aquaponics in the Classroom. *Appl. Environ. Educ. Commun.* **2017**, *16*, 93–104. [CrossRef]
65. Fernández-Juárez, E.; del Pillar Navarro-Rodríguez, M.; Landero-Torres, I.; Gómez-Merino, F.C.; Pérez-Sato, J.A. La Acuaponía Rústica: Una Alternativa Para Contribuir a La Soberanía Alimentaria en Comunidades Rurales. *Agro Product.* **2019**, *12*, 93. [CrossRef]
66. FAORLC. *Panorama de La Pesca Marina y Continental en America Latina y El Caribe*; FAORLC: La Havana, Cuba, 2019.
67. FAORLC. *Panorama de Pesca Continental y La Acuicultura en América Latina y El Caribe*; FAORLC: Panamá, Panama, 2018.

68. Gómez-Merino, F.C.; Ortega-López, N.E.; Trejo-Téllez, L.I.; Sánchez-Páez, R.; Salazar-Marcial, E.; Salazar-Ortiz, J. Aquaponics: Sustainable and Potential Alternative for Food Production in Mexico. *Agroproductividad* **2015**, *8*, 60–65.
69. BOFISH Proyectos. Bofish Acuaponia. Jalisco. Available online: https://www.acuaponia.com/proyectosbofish (accessed on 11 August 2022).
70. CONACYT. Desarrolla Cibnor Sistema de Acuaponía Con Agua Salobre. cienciamx noticias. 2016. Available online: https://aquahoy.com/desarrolla-cibnor-sistema-de-acuaponia-con-agua-salobre/ (accessed on 21 January 2024).
71. BOFISH. 1er Curso-Congreso Internacional de Acuaponia. 2000Agro 2008, pp. 1–28. Available online: https://www.jornada.com.mx/2008/04/15/index.php?section=ciencias&article=a02n1cie (accessed on 21 January 2024).
72. IAES Desarrollan en Sonora Sistema Acuapónico. Available online: https://www.iaes.gob.mx/index.php?pag=m_blog&gad=detalle_entrada&entry=429&tags=acuaponia&n_pag=1 (accessed on 15 May 2022).
73. Campos-Pulido, R.; Alonso-López, A.; Asiain-Hoyos, A.; Reta-Mendiola, J.; Avalos-De la Cruz, D. La acuaponía, diversificación productiva sustentable. Agro Productividad, 2021, Volume 8. Available online: https://revista-agroproductividad.org/index.php/agroproductividad/article/view/663 (accessed on 21 January 2024).
74. Kotzen, B.; Appelbaum, S. An Investigation of Aquaponics Using Brackish Water Resources in the Negev Desert. *J. Appl. Aquac.* **2010**, *22*, 297–320. [CrossRef]
75. Love, D.C.; Fry, J.P.; Li, X.; Hill, E.S.; Genello, L.; Semmens, K.; Thompson, R.E. Commercial Aquaponics Production and Profitability: Findings from an International Survey. *Aquaculture* **2015**, *435*, 67–74. [CrossRef]
76. Muscat Horizons International Al-Arfan Farms. Available online: https://www.omanaquaponics.com/ (accessed on 17 October 2021).
77. Gulf Times Agrico's Aquaponics Farm Opened at Carrefour. Available online: https://www.gulf-times.com/story/713646/Agrico-s-aquaponics-farm-opened-at-Carrefour (accessed on 13 June 2022).
78. Kloas, W.; Groß, R.; Baganz, D.; Graupner, J.; Monsees, H.; Schmidt, U.; Staaks, G.; Suhl, J.; Tschirner, M.; Wittstock, B.; et al. A New Concept for Aquaponic Systems to Improve Sustainability, Increase Productivity, and Reduce Environmental Impacts. *Aquac Environ. Interact* **2015**, *7*, 179–192. [CrossRef]
79. Blanchard, C.; Wells, D.E.; Pickens, J.M.; Blersch, D.M. Effect of PH on Cucumber Growth and Nutrient Availability in a Decoupled Aquaponic System with Minimal Solids Removal. *Horticulturae* **2020**, *6*, 10. [CrossRef]
80. United Nations UN, Sustainable Development Goals (SDGs). Available online: https://sdgs.un.org/ (accessed on 29 August 2021).
81. Mexican Government; INEGI México; SIODS. Sistema de Información de Los Objetivos de Desarrollo Sostenible. Available online: https://agenda2030.mx/ODSGoalSelected.html?ti=T&cveArb=ODS0020&goal=0&lang=es#/ind (accessed on 21 June 2023).