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Review on Aquaponics Exordium: A Key Towards Sustainable Resource Management

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ABSTRACT: In China, fish and vegetables were first grown simultaneously 1,500 years ago. This has spread globally. Aquaponics mixes fish and plants for maximum productivity and resource conservation. 1970s: This approach was developed. Aquaponics combines recirculating aquaculture and soilless hydroponics. Aquaponics uses water and nutrients efficiently, reduces or eliminates negative environmental effects, and incorporates living and ecological activities. Aquaculture systems grow plants and fish. This page presents a comprehensive overview of aquaponics, including its origins, two main components (hydroponics and recirculatory aquaculture), benefits, and drawbacks. Aquaponics combines plant and aquatic growth in one system. Population growth, urbanization, industrialization, and other factors boost the need for food. Aquaponics is environmentally good since plants can consume fish excrement (plants). It might ensure long-term food availability. Commercial aquaponics will have problems adapting high-value flowering crops like sweet peppers, tomatoes, or cucumbers due to suboptimal nutrient ratios in the aquaponic solution, particularly the reduced K^+ and Ca^+. This was discovered in publications looking into challenges. Overall, it was discovered that the function of plant-promoting microbes in nutrient uptake is the most significant aspect of aquaponics that requires further study.

Keywords: Aquaponic, Hydroponic, Recirculatory Aquaculture System, Sustainable.

INTRODUCTION

Aquaponics combines hydroponics and recirculating aquaculture systems to grow plants and fish in a closed-loop system. Plants and fish both benefit from nutrient-rich fish excrement effluent (Fig. 1), while plants help filter fish-needed water (Pattillo and Allen 2017). "Aquaponics" combines "aquaculture" and "hydroponics". Aquaculture is the farming of aquatic creatures, including mollusks, fish, crabs, and aquatic plants. Hydroponics is the soilless growing of plants where water supplies all nutrients for growth (Diver, 2006). Aquaponics combines hydroponic plant production with recirculating aquaculture systems for fish culture, according to Lenard and Leonard (2006). Aquaponics mixes plant hydroponics and fish farming (RAS). According to Lenard (2009), aquaponics combines fish farming in a recirculating system with hydroponic plant farming. Aquaponics involves hydroponically cultivating fish and plants. Aquaponics is a subset of IAAS, according to Gooley and Gavine (2003). (IAAS). Aquaponics combines hydroponics (soilless) and recirculating aquaculture systems to grow plants and fish (Rakocy *et al*., 2006). Aquaponics is the symbiotic creation of fish and plants, as plants rely on fish waste and filter fish waste water. Fish waste helps plants flourish, and plants purify fish farm water. It's gained attention for its ability to conserve water quality, reduce freshwater consumption, and produce a sellable crop (McMurtry *et al*., 1997a, 1997b; Adler *et al*., 2000a; Lennard and Leonard 2005; Graber and Junge 2009; Danaher *et al*., 2011, Pantanella *et al*., 2013; Pantanella *et al*., 2015; Espinosa Moya *et al*., 2016; Shet *et al*., 2016; Mohapatra *et al.,* 2021; Kumar *et al.,* 2021; Adler *et al.,* 2000). Microbes take fish waste and feed it to soilless plants (Zou *et al*., 2016a). Water is cleansed before being recycled into the fish culture system (Endut*et al*., 2009; Tyson *et al*., 2011; Nichols and Savidov 2012; Nuwansi *et al*., 2016; Medina *et al*., 2016). It's environmentally friendly because it reuses fish waste, water, and nutrients. Aquaponics occupies space in recirculating aquaculture systems (RAS). In these structures, marine waste passes through bacteria-filled chambers. Microbes break down organic compounds for plant absorption. Nitrifying bacteria convert ammonia (NH_3^+) into nitrate (NO_3^-) as part of nutrition change. Aquaponics systems are expected to have a high water use efficiency, use a negligible amount of artificial fertilizer, eliminate the need for herbicides, pesticides, or antibiotics, produce fish and plants instantly, and reduce aquaculture waste released into the environment (Brandon and Youbin

2019). Aquaponics products are predicted by plant chemistry, toxicity, oxygen added to wastewater, and biogen consumption (Cohen *et al.*, 2018; Greenfeld *et al.*, 2020). Aquaponics is an environmentally beneficial model for bio-integrated food production (Diver, 2006; Goddek *et al.*, 2015). These devices maintained the water quality in the aquaponic system, in which plants absorb fish waste and microbial byproducts (McMurtry *et al*., 1993; Danaher *et al*., 2013). Gas volatilization was utilized to remove hazardous gases, like in the produced wetland (Mander *et al*., 2014; Maucieri *et al*., 2017). This approach may soon ensure urbanites have enough protein (Alexandratos and Bruinsma 2012).

According to König *et al.* (2018), commercial aquaponics is still in its early stages as an "emerging sector," and many of the companies involved struggle to make a profit (Engle 2015; Villarroel *et al.,* 2016). In their evaluation of the financial viability of aquaponic systems, Greenfeld *et al.* (2018) made a distinction between "proftable systems" (for the grower) and "net-beneficial systems" (to society). According to some studies, aquaponics is only slightly profitable (Goodman 2011; Tokunaga *et al*., 2015); unprofitable with net losses on the farm but net gains on vegetables (Love and Tokunaga 2015); or profitable with a high sensitivity to product market prices. Greenfeld *et al.* (2018) examined provability studies that contrasted separate growing systems with the aquaponics method of growing fish and vegetables simultaneously. Recent studies have confirmed the difficulty of evaluating aquaponics systems economically and the possibility that external benefits may hold the key to increasing the use of aquaponics in business settings (Goddek *et al.* 2019; Turnek *et al.* 2019). Greenfeld *et al.* (2022) have studied the environmental impact through the lifecycle assessment of aquaponic systems.

The future of conventional farming comprises intensive animal protein production, variable growth, shifting energy prices, and marketing challenges. In the same vein, shortages of resources including surface, freshwater, soil deterioration, and soil nutrient depletion contribute to the challenges (Bindraban *et al*., 2012; Klinger and Naylor 2012). This signals to most scientists that they need to take scientific action to compensate for the growing deficit in aquaponic fish output. However, its technological capabilities and cost-effectiveness have not been fully understood. Aquaponics could be a solution to these problems, say reviewers (Rakocy, 2012). This gain in economic power is due to the similar energy and heat needs of cultivated plants and cultured fish (Grigoriev *et al*., 1822; Kuryleva and Yurina 2016). This research looked at the systematic literature on aquaponics' practical and economic potential for sustainable resource management.

METHODS

This review effort was finished with the help of a strategic, methodical, and comprehensive review of the literature based on relevant articles that were examined by other researchers. This was achieved by conducting research on every article that contained the word "aquaponic" somewhere in the text, from the earliest extant publication (1822) to the most recent (2021). Publications that were determined to have significant value after this quest have been saved in the Mendeley reference program. Publications were well-thought-out and of noteworthy value if they possessed the following characteristics: they were peer-reviewed, they addressed current trends and difficulties in aquaponics, they addressed resource management in a sustainable way, and they employed exemplary scientific procedures. All of the publications were sorted into the following categories: the history of aquaponics, the general structure of aquaponic systems, and comparisons of aquaponics with other forms of independent cultivation.

HISTORY

Aquaponics has appeared on academic book covers since the late 1990s. In the 1970s and 1980s, aquaponics was known by other names: ""pond of hydroponic aquaculture," "pond of hydroponic solar," "integrated aquaculture," "integrated agriculture," "system of integrated culture of fish, production of hydroponic vegetables, and System of Integrated Aqua-Vegiculture" (Goodman, 2011). Early portrayals of one division may refer to the lowland Maya, who were followed by the Aztecs, who raised plants on a raft across a lake around 1,000 A.D. Chinampas was identified in a 1992 permaculture book as one of the first systems to employ fish excrement to irrigate and nurture terrestrial plants. Pioneering system Chinampas (Mollison, 2004). Chinampas are man-made islands with artificial flora built on shallow lakebeds. This island practiced agriculture, using the lake as its principal water source and fertilizer (Chinampa, 2011). The lake's fish are wild, not farmed for human consumption. Since the 1930s, rice field fish have been grown as part of Malaysia's integrated agriculture and aquaculture system (Ahmad and Raihan 2001). In east Java, prawns, rice, and fish live in freshwater and brackish water (Cruz, 2001). In 1959, these systems produced 700,000 hectares, although that fell during the Cultural Revolution. In 1986, it rebounded to 1,000,000 hectares, mostly in the Yangtze River Basin (Guo, 2001). John, Todd, and McLarney founded INA in 1969. Their hard work and dedication produced the "Ark" bio-shelter prototype. The "Ark" was self-sufficient, solar-powered, and had a bio-shelter. It provides fish, shelter, and vegetables year-round.

Researchers at NC State's New Alchemy Institute originally used this technique in the 1970s and 1980s. UVI supported this technology in 1980. Doug Sanders and Mark McMurtry created a closed-loop aquaponic system in the 1980s. He also noted that aquaponics research at North Carolina State University from the 1980s to 2006 was outmoded because it was ready for commercial usage. Falmouth, Massachusetts, was the first to combine vegetable and fish farming, according to Diver's (2006). Falmouth, Massachusetts, is the first to combine vegetable and fish farming, according to Diver's (2006). Diver (2006) said the Institute of Freshwater in Shepherdstown, West Virginia, researched aquaponics in the 1990s. Tim and Susanne Friend brought the Rakocyaquaponics system to Hawai'i in 2007 and launched a commercial operation there; therefore, training is no longer offered as often. Since then, aquaponics systems have gained favor, according to a review (Love *et al*., 2014), and acceptability is growing. In the 1970s and 1980s, the US began integrating fish and vegetable farming. Fish and vegetables were grown using hydroponics and recirculating aquaculture systems.

AQUAPONIC SYSTEM

Aquaponics is a method of farming that involves the recycling of water used in aquaculture by means of a system in which fish waste is used to fertilize and water various plant species. There are two main parts to an aquaponics setup: the recirculating aquaculture system and the hydroponic setup (soilless plant cultivation).

A. Recirculatory aquaculture technology

Recirculatory aquaculture systems are intensive fish production setups where water is treated to remove contaminants and allow for reuse. RAS include a device to remove solids from water, such as fish feces, uneaten feed, and bacterial flocs (Chen *et al*., 1994; Couturier *et al*., 2009). RAS incorporates nitrifying biofilters to oxidize fish ammonia into nitrates (Gutierrez-Wing and Malone 2006). Third, gas exchange devices remove dissolved CO_2 from farmed fish and supply oxygen for survival and nitrifying bacteria (Colt and Watten 1988; Wagner *et al.,* 1995; Summerfelt, 2003; Moran, 2010). RAS may utilize UV irradiation for disinfection (Sharrer *et al*., 2005; Summerfelt *et al*., 2009), protein skimming and ozonation for microbial and fine solids management (Summerfelt and Hochheimer 1997; Gonçalves and Gagnon 2011; Attramadal *et al*., 2012a), and denitrification to remove nitrates (Rijn *et al*., 2006).

B. Control of water quality in RAS

More than forty different aspects of water quality can be estimated when attempting to determine the quality of aquaculture water (Timmons and Ebeling 2010). Because other water qualities have negative impacts that have not been identified in practice, only a handful of the 40 qualities of water in the RAS are ever assessed or controlled. This is because other water qualities have detrimental effects.

C. Dissolved oxygen (DO)

Dissolved oxygen (DO) is a key water quality metric in aquaculture. Low dissolved oxygen can cause stress in cultured fish, biofilter dysfunction, and fish losses. Aeration, pure oxygen, or a combination of the two can help measure dissolved oxygen in the RAS. Recirculating aquaculture can use liquid-to-gas and gas-to-liquid aerators and oxygenators (Lekang, 2013).

D. Ammonia

Fish create ammonia as a byproduct of protein metabolism (Altinok and Grizzle 2004). If untreated, this ammonia can build up in the culture water and kill the fish. Ammonia's acute toxicity value is 2.79 mg (NH3L-1) (Randall and Tsui, 2002). In the past, nitrifying biofilters were employed to treat ammonia in recirculating aquaculture systems (NO_3). Chemoautotrophic nitrifying bacteria include Nitrosomonas, Nitrospira, Nitrosococcus, Nitrococcus, and Nitrobacter (Prosser, 1989). Recent commercial RAS have standardized on growth biofilter approaches such as the moving bed bioreactor (Rusten *et al*., 2006), the fluidized sand filter bioreactor (Summerfelt, 2006), and the fixed-bed bioreactor (Zhu and Chen 2002; Emparanza, 2009).

E. Biosolids

Biosolids, which come from human waste, fish food, and biofilms, are a troublesome water quality parameter in the RAS (Timmons and Ebeling 2010). Heterotrophic bacteria devour biosolids; hence, a rise in biosolids content would reduce biofilter performance, increase turbidity, and deplete oxygen (Murray and Watson 1965). Biosolids can be categorized by size and technique. Gravity separation removes materials 100 m or larger that settle. Materials in suspension between 100 and 30 micrometers are removed mechanically (i.e., sieving). Micro-screen filters are another way to reduce suspended particle effects (Dolan *et al*., 2013; Fernandes *et al*., 2015). Bead filters and fast sand filters are depth filters.

F. Carbon dioxide (CO_2)

Dissolved CO_2 in cultured water prevents CO_2 from diffusing into fish blood. High blood carbon dioxide levels in fish lower blood pH and oxygen affinity for hemoglobin (Noga, 2010). Salmonids exposed to high CO_2 levels develop systemic granulomas, nephrocalcinosis, and chalky deposits (Noga, 2010). Bacteria and fish release carbon dioxide through heterotrophic respiration. Since RAS needs a carbon dioxide remover, pure oxygen should be available (Loyless and Malone 1998; Eshchar *et al*., 2003). Most commercial RAS use cascade aerators and trickling biofilters for oxygenation (Colt and Bouck 1984; Summerfelt, 2003; Moran, 2010).

G. Total gas pressure (TGP)

The amount of pressure imposed by the dissolved gases is known as the total gas pressure (TGP) (aqueous). As a whole, the gas pressures in a fish tank must equal atmospheric pressure. Excess gas (often nitrogen) exoduses the bloodstream and creates bubbles if fish breathe water with a high TGP, which can be fatal to the fish (Noga, 2010). Gas bubble illness in fish is a common problem in the aquaculture industry. Safest methods for removing TGP from RAS include using carbon dioxide strippers (which also strip nitrogen) and medicating the necessary amount of technical oxygen.

H. Nitrate (NO_3)

Nitrate, the end product of nitrification, has a lesser effect on toxicity because it is less able to permeate the gill membrane of fish (Schroeder *et al*., 2011; Rijn, 2013; Davidson *et al*., 2014). (Camargo and Alonso 2006). In terms of their harmful effect, which is to reduce the amount of oxygen that molecules can carry, nitrate and nitrite are very similar. Nitrate concentrations in RAS can be managed using standard dilution techniques. Nitrate in RAS can also be treated with denitrification reactors.

I. Alkalinity

The term "alkalinity" refers to the buffering capacity of water in terms of pH. (Timmons and Ebeling 2010). The elimination of alkalinity by nitrification, which is known to be an acid-producing process, highlights the need for controlling alkalinity in the RAS. Swings in pH and the inability of the nitrifying biofilter to work properly are both consequences of a low alkalinity level (Colt, 2006; Summerfelt *et al*., 2015).

J. Advances in RAS

In recent years, farmers have used more recirculating aquaculture systems. The next part describes RAS technology and procedures. Low-head oxygen transfer systems use liquid oxygen with pressure-operated diffusers. Gravity-operated First, a low-head oxygenator supplied water into the biofilter and column (Summerfelt *et al*., 2004). The RAS anammox process eliminates ammonia without oxygen (Tal *et al*., 2006). Nitrogen waste can be autotrophically removed with anammox (Rijn *et al*., 2006). Instead of a biofilter, electrochemical oxidation removes ammonia. Using ion exchange, zeolites removed dissolved ammonia from the RAS (Lekang, 2013). Modern RAS fine solids management uses ozonation, flotation, protein skimming, membrane filtration, and cartridge filtering (Summerfelt and Hochheimer 1997; Cripps and Bergheim 2000; Couturier *et al*., 2009; Wold *et al*., 2014). Protein skimmers (sometimes termed foam fractionators) regulate dissolved particle concentration in marine settings (Badiola *et al*., 2012). Due to its position as a predominant oxidizer, ozone is used to eliminate nitrite, bacteria, and humic substances (Gonçalves and Gagnon, 2011). Ozonation enhances micro-screen filter efficiency and minimizes dissolved material buildup (Summerfelt *et al*., 2009). The dissimilatory route purges nitrate from water using carbon, which converts nitrate to nitrogen gas, and anaerobic bacteria (Rijn *et al*., 2006). RAS 'zero exchange' is a common denitrification method (Yogev *et al*., 2016). Adding probiotic bacteria to the RAS will starve pathogenic bacteria and reduce their growth, making biofilm colonization tougher (Defoirdt *et al*., 2007; Kesarcodi-Watson *et al*., 2008; Defoirdt *et al*., 2008). Despite efforts, microbial population management in reactors is problematic (Leonard *et al*., 2000; Schreier *et al*., 2010; Rojas-Tirado *et al*., 2017), leading to RAS inefficiencies (Martins *et al*., 2010b). Bacteria turn fish waste's ammonium into appropriate plant fertilizers with a balance of nitrates and ammonium (Somerville *et al*., 2014).

K. Hydroponic system

Farming methods Aquaponics combines soilless hydroponics with aquaculture. The RAS is part of the bigger agri-aquacultural aquaponics arrangement. There are closed and open hydroponic systems. Many greenhouse farmers are turning to soilless agriculture to avoid soil-borne plant diseases. Hydroponic systems don't transmit soilborne infections; plant development can be regulated by mixing targeted nutrients; the system is independent of cultivation area; surplus nutrients may be recovered by water recycling; and environmental factors can be manually managed (Maucieri *et al*., 2019).

L. Soilless cultivation systems

In the 1970s, soilless agriculture substrates were tested (Verwer, 1978; Blok *et al*., 2008; Wallach, 2008). Solid substrates include perlite, stone wool, coir, polyurethane foam, peat, and bark. Fibrous substrata have significant water retention (60–80%) and variable air capacity (porousness) (Wallach, 2008). Granular substrates are inorganic (expanded clay, pumice, sand, and perlite) and have varying particle sizes. 10–40% of the water it gets evaporates (Maher *et al*., 2008).

*M. Forms*of substrates

The choice of substrates can range from items of mineral or organic origin that are found in nature to those that need to be processed in a particular way (for example, peat, vermiculite, and perlite) (Maucieri *et al*., 2019).

N. Organic materials

This group includes agricultural by-products (straw, manure, etc.), industrial by-products (wood industry), and urban rubbish (sewage sludge). Peat is the most important organic material for making substrates, either by itself or with other organic materials. Peat consists of Cyperaceae (Eriophorum, Trichophorum, and Carex) and bryophytes (Sphagnum). Coir, or coconut fibers, are made from the lignin-rich coconut husk. Coconut fiber has similar physiochemical qualities to blonde peat; hence, its health advantages have been researched (Maucieri *et al*., 2019). Commercial plant production wastes wood chips, wood, sawdust, and bark (Maher *et al*., 2008).

O. Inorganic materials

This category includes pumice, sand, and industrial mineral goods (e.g., perlite, vermiculite). Hydroponic systems with 10–30% organic ingredients need 0.05–0.5 mm fine sands. Pumice is a volcanic aluminum silicate. Gardening pumice should be 2–10 mm in size (Kipp *et al*., 2001). Vermiculite can be used alone; however, it works best with peat or perlite. Perlite is a volcanic aluminum silicate with 13% Al_2O_3 and 75% SiO_2. Perlite can be reused for years if properly sanitized. Expanded clay can enhance the volume of organic materials by 10–35% through increased aeration and drainage (Lamanna *et al*., 1990). Soilless societies used stone wool. It was made by fusing magnesium silicates, aluminum, calcium, and carbon coke at 1500–2000°C (Maucieri *et al*., 2019). Variable zeolite formulations with different levels of nitrogen and phosphorus are indicated for seed starting, cutting rooting, and crop development (Pickering *et al*., 2002).

P. Synthetic materials

Low-density plastics and ion-exchange synthetic resin are both included in the category of synthetic materials. Expanded polystyrene is manufactured into crumbs with a closed-cell structure and a diameter of 4–10 mm. It is added to the substrate to increase drainage and porosity, as it has no CEC and almost no buffering capacity on its own. Soil-free gardening also makes use of polyurethane foam (Maucieri *et al*., 2019).

Categories of hydroponic systems (according to water distribution)

A. Deep flow technique (DFT)

Deep Flow Technique (DFT) grows plants in ampules with 10–20 cm of nutritional solutions (Van *et al*., 2008). Many uses exist, distinguished by volume, depth, oxygenation, and recirculation procedures. An aquaponics system will contain a 20- to 30-centimeter-deep tank made of polyethylene films to ensure watertightness. Floating rafts support the plants above water, while their roots travel over the tank floor. At the end of each cycle, a higher amount of solution is used to replenish the nutrient solution, and the oxygen reserve is measured regularly (Mauceri*et al*., 2019).

B. Nutrient film technique (NFT)

The Nutrient Film Technique is a type of classical hydroponic agriculture in which a 1-2 cm-thick water film circulates nutrient solutions (Jensen and Collins, 1985; Van *et al*., 2008). This approach eliminates substrates and recycles nutritional solutions. Its automated capabilities may minimize labor costs. Temperature variations in the nutritional solution can stress plants, causing sickness. Some of the developing root system stays exposed to air above the nutrient flow, causing problems with early plant growth. We designed a multilayer flow through technology to fix this (Maucieri *et al*., 2019).

C. Aeroponic systems

Plastic panels or polystyrene are placed horizontally in the growth boxes to provide support for the plants. Steel, plastic-coated polystyrene boards, and plastic film were used to support these panels, creating a closed enclosure in which the plant roots could flourish. The fertilizer solution is sprayed directly onto the roots in the box using static sprinklers. Spray times range from 30 seconds to 60 seconds, depending on planting and harvesting schedules (Maucieri *et al*., 2019).

D. Nutrient management

Since the 1970s, when soilless horticulture gained popularity, numerous fertilizer solutions have evolved and been adapted to growers' demands (Kreij*et al*., 1999). All combinations adhere to the notion of spare availability of complete elements to prevent deficits and keep cations from competing during plant nutrient uptake (Hoagland and Arnon, 1950; Steiner, 1961; Steiner, 1984; Sonneveld and Voogt 2009). Root zone electrical conductivity (EC) was limited. In tomatoes, the nutrient solution's EC is roughly 3 dS/m (deciSiemens per meter), while the stone wool slabs' EC is 4 or 5 deciSiemens per meter. Hotter growing conditions and a higher EC may promote tip-burn illnesses in lettuce. Aquaponics nutrient management is more difficult than hydroponics because of fish density, feed type, and feeding frequency. citation (Maucieri *et al*., 2019).

E. General principles of aquaponics

Here are several aquaponic system-wide concepts: Utilizing additional nutrients in an aquaponic system to produce plant and fish biomass is a basic premise of this technology (Rakocy and Hargreaves 1993; Delaide *et al*., 2016; Knaus and Palm 2017). The most fundamental aquaponics premise is to maximize fish and plant production by using nutrients efficiently (Lennard and Goddek 2019). Real-world water and nutrient efficiency drive several aquaponic design principles. Aquaponics uses fish wastes as major fertilizers for hydroponically grown plants. This premise supports aquaponics (Rakocy and Hargreaves 1993). Second, plant-cultivation and fish-keeping practices that don't absorb or waste nutrients or water should be encouraged (Lennard, 2017). Finally, the system design doesn't waste water or food (Tyson *et al*., 2011). Fourth, systems should minimize or eliminate direct nutrient and water environmental consequences (Tyson *et al*., 2011). Aquaponic systems should be located in biologically managed environments (like fish rooms or greenhouses) (Lennard, 2017). Strategic considerations are often but not always relevant to the aquaponic system's production environment. In aquaponics, fish fed fake diets fertilize the water and create more fish. After bacteria digest fish waste and cultured plants absorb remaining nutrients, the water is clean enough for fish farming (Rakocy and Hargreaves 1993; Love *et al*., 2015a, 2015b). Once fish are stocked in tanks, the water is treated to filter or eliminate waste products (dissolved gases of ammonia and solids) from the fish's metabolism. The water (along with the accompanying nutrients) is then transferred to the plant culturing unit, where the plants use the fish excreta as part of their nutrient resource (Timmons *et al*., 2002). In a standard hydroponics system, mineral fertilizers such as nitrate, potassium, phosphate, calcium, and so on are added to the water to feed the plants (Resh, 2013). In recirculating aquaculture, fish waste must be handled through daily water exchanges (Timmons *et al*., 2002). In aquaponics, fish waste provides plant and animal nutrition (Rakocy and Hargreaves 1993; Lennard, 2017). Not all plant-growing components may be obtained from fish excrement (Lennard and Goddek 2019). Hydroponics and substrate cultures use ionic nutrients in water (Resh, 2013). Aquaponic microflora converts toxic ammonia into safer nitrate for hydroponic crops (Lennard, 2017). Aquaponic system integration optimization focuses on regulating fish waste production (as effected by fish meal input) and plant nutrient use (Rakocy and Hargreaves 1993; Lennard and Leonard 2006; Goddek *et al*., 2015).

If an aquaponic system's water source contains calcium, the plants need less supplementary calcium (Lennard, 2017). Unabsorbed sodium (Na+) in the water can potentially poison plants (Rakocy *et al*., 2006). Rainwater or water purified by reverse osmosis is optimal for aquaponics (Rakocy *et al*., 2004a, b; Lennard, 2017). Groundwater can also be used, but it must be analyzed for dangerous compounds or salts (such as iron, magnesium, or sodium) (Lennard, 2017). River water can be used in aquaponics, but it must be introduced cautiously owing to industrial pollutants, insect larvae, microorganisms, etc. Urban water supplies can be used in aquaponics (Love *et al*., 2015a; Love *et al*., 2015b), but only if they are low in nutrient, salt, and chemical concentrations. River and town water containing microorganisms from agriculture and human waste must be cleaned before use (Lennard, 2017).

Species selection in aquaponics

Plant species

When picking hydroponic plant species, consider fish density and nutrient concentration (in aquaponics). Because the technique emphasizes nitrogen-rich water and leafy greens mature quickly, they are the principal crop grown this way. Herbs, lettuces, and greens (such as spinach, basil, chives, and watercress) thrive well in the aquaponic system (Diver, 2006). Bell peppers, tomatoes, and cucumbers have a high nutritional demand and thrive well in an aquaponics system (Diver, 2006). Greenhouse tomato cultivars flourish in the dim light and high humidity of greenhouses (Diver, 2006). Flowering plants have higher economic value than leafy vegetables, but they're challenging to grow in aquaponic systems due to longer growing cycles, higher nutrient requirements (particularly phosphate and potassium), and disease and pest susceptibility (Rakocy, 2003).

Fish selection

Arctic char, tilapia, perch, trout, and bass adapt well to recirculating aquaculture systems (Diver, 2006). Tilapia is the best-suited species for commercial aquaponics cultivation in North America (Diver, 2006). They are highly versatile and can survive water's oxygen, pH, dissolved particles, and temperature (Diver, 2006). Out of 257 commercial aquaponic system users, 69 percent grow *Oreochromis niloticus* (tilapia), 43 percent grow ornamental fish, and 25 percent grow catfish (Siluriformes). Common carp (*Cyprinus carpio*), rainbow trout (*Oncorhynchus mykiss*), barramundi (*Lates calcarifer*), pacu (*Piaractus mesopotamicus*), largemouth bass (*Micropterus salmoides*), murre (*Maccullochella peelii*), and crappie (*Pomoxis sp.*) are some aquaponic fish species (Rakocy *et al*., 2006). Optimal stocking density for aquaponic fish is 0.06 kg L1. (Rakocy *et al*., 2006).

Sustainability of aquaponics

"Triple-bottom-line" approaches are used to examine the long-term viability of aquaponics activities, which includes examining their economic, environmental, and community implications (Pusnik *et al*., 2014). Aquaponics recirculates water between fish and plant cultures (Rakocy *et al*., 2006; Lennard, 2017). Using as few biotic and ecological resources as possible helps water systems colonize. Hydroponics had enough nitrifying bacteria to convert fish ammonia to nitrates (Rakocy *et al*., 2006). It could reduce nutrient and water loss in aquaculture and boost yields with less fertilizer. Due to the dangers of combining aquaculture and hydroponics, aquaponics needs expert evaluations and conversations (Goddek *et al*., 2015). Aquaponics saves energy, water, GHGs, and organic waste. Aquaponics water can be reused. Aquaponics saves soil labor and costs. Water, fish feces, and media feed aquaponics. Aquaponics produces no solid waste, making it sustainable (Mishra *et al*., 2020). Large-scale aquaponics systems require additional fossil fuels, pharmaceuticals, and other inputs. Sustainable systems are smaller. Emerging and rich nations need food security, education, and protein. Producing food in cities can enhance economics, productivity, commodities, and services.

Costs of fertilizer, water, and land are reduced, while infrastructural costs are spread out (Bildaru *et al*., 2011). In the early 1990s, agroecology pioneers pushed an integrated system of fisheries and agriculture called the Village Aquaculture Ecosystem (VAE) for Sub-Saharan Africa. Malawian smallholder farmers earn "six times" as much as Village Aquaculture Ecosystem farms (Randall and Barry 2002).

DISCUSSION

RAS for fish culture and hydroponics for plant culture are both fast-growing technologies that could be combined. RAS yields more fish per unit of feed weight than other aquaculture systems (Lennard, 2017). RAS's higher fish densities also boost collective biomass growth (Rakocy *et al.,* 2006; Lennard, 2017). Hydroponic and substrate cultivation give more consistent and faster crop yields than traditional farming and horticulture (Resh, 2013). Lennard (2005) found that lettuce yielded 5.77 kg/m^2 in aquaponics and 5.46 kg/m^2 in hydroponics. His investigation showed that advancements in unified or totally recirculating aquaponics designs may be similar to hydroponic plants' production rates, so he optimized the system based on the improvement recommendations. Lenard (2005) found that the same fish species had the same FCR, SGR, and growth rates in RAS and pond aquaculture (Australian Murray Code). *Tilapia* spp. growth rates are comparable to industry norms established by common aquaculture production methods, UVI's Rakocy and his team found (Rakocy and Hargreaves, 1993; Rakocy *et al*., 2004a, 2004b, 2006, and 2011). These and other studies show that linked or decoupled aquaponic systems can achieve plant growth rates on par with or above standard hydroponic systems and fish growth rates comparable to the RAS. Lenard (2005) found that conventional aquaculture (RAS), a regulated system in which water was shifted to regulate nitrate accumulations, conserved 90 percent or more water. Aquaponics minimizes water use compared to conventional aquaculture (RAS). McMurtry's aquaponics system used only 1 percent of the water needed for pond aquaculture (1990). Aquaculture requires around 1 percent as much water as pond-based systems, according to Rakocy (1989). An aquaponics system can make optimal use of water and minimize the need for frequent watering or rebuilding soggy soil (Lennard, 2017). Coupled aquaponic systems increase production and reduce water use (Lennard, 2017). Aquaponics allows for more effective fertilizer use (Rakocy *et al*., 2006; Blidariu and Grozea 2011; Goddek *et al*., 2015; Suhl *et al*., 2016). Conventional RAS aquaculture employs fish meal nutrients to grow fish while discarding the rest. Aquaponics uses RAS nutrient waste for plant production, so surplus nutrients are used more efficiently. One input grew two crops (Rakocy and Hargreaves 1993; Timmons *et al*., 2002; Lennard, 2017). Aquaponics systems don't require soil, another perk (Blidariu and Grozea 2011; Love *et al*., 2015a, b). Since aquaponics doesn't require soil, it can be set up wherever the operators desire (Love *et al*., 2015a, b). It's better than soil-based farming. Aquaculture's nutrient-rich effluent has detrimental environmental effects, especially in aquatic habitats (Boyd and Tucker 2012). Some hydroponic approaches may be similar. In an aquaponics system, the fish waste is used as a source of nutrients for the plants, reducing or eliminating the direct environmental impacts of the nutrient-rich wastewater (Rakocy *et al*., 2006; Blidariu and Grozea 2011; Goddek *et al*., 2015; Lennard, 2017).

In typical aquaponics systems, fish effluent is different from plant nutrients. Decoupled aquaponic systems (DAPS), in which water from the fish culture unit is used but not returned, may produce better outcomes than standard designs. Decoupled sludge digesters maximize the use of recovered fish waste as plant food (Goddek, 2017; Goddek *et al*., 2018). Unexplored is also the effective use and reuse of energy. Aquaponic systems need room and power to work. Incorporating solar PV, solar desalination, and solar thermal heat sources into aquaponics systems is a realistic solution. Lack of nutrients, low nitrogen use efficiency (NUE), low pH, and solid accumulations in the water system hinder plant and fish productivity. Improving nitrogen usage efficiency (NUE) is a fascinating research area, while nitrogen deficiency isn't a major issue in aquaponics. Frequent feeding enhances NUE (from 4.9% to 11.1% fish growth and 8.1% plant growth) (Liang and Chien 2013). Aquaponics nutrient ratios are another limiting factor. Ca, Mg, K, and Fe are aquaponics plants' most limiting nutrients (Rakocy, 2003; Villarroel *et al*., 2011). Some add potassium hydroxide to aquaponic water to prevent nutrient deficits (Rakocy, 2003). Aquaponic systems can make up for nutrient shortages and boost yields by using as little synthetic fertilizer as possible. Fish, plants, and nitrifying bacteria all have varied pH and growth requirements in aquaponic systems. Nile tilapia like a pH between 7.0 and 9.0, while nitrifying bacteria prefer 7.5 to 8.3. Rakotocy, 2003; Goddek *et al*., 2015) Hydroponic plant development is optimal between 5.8 and 6.2 pH. (Sonneveld and Voogt 2009) Since different organisms have different optimum pH ranges, no aquaponics system can guarantee optimal growth for every organism. Stale feed, mold, algae, and fish feces can harm aquaponics. Mineralization (in filtration tanks) requires a certain amount of solid buildup, but too much might be detrimental. Organic sludges create an anaerobic environment that can lead to the release of fish-killing gases by anaerobic bacteria (Rakocy *et al*., 2006). Solid buildup surrounding plant roots can produce an anaerobic environment, cutting off the oxygen needed for nutrient absorption (Rakocy *et al*., 2006). Future research and monitoring should address these difficulties.

The most popular solution to the problem of numerous products in aquaponic systems was the allocation of environmental effects according to mass. According to some studies (Cohen *et al.,* 2018; Greenfeld *et al.,* 2021; Maucieri *et al*. 2018), findings were published without distinguishing between fish and plant production. Boxman *et al.* (2017) employed an economic displacement strategy, applying the fertilizer cost savings from basil cultivation to the production of fish. The ability to produce high yields with only a small amount of additional nutrients is the primary benefit that could be realized from the implementation of aquaponic systems. These systems also have the potential to significantly cut down on the amount of nutrients discharged from aquaculture and the amount of water that is lost as a result. The exponential growth in the number of publications on aquaponics that has occurred over the past three years is one indication that there is an increasing interest in environmentally friendly agricultural practices such as aquaponics. As a result of these recent developments, there are obvious trends, implications, and requirements for future research on system design, components of hydroponic systems, and ideal species of fish, plants, and microorganisms.

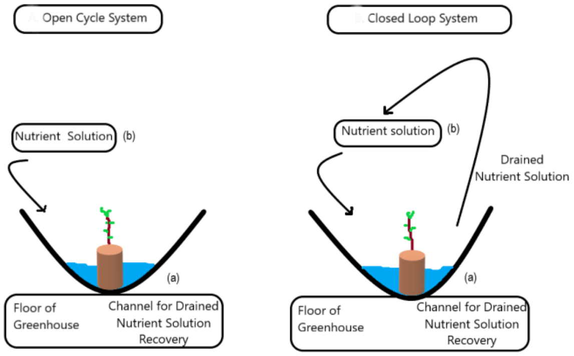

Fig. 1. Mechanism of open cycle system, (a) Main tank. (b) Nutrient solution; Closed-loop cycle, (a) Main tank. (b) Cycled nutrient solution.

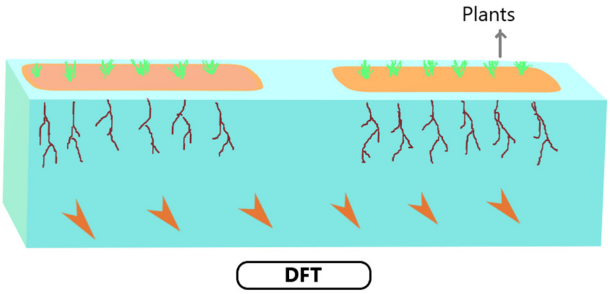

Fig. 2. Deep Flow Technique of Aquaponic System.

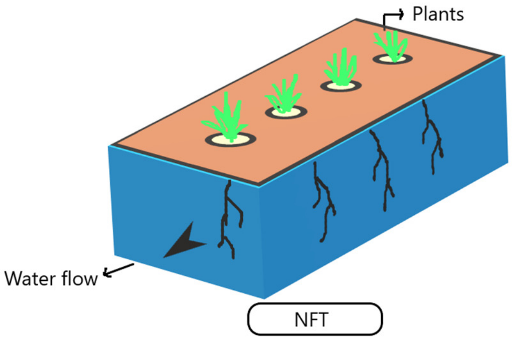

Fig. 3. Nutrient Film Technique of Aquaponic System.

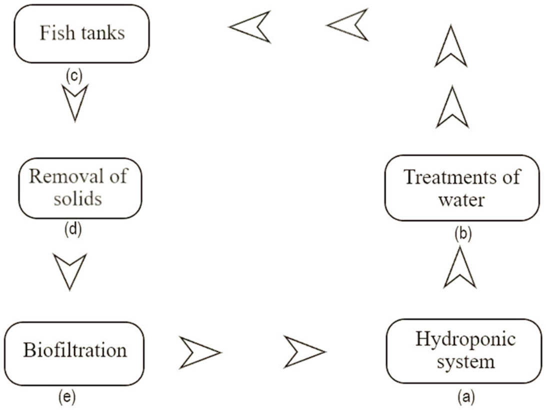

Fig. 4. Cycle of water in a sustainable aquaponic system.

CONCLUSIONS

It was an innovative technology with sustainable supplies of food all over the world that, by marginalizing the supply chains, had the potential to advance food security and the pliability of the food system. Aquaponic systems were responsible for this. It is able to produce a high yield with only a minimal addition of nutrients, drastically reducing the amount of nutrients that are discharged and the amount of water that is lost from the aquaculture. In the not-too-distant future, productive research will be required on the hydroponic components, system design, knowledgeable fish selections, the introduction of flowering or fruit plant cultivation, and the incorporation of species of mutually beneficial microorganisms in order to increase the effectiveness of the aquaponic system.

FUTURE SCOPE

The model used by the government in relation to natural resources needs to be adapted to an aquaponics system, and appropriate instruction on the management of aquaponics production systems needs to be provided. There are not currently any standards in place that must be adhered to before aquaponic products can be sold with the quality, safety, and authenticity of their cultivation being verified. For the purpose of contributing to the formation of a more established market for aquaponic products, a distinct collection of aquaponic standards ought to be developed. The use of aquaponics has the potential to improve both food security and agricultural sovereignty. Aquaponics has the potential to provide a sustainable food supply in countries with low and medium incomes, particularly in locations with favorable climatic conditions. The production of food using aquaponics has been shown to have fewer negative effects on the environment than conventional farming methods. Within this framework, aquaponics demonstrates the possibility of the environmentally responsible expansion of food production. In addition, it eliminates the problem of poor soil and other difficulties that are encountered during conventional cultivation. As a result, the aquaponics system played a significant part in the advancement of environmental, social, and economical sustainability, which ultimately led to overall sustainability.

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Conflict of Interest. None.

REFERENCES

Adler, P. R., Harper, J. K., Wade, E. M., Takeda, F. and Summerfelt, S. T. (2000). Economic analysis of an aquaponic system for the integrated production of rainbow trout and plants. *International Journal of Recirculating Aquaculture*, *1*(1), 15-34.

Ahmad, M. and Raihan, S. (2001). *Fodder-fish integration practice in Malaysia. A primer, FAO Fisheries Technical Paper in Integrated agriculture-aquaculture: FAQ. 33 p.p.*

Alexandratos, N. and Bruinsma, J. (2012). World agriculture towards 2030/2050. *Land Use Policy*, *20*(4). 375 pp.

Altinok, I., and Grizzle, J. M. (2004). Excretion of ammonia and urea by phylogenetically diverse fish species in low salinities. *Aquaculture*, *238*(1–4), 499–507.

Attramadal, K. J. K., Salvesen, I., Xue, R., Øie, G., Størseth, T. R., Vadstein, O. and Olsen, Y. (2012a). Recirculation as a possible microbial control strategy in the production of marine larvae. *Aquacultural Engineering*, *46*, 27–39.

Badiola, M., Mendiola, D. and Bostock, J. (2012). Recirculating aquaculture systems (RAS) analysis: Main issues on management and future challenges. *Aquacultural Engineering*, *51*, 26–35.

Bill, C. M. (2004). *Permaculture: A designers' manual* (2nd ed) Tyalgum, and Tagari. *Australia. 462–463 p.p.*

Bindraban, P. S., van der Velde, M., Ye, L., van den Berg, M., Materechera, S., Kiba, D. I. and van Lynden, G. (2012). Assessing the impact of soil degradation on food production. *Current Opinion in Environmental Sustainability*, *4*(5), 478–488.

Blidariu, F., and Grozea, A. (2011). Increasing the economic efficiency and sustainability of indoor fish farming by means of aquaponics – Review. *Animal Science Biotechnology*, *44*(2), 1-8.

Blidariu, F., and Grozea, A. (2011). Increasing the economical efficiency and sustainability of indoor fish farming by means of aquaponics-review. *Scientific Papers Animal Science and Biotechnologies*, *44*(2), 1-8.

Boxman, S. E., Zhang, Q., Bailey, D. and Trotz, M. A. (2017). Life cycle assessment of a commercial-scale freshwater aquaponic system. *Environmental Engineering Science*, *34*(5), 299–311.

Brandon, Y. and Youbin, Z. (2019). Aquaponic trends and challenges e A review. *Journal of Cleaner Production*: 1586e1599, 228, 1586–1599.

Camargo, J. A. and Alonso, A. (2006). Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. *Environment International*, *32*(6), 831–849.

Chen, S., Coffin, D. E., and Malone, R. F. (1994). Suspended solids control in recirculating aquaculture systems. In *Aquaculture water Reuse Systems: Engineering Design and management* (eds. M.B. Timmons and T.M. Losordo) (pp. 61–100). Eurekamag OU. Tallinn, Estonia.

Cohen, A., Malone, S., Morris, Z., Weissburg, M. and Bras, B. (2018). Combined fsh and lettuce cultivation: An aquaponics life cycle assessment. *Procedia CIRP*, *69*, 551–556.

Colt, J. (2006). Water quality requirements for reuse systems. *Aquacultural Engineering*, *34*(3), 143–156.

Colt, J. E. and Watten, B. J. (1988). Applications of pure oxygen in fish culture. *Aquacultural Engineering*, *7*(6), 397–441.

Colt, J., and Bouck, G. (1984). Design of packed columns for degassing. *Aquacultural Engineering*, *3*(4), 251–273.

Couturier, M., Trofimencoff, T., Buil, J. U. and Conroy, J. (2009). Solids removal at a recirculating salmonsmolt farm. *Aquacultural Engineering*, *41*(2), 71–77.

Cripps, S. J. and Bergheim, A. (2000). Solids management and removal for intensive land-based aquaculture production systems. *Aquacultural Engineering*, *22*(1–2), 33–56.

Cruz, D. (2001). Integrated agriculture-aquaculture: A Pimer. *FAO Fisheries Technical Paper*, *407*, FAQ, 71–72.

Danaher, J. J., Shultz, C. R., Rakocy, J. E., Bailey, D. S. and Knight, L. (2011). Effect of a parabolic screen filter on water quality and production of Nile tilapia (*Oreochromis niloticus*) and water spinach (*Ipomoea aquatica*) in a recirculating raft aquaponic system. *International Journal of Recirculating Aquaculture*, *12*(1), 35-53.

Danaher, J. J., Shultz, R. C., Rakocy, J. E. and Bailey, D. S. (2013). Alternative solids removal for warm water recirculating raft aquaponic systems. *Journal of the World Aquaculture Society*, *44*(3), 374–383.

Davidson, J., Good, C., Welsh, C. and Summerfelt, S. T. (2014). Comparing the effects of high vs. low nitrate on the health, performance, and welfare of juvenile rainbow trout Oncorhynchus mykiss within water recirculating aquaculture systems. *Aquacultural Engineering*, *59*, 30–40.

De Blok, C., Kreij, C., Baas, R. and Wever, G. (2008). Analytical methods used in soilless cultivation. In L. Raviv(Ed.) 245-290 pp. Amsterdam: Elsevier.

De Kreij, C., Voogt, W., and Baas, R. (1999). Nutrient solutions and water quality for soilless cultures. *Research Station for Floriculture and Glasshouse Vegetables*, Report 196.

Defoirdt, T., Boon, N., Sorgeloos, P. Verstraete, W., and Bossier, P. (2007). Alternatives to antibiotics to control bacterial infections: Luminescent vibriosis in aquaculture as an example. *Trends in Biotechnology*, *25*(10), 472–479.

Defoirdt, T., Boon, N., Sorgeloos, P., Verstraete, W. and Bossier, P. (2008). Quorum sensing and quorum quenching in Vibrio harveyi: Lessons learned from in vivo work. *ISME Journal*, *2*(1), 19–26.

Delaide, B., Goddek, S., Gott, J., Soyeurt, H. and Jijakli, M. (2016). Lettuce (*Lactuca sativa* L. var. Sucrine) growth performance in complemented aquaponic solution outperforms hydroponics. *Water*, *8*(10), 467.

Diver, S. (2006). *Aquaponics—Integration of hydroponics with aquaculture. Amy Smith, production. A publication of ATTRA—National sustainable agriculture information service*. Retrieved from http://www.attra.ncat.org. Cited, *2006*.

Elisha, R. (2011). *Goodman*. Aquaponics. *Community and economic development. the Department of Urban Studies and Planning. 15 p.p.*

Emparanza, E. J. M. (2009). Problems affecting nitrification in commercial RAS with fixed-bed biofilters for salmonids in Chile. *Aquacultural Engineering*, *41*(2), 91–96.

Endut, A., Jusoh, A., Ali, N., Wan Nik, W. N. S. W., and Hassan, A. (2009). Effect of flow rate on water quality parameters and plant growth of water spinach (Ipomoea aquatica) in an aquaponic recirculating system. *Desalination and Water Treatment*, *5*(1–3), 19–28.

Engle, C. R. (2015). *Economics of aquaponics, Southern Regional Aquaculture Center Publication no. 5006*. AR.

Eshchar, M., Mozes, N., and Fediuk, M. (2003). Carbon dioxide removal rate by aeration devices in marine fish tanks. *Israeli Journal of Aquaculture Bamidgeh*, *55*: 79-85.

Espinosa Moya, E. A., Angel Sahagún, C. A. A., Mendoza Carrillo, J. M., Albertos Alpuche, P. J., Álvarez-González, C. A., and Martínez-Yáñez, R. (2016). Herbaceous plants as part of biological filter for aquaponics system. *Aquaculture Research*, *47*(6), 1716–1726.

FAO Fisheries Technical Paper. (2001). Ricefish systems in Indonesia. Catalino, D. Cruz. Rome: FAQ, *407*, "in*Integrated agriculture-aquaculture: A primer*. FAQO fisheries technical Paper 407. *FAQ*.

Food and Agriculture Organization of the United Nations. (1988). Definition of aquaculture. In *Seventh Session of the IPFC Working Party of Expects on Aquaculture*. 1-3 pp.

Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K., Jijakli, H. and Thorarinsdottir, R. (2015). Challenges of sustainable and commercial aquaponics. *Sustainability*, *7*(4), 4199–4224.

Goddek, S., Joyce, A., Kotzen, B. and Dos-Santos, M. (2019). Aquaponics and global food challenges. In *Aquaponics food production systems* (pp. 3–17). Berlin: Springer.

Gonçalves, A. A. and Gagnon, G. A. (2011). Ozone application in recirculating aquaculture system: An overview. *Ozone: Science and Engineering*, *33*(5), 345–367.

Goodman, E. R. (2011). *Aquaponics: Community and economic development* [Dissertation]. Massachusetts Institute of Technology.

Gooley, G. J. and Gavine, F. M. (2003). *Integrated agri-aquaculture systems: A resource handbook for Australian industry development*. RIRDC Publication No. 03/012.

Graber, A. and Junge, R. (2009). Aquaponic systems: Nutrient recycling from fish wastewater by vegetable production. *Desalination*, *246*(1–3), 147–156.

Greenfeld, A., Becker, N., Bornman, J. F., Dos Santos, M. J. D. and Angel, D. (2020). Consumer preferences for aquaponics: A comparative analysis of Australia and Israel. *Journal of Environmental Management*, *257*, 109979.

Greenfeld, A., Becker, N., Bornman, J. F., Spatari, S. and Angel, D. L. (2021). Monetizing environmental impact of integrated aquaponic farming compared to separate systems. *Science of the Total Environment*, *792*, 148459.

Greenfeld, A., Becker, N., Bornman, J. F., Spatari, S. and Angel, D. L. (2022). Is aquaponics good for the environment?—Evaluation of environmental impact through life cycle assessment studies on aquaponics systems. *Aquaculture International*, 30(1), 305–322.

Greenfeld, A., Becker, N., Mcilwain, J., Fotedar, R. and Bornman, J. F. (2019). Economically viable aquaponics? Identifying the gap between potential and current uncertainties. *Reviews in Aquaculture*, *11*(3), 848–862.

Grigoriev, A. V., Kovalyova, A. V. and Sorokina, M. N. (2015). Experience of joint cultivation of klariyevy som (Clarias gariepinus Burchell, 1822) and salad (*Lactuca sativa* L.) method of aquaponics. *Natural Science*, *4*(53), 96-101.

Gutierrez-Wing, M. T. and Malone, R. F. (2006). Biological filters in aquaculture: Trends and research directions for freshwater and marine applications. *Aquacultural Engineering*, *34*(3), 163–171.

Hoagland, D. R. and Arnon, D. I. (1950). *The water culture method for growing plants without soil*, Circular 347. CA: University of California Berkeley.

Jensen, M. H., and Collins, W. L. (1985). Hydroponic vegetable production. *Horticulture Research*, *7*, 483-558.

Kesarcodi-Watson, A., Kaspar, H., Lategan, M. J. and Gibson, L. (2008). Probiotics in aquaculture: The need, principles and mechanisms of action and screening processes. *Aquaculture*, *274*(1), 1–14.

Kipp, J. A., Wever, G. and De Kreij, C. (2000). International substrate manual. elsevier international business information. PO box, *4*, 7000.

Klinger, D. and Naylor, R. L. (2012). Searching for Solutions in aquaculture: Charting a sustainable course. *Annual Review of Environment and Resources*, *37*(1), 247–276.

Knaus, U. and Palm, H. W. (2017). Effects of the fish species choice on vegetables in aquaponics under spring–summer conditions in northern Germany (Mecklenburg Western Pomerania). *Aquaculture*, *473*, 62–73.

König, B., Janker, J., Reinhardt, T., Villarroel, M., and Junge, R. (2018). Analysis of aquaponics as an emerging technological innovation system. *Journal of Cleaner Production*, *180*, 232–243.

Kumar, N., Bahadur, V., Thomas, T. and Topno, S. E. (2021). *Effect of different level of Nutrienton growth, yield and quality of spinach beet (Beta vulgaris var. bengalensis) in hydroponic system under shade net condition. Biological Forum – An International Journal, 13*(4), 479–482.

Kuryleva, N. V. and Yurina, A. V. (2016). Gidroponika-kak metod vyrashchivaniya zelenykh kultur (Hydroponics as a method of cultivating green crops. Molodezh i Nauka, *5*, 69.

Lamanna, D., Castelnuovo, M.,and D'Angelo, G. (1991). Compost-based media as alternative to peat on ten pot ornamentals. *Acta Horticulturae*, *294*(294), 125–130.

Lekang, O. I. (2013). *Aquaculture engineering* (2nd ed). Chichester, UK: Wiley.

Lennard, L. (2009). *Aquaponics: The integration of recirculating aquaculture and hydroponics*, *1*: 40 p. 23. World Aquaculture Communications.

Lennard, W. (2017). *Commercial aquaponic systems: Integrating recirculating fish culture with hydroponic plant production*.

Lennard, W. A. (2005). *Aquaponic integration of Murray Cod (Maccullochella peelii peelii) aquaculture and lettuce*

(*Lactuca sativa*) *hydroponics* [PhD Thesis]. Melbourne: RMIT University.

Lennard, W. A. and Leonard, B. V. (2005). A comparison of reciprocating flow versus constant flow in an integrated, gravel bed, aquaponic test system. *Aquaculture International*, *12*(6), 539–553.

Lennard, W. A., and Leonard, B. V. (2006). A comparison of three different hydroponic sub-systems (gravel bed, floating and nutrient film technique) in an aquaponic test system. *Aquaculture International*, *14*(6), 539–550.

Lennard, W. and Goddek, S. (2019). *Aquaponics: The basics hydroponic technologies, aquaponics food production systems.* 113–140.

Leonard, N., Blancheton, J. P. and Guiraud, J. P. (2000). Populations of heterotrophic bacteria in an experimental recirculating aquaculture system. *Aquacultural Engineering*, *22*(1–2), 109–120.

Love, D. C., and Tokunaga, K. (2015). Water use and economics of small-scale commercial aquaponics. https:. Retrieved from http://globalwaterforum.org/2016/05/23/water-use-and-economics-of-small-scale-commercial-aquaponics/

Love, D. C., Fry, J. P., Genello, L., Hill, E. S., Frederick, J. A., Li, X. and Semmens, K. (2014). An international survey of aquaponics practitioners. *PLOS ONE*, *9*(7), e102662.

Love, D. C., Fry, J. P., Li, X., Hill, E. S., Genello, L., Semmens, K. and Thompson, R. E. (2015). Commercial aquaponics production and profitability: Findings from an international survey. *Aquaculture*, *435*, 67–74.

Love, D. C., Uhl, M. S. and Genello, L. (2015b). Energy and water use of a small-scale raft aquaponics system in Baltimore, Maryland, United States. *Aquacultural Engineering*, *68*, 19–27.

Loyless, J. C. and Malone, R. F. (1998). Evaluation of air-lift pump capabilities for water delivery, aeration, and degasification for application to recirculating aquaculture systems. *Aquacultural Engineering*, *18*(2), 117–133.

Maher, M. J., Prasad, M. and Raviv, M. (2008). Organic soilless media components. In L. Raviv(Ed.), *Soilless culture, theory and practice. Elsevier, Amsterdam,* pp 459–504.

Mander, Ü., Tournebize, J., Kasak, K. and Mitsch, W. J. (2014). Climate regulation by free water surface constructed wetlands for wastewater treatment and created riverine wetlands. *Ecological Engineering*, *72*. http://, 103–115.

Martins, C. I. M., Eding, E. H., Verdegem, M. C. J., Heinsbroek, L. T. N., Schneider, O., Blancheton, J. P. and Verreth, J. A. J. (2010b). New developments in recirculating aquaculture systems in Europe: A perspective on environmental sustainability. *Aquacultural Engineering*, *43*(3), 83–93.

Maucieri, C., Barbera, A. C., Vymazal, J. and Borin, M. (2017). A review on the main affecting factors of greenhouse gases emission in constructed wetlands. *Agricultural and Forest Meteorology*, *236*, 175–193.

Maucieri, C., Forchino, A. A., Nicoletto, C., Junge, R., Pastres, R., Sambo, P. and Borin, M. (2018). Life cycle assessment of a micro aquaponic system for educational purposes built using recovered material. *Journal of Cleaner Production*, *172*, 3119–3127.

Maucieri, C., Nicoletto, C. and E. V. (2019). Os, D. Anseeuw, R. V. Havermaet, and R. Junge. *Hydroponic Technologies, Aquaponics Food Production Systems*, 78-107.

McMurtry, M. (1990). *Performance of an integrated aquaculture-olericulture system as influenced by component ratio. PhD* [Dissertation]. North Carolina State University.

McMurtry, M. R., Sanders, D. C., Cure, J. D. and Hodson, R. G. (1997a). Effects of biofilter/culture tank volume ratios on productivity of a recirculating fish/vegetable co-culture system. *Journal of Applied Aquaculture*, *7*(4), 33–51.

McMurtry, M. R., Sanders, D. C., Cure, J. D., Hodson, R. G., Haning, B. C. and Amand, E. C. S. (1997b). Efficiency of water use of an integrated fish/vegetable co-culture system. *Journal of the World Aquaculture Society*, *28*(4), 420–428.

McMurtry, M. R., Sanders, D. C., Patterson, R. P. and Nash, A. (1993). Yield of tomato irrigated with recirculating aquacultural water. *Journal of Production Agriculture*, *6*(3), 428–432.

Medina, M., Jayachandran, K., Bhat, M. G. and Deoraj, A. (2016). Assessing plant growth, water quality and economic effects from application of a plant-based aquafeed in a recirculating aquaponic system. *Aquaculture International*, *24*(1), 415–427.

Mishra, R. P., Das, S. K., Kumar, N. and Mishra, Jp. (2020). Sustainable aquaponics system and its challenges: A review. *International Journal of Current Microbiology and Applied Sciences*, *9*(5), 577–588.

Mohapatra, B. C., Sahoo, P. K., Chandan, N. K., Mahapatra, M., Panda, S. K., Majhi, D. and Pillai, B. R. (2021). *Rearing of Fish, Puntius gonionotus seed and Marigold, Tagetes patula Plant in NFT Aquaponics System for Economic Returns. Biological Forum – An International Journal, 13*(3), 444–449.

Moran, D. (2010). Carbon dioxide degassing in fresh and saline water. I: degassing performance of a cascade column. *Aquacultural Engineering*, *43*(1), 29–36.

Nichols, M. A. and Savidov, N. A. (2012). Aquaponics: A nutrient and water efficient production system. *Acta Horticulturae*, *947*(947), 129–132.

Noga, E. (2010). *Fish disease: Diagnosis and treatment* (2nd ed). Chichester, UK: Wiley.

Nuwansi, K. K. T., Verma, A. K., Prakash, C., Tiwari, V. K., Chandrakant, M. H., Shete, A. P. and Prabhath, G. P. W. A. (2016). Effect of water flow rate on polyculture of koi carp (*Cyprinus carpio* var. koi) and goldfish (*Carassius auratus*) with water spinach (*Ipomoea aquatica*) in recirculating aquaponic system. *Aquaculture International*, *24*(1), 385–393.

Pantanella, E., Cardarelli, M., Colla, G., Rea, A. and Marcucci, A. (2010). Aquaponic vs hydroponic: Production and quality of lettuce crop. *Acta Horticulturae* 927: 887-893.

Pantanella, E., Cardarelli, M., Danieli, P. P., MacNiven, A. and Colla, G. (2011). Integrated aquaculture – Floating agriculture: Is it a valid strategy to raise livelihood. *Acta Horticulturae*, *921*(921), 79–86.

Pantanella, E., Cardarelli, M., Di Mattia, E. and Colla, G. (2015). Aquaponics and food safety: Effects of uv sterilization on total coliforms and lettuce production. *Acta Horticulturae*, *1062*(1062), 71–76.

Pattillo, D. and Allen (2017). *An overview of aquaponic systems: Aquaculture components. NCRAC technical bulletins*. Retrieved from http://lib.dr.iastate.edu/ncrac_techbulletins/20, *20*.

Pickering, H. W., Menzies, N. W. and Hunter, M. N. (2002). Zeolite/rock phosphate – A novel slow release phosphorus fertiliser for potted plant production. *Scientia Horticulturae*, *94*(3–4), 333–343.

Prosser, J. I. (1989). Autotrophic nitrification in bacteria. *Advances in Microbial Physiology*, *30*, 125–181.

Pušnik, M., Sučić, B., Al-Mansour, F., Crema, L., Cozzini, M., Mahbub, S. and Kohlmaier, J. (2014). Framework for sustainability assessment of small and medium-sized enterprises. *Chemical Engineering Transactions*, *42*, 121-126.

Rakocy, J. E. (1989). *Vegetable hydroponics and fish culture, a productive interface* p. 20: 42-47. World Aquaculture Communications.

Rakocy, J. E. (2003). Aquaponics d integrating fish and plant culture. In *Aquaculture Production Systems* 343, Chapter14,

Rakocy, J. E. (2012). Aquaponics-integrating fish and plant culture. pages 344–386. *Aquaculture production systems*. Wiley-Blackwell.

Rakocy, J. E.,and Hargreaves, J. A. (1993). Integration of vegetable hydroponics with fish culture: A review. In J. Wang(Ed.), *Techniques for modern aquaculture*. American Society of Agricultural Engineers.

Rakocy, J. E., Bailey, D. S., Shultz, R. C. and Danaher, J. J. (2011). A commercial scale aquaponic system developed at the University of the Virgin Islands. In *Proceedings of the 9th International Symposium on Tilapia in Aquaculture*.

Rakocy, J. E., Bailey, D. S., Shultz, R. C., Thoman, E. and Thoman, S. (2004a). Update on tilapia and vegetable production in the UVI aquaponic system. In *New dimensions on farmed tilapia*. *Proceedings of the Sixth International Symposium on Tilapia in Aquaculture, Manila*, 676-690 pp.

Rakocy, J. E., Masser, M. P. and Losordo, T. M. (2006). *Recirculating aquaculture tank production systems: Aquaponics- integrating fish and plant culture* p. 454: 16. SRAC Publication—Southern Regional Aquaculture Center.

Rakocy, J. E., Masser, M. P. and Losordo, T. M. (2006). *Recirculating aquaculture tank production systems: Aquaponics – Integrating fish and plant culture*. SRAC Publication No. 454. Southern Regional Aquaculture Center.

Rakocy, J. E., Masser, M. P. and Losordo, T. M. (2006). Recirculating aquaculture tank production systems: Aquaponics- integrating fish and plant culture. SRAC Publ. – South. *Reg. Aquac. Cent*, *16*.

Rakocy, J. E., Shultz, R. C., Bailey, D. S. and Thoman, E. S. (2004b). Aquaponic integration of tilapia and Basil: Comparing a batch and staggered cropping system. *Acta Horticulturae*, *648*, 63-69.

Randall, D. J. and Tsui, T. K. N. (2002). Ammonia toxicity in fish. *Marine Pollution Bulletin*, *45*(1–12), 17–23.

Randall, E. B. and Barry, C. P. (2002). Village-based aquaculture ecosystems as a model for sustainable aquaculture development in sub-Saharan Africa. In *Ecological aquaculture: The evolution of the blue revolution (Oxford UK; Malden MA: Blackwell science) 153,* 145 p.p.

Resh, H. M. (2013). *Hydroponic food production* (7th ed). Boca Raton, FL: CRC Press.

Rojas-Tirado, P., Pedersen, P. B. and Pedersen, L. F. (2017). Bacterial activity dynamics in the water phase during start-up of recirculating aquaculture systems. *Aquacultural Engineering*, *78*, 24–31.

Rusten, B., Eikebrokk, B., Ulgenes, Y. and Lygren, E. (2006). Design and operations of the Kaldnes moving bed biofilm reactors. *Aquacultural Engineering*, *34*(3), 322–331.

Schreier, H. J., Mirzoyan, N., and Saito, K. (2010). Microbial diversity of biological filters in recirculating aquaculture systems. *Current Opinion in Biotechnology*, *21*(3), 318–325.

Schroeder, J. P., Croot, P. L., Von Dewitz, B. V., Waller, U. and Hanel, R. (2011). Potential and limitations of ozone for the removal of ammonia, nitrite, and yellow substances in marine recirculating aquaculture systems. *Aquacultural Engineering*, *45*(1), 35–41. Sharrer, M. J., Summerfelt, S. T., Bullock, G. L., Gleason, L. E. and Taeuber, J. (2005). Inactivation of bacteria using ultraviolet irradiation in a recirculating salmonid culture system. *Aquacultural Engineering*, *33*(2), 135–149.

Shete, A. P., Verma, A. K., Chadha, N. K., Prakash, C., Peter, R. M., Ahmad, I. and Nuwansi, K. K. T. (2016). Optimization of hydraulic loading rate in aquaponic system with Common carp (*Cyprinus carpio*) and Mint (*Mentha arvensis*). *Aquacultural Engineering*, 72–73, 53–57.

Somerville, C., Cohen, M., Pantanella, E., Stankus, A. and Lovatelli, A. (2014). Small-scale aquaponic food production: Integrated fish and plant farming. Rome, Italy. In *FAO fisheries and aquaculture technical paper food and agriculture organization of the United Nations*.

Sonneveld, C. and Voogt, W. (2009). *Plant nutrition of greenhouse crops. Springer.* 40 p.p.

Steiner, A. A. (1961). A universal method for preparing nutrient solutions of a certain desired composition. *Plant and Soil*, *15*(2), 134–154.

Steiner, A. A. (1984). The universal nutrient solution. In Proceeding 6th International congress on soilless culture. ISOSC. *633–649 p.p.*

Suhl, J., Dannehl, D., Kloas, W., Baganz, D., Jobs, S., Scheibe, G. and Schmidt, U. (2016). Advanced Aquaponics: Evaluation of intensive tomato production in aquaponics vs conventional hydroponics. *Agricultural Water Management*, *178*, 335–344.

Summerfelt, S. T. (2003). Ozonation and UV irradiation – An introduction and examples of current applications. *Aquacultural Engineering*, *28*(1–2), 21–36.

Summerfelt, S. T. (2006). Design and management of conventional fluidized-sand biofilters. *Aquacultural Engineering*, *34*(3), 275–302.

Summerfelt, S. T. and Hochheimer, J. N. (1997). Review of Ozone processes and applications as an oxidizing agent in Aquaculture. *Progress Fish-Culturist*, *59*, 94-105.

Summerfelt, S. T., Davidson, J. W., Waldrop, T. B., Tsukuda, S. M. and Bebak-Williams, J. (2004). A partial-reuse system for coldwater aquaculture. *Aquacultural Engineering*, *31*(3–4), 157–181.

Summerfelt, S. T., Sharrer, M. J., Tsukuda, S. M. and Gearheart, M. (2009). Process requirements for achieving full-flow disinfection of recirculating water using ozonation and UV irradiation. *Aquacultural Engineering*, *40*(1), 17–27.

Summerfelt, S. T., Zühlke, A., Kolarevic, J., Reiten, B. K. M., Selset, R., Gutierrez, X. and Terjesen, B. F. (2015). The effects of alkalinity on ammonia removal, carbon dioxide stripping, and pH in semicommercial scale water recirculating aquaculture systems operated with moving bed bioreactors. *Aquacultural Engineering*, *65*, 46–54.

Tal, Y., Watts, J. E. M. and Schreier, H. J. (2006). Anaerobic ammonium-oxidizing (anammox) bacteria and associated activity in fixed-film biofilters of a marine recirculating aquaculture system. *Applied and Environmental Microbiology*, *72*(4), 2896–2904.

Timmons, M. B. and Ebeling, J. M. (2010). *Recirculating aquaculture* (2nd ed) Cayuga Aqua Ventures. Ithaca.

Timmons, M. B., Ebeling, J. M., Wheaton, F. W., Summerfelt, S. T., and Vinci, B. J. (2002). *Recirculating aquaculture systems* (2nd ed) Cayuga Aqua Ventures, Ithac.

Tokunaga, K., Tamaru, C., Ako, H. and Leung, P. (2015). Economics of small-scale commercial aquaponics in Hawai'i. *Journal of the World Aquaculture Society*, *46*(1), 20–32.

Turnšek, M., Morgenstern, R., Schröter, I., Mergenthaler, M., Hüttel, S. and Leyer, M. (2019). Commercial aquaponics: A long road ahead BT – Aquaponics food production systems: Combined aquaculture and hydroponic production technologies for the future. In S. Goddek, A. Joyce, B. Kotzen and G. M. Burnell(Eds.), *Aquaponics food production systems* (pp. 453–485). https:. Cham, Germany: Springer International Publishing.

Tyson, R. V., Treadwell, D. D. and Simonne, E. H. (2011). Opportunities and challenges to sustainability in aquaponic systems. *HortTechnology*, *21*(1), 6–13.

Van Os, E. A., Gieling, T. H. and Lieth, J. H. (2008). Technical equipment in soilless production systems. In L. Raviv(Ed.) Soilless culture, *Theory into practice*. Amsterdam: Elsevier. 157-207 pp.

van Rijn, J. (2013). Waste treatment in recirculating aquaculture systems. *Aquacultural Engineering*, *53*, 49–56.

van Rijn, J., Tal, Y. and Schreier, H. J. (2006). Denitrification in recirculating systems: Theory and applications. *Aquacultural Engineering*, *34*(3), 364–376.

Verwer, F. L. J. A. (1978). Research and results with horticultural crops grown in rockwool and nutrient film. *Acta Horticulturae*, *82*(82), 141–148.

Villarroel, M., Junge, R., Komives, T., König, B., Plaza, I., Bittsánszky, A. and Joly, A. (2016). Survey of aquaponics in Europe. *Water*, *8*(10), 3–9.

Wagner, E. J., Bosakowski, T. and Miller, S. A. (1995). Evaluation of the absorption efficiency of the Low Head Oxygenation System. *Aquacultural Engineering*, *14*(1), 49–57.

Wallach, J. (2008). Physical characteristics of soilless media. In L. Raviv(Ed.) Soilless culture, *Theory into practice*. Amsterdam: Elsevier.41-116 pp.

Wikzjedia and the Free (2011). Engclopedia. *Chinampa. Wikipedia.* Retrieved from http://en.wikipedia.org/wiki/Chinampa

Wold, P. A., Holan, A. B., Øie, G., Attramadal, K., Bakke, I., Vadstein, O. and Leiknes, T. O. (2014). Effects of membrane filtration on bacterial number and microbial diversity in marine recirculating aquaculture system (RAS) for Atlantic cod (*Gadus morhua* L.) production. *Aquaculture*, 422–423, 69–77.

Yixian, G. (2001). Ricefish systems in China. Integrated agriculture-aquaculture: A primer, FAO fisheries technical Paper. In p. 72: 407 pp. Rome: Food and Agriculture Organization.

Yogev, U., Sowers, K. R., Mozes, N. and Gross, A. (2016). Nitrogen and carbon balance in a novel near-zero exchange saline recirculating aquaculture system. *Aquaculture*, *467*, 118-126.

Zhu, S. and Chen, S. (2002). The impact of temperature on nitrification rate in fixed film biofilters. *Aquacultural Engineering*, *26*(4), 221–237.

Zou, Y., Hu, Z., Zhang, J., Xie, H., Liang, S., Wang, J. and Yan, R. (2016a). Attempts to improve nitrogen utilization efficiency of aquaponics through nitrifies addition and filler gradation. *Environmental Science and Pollution Research International*, *23*(7), 6671–6679.

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