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Review Article

Phytopathogen Biocontrol In Aquaponics Systems.

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Abstract

An alternate approach to food production that offers the benefits of both economic and biological resource protection is aquaponics. However, the emergence and spread of infections may be one of the primary challenges associated with aquaponics systems. Because conventional therapies have the potential to harm humans, fish, plants, and beneficial microorganisms, they must be administered cautiously. When plant diseases arise, aquaponics practitioners are comparatively defenseless against them, particularly when it comes to root pathogens. In aquaponics systems, biological control agents (BCAs) could be a useful substitute for chemical inputs in the fight against plant diseases. Although there is little research on BCAs in aquaponics systems, many articles on their application in soilless plant disease control demonstrate the promise of BCAs in aquaponics systems. The primary plant pathogens, conventional and alternative BCA treatments for aquaponics systems, and related research on aquaculture and soilless (i.e., hydroponic) systems for their applicability to aquaponics as well as future perspectives on biological control were all summarized in this review. Lastly, we underlined the point that research on plant biological control agents has a largely unrealized potential thanks to aquaponics systems. The disruption effects of traditional treatments on microbial populations, fish and plant physiology, and the overall operation of the aquaponics system may be lessened by biological management.

Keywords : *Plant protection, soilless systems, aquaponics, phytopathogens, and biocontrol.*

INTRODUCTION

By 2050, the population is expected to have grown to 10 billion [1]. Production must rise by 50% to meet the world's food needs [1]. Regrettably, this need will be impacted by elements including pollution, climate change, and the limited amount of arable land, water, and mineral nutrients that are accessible [2,3]. The United Nations (UN) General Assembly presented "The 2030 Agenda for Sustainable Development" in an attempt to avert these situations, coming to the conclusion that systems of intensive food production must give way to sustainable ones [4]. Aquaponics is a different approach to food production that mixes the cultivation of plants and fish. technology by offering resource benefits, as well as economic and biological preservation [5].

It is an environmentally friendly and healthful method of producing food, which has prompted research into a wide range of topics [6]. Regarding output and profitability, aquaponics has been contrasted with hydroponic [9–12] and aquaculture [2,7,8] methods. Sustainability [13–15], economic optimization [16–18], functional setup [19,20], stocking density [21,22], cultivation media [23,24], water recirculation [25,26], food safety [9,27], fish-plant pathogens [6,28], and beneficial microorganisms [29,30] have been the main topics of aquaponics research up to this point.

It has recently been shown that improving the entire aquaponics system requires a thorough understanding of the hydroponic subsystem [31]. The potential spread of pathogens is one of the primary challenges associated with aquaponics systems [6], as water recirculation and carefully regulated variables like temperature create the ideal conditions for pathogen growth [28]. Evidence of prior outbreaks in hydroponics and aquaculture demonstrates the effects of such occurrences. 40% of Barramundi fish died from Streptococcus iniae [32], and 100% of the plantation became infected with Pythium aphanidermatum after three days of inoculation in a hydroponic cucumber [33]. Because of the large initial investment cost, such outbreaks could destroy an entire crop or possibly lead to the collapse of the entire production system [34].Depending on the technique, disinfecting water at different stages of aquaponics systems is the primary means of controlling diseases [6]. Aquaponics and hydroponics systems have used both chemical and non-chemical disinfection techniques to eradicate microorganisms from the recirculating water [6,28]. These techniques must be used with caution, though, as they may be detrimental to fish, plants, humans, and helpful microbes [35]. As of right now, no pesticide or biopesticide has been created especially

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for aquaponics systems [6,28,35,36]. Inorganic chemicals that could be utilized in aquaponics to combat fungi were mentioned by Somerville et al. [36]. Nevertheless, "at the moment aquaponics practitioners operating a coupled system are relatively helpless against plant diseases when they occur, especially in the case of root pathogens," according to Stouvenakers et al. [28].

As stated earlier, one of the research topics on aquaponics systems depends on helpful microorganisms; nevertheless, the majority of these studies have concentrated on either plant growth promoters rhizobacteria (PGPR) [35,38,39] or nitrifying bacteria [24,30,37]. When it comes to controlling plant diseases in aquaponics systems, biological control agents (BCAs) could be a useful substitute for chemical inputs [40]. As a result, there is a chance to collaborate with BCAs to address the following issues: (i) plant disease in aquaponics systems due to the sparse application of chemical treatments; (ii) the initial production cost; and (iii) the expansion of the entire aquaponics food production system [28]. Although there isn't much study on BCAs in aquaponics systems, there have been more publications in recent years [28, 40]. The employment of BCAs (microorganisms or their compounds) as antagonists to control plant disease is known as biological control [44]. The current review's objectives were to provide an overview of the main plant diseases, conventional and alternative BCA treatments for aquaponics systems, and future perspectives on biological control while taking into account related research on aquaculture and soilless systems (like hydroponics) for its applicability to aquaponics. Lastly, we highlighted the argument that research on plant biological control agents has a largely unrealized potential thanks to aquaponics systems.

OVERVIEW OF AQUAPONICS SYSTEM DESCRIPTION

By exchanging water and nutritional resources between fish and plant subsystems, current aquaponics has been centered on sustainable practices since its inception in the 1970s [2,45,46]. The complicated system known as aquaponics combines the subsystems of hydroponics, which grows plants in soilless media, with aquaculture, which raises fish in tanks [2]. A fish tank connected to a hydroponics unit that is connected back to the fish tank forms a recirculating system, which is the most basic form of the aquaponics system [7].

Other parts including biofilters, water clarifiers, and pumps are also incorporated, depending on the system's design and performance [36]. After the fish digest their food, the Microbial communities convert waste and excrement, making nutrients available to plants while also purifying water and recycling nutrients [31]. The entire system is briefly explained in this study because aquaponics requires more technical expertise than hydroponics and aquaculture to maintain equilibrium among all system components and, in particular, to prevent plant pathogen illnesses [2].

Two criteria are used to categorize aquaponics systems: (1) the technology utilized to cultivate plants and fish, and (2) the coupling or uncoupling subsystems [36]. Generally speaking, aquaponics systems operate as follows: fish are raised in tanks made of various materials, such as concrete, fiberglass, and plastic [47].

While bio-filters expand the area for the growth of beneficial bacteria that convert ammonia (NH3 −) and nitrite (NH2 −) into nitrates (NO3 −) to detoxify water for fish and assimilate available nitrogen for plants, mechanical filters retain the majority of the solids dissolved in water to prevent the formation of biofilm that could reduce the oxygen available to plant roots [36]. In the end, the water either returns to the aquaculture subsystem (coupled subsystem) or is discharged and/or used as irrigation water in conventional crops (uncoupling subsystem) after plants absorb the nutrients from the water, lowering the concentrations of dissolved solids and ions [35].

As previously said, the aquaponics plant modules are categorized based on the growth technology. The rising technology type will be closed in reference to the overall production goal [48]. Three technologies are used in plant cultivation: media bed units, deep water culture, and nutrient film technology (NFT) [49]. The two most often used production technologies are NFT and DWC [50].

AQUAPONICS SYSTEMS AND PLANT DISEASE

Source of Inoculum

The foundation of aquaponics is the recirculation of water throughout the system, creating ideal conditions for the spread of pathogens [6]. Since water circulates across all subsystems, transports nutrients, and affects the growing environment for fish, plants, or microbes, it is a crucial component of the overall aquaponics system [2]. Microbial pathogens that affect fish, plants, and even human health can be found in water sources. For example, rainwater used to be free of microbes, but storage conditions may have allowed them to proliferate. Depending on the source area, such as animal husbandry and human waste treatment, ground and river water may also contain microbial pathogens [31]. When a plant pathogen is spread by an inoculum source—that is, when sick plants release the pathogens, which are then absorbed by healthy plant roots—this is known as waterborne dispersion [51]. Furthermore, virus shedding and survival capacity in the circulating water are linked to the rate of spread [6].

Reusing growing media, dust particles, insects, rodents, and humans—such as clothing, tools, and handling—could all be additional sources of inoculum [52,53].

Phytopathogen Proliferation-Related Factors

The growth of phytopathogens in aquaponics has been linked to a number of elements, including environmental parameters, the pathogens' ability to infect plants, and plant resistance mechanisms. To maximize productivity, plants are bred under carefully monitored conditions in aquaponics systems [53]. However, phytopathogens might take advantage of these regulated circumstances [28].

Plant cultivation density, abundant nutrient availability, and warm, humid conditions all promote the growth of microorganisms, especially fungal phytopathogens, which spread swiftly through the release of zoospores into recirculating water and result in significant die-offs, including Phytophthora and Pythium species [54]. Infected materials, mechanical wounds, infected equipment, vectors, and particles can spread other bacteria, viruses, and fungus [55]. In addition to being a crucial factor in preserving the physiological growth of fish and plants, the temperature of recirculating water has been shown to encourage the growth of phytopathogens, such as Phytium spp. caused 100% mortality on spinach grown in a hydroponic system at 30°C and 69% mortality on spinach grown at 20°C, respectively [56]. Temperatures that are ideal for the growth of phytopathogens are linked to variations in disease severity [6]. While damage is not a significant factor in soilless systems, it is a factor in conventional agriculture that promotes the colonization of phytopathogens, leading to worse disease outcomes [57].

Inoculum density, exposure duration, and phytopathogen viability time are all factors that are directly associated to phytopathogens [6]. The phytopathogens have a greater chance of colonizing roots when exposed for longer periods of time and at higher concentrations [58]. Different phytopathogens have different rates of survival in soilless environments; for example, tobacco mosaic virus (TMV), potato virus, and pepino mosaic virus can all live for longer than five to twenty-one days [51,59]. The pathogen concentration and plant mortality rate have a favorable dose-response relationship [58].

Following phytopathogen contact with the plant, a number of plant resistance-related cases could arise: Plant-sensitive means that the pathogen infects the plant but does not cause severe symptoms; incompatible means that disease does not develop; tolerance means that there is a host-plant relationship but the plant does not exhibit symptoms; resistance means that the pathogen and plant are compatible but defense mechanisms prevent the disease progression; and severe disease means that symptoms could kill the plant [60].

The Most Typical Plant Pathogens

Numerous phytopathogens, including bacteria, viruses, fungi, and parasites, can harm plants grown in soilless systems like aquaponics. Due to the constant presence of water, plant diseases in aquaponics systems may resemble those in hydroponics [28]. The most frequent diseases studied on plants like tomatoes and cucumbers were oomycetes and viruses [31].

The most prevalent plant root diseases are oomycetes, Pythium and Phytophthora, which are well suited to humid and aquatic environments [28]. These oomycetes can spread by moving freely in aquatic conditions thanks to a motile component called a zoospore [61]. The genera Thielaviopsis, Rhizoctonia, Colletotrichum, and Fusarium may be opportunistic phytopathogens [52,62]. In a hydroponic system with recirculating water, tobacco mosaic virus can live for almost five days [59].

For one, three, and seven weeks, the potato virus, mosaic virus, and potato spindle tuber virus are still contagious [51].

It is crucial to note that, in certain soilless plant diseases, the causative agent is still unknown due to a lack of technical understanding of phytopathology [31,63]. Additionally, there is cross-contamination between aquaponics and phytopathogens; for example, Gilbertella persicaria is a phytopathogen that has the potential to seriously harm and kill black tiger shrimp (Penaeus monodon) [64].

There have also been reports of interspecies transmission, such as Colletotrichum coccodes spreading from an eggplant co-culture to tomatoes [65]. Shrimp may potentially be infected by plant pathogens [66]. The findings of the first worldwide assessment on plant disease in aquaponics systems that affected practitioner members of the European Union (EU) Aquaponics Hub, the American Aquaponics Association, and COST FA1305 were compiled by Stouvenakers et al. [28]

Typical Defense Against Phytopathogens

Since no pesticide or biopesticide has been created especially for aquaponics use, practitioners today have few options for protecting plants [36,40,67]. By lowering the inoculum, the concentration of phytopathogens, and their growth, disinfecting the water is one way to manage illness [6]. Depending on the technique, disinfection can be used in a variety of system components. There are two categories of conventional procedures: chemical methods like ozonation and chlorination, and physical treatments like heat, sonication, media filtration, and ultraviolet (UV) irradiation. However, techniques of disinfection may harm fish, plants, and other beneficial microorganisms which cohabit in the system, or even human health, so their use must be limited [35].

Physical Disinfection Methods

Agents that do not depend on chemical or biological control agents are referred to as physical disinfection approaches [6]. These techniques lower the concentration of phytopathogens, although they are ineffective.when the plant disease is already present [28]. UV disinfection is the most researched technique for soilless production systems, claim Mori et al. [6]. Recirculating water is subjected to light with a wavelength of 225–312 nm in the UV technique [68]. These treatments work by impairing the replication of DNA [69]. The energy per unit area over a duration of exposure determines inactivation with UV, and this is generally stated in mJ/cm2 [70]. More than 95% of Pythium spp. can be eradicated by UV irradiation at levels of 250 to 300 mJ/cm2 hydroponics [71]. Too many variables, including the device being utilized, light reflection, refraction, intensity, exposure duration, and the presence of particulate matter, affect dosage and outcomes [6,72]. Furthermore, there are species-specific and strain-specific variations in phytopathogen sensitivity to UV [72]. To stop phytopathogens from recirculating, media filters could be placed either before or after production tanks [6]. Particles from the recirculating water are retained during slow filtration, a mechanical and biological process in which waterborne microorganisms interact with filter-growing microorganisms [73]. Slow filtration techniques' two main drawbacks are their limited flow rates, which are insufficient for big production systems, and the layer that is created by the deposition of suspended materials [6]. More than 95% of infections, including Phytophthora, Pythium, and Fusarium species, have been eliminated by media filtering [74–76].

Research on filter bed depth, flow rate, grain size, and material density is lacking, making it challenging to reproduce the findings [6]. When tested for their ability to eradicate the phytopathogen Xanthomonas campestri, rockwool outperformed sand, anthracite, and pumice [77]. 40 cm of sand was more successful than 20 cm of sand at eliminating 100% and >98% of oomycetes, respectively [78]. Additionally, the depth is dependent on the size of the particles; for instance, it was discovered that a 0.8 m big sand filter with pore sizes of ≤0.8 mm did not infect the inoculated Phytophthora cinnamonomi [79]. One crucial factor is how long the microorganisms in the filter take to mature.

Heat deactivates phytopathogens by denaturing their proteins. When the recirculating water is transferred to a different tank and heated to a specific temperature for a while, this treatment is used [80]. Following 48 to 95 °C for 0.5 to 5 minutes of heat exposure or water recirculation, Pythium species, Fusarium oxysporum, tomato mosaic virus, and Radopholus similis were rendered inactive [80–82]. However, some research revealed that lower temperatures are enough without extending exposure times. Heating the water in a hydroponics system to 60 °C for one minute decreased Pythium aphanidermatum root damage by more than 95% [83]. More study is needed to show that heat treatment may eradicate plant and fish diseases in soilless systems. Cavitation is the mechanism by which cells collapse during sonication when a probe transmits high-frequency probes (2040 KHz) into the nutritional solution to create low-pressure pockets inside the cells [84]. In vitro and in vivo small solution experiments show that sonication efficiently deactivates plant pathogens such as P. aphanidermatum [81,83]. When used in combination, sonication at 25 KHz and UV at 40 mJ/cm2 did not outperform UV treatment in terms of killing Anguillicoloides crassus and P. aphanidermatum [84]. The effectiveness of sonication in large-scale production systems with hundreds of liters of effluent solution, as well as the frequency and exposure durations, are still unknown.

Chemical Treatments

Before continuing the recirculating process, ozone (O3) is injected into the stored water for a while. It reacts with iron chelate and damages cell viability [85]. All phytopathogens can be eradicated with an ozone treatment lasting 1 to 10 hours per m3 [86]. Additionally, in a soilless vegetable growing system, ozone treatment decreased the microbial population [87]. However, as ozone can harm mucosal membranes, human exposure should be avoided [85].

An oxidizing chemical called hydrogen peroxide (H2O2) interacts to produce oxygen radicals and water. Commercially available activators, such as formic acid and acetic acid, lower the pH of the nutrient solution to encourage the reaction [85]. It is a cheap, ineffective technique that works better for cleaning than disinfection. Although Pythium spp., Fusarium spp., and other fungi can be effectively controlled with doses of 0.01 to 0.005%, larger concentrations have been shown to be detrimental to plant roots [88].There are numerous commercial names for the chemical compound sodium hypochlorite (NaOCl).It is commonly used and reasonably priced for treating water, particularly in swimming pools [85]. It combines with water to produce Cl− and O+, which strongly oxidizes any organic molecule. Climate affects how sodium hypochlorite reacts chemically; for instance, high temperatures and air contact trigger quick breakdown, producing NaClO3 [89]. Sodium hypochlorite works well against many pathogens; for example, 15 mg Cl L−1 over two hours decreased 90–99% of Fusarium oxysporum. However, it is ineffective against viruses, and rising Na+ and Cl− concentrations impair growing systems' productivity [85].

Preventive Treatments

However, a poll of members of the EU Aquaponic Hub indicates that further research is needed in the field of managing certain plant pests in aquaponics systems [63]. The type of system (coupled or decoupled) will determine which choice is best [28]. Due to the existence of microbial communities, certain chemical products (pesticides and chemical disinfection agents) may be permitted but not encouraged if the water does not return to the fish section following plant root circulation [28]. As previously stated, no particular chemical products, such as insecticides or biopesticides, have been created especially for aquaponics [40,67,90]. Aquaponics systems therefore primarily encourage preventive rather than curative treatments.

Within aquaponics systems, there are good agricultural practices (GAPs) that limit and stop phytopathogen growth or spread [91]. GAPs aim to prevent or restrict the spread of phytopathogens by limiting the inoculum's entrance [28]. Certain clothing, certified seeds, a germination room, and physical barriers are required to restrict the entry of the inoculum by measures including room sanitization (i.e., the removal of plant waste) [36]. Actions such as choosing resistant plant kinds, disinfecting to prevent plant stress, maintaining healthy plant densities, and environmental management should be encouraged in order to restrict and/ or prevent the spread of phytopathogens [28].

Aquaponics Using Biological Control as an Alternative Therapy

Nitrifying bacteria [29] and plant growth boosters [35] have been the main subjects of research on adding microorganisms to aquaponics systems. Because traditional therapies are ineffective against phytopathogens grown in aquaponics, research on biological control agents is required [36, 40].

Furthermore, nothing is known about biological control agents that combat phytopathogens in aquaponics [28]. Antagonistic microorganisms known as biological control agents restrict or halt the growth of fungal phytopathogens [92].For the purpose of inhibiting Pythium ultimum, Sirakov et al. [40] screened bacterial isolates from various aquaponics system compartments. 86 of the 964 bacterial isolates that were examined shown efficacy as P. ultimum antagonists in vitro. More investigation is required to assess the isolates' in vivo potential and identify them at the species level for the Bacillus and Pseudomonas genera.

The most often researched biological control agents in hydroponics systems are Pseudomonas species [28]. Pseudomonas species linked to lettuce plant roots may have been chosen for their innate activity as potential biological control agents, according to Schmautz et al. [29]. Bacillus and Pseudomonas species may be able to manage phytopathogens in soilless systems through modes of action like as space, nutrition compaction, and resistance induction

Aquaponics systems may benefit from and be applicable to numerous studies on biological control agents against plant diseases in soilless and hydroponic systems [28]. Microbial antagonists are chosen based on their biological cycle or capacity to proliferate in water [54].

Pythium species, Fusarium species, Pseudomonas species, Bacillus species, and Lysobacter species are the most frequently found in literature [35,54,96]. Nonetheless, studies are still being conducted to identify more effective antagonists and strategies to increase their effectiveness [44]. As a substitute for plant disease control, secondary metabolites such as bio-surfactants have been investigated [97,98]. The range of activity and efficacy of individual treatments may be expanded by the combination of appropriate microbial antagonists [92,99].

How Microbial Communities Help Aquaponics Suppress Phytopathogens

Because of their function in nutrient recycling, organic matter breakdown, illness treatment, and disease control, microbial populations are crucial to aquaponics systems [100]. Although microbial diversity in aquaponics systems is dependent on the availability of nutrients and the environmental conditions, it generally falls into one of the following bacterial groups: actinobacteria, alpha-proteobacteria, beta-proteobacteria, gamma-proteobacteria, firmicutes, bacteriodetes, and archaea (Table 3) [101–103].

As previously indicated, aquaponics systems can consist of a variety of components, making the study of microbial populations and their variations among compartments an intriguing area of research [36]. The microbial communities of fish feces from the genus Cetobacterium in the biofilter were primarily composed of nitrification bacteria, but there were also trace amounts of periphyton or plant roots, according to Schmautz et al. [29]. By encouraging nutrient uptake, accelerating plant growth, and serving as an antagonist against phytopathogens, microorganisms in the medium interact with plant roots [104,105].

Because aquaponics systems are not sterilized, a natural ecosystem is created in which microflora interact with other living things and with one another. Fish and plants in the system are not harmed by this microflora because it promotes a space-nutrient competition that prevents any one pathogen microbe from dominating [2]. The presence of fish, plants, and microorganisms in the same aquatic environment is generally thought to have a synergistic effect on the system as a whole [106]. The majority of studies on microbial communities in aquaponics systems have concentrated on either promoting plant development [35] or nitrifying bacteria [29]. Microbial communities' ability to inhibit diseases such as Phytophthora cryptogea in soilless environments was examined by Postma et al. [42] and Vallance et al. [62].

Future Perspectives

In Soilles Systems, Biological Control

Understanding the relationships between biological control agents, phytopathogens, and plant roots may be possible through research on biological control in soilless systems like aquaponics. Although biological control agents have been extensively studied, it is challenging to determine the underlying mechanisms from soil-based research [107]. Soil is chemically complicated, and microbial diversity in soil matrix is diverse [108]. The technology to investigate this interaction is limited by the soil matrix; that is, studies based on the soil matrix rely on DNA extraction and subsequent sequence-based analysis, which leaves out the investigation of the structure of the microbial community [109], genetic data regarding the flux of nutrients [110], and microbial screening of potential biological control agents [111]. Aquaponics systems, on the other hand, function within regulated parameters (temperature, pH, and nutrient concentrations), and its matrix is not overly complicated. [35] Aquaponics and other soilless systems are hence scalable, reproducible, and adaptable labs where outcomes are likely to be technologically transferred [35].

In addition to other bacterial isolates from the aquaponics system, the researchers found that Pseudomonas spp. worked well as a biological control agent against the phytopathogen Pythium ultimum and the fish pathogen Saprolegnia parasitica.

In contrast to fish-plant pathogens, mixed treatment

Fish and plants may both benefit from manipulating biological control agents due to the overlap between the rhizosphere and fish gut microbiomes [112]. Numerous studies have been conducted on Bacillus species as biological control agents in hydroponics and probiotics in aquaculture [113]. Bacillus species have been used in aquaponics systems as nutrient fixers and plant growth promoters in tilapia-lettuce production systems [39]. Research on how to demonstrate that microorganisms used in aquaculture subsystems that assist fish would also benefit plant development and health, and vice versa, is still lacking. Determining the inoculum site—that is, whether it is in a fish production tank, plant roots, nutrient solution, or bio-filters—is also crucial [30]. In order to demonstrate their inhibitory effect on fish and plant diseases, Sirakov et al. [40] screened bacterial isolates from several aquaponics system compartments.

Omic Technologies

Future research on microbial communities in aquaponics systems will rely on omics technologies such as metagenomics and metatranscriptomics analysis [114]. New methods for assessing microbial diversity and a deeper comprehension of interactions within bacterial communities are revealed by recent research that relies on 16S rRNA and functional gene-specific probes or libraries rather than culture techniques [115]. In order to investigate these microbiotas, other developments in eukaryotes, fungi, and yeast rely on 18S, 26S, and 16S rRNA fragments [116]. It has been shown that changes in influent water, such as C/N ratios and bio-filter performance, are related to the dynamics and adaptability of microbial communities [117]. Studying and managing the microbial community is still challenging [118–120], and many of these challenges may be caused by the previously listed reasons [121]. The influence of microbial populations on plant roots, growth, and health in aquaponics systems is currently little understood.

Lack of knowledge restricts the systems' ability to function efficiently and enhance the overall system's health by providing a particular comprehension of the various interactions among living things [30].

CONCLUSIONS

To enhance their management and treatment, further research is required on the various phytopathogens that impact many plants grown in aquaponics systems. Research on bacteria is scarce, particularly on how the microbiota interacts with the various system compartments.

In aquaculture systems, microbial communities support plants in a variety of ways that would not be possible in conventional hydroponic cultures where the water is sterilized. The use of conventional therapies in soilless environments must be restricted since they may harm fish, plants, and beneficial microbes that coexist there. The structure of microbial communities, metabolic processes, and relationships may be clarified by "omics" techniques, which would improve the identification of strains and their metabolites for particular uses. The disruption effects of traditional treatments on microbial populations, fish and plant physiology, and the overall operation of the aquaponics system may be lessened by biological management.

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