Aquaponics

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Aquaponics is an alternative method of food production that confers advantages of biological and economic resource preservations. Nonetheless, one of the main diculties related to aquaponics systems could be the outbreak and dissemination of pathogens. The present review summarized the principal plant pathogens, the conventional and alternative BCA treatments on aquaponics systems, while considering related research on aquaculture and soilless systems (i.e., hydroponic) for its applicability to aquaponics and future perspectives related to biological control.

Keywords: aquaponics ; soilles systems ; plant protection ; phytopathogens ; biocontrol

1. Introduction

The growing population projected in 2050 will be of 10 billion people [1]. To supply global food demand, production will need to increase by 50% [1]. Unfortunately, this demand will be affected by factors such as climate change, pollution, and the available resources i.e., arable land, available water and mineral nutrients which are finite [2][3]. Trying to prevent these scenarios, the General Assembly of the United Nations (UN) presented "The 2030 Agenda for Sustainable Development", concluding that there is a need to change from intensive food production systems towards sustainable ones [4]. Aquaponics is an alternative method of food production that combines fish and plant growing technologies by conferring advantages of resources, and biological and economic preservation [5]. It is a healthy and environmental option for food production which has encouraged research into many different aspects [6]. Aquaponics has been compared with aquaculture [2][7][8] and hydroponic [9][10][11][12] technologies in terms of production and profitability. Up to now, the research on aquaponics has been focused on sustainability [13][14][15], economic optimization [16][17][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].

Recently, it has been demonstrated that a complete understanding of the hydroponic subsystem is essential to improving the whole aquaponics system [31]. One of the main difficulties related to aquaponics system is the potential dissemination of pathogens [6], because water recirculation and controlled parameters such as temperature provides the perfect environment for pathogen proliferation [28]. Evidence of previous outbreaks in aquaculture and hydroponics shows the consequences of such events. Streptococcus iniae caused 40% mortality on Barramundi fish [32] and, Pythium aphanidermatum after three days of inoculation in a hydroponic cucumber, infected 100% of the plantation [33]. Such outbreaks could ruin an entire crop, or even provoke the end of all the production system because of the high initial investment cost [34]. Diseases control is mainly based on disinfecting water methods at various points of the aquaponics systems, depending on the method [6]. Chemical and non-chemical disinfection methods have been applied in aquaponics and hydroponics systems to kill pathogens on the recirculating water [6][28]. However, these methods need to be administrated carefully because they could be harmful to humans, fish, plants and beneficial microorganisms [35]. At the moment, there is no pesticide nor bio-pesticide specifically developed for aquaponics systems [6][28][35][36]. Somerville et al. [36] mentioned inorganic compounds which could be used against fungi in aquaponics. Nonetheless, as Stouvenakers et al. [28] state, "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".

As previously mentioned, one of the research topics on aquaponics system relies on beneficial microorganisms, but, most of them have been focused on nitrifying bacteria [24][30][37] or plant growth promoters rhizobacteria (PGPR) [35][38][39]. Biological control agents (BCAs) may be an effective alternative to chemical inputs for dealing with pathogens of plants under aquaponics systems [40]. Therefore, there is an opportunity to work with BCAs to manage: (i) plant disease under aquaponics systems because of the limited use of chemical treatments, (ii) the initial investment cost production, and (iii) the increase of whole aquaponics food production system [28]. There is limited research of BCAs on aquaponics systems, but publications have increased in the last few years [28][40]. Additionally, there are numerous publications on BCAs to control plant pathogens under soilless systems which confirm its potential use on aquaponics systems [41][42][43]. Biological control is defined as the use of BCAs (microorganisms or their derivatives) as antagonists to manage plant disease [44].

2. General Description of Aquaponics Systems

Since modern aquaponics started in 1970s, they have been focused on sustainable practices by sharing water and nutrient resources between fish and plants subsystems [2][45][46]. Aquaponics is a complex system which combine aquaculture (raising fish in tanks) and hydroponics (growing plants in soilless media) subsystems [2]. Simplifying the aquaponics system, it is composed of a fish tank connected to a hydroponics unit connected back to fish tank creating a recirculating system [7]. Additionally, depending of the type and functionality of the system, other components such as biofilters, water clarifiers and pumps are included [36]. The fish metabolize their feeding, then the faeces and waste are transformed by microbial communities which make available the nutrients for plants, simultaneously cleaning the water and recycling nutrients [31]. Aquaponics demand more technical knowledge than hydroponics and aquaculture to maintain a balance between all the elements of the system and, specifically, to prevent plant pathogen diseases [2], and for that reason the whole system is described briefly in this review.

Aquaponics systems are classified according to: (1) the growing technology used for fish and plants; and (2) the coupling or uncoupling subsystems [36]. In general, the aquaponics systems work as follows, fish grow in tanks of different materials (plastic, fiberglass, concrete, among others) [47]. Mechanical filters retain most of the solids dissolved in water to avoid the formation of biofilm that could reduce the oxygen available to the roots of plants; and bio-filters increase the area for the growth of beneficial bacteria that transform ammonia ($NH3-$) and nitrite ($NH2-$) into nitrates ($NO3-$) in order to detoxify water for fish and to assimilate available nitrogen for plants [36]. Plants absorb the nutrients from water, thereby reducing dissolved solids and ion concentrations; and finally the water returns to the aquaculture subsystem (coupled subsystem) or is discarded and/or used as irrigation water in conventional crops (uncoupling subsystem) [35].

The modules of plants in aquaponics are classified, as mentioned, by the growing technology used. The type of growing technology will be closed in relationship with the general objective of production [48]. The technologies applied in plant cultivation are, (1) nutrient film technique (NFT), (2) deep water culture (DWC), and (3) media bed units [49]. NFT and DWC are the most common production technologies [50].

3. Plant Disease in Aquaponics Systems

3.1. Source of Inoculum

Aquaponics is based on recirculation of water through the entire system which makes perfect conditions for pathogen dissemination [6]. Water is an important element on the entire aquaponics system, because it circulates in all the subsystems, transport the nutrients and influence the growing environment of fish, plant or microorganisms [2]. Water sources may contain microbial pathogens affecting fish, plants and even human health, i.e., rainwater used not to contain microbes but the way it is stored may allow microbial proliferation, and ground and river water could contain microbial pathogens depending on its source area like animal farming and human waste treatment [31]. Waterborne dissemination occurs when the plant pathogen is transferred by an inoculum source i.e., infected plants release the pathogens which then are absorbed by healthy plant roots [51]. Moreover, the rate of dissemination is related to pathogen shedding and survival ability in the circulating water [6]. Other source of inoculum could be the reuse of growth media, particles i.e., dust, vectors i.e., insects and rodents, and human i.e., cloths, tools and handling [52][53].

3.2. Factors Related to Phytopathogen Proliferation

Several factors have been associated to phytopathogens proliferation in aquaponics; some are related to environmental conditions, and others to phytopathogens infective capacity and plant mechanism of resistance. In aquaponics systems, plants are breeding under controlled conditions to optimize their yield [53]. Nonetheless, these controlled conditions could be exploited by phytopathogens [28].

After the phytopathogens come into contact with the plant, several cases related to plant resistance are possible: (1) incompatible is when disease not develop; (2) tolerance is when there exists a host relation but the plant does not show symptoms; (3) resistance occurs when pathogen and plant are compatible but defense mechanism inhibit the disease progression; (4) plant-sensitive is when the pathogen infects the plant, but does not cause severe symptoms; and (5) severe disease is when symptoms could cause its death [54].

3.3. Most Common Phytopathogens

There are a variety of phytopathogens such as fungi, bacteria, viruses and parasite that could damage plants under soilless systems like aquaponics. Plant diseases in aquaponics systems might be similar to those in hydroponics because of the continuous presence of water [28]. Oomycetes and virus were the most common pathogens investigated on plants such as tomato and cucumber [31]. Pythium spp. and Phytophthora spp. are oomycetes well adapted to the humid/aquatic conditions and are the most common plant root pathogens [28]. These oomycetes have a motile structure called zoospore which allow them dissemination by moving independently in aqueous media [55]. Fusarium, Colletotrichum, Rhizoctonia and Thielaviopsis genera could be opportunistic phytopathogens [52][56]. Tobacco mosaic virus survive for more than 5 days in recirculating water on a hydroponic system [57]. Potato virus, mosaic virus and potato spindle tuber viroid remain infectious for 1, 3 and 7 weeks [51].

4. Conventional Protection Against Phytopathogens

Nowadays, practitioners are limited in how to protect plants because no pesticide nor biopesticide is specifically developed for aquaponics use [36][40][58]. Disinfecting the water is an option to control disease by decreasing the inoculum, the phytopathogens concentration and their proliferation [6]. Disinfecting can be applied in many parts of the system, depending of the method. The conventional methods available are divided into physical treatments such as ultraviolet (UV) irradiation, media filtration, heat, sonication; and chemical methods such as chlorination, and ozonation. Nonetheless, disinfecting methods could have negative effects on fish, plants and beneficial microorganisms which cohabit in the system, or even human health, so their use must be limited [35].

5. Biological Control as Alternative Treatment in Aquaponics

There are many research works on biological control agents against plant pathogens in hydroponics and soilless systems that could be useful and applicable to aquaponics systems [28]. Microbial antagonists are selected by their ability to grow in aqueous conditions or by their biological cycle [59]. The most common in literature are Pythium spp., Fusarium spp., Pseudomonas spp., Bacillus spp., and Lysobacter spp. [35][59][60]. However, research continues into finding better antagonists and ways to improve their efficiency [44]. Secondary metabolites like bio-surfactants have been studied as alternatives to plant disease control [61][62]. The mixture of compatible microbial antagonists could increase the spectrum of activity and effectiveness of individual treatments [63][64].

6. Conclusions

There is a need to investigate in more depth different phytopathogens that affect numerous plants under aquaponics systems in order to improve their management and treatment. There is limited research on microbes, especially on microbiota interactions into each compartments of the system. Microbial communities assist plants growing in aquaculture systems in many ways that could not be the case if the water were sterilized like in standard hydroponic cultures. Conventional treatments in soilless systems could have negative effects on fish, plant and beneficial microorganisms which cohabit in the system, so their use must be limited. "Omics" techniques could elucidate the structure of microbial communities, metabolic functions and interactions for a better identification of strains and their metabolites with specific purposes. Biological control has the potential to reduce the perturbation effects of conventional treatments on microbial communities, fish and plant physiology, and the whole function of the aquaponics system.

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