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Review

Beneficial bacteria and fungi in hydroponic systems: Types and characteristics of hydroponic food production methods

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ABSTRACT

Hydroponic systems have gained worldwide popularity and are increasingly used for various purposes in different geographic areas. The purpose of this review is to present information concerning hydroponic systems, including: the different types and methods of operation; trends, advantages and limitations, the role of beneficial bacteria and fungi in reducing plant disease and improving plant quality and productivity. In order to produce more and improved hydroponic crops, a variety of modified hydroponic systems have been developed, such as: the wick, drip, ebb-flow, water culture, nutrient film technique, aeroponic, and windowfarm systems. According to numerous studies, hydroponics have many advantages over field culture systems, such as: reuse of water, ease in controlling external factors, and a reduction in traditional farming practices (e.g., cultivating, weeding, watering, and tilling). However, several limitations have also been identified in hydroponic culture systems: i.e., high setup cost, rapid pathogen spread, and a need for specialized management knowledge. In addition, many phytopathogens can easily grow in hydroponic systems due to high nutrient concentrations and then they can ruin the entire crop through rapid spreading in water circulation system. Among the various approaches used for controlling pathogens with physical, chemical, and biological methods, we focused on biological controls, especially plant growth-promoting rhizobacteria that are used for biofertilizers, biocontrol agents, and bioremediators. This review intends to provide a better understanding of hydroponics and newly applied systems and the optimization of techniques in existing systems to reduce plant diseases and enhance food quality and quantity.

Contents

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1. Introduction

Hydroponic systems are cultivation technologies that use nutrient solutions rather than soil substrates. Sometimes natural or artificial media are used, such as peat moss, sawdust, charcoal, rockwool, coco coir, clay granules, gravel, or ceramics to provide physical support for plants (Bhattarai et al., 2008; Jones, 1997; Roberto, 2004; Yu et al., 1993). Hydroponic systems offer a number of benefits, including: the ability to reuse water and nutrients, easy environmental control, and prevention of soil-borne diseases and pests (Lommen, 2007; Molitor, 1990). Since hydroponic production techniques can offer higher yields and higher quality products, the supply of, and demand for, hydroponic systems have dramatically increased in the United States (US) (Brentlinger, 2007; van Patten, 2011). The commercial hydroponics industry has grown approximately fivefold in the last 10 years, and its global value is currently estimated to be about $8 billion US dollars (Carruthers, 2002). A large amount of hydroponic crops are produced in developed countries to meet consumer demand. For the past several decades, hydroponic research has increased steadily, especially in the topics of improving crop productivity and solving limitations of hydroponic systems (Fig. 1). Many different crops have been studied in hydroponic systems, including beans, cucumbers, lettuce, tomatoes, etc. (Table 2). The US and China are the leading two countries generating the most publications about hydroponic plants systems. Majority of the research focused on promoting growth of plants, managing nutrients, and investigating defense system against phytopathogens or response stress from nutrient deficiency, heavy metal, salts, drought, high temperature, and etc. (Fig. 1) (Carruthers, 2002). Although hydroponics are commonly used for personal gardening, education, and research, most systems have been used for commercial vegetable and cut flower production, i.e., tomatoes, beans, spinach, strawberries, cucumbers, lettuce, gerbera, and rose (Nichols, 2006; Savvas et al., 2002; Silberbush and Lieth, 2004; Stajano, 2003).

Hydroponic techniques for cultivating crops began in the late 1920s and commercial scale hydroponic systems were developed in the 1940s (Bouchar, 1998). Currently, with the development of materials and equipment (e.g., media, tubes, connectors, valves, pots, water reservoirs or tanks, air or water pumps and electronic timers), various hydroponic systems have become available, notably: the gravel flow sub-irrigation (1930), ebb and flow (1940), drip irrigation (1960), nutrient film (1960), root mist (1970), fog feed(1970), aeroponic (1970), raceways (deep flow) (1980), and aerated flow (1980). Most hydroponic systems operate automatically to control the amount of water, nutrients, and lighting time, based on the requirements of different plants (Hochmuth and Hochmuth, 2011; Resh, 2013). Likewise, different natural or artificial media can provide different particle sizes, shapes, and penetrability; each medium affects plants and roots differently by retaining water, supporting plants, and making pore space at different rates (Asao et al., 1999). The selection of a medium depends on the nature of the plants, cost, and the type of hydroponics that is employed (Jones, 1997).

Almost all hydroponic systems are indoor, located in greenhouses, so they may rely less on external conditions and have less impact on the environment than a soil culture system (Sundin et al., 1995). Because they can be used not only in urban areas, but also in non-arable lands, their current applications include supplying food for astronauts in space, growing crops in desert areas or the Polar regions, and providing food for poor or rural communities (Iacuzzo et al., 2011; Jones, 1997; Stajano et al., 2003). For instance, people living in underdeveloped and poor regions of Thailand cannot grow enough food using traditional farming practices because of high soil salinity and a lack of natural nutrients in the soil, but hydroponic systems can successfully generate additional crop production and provide agricultural education for the regions' children (Ortiz et al., 2009).

Since hydroponics systems have many benefits, hydroponic systems have been used widely for growing various plants in many different fields and demand for hydroponic produce is increasing. However, treatment of waste water and non-renewable resources that go into hydroponics is an issue. In addition, waterborne diseases can contaminate and spread through the water tubing systems. Species of *Colletotrichum*, *Fusarium*, *Phytophthora*, *Pythium*, and *Phizoctonia* are the common plant pathogens detected in hydroponic systems (Constantino et al., 2013; Li et al., 2014; Nahalkova et al., 2008; Win et al., 2009). Therefore, many studies have focused on preventing fungal infections or developing remedial agents for phytopathogens (Itoh et al., 1998; Chatterton et al., 2004; Song et al., 2004). Thus, the aims of this review are to: (1) introduce different types of hydroponic systems and methods of operation; (2) characterize the trends, advantages, and limitations of hydroponic systems; and (3) discuss research being conducted in plant diseases and the role of beneficial bacteria to control disease and improve plant quality and quantity.

2. Hydroponic models: types and methods of operation

Hydroponic systems are highly customizable and many modified versions have been used to optimize growing conditions for particular plants. They are divided into two forms depending on whether the nutrient solution and supporting media are reused or recycled; nutrient solution and supporting media in open systems are not reused or recycled whereas, in closed systems, they are reused or recycled (Jensen, 1999). In general, open hydroponic systems may be less sensitive to salinity of the water than closed systems, but closed systems are more cost-effective than open systems (Lippert, 1993). Six commonly used hydroponic systems are described herein: the wick, drip, ebb-flow, water culture, nutrient film, aeroponic, and windowfarm model, which has been recently introduced.

2.1. The wick system

The wick or passive system is an excellent model for cultivating indoor plants: it is a self-feeding model and does not require a water pump (Fig. 2a) (Shrestha and Dunn, 2013). Water or a nutrient solution in a reservoir is supplied through a wick or fibrous materials (typically nylon) that can absorb and transport water from the reservoir to the root area by capillary action. The wick system is rarely used commercially, but the system has been used in small-scale gardens, such as personal home or office gardens, to grow flowering plants because of its simplicity. Even though it effectively inhibits the diseases common to overwatering, the wick system is not suitable for large or long term plants, which need a larger amount of water than the wick can supply (Harris, 1988).

2.2. The drip system

The drip or drip irrigation system has been widely used in commercial system for many years (Reed, 1996). Water or a nutrient solution in the reservoir is delivered to each plant or pot using a pump with the amount of water for each plant adjusted by an electronic timer (Fig. 2b) (Rouphael and Colla, 2005). The drip system is divided into two models, recovery and non-recovery, depending on the processing of the reused water or nutrient solution (Saaid et al., 2013). In the recovery system, the water or nutrient solution is collected and returned to the reservoir and then recirculated through the system (Schröder and Lieth, 2002). This makes it more economical than the non-recovery model, but reusing the solutions

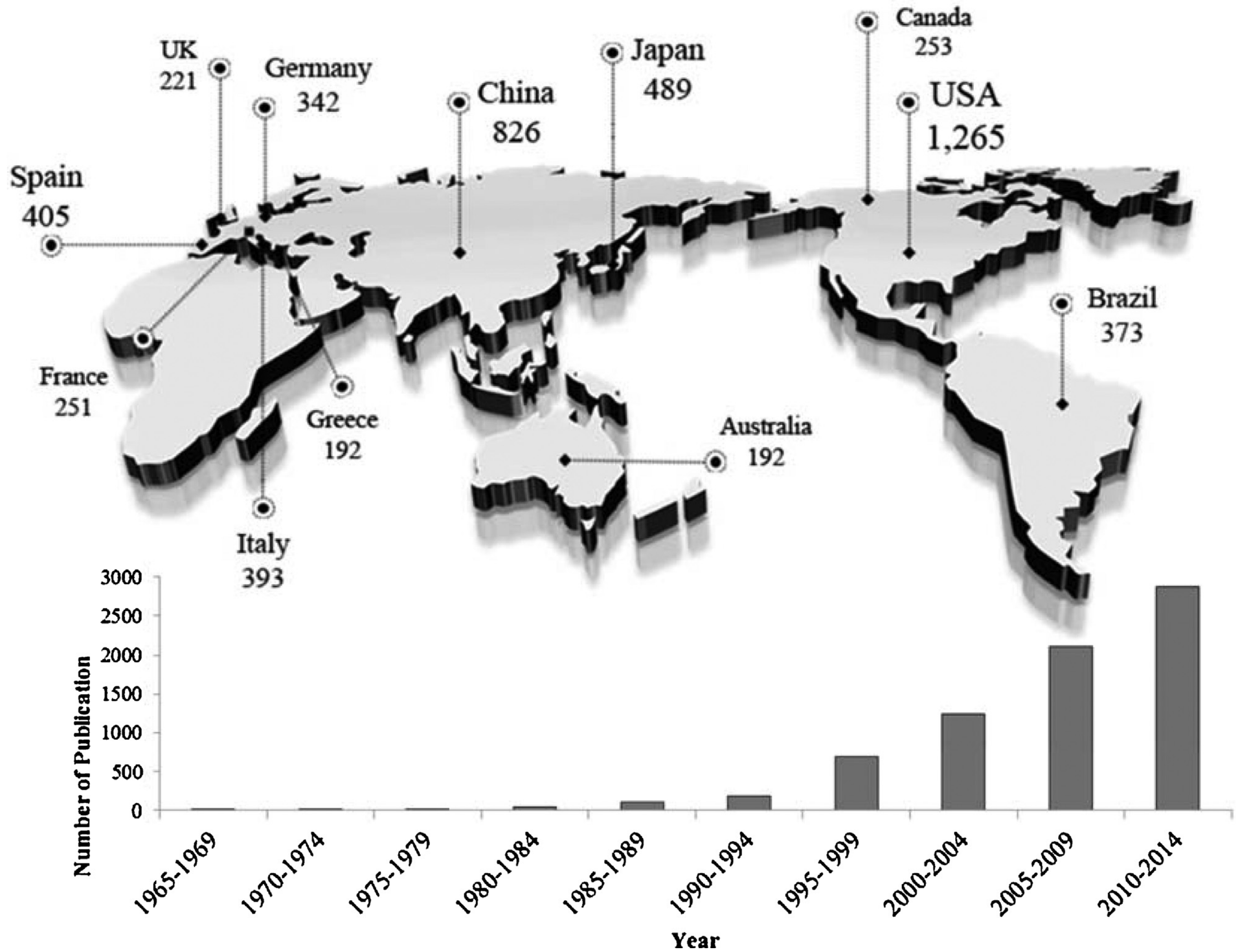

Fig. 1. The number of documents related to hydroponic systems by country from 1965 to 2014. Trends in the total number of documents concerning hydroponic systems by year. The small figure shows a time series plot of the number of hydroponic system papers since 1965s. The key words used for database searching [Scopus] were: hydroponics, hydroponic system, and hydroponic food. Journal articles and books were included.

may result in pH changes and growth of algae or mold in the reservoir or tubing system. In the non-recovery drip system, amount of water or nutrient solution needs to frequently be monitored in the reservoir to ensure that enough water or nutrient solution reaches the roots of the plants (Santamaria et al., 2003). The system is also vulnerable to power outage causing stress or death to plants.

2.3. The ebb and flow system

The ebb and flow system, that was one of the first commercial hydroponic systems, uses an automatic flood and drain watering technique, in which plants are flooded temporarily and periodically (Fig. 2c) (Buwalda et al., 1994). Application of various media around root area is the great strength in the system. The water or nutrient solution in the reservoir ascends to a growth tray via a water pump, accumulates to a certain level, and stays in the growth tray for a set amount of time, providing water and nutrients to the plants. After a predetermined time, the solution is drained back into the reservoir through a tubing system. This circulation system requires continual observation to control the amount of water provided to the system. Although it is possible to grow many different kinds of plants and provide them with a large amount of water, root disease and growth of algae or molds may easily occur in this system; therefore, some modified ebb-flow systems include a filtration step or other method for sterilization of the water (Buttner et al., 1995; Nielsen et al., 2006).

2.4. The (deep) water culture system

Most modified hydroponic systems were originally derived from the water culture system (Harris, 1988). The water culture system is a simple model, composed of a reservoir, an air stone, a tubing system, an air pump, and a floating platform (Fig. 2d) (Hoagland and Arnon, 1950). With improvement of aeration methods to keep dissolved oxygen, the deep water culture system was developed so that plants can be grown with roots constantly suspended in water. Unlike the wick system, it produces food actively: a floating platform supports plants or pots in a reservoir, where the root parts are constantly immersed in the water or nutrient solution and oxygen is supplied by an air pump and air stone (Saaid et al., 2013). For optimization of growing conditions, it is necessary to monitor the oxygen and nutrient concentrations, salinity, and pH (Domingues et al., 2012). Although all kinds of plants, especially cucumber and radish, grow well in this system, large or long-term crops may not, and algae and molds can grow rapidly in the reservoir.

2.5. The nutrient film technique system

The nutrient film technique (NFT) system was generated in the 1960s to compensate for the weak points of the ebb and flow sys-

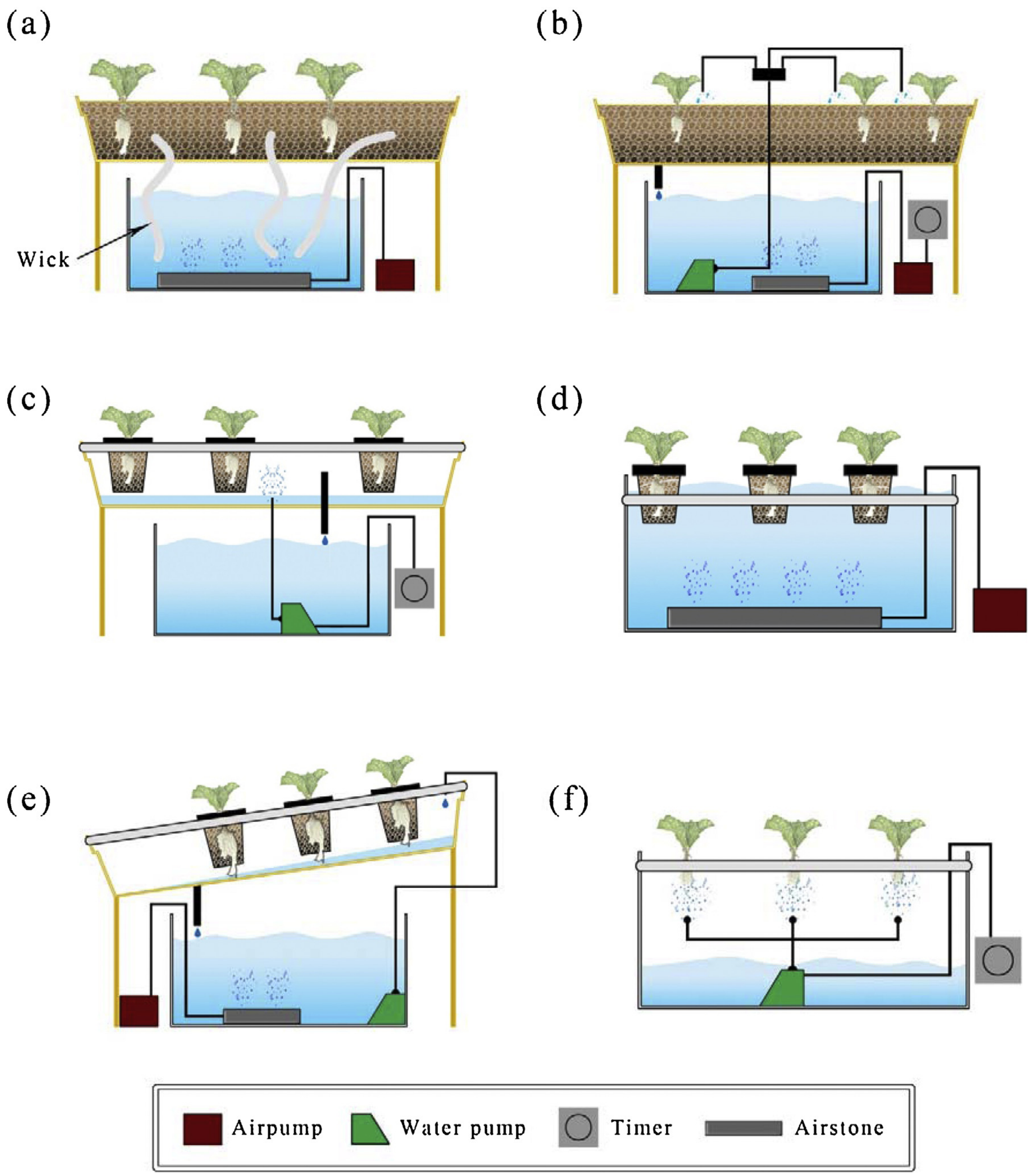

Fig. 2. Six different types of traditional hydroponic systems. (a) wick system, (b) drip system, (c) Ebb-Flow system, (d) water culture system, (e) nutrient film technique, and (f) aeroponic system.

tems. NFT systems can provide water and nutrient constantly and make oxygen-rich conditions by controlling flow and water depth (Fig. 2e) (Jones, 1997). Water, or a nutrient solution in a reservoir, circulates throughout the entire system; it enters the growth tray via a water pump without a time control, and then constantly flows around the roots (Domingues et al., 2012). The solution is collected and reused, and the amount of water is controlled by the slope of the tray and the power of the water pump. However, the roots are susceptible to fungal infection because they are constantly immersed in water or nutrient solution (Thinggaard and Middelboe, 1989).

2.6. Aeroponic system

An aeroponic system, made in the 1980s, enables even control over the root system delicately and does not require media. Using a high pressure sprayer with a micro-inject nozzle, water or a nutrient solution is sprayed around the roots by a water pump and provides a highly oxygenated nutrient solution to plants (Fig. 2f). Supports maintain the pots or plants, the water or nutrient solution is in a mist form, and is supplied for a specified period using a special nozzle and an electronic timer. Customizing the misting cycles to particular plants is important, because their roots are exposed to the air and can dry rapidly. The mist can easily be affected by the outside temperature, which makes these systems difficult to operate under cold or frigid conditions. This system is rarely used commercially because the system is expensive for installation and maintenance as it needs frequent cleaning to prevent plant disease and clogging of spray heads. Also, partial failure of the aeroponic systems may easily cause damage or kill plants.

2.7. Hydroponic window farming: an emerging model

Window farming is an emerging concept in urban agriculture for space-saving and enabling residents to grow vegetables and herbs all year-round in urban settings with an available window (Lee et al., 2015). The window farm system is generally a vertical hydroponic system constructed of simple household materials (Lee et al., 2015), including plastic bottles, a water reservoir, and a small scale water pump with tubing (Fig. 3). Water circulates through the system via an automatic drip configuration using a pump and an electronic timer. The sun supplies natural light, although artificial light may be needed on cloudy days.

The vertical windowfarm system requires much less space than traditional hydroponic systems and provides an alternative method for growing crops in urban environments; an innovation of special interest to people in congested cities (Resh, 2013). This trend is expected to continue, as window farming needs low input, creates sustainable agriculture in urban areas, including food deserts, and is able to provide urban residents with fresh and healthy foods.

3. Advantages and limitations of hydroponics

There are many advantages of hydroponic systems over soil culture systems (Table 1). Hydroponics perform well, even in areas that are otherwise unsuitable for growing crops due to toxic chemicals or heavy metals contaminating the soil (Jones, 1997). Indoor hydroponic systems also make it easy to control growth conditions, such as temperature, flow velocity and volume of water, nutrients, relative humidity, and duration of lighting in order to optimize crop production (Norén et al., 2004). In addition, plants in hydroponic systems are not easily influenced by climate change; therefore, plants can be cultivated year-round under a wide range of conditions (Gibeaut et al., 1997; Manzocco et al., 2011; Norström et al., 2004). Further, as the systems operate automatically, they may be expected to reduce labor and several traditional agricultural practices can be eliminated, such as cultivating, weeding, watering, and tilling (Jovicich et al., 2003).

Soil-based crops can be exposed and contaminated by many harmful biotic or abiotic compounds, some of which are hard to prevent. However, using hydroponics, most media and other materials can be sterilized by ultraviolet (UV) irradiation, chemical compounds (e.g., alkylating and oxidizing agents), steam, and/or high temperatures (Knutson, 2000). Furthermore, indoor hydroponics are not expected to be infected by diseases common to plants cultivated in soil, thereby reducing or eliminating the use of pesticides and their resulting toxicity (Fu et al., 1999; Stanghellini, 1994; Zlnnen, 1988). Delivering recycled or used water directly or indirectly to the root area provides a more effective utilization of resources, reduces water loss, and distributes nutrients evenly to each plant (Deng-lin, 1999; Güohler et al., 1989; Midmore and Resh, 2013). Finally, pH can be easily controlled, according to the plant's requirements (Rolot and Seutin, 1999). Because of these advantages, many studies report that hydroponic systems can increase the yield and quality of crops (Cornish, 1992; Resh, 2013; Sarooshi and Cresswell, 1994).

However, there are also some limitations to hydroponic systems (Table 1). The main problem is the high initial setup cost, as the fundamental supplies are expensive (Domingues et al., 2012; Resh, 2013). Hydroponic systems are also vulnerable to power outages, as the electrical-driven machines in the systems cannot supply water or nutrient solution without power (Knutson, 2000). In addition, when phytopathogens (microorganisms such as *Verticillium*, *Pythium*, and *Fusarium*) contaminate solutions or crops, waterborne diseases can rapidly spread through the entire systems as water tubing systems are connected to each pot (Ikeda et al., 2002). These infectious agents may multiply and accumulate, potentially causing a severe disease outbreak in the system (Schnitzler, 2004). Hydroponic system operators need specialized skills and knowledge to produce high yields of crops; they must learn the proper amounts of nutrients and lighting, manage complex nutritional problems, maintain pest control, and prevent the production of biofilms in the water tubing system (Guo et al., 2002; Sutton et al., 2000; Zekki, 1996). Finally, although nutrient-rich hydroponic solution and plastic materials can be reused, hydroponic systems still generate large amount of waste nutrient solution and plastic waste that can have negative impacts on the environment (Kumar and Cho, 2014).

4. Beneficial bacteria in hydroponic systems

Even though hydroponics can grow plants in indoor systems, pathogens still threaten viability of plants (Owen-Going et al., 2003). Many pathogens can grow under hydroponic conditions due to high nutrient concentrations (Xu and Warriner, 2005). Pathogens can be introduced to crops and may ruin the entire crop by circulation of contaminated water in the system (Stanghellini and Rasmussen, 1994). Especially, closed hydroponic systems have a potential risk of accumulation of toxic compounds and harmful plant pathogens, even though closed hydroponic systems can reduce release of large amount of waste hydroponic solutions (Waechter-Kristensen et al., 1999). However, further research is warranted to investigate the differences in microbial community between open and closed hydroponic systems and their effects on crops. Although different usage of supporting media and different types of hydroponic systems may affect growth conditions for microorganism, *Fusarium, Phytophthora,* and *Pythium* are the most common plant pathogens found in hydroponic systems (Li et al., 2014; O'Neill et al., 2014).

Pythium spp. are common root pathogens that are spread through water circulation systems and cause root rot in hydroponically grown cucumber, pepper, and lettuce (Khan et al., 2003; Rankin and Paulitz, 1994; Stanghellini et al., 1996; Utkhede et al., 2000). *Pythium ulimum* has been shown to cause root rot in tomatoes, whereas *Pythium aphanidermatum* and *Pythium dissotocum* cause root rot in spinach cultivated in temperature between 17 and 27 °C (Gold, 1985; Gravel et al., 2006). *Fusarium* spp. are ubiquitous and cause wilt and root diseases in various plants (Fravel, 2002). *Fusarium oxysporum* is responsible for root rot in basil, lettuce, and tomatoes (de Ascensao and Duber, 2000; Nahalkova et al., 2008). All of these fungal diseases present critical damage to produce (Chinta et al., 2014). Consequently, managing fungal infections is a vital component of hydroponic operations.

Options for preventing pathogen contamination include physical, chemical, and biological methods (Igura et al., 2004; Song et al., 2004; Zhang and Tu, 2000). The introduction of high dose of ultraviolet irradiation and gamma irradiation have been applied to inactivate growth of pathogens in the nutrient solutions and to prevent disease outbreaks in hydroponic systems. In addition, the physical treatments can disinfect nutrient solution effectively, while maintaining rhizosphere (Yogev et al., 2006). However, high cost for installation and periodic maintenance of the disinfection systems are challenging (Lee et al., 2015; Yogev et al., 2006; Zhang and Tu, 2000). Chemical control strategies, such as using carbendazim, hymexazol, imidazole, prochloraz triazole, etc., suppressed growth or symptoms of plant diseases in hydroponic systems. However, toxicity of fungicides, by-products and evolution of fungicide resistant microorganisms make other problems (Hibar et al., 2006; Song et al., 2004). These chemical control methods may also decrease population of beneficial microorganisms in hydroponic systems (Hibar et al., 2006). We and others have studied the effect

Table 1
The advantages and limitation of hydroponic systems compare to soil-based culture.

Issues	Hydroponic system	Soil Culture	Reference
Land usage and effect of environment	Less affected by soil and external factors Indoor system; easy nutrient control; control of the environment such as temperature, humidity and lighting time; cultivation all year round everywhere	Unsuitable if soil is contaminated with heavy metal and plant disease; Limited by nutrients in soil; hard to control external environments; cultivation all year round is limited in certain areas	Gibeaut et al. (1997), Jones (1997), Norén et al. (2004), Norström et al. (2004)
Labor	Traditional practices are largely eliminated	Cultivating, weeding, watering, tilling and additional practices	Jovicich et al. (2003)
Sanitation	Easy handling of medium and all materials and maintaining sanitary conditions	Difficult to sanitize soil and equipment; hard to maintain sanitation conditions consistently	Knutson (2000)
Diseases and pest	Prevent soil-borne diseases; easy to control insects and animals; reducing amount of pesticide usage	Soil-borne diseases; hard to control insects and animals (loss of crop yield)	Zlnnen (1988), Jones (1997)
Water	Efficient water usage; water can be recycled or reused; no nutrient waste due to water runoff; Water goes directly to root areas; possibility of controlling water-holding ability by using different kinds of medium	Inefficient water usage; water cannot be recycled or reused; eutrophicastion of the environment due to run-off; hard to control water-holding capacity	Güohler et al. (1989), Midmore and Deng-lin (1999)
Fertilizers and nutrient solution	Even distribution to crops; efficient use of fertilizers and saving the cost; easy control of pH and amount of nutrient	Uneven distribution to crops (partial deficiency); often use of excessive amount of nutrient; high variation, hard to control pH and amount of nutrient	Rolot, (1999), Resh (2013)
Quantity and quality of crop	Stable and even amount of production; tomato,14–74 kg per m^2; cucumber, 6900 kg per m^2; lettuce, 5200 kg per m^2; bean, 5 kg per m^2; even quality of production	Unstable and uneven amount of production due to pests/soilborne pathogens; tomato, 1.2–2.5 kg per m^2; cucumber, 1700 kg per m^2; lettuce, 2200 kg per m^2; bean, 1.2 kg per m^2; uneven quality of production	Cornish (1992), Sarooshi and Cresswell (1994), Rolot (1999), Resh (2012)
Limitations of hydroponic system	• High initial setup cost for supplies and continuous replacement cost for maintaining • Generation of waste materials and hydroponic waste solution containing high nutrients • Vulnerable to power outage leading to problems in water or nutrient supply, and witheredness • Easy spread of phytopathogens throughout water tubing systems • Requirement of experts to maintain the systems for optimum production • Needs of nutrients background to controlling amounts of nutrients • Growth of unwanted algae and fungus in nutrient solution • Biofilm build-up in the system interfering nutrient uptake and reducing life span of the system • Not all plants are available for hydroponic systems		Zekki et al. (1996), Knutson (2000), Sutton et al. (2000), Guo et al. (2002), Schnitzler (2004), Domingues et al. (2012), Resh (2013)

Table 2
List of beneficial microorganism for plant in hydroponic system.

Microorganism		Host plant	Reference
Genus	Species		
Pseudomonas	*Aeruginosa, aureofaciens, chlororaphis, corrugate, fluorescens, fulva, marginalis, oligandrum, plecoglossicida, putida, syringae*	Bean, carnation, chickpea, cucumber, lettuce, peppers, potato, radish, tomato	Peer and Schippers (1989), Rankin, (1994), Chatterton et al. (2004), Renault et al. (2007), De et al. (1999), Hultberg et al. (2000), Chen et al. (1999), Chen et al. (2000), Inam-ul-haq et al. (2003), Gravel et al. (2006)
Bacillus	*Amyloliquefaciens, cereus, subtilis, thuringiensis*	Carrot, chrysanthemum, cucumber, lettuce, pepper, tomato	Renault et al. (2007), Liu et al., (2007), Gül et al., (2008), Bochow, (1992), Sopher and Sutton (2011), Zhang et al. (2011), Chinta et al. (2014)
Enterobacter	*Aerogenes*	Cucumber	Utkhede et al. (1999)
Streptomyces	*Griseoviridis*	Cucumber, tomato	Punja and Raymond (2003), Khalil and Alsanius (2010)
Gliocladium	*Catenulatum*	Cucumber, tomato	Rose et al. (2003)
Trichoderma	*Asperellum, atroviride, harzianum, virens*	Bean, cotton, cucumber, maize, rice	Yedidia et al. (2001), Harman et al. (2004), Djonovic et al. (2007)

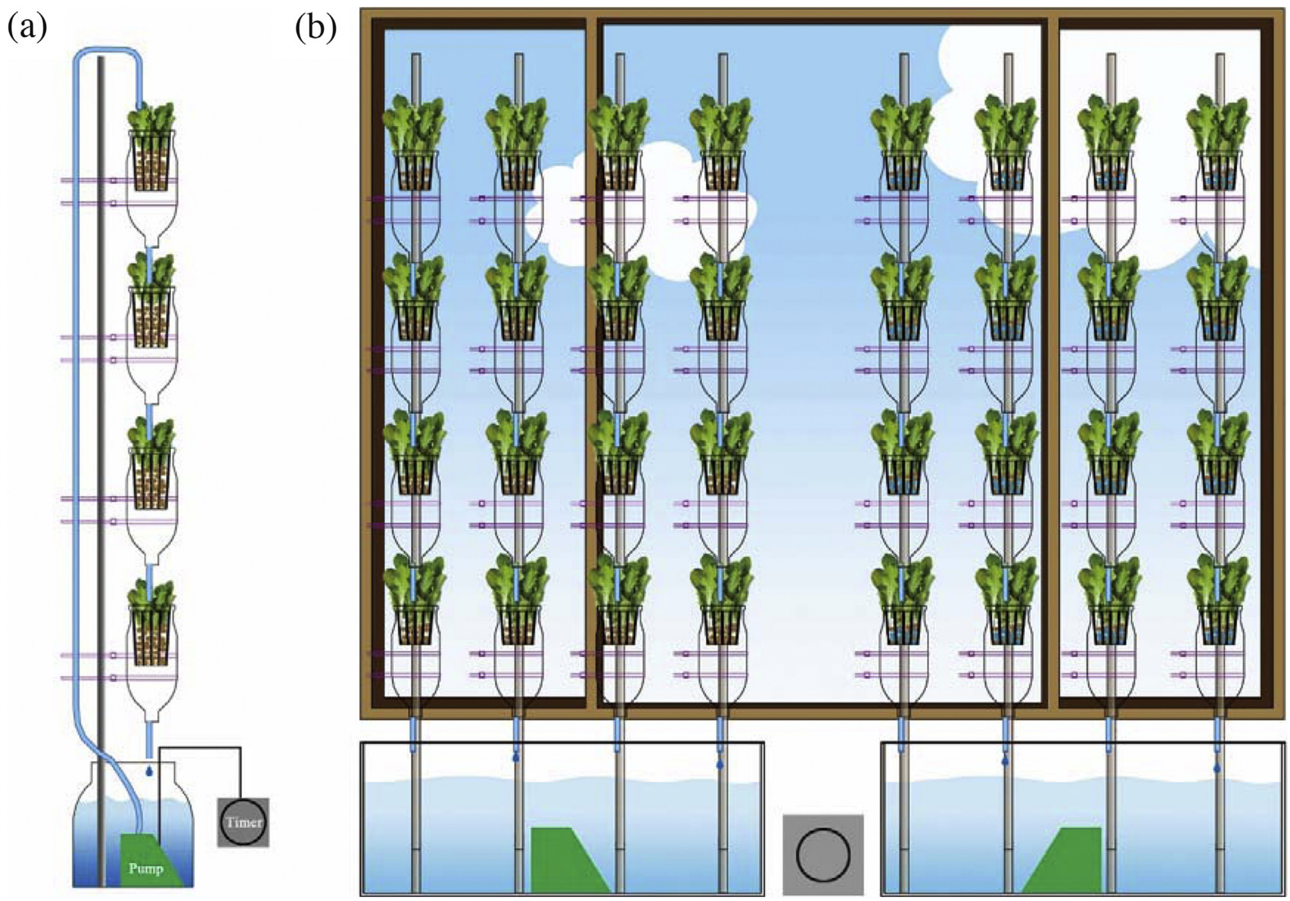

Fig. 3. Schematic diagram of a single unit of a vertical windowfarm system (a) and a multiple-unit windowfarm system (b). Water in the water reservoir goes up through tubing to each pot using an air pump and watering time can be control by an electronic timer.

of plant growth-promoting rhizobacteria (PGPR) in hydroponic systems (Table 2). These microorganisms have been used in agriculture as biofertilizers, biocontrol agents, and bioremediators. PGPR have been introduced into both soil and hydroponic systems with positive effects on plant quality and quantity (Kıdoğlu et al., 2009; Lee et al., 2010, 2015; Woitke and Schitzler, 2005). PGPR act through: N_2 fixation, control of plant stress, extracting nutrients from soil, competition with pathogens, production of various kinds of plant hormones and biological controls, and promotion of plant growth (Bull et al., 1991; Freitas et al., 1993; Gaskins et al., 1985; Kloepper, 1993; Lugtenberg and Kamilova, 2009). In general, microflora may develop rapidly after planting crops in hydroponic systems and use plant exudates, compounds in nutrient solution, and dead plant materials (Waechter-Kristensen et al., 1996). The composition of the microflora in hydroponic systems may be affected by environmental factors and the source of nutrients (Khalil and Alsanius, 2001). Some of the microflora can be plant pathogens, but the pathogens are commonly outnumbered by the population of non-pathogenic organisms (Khalil et al., 2001). *Bacillus* spp. *Gliocladium* spp., *Trichoderma* spp., and *Pseudomonas* spp., were known to be commonly found beneficial resident microflora and expected to act as a biocontrol; however, their beneficial effects were not big enough to prevent disease outbreak in many cases (Khalil and Alsanius, 2009).

Other research using *Bacillus* spp., *Pseudomonas* spp., and *Streptomyces griseoviridis* has suggested that these bacteria may prevent or diminish the effect of plant pathogens (Raaijmakers et al., 2010). When *Pseudomonas chlororaphis* or *Bacillus cereus* was applied to chrysanthemums, infection by *Pythium* decreased by about 20% (Liu et al., 2007). Although the mechanism whereby *Bacillus* spp. promotes plant growth and prevents diseases is still poorly understood, they can produce antibiotics against phytopathogens (Nihorimbere et al., 2012). *Bacillus subtilis,* a Gram-positive bacterium, is well known as a plant growth enhancer with the ability to decrease high salinity concentrations of water or nutrient solutions (Bochow 1992; Böhme, 1999). *Bacillus amyloliquefaciens* was shown to increase efficiency of water use in tomatoes, along with the quality (higher vitamin C than control groups) and quantity (8–9%) (Gül et al., 2008). *Bacillus licheniformis* has increased the diameter and weight of tomatoes and peppers, and promoted higher yields of each crop (García et al., 2004). *Pseudomonas* spp. show antagonistic and antifungal activity against *Fusarium graminearum* and prevent root rot, whereas treatment of hydroponically grown tomatoes, cucumbers, lettuce, and potatoes bring about increased root and shoot weight and reduce root rot (Benizri et al., 1995; Peer and Schippers, 1989; Rankin and Paulitz, 1994;). The introduction of *P. chlororaphis* on peppers in a hydroponic system was effective in suppressing infection of *P. aphanidermatum* and *P. dissotocum* and in controlling root rot (Chatterton et al., 2004). The biofungicide produced by *S. griseoviridis* was effective in reducing plant diseases caused by *Rhizoctonia solani* (collar rot), *Verticillium spp.* (verticillium wilt) and *Fusarium* spp. (root rot) in cucumbers and tomatoes grown (Rose et al., 2003; 2010; Minuto et al., 2006 Minuto et al., 2006). A commercial biofungicide products based on *S. griseoviridis* K61 such as Mycostop and Actinovate, have been used for stimulating root growth and controlling wilt and root disease or damage caused by *Botrytis*, *Fusarium*, *Phomopsis*, *Pythium*, *Rhizoctonia*, *Verticillium* and others.

In order to manage plant diseases in crops, the effect of beneficial fungi, such as *Trichoderma* spp. and *Gliocladium catenulatum,* under hydroponic systems was investigated (Khalil et al., 2009). *Trichoderma* spp. have been reported to improve resistance of plants against disease by changing plant cell wall compounds, increasing enzyme activities, and/or production of pathogenesis-related proteins (Zamir and Utkhede, 2003). *T. virens* induced terpenoid and peroxidase activity around roots and inhibited plant disease, such as seedling disease in cotton (*Gossypium hirsutum*) by *Rhizotonia solani* and foliar pathogen in maize (*Zea mays*) (Howell et al., 2000). The treatment of *T. asperellum* to roots reduced symptoms of angular leaf spot in cucumbers and *T. harzianum* and *T. atroviride* stimulated growth and yields of cucumbers and tomatoes (germination rate, dry weight, shoot length, and leaf area) (Yedidia et al., 2001). Finally, the biocontrol agents produced by *Gliocadium catenulatum* were effective in reducing root diseases caused by *Pythium* or *Fusarium* in cucumbers and tomatoes grown in hydroponic systems (Rose et al., 2003; Khalil and Alsaniu, 2010).

Development of techniques to suppress plant diseases in hydroponic systems is still in progress: (1) corn steep liquor and salicylic acid were used to inhibit lettuce root rot caused by *F. oxysporum* (Chinta et al., 2014; Xue et al., 2014); (2) *Bacillus velezensis* and *P. chlororaphis* increase plant growth and reduce root rot (Kanjanamaneesathian et al., 2014; Lee et al., 2015). Recently, owing to advanced molecular techniques, especially next-generation sequencing, the study on whole genome identification of PGPR, microbial community analysis, and changes in crop genotypes were examined. Niazi et al. (2014) showed that *Bacillus* genomes have a capability for promoting plant growth and suppressing plant diseases by producing phytohormones and antibacterial/antifungal compounds. *Pseudomonas* spp. have functional genes to produce siderophores, chitinase, phenazine, peroxidases, and others (Gupta et al., 2014). Introduction of diazotrophic bacteria affected gene regulation of maize to induce specific stress responses in hydroponic systems (Thiebaut et al., 2014). Ding et al. (2014) demonstrated that composition of bacteria community in hydroponic systems was affected by interactions between plant (*Cucumis sativus* L.) and pathogen (*F. oxysporum*). Small changes in microbial community, such as *Pseudomonas fluorescens* treatment, may lead to a large change in the genotypes of Arabidopsis (Haney et al., 2015).

5. Conclusion

The popularity of hydroponic systems has increased significantly, both in personal gardening and agriculture, because of their notable advantages over soil cultures. Various modified hydroponic models have been developed to improve materials and tools, but some problems still exist: fungal infections, wastewater treatment, maintenance of the system, construction cost per acre, and education for system operators (Arteca and Arteca, 2000). Further innovations will no doubt address these problems, particularly by understanding the mechanisms whereby beneficial bacteria promote plant growth and prevent damage by phytopathogens. In the future, hydroponic systems may be widely used in underdeveloped countries to produce food in harsh climates or in areas with limited space; applications may also be developed for use in outer space. Furthermore, the demand for indoor hydroponic systems may surge in the near future, due to the effect of extreme weather events on plant yield by climate change and the need for alternate sources of high-quality vegetable products using controlled agriculture.

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