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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.

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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