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Biochar, a potential hydroponic growth substrate, enhances the nutritional status and growth of leafy vegetables

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ABSTRACT

A hydroponics system developed using a nutrient film technique was used to evaluate the effectiveness of rice husk biochar (RB) alone or in combination with perlite (PL) as substrates for increasing the growth of leafy vegetables compared with that of PL. Seedlings of cabbage, dill, mallow, red lettuce, and tatsoi were grown hydroponically in PL, RB, and PL + RB (1:1 ratio of PL to RB, v/v) substrates for a 30-d under optimal environmental conditions in a greenhouse. Shoot length and fresh/dry masses of cabbage, dill, and red lettuce plants grown in RB substrate were decreased by 49% on average compared to those plants grown in PL substrate. In contrast, PL + RB substrate led to approximately 2-fold increases in shoot length, number of leaves, and fresh/dry masses of leafy vegetable plants compared with those grown in PL substrate. Foliar nutritional composition (Ca, Mg, K, Na, Mn, Fe, and Zn) and nitrogen status (SPAD index) of plants grown in PL + RB and PL substrates suggested the presence of optimal growth conditions for ensuring optimum yield with high quality. In addition, RB substrate contributed to respective increases of 1.2–3.5-fold in leaf K, Mg, Mn, and Zn contents in most vegetable plants compared with those grown in PL substrate. The RB alone or in combination with PL substrates decreased algal growth in the nutrient solutions as confirmed by scanning electron micrographs of microalgae on the RB surface. The results also indicated that use of PL + RB hydroponic substrate could be an alternative and effective technology for the better management of unwanted algal growth in nutrient solutions and high production of leafy vegetables.

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1. Introduction

Water shortage is a great threat to crop production sustainability and food security (Power and Jones, 2016). To cope with this challenge, hydroponics is a rapidly developing eco-industrial technology for the production of commercial crops in nutrient-rich solutions, instead of soil (Jones Jr., 2016; Nhut et al., 2006; Resh, 2012). Hydroponics offers several benefits such as improved yield and good-quality products, precise nutrient and disease management, short cultivation times, and safe food and growth environments (Nhut et al., 2006; Resh, 2012). Inert substrates such as coconut coir, peat, perlite (PL), and vermiculite have commonly been used to support plant root systems and maintain an appropriate concentration of the nutrient solution around the roots (Ok et al., 2015b).

As associated problems with hydroponics substrates, recirculation of nutrient solution in hydroponics systems provides a favorable condition for algal growth (Coosemans, 1993; Schwarz and Gross, 2004). Microalgae were easily found in hydroponics containers and had an adverse effect on the water supply system and nutrient uptake by plants, leading to a remarkable reduction in crop yield (Schwarz and Gross, 2004). Further, the odor and appearance of crops grown in a hydroponics system containing algae might reduce their value of product, and such algae may also secrete toxins that are harmful to human health (Corbel et al., 2014; Magee et al., 2013; Sayre, 2010). In terms of food safety, some types of algae found in hydroponics containers secrete certain toxic compounds that inhibit the growth of organisms, including crops, by decreasing the light-dependent photosynthetic reactions (Corbel et al., 2014; Schwarz et al., 2005; Schwarz and Gross, 2004). Since algal toxins might be taken up by plants, they pose a health hazard to people who consume these plants (Burgoon and Bottino, 1976; Meriluoto and Spoof, 2008). Therefore, developing alternative industrial substrates for hydroponics that maintain the water quality by eliminating/reducing algal growth, thereby increasing crop production, is necessary for ensuring sustainable crop production in hydroponics (Jones Jr., 2016; Kaudal et al., 2016; Resh, 2012).

Biochar (BC) is a carbon-rich product of the pyrolysis of biomass such as wood, crop residues, and manure in a closed container with little or no oxygen (Lehmann and Joseph, 2015). Biochar increases plant growth by improving the physicochemical and biological properties of soil and has been known to retain soil fertility, and remediate organic/inorganic contaminants (Jeffery et al., 2015; Lehmann et al., 2015; Ok et al., 2015a; Van Zwieten et al., 2010). In particular, rice husk BC (RB) reduced the bioavailability of Pb and increased the germination rate and root elongation of lettuce in contaminated soil (Ahmad et al., 2012). From practical viewpoint, BC is stable and highly resistant to microbial degradation due to the recalcitrant nature of BC molecules (Kuzyakov et al., 2014; Singh et al., 2012); therefore, it can be efficiently used as a growth substrate in hydroponics systems. The physicochemical characteristics of BC are similar to those of the standard industrial substrate coir peat and can be used as an alternative growing medium (Kaudal et al., 2016). The agronomic applications of BC need to be better understood, as recommended in 2010 by the American Society of Agronomy–Soil Science Society of the American Environmental Quality Division (Ippolito et al., 2012). Notably, further research is needed to assess using BC as an inert substrate to produce vegetables in hydroponics systems.

We hypothesized that RB alone or in combination with PL as a commercial substrate might increase vegetable production because of its high capacity for binding nutrients while promoting plant growth in nutrient-rich solutions by enhancing root growth. Biochar may also optimize water quality and maintain nutrient solution around plant roots in hydroponics systems by reducing/eliminating algal growth in hydroponics containers. In this study, we investigated whether RB alone or in combination with PL as inert substrates could enhance the growth of leafy vegetables (cabbage, dill, mallow, red lettuce, and tatsoi) and eliminate the growth of algae in the nutrient solutions in a hydroponics system.

2. Materials and methods

2.1. Hydroponics substrates and vegetable cultivars

Perlite (PL), a hydroponics substrate (average particle size, 1.2 mm; GFC Co., Ltd., Korea) and RB produced at 500 °C (≤2 mm; DAEWON GSI Co., Korea) were purchased from commercial sources. The PL and RB substrates were characterized using scanning electron microscopy (SEM; Model S-4300, Hitachi, Tokyo, Japan) operated at 15 keV with energy dispersive X-ray spectroscopy (EDS). Scanning electron micrographs of PL and RB substrates showing their surface structures are shown in Fig. 1. The scanning electron microscopy (SEM) images revealed that the surface of PL is rugged, irregular, and porous, whereas that of RB is covered with well-aligned, small, irregularly shaped particles. Rice husk biochar was previously characterized by Kim et al. (2015) as follows: cation exchange capacity (CEC), total carbon (TC), and total nitrogen (TN) of 50.4 $cmol_c\ kg^{-1}$, 20.5%, and 0.26%, respectively. In addition, the pH and electrical conductivity (EC) of RB were 10.2 and 0.82 $dS\ m^{-1}$, respectively. Leafy vegetable cultivars of hybrid Chinese cabbage (Asia Alpine F1; *Brassica rapa* L. ssp. *pekinensis*), dill (*Anethum graveolens* L.), curled mallow (*Malva verticillata* L.), red lettuce (*Lactuca sativa* L.), and tatsoi (*Brassica rapa* var. *rosularis*) were obtained from commercial companies in Korea (Asia Seed Co., Ltd. and Jeil Seed & Agricultural Products Co., Ltd.).

2.2. Raising nursery seedlings

Cabbage, dill, mallow, lettuce, and tatsoi seeds were sown in 128-cell plug trays (Bumnong. Co., Ltd., Korea) filled with commercial growth substrate (BM2; Berger Group Ltd., Canada) on April 11, 2015. The BM2 growth substrate consisted of 70%–80% fine sphagnum peat moss, fine PL, and fine vermiculite. Seedling trays were fertilized by overhead irrigation twice a week with Wonder Grow fertilizer (Chobi Co., Ltd., Korea). Uniform and vigorous 30-day-old seedlings were transplanted to pots after the removal of the growth substrate by rinsing the roots with tap water.

2.3. Hydroponics experiment

Six nutrient film technique hydroponics systems were purchased from a commercial company (Easy-Farm, Korea). The hydroponics systems, with an area of 105 cm × 40 cm and a height of 167 cm, consisted of a nutrient solution container (30 L) for growing 48 plants and a 20 W Young IL water pump (model YI-20; Fig. S1). More details about the hydroponics systems are available from the Easy-Farm company website (http://www.easy-farm.com). Uniform seedlings of each vegetable crop were planted in plastic pots (4.5 cm × 3 cm × 4.5 cm), which were then filled with PL, RB, or a combination of both (PL: RB at a 1:1 ratio (v/v)). Pots with hydroponic growth systems were placed inside a greenhouse fitted with a roof that automatically opens and closes at the Agricultural Farm of the College of Agriculture and Life Sciences, Kangwon National University, Gangwon Province, Korea, for 30 days. Plants were grown under greenhouse conditions according to Siddiqui et al. (2001). Briefly, the mean temperature was maintained at 18 °C (night) and 25–28 °C (day), and humidity was maintained in the range of 70%–85%. The movable hydroponics units were arranged in a random fashion in the greenhouse, and the