Acta Astronautica 113 (2015) 13–21

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Nutritional status and ion uptake response of *Gynura bicolor* DC. between Porous-tube and traditional hydroponic growth systems

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ARTICLE INFO

Article history:
Received 13 October 2014
Received in revised form
16 March 2015
Accepted 20 March 2015
Available online 28 March 2015

Keywords:
Porous-tube Nutrient Delivery System
Gynura bicolor DC
Ion uptake
Nutritional quality
Antioxidant defense system
BLSS

ABSTRACT

Hydroponic culture has traditionally been used for Bioregenerative Life Support Systems (BLSS) because the optimal environment for roots supports high growth rates. Recent developments in Porous-tube Nutrient Delivery System (PTNDS) also offer high control of the root environment which is designed to provide a means for accurate environmental control and to allow for two-phase flow separation in microgravity. This study compared the effects of PTNDS and traditional hydroponic cultures on biomass yield, nutritional composition and antioxidant defense system (T-AOC, GSH, H_2O_2 and MDA) of *G. bicolor*, and ionic concentration (NH_4^+, K^+, Mg^{2+}, Ca^{2+}, NO_3^-, $H_2PO_4^-$, SO_4^{2-}) of nutrient solution during planting period in controlled environment chambers. The results indicated that the biomass production and yield of *G. bicolor* grown in PTNDS were higher than in hydroponic culture, although Relative water content (RWC), leaf length and shoot height were not significantly different. PTNDS cultivation enhanced calories from 139.5 to 182.3 kJ/100 g dry matter, and carbohydrate from 4.8 to 7.3 g/100 g dry matter and reduced the amount of protein from 7.3 to 4.8 g/100 g dry matter and ash from 1.4 to1.0 g/100 g dry matter, compared with hydroponic culture. PTNDS cultivation accumulated the nutrition elements of Ca, Cu, Fe and Zn, and reduced Na concentration. T-AOC and GSH contents were significantly lower in PTNDS than in hydroponic culture in the first harvest. After the first harvest, the contents of MDA and H_2O_2 were significantly higher in PTNDS than in hydroponic culture. However, the activity of T-AOC and GSH and H_2O_2 and MDA contents had no significant differences under both cultures after the second and third harvest. Higher concentrations of K^+, Mg^{2+} and Ca^{2+} were found in nutrient solution of plants grown in hydroponics culture compared to PTNDS, wherein lower concentrations of NO_3^-, $H_2PO_4^-$ and SO_4^{2-} occurred. Our results demonstrate that PTNDS culture has more potential to maintain nutritional quality and the optimal root zone environment for *G. bicolor* compared with hydroponic culture. And further refinements in PTNDS culture would make it a viable alternative for achieving high productivity in a BLSS.

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; BLSS, Bioregenerative Life Support Systems; CAT, catalase; DW, dry weight; FW, fresh weight; *G. bicolor*, *Gynura bicolor* DC; GSH, glutathione; HGS, traditional hydroponic growth system; LN, leaf number; MDA, malondialdehyde; NDF, neutral detergent fiber; Pn, net photosynthetic rate; POD, peroxidase; PTNDS, Porous-tube Nutrient Delivery System; SH, stem height; ROS, reactive oxygen species; RWC, Relative water content; SFW, saturated fresh weight; SOD, superoxide dismutase; T-AOC, total anti-oxidative capacity; WC, water content

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http://dx.doi.org/10.1016/j.actaastro.2015.03.023

1. Introduction

As an integral part of Bioregenerative Life Support System (BLSS) for long-term, human space exploration, higher plants will be utilized for CO_2 removal from the air that is respired from explorers, they will act as oxygen regeneration and water purification systems, and they will be a source of food and fiber for human use [26,43]. Hydroponic culture has traditionally been used for BLSS obtaining high growth rates because the optimal environment for roots through the regulation of their mineral nutrition during ontogenesis [36].

Gynura bicolor DC (*G. bicolor*), which originates in the tropical area of East Asia, is one of perennial vegetables grown for its edible young immature leaves and stems. It contains relatively high levels of vitamin C, crude protein, essential amino acids and anti-lipid peroxidation with higher antioxidant activity [27,28]. Moreover, under the various growing conditions, healthy growth of *G. bicolor* needs less labor intensive because of few diseases and insect damage and then stable yields are obtained [27,45]. *G. bicolor* is also rich in anthocyanins which were shown to have antitumor, antiulcer, antioxidant and anti-inflam matory activities [44,35]. The hot water extract of *G. bicolor* and the SepPakC18 column adsorbed fraction showed inhibitory effect of the HL60 human leukemia cell growth [20]. in vitro cell and tissue cultures are frequently used for the production of secondary metabolites [46,10]. Therefore, *G. bicolor* cultivated in BLSS may be a potential method to mitigate the harmful effects of the radiation with high energy and particle charge during long-term space flight in a microgravity environment.

The Porous-tube Nutrient Delivery System (PTNDS) was designed to provide a means for accurate environmental control of crop culture in microgravity [18,25,31,11] and ground conditions [13], especially suitable for providing water and nutrients to the roots through surface tension.

The PTNDS system have permitted plant growth at very small water tensions and are modifications of varied types of procedures used in research studies to simulate large water tensions of field soils [7]. Similar PTNDS have been used in the Space Shuttle or Space Station [15,32]. Prior research has centered around experimenting the system with various crop plants [17,16,6], developing hydraulic pressure control systems for laboratory-scale crop tests [12], measuring the suitability of different porous materials, developing physical and mathematical models to describe the operation of the system [40,39], utilizing the system to grow crop plants in the confines of ground-based spaceflight plant growth unit such as the one patterned after the Russian SVET hardware [9] and the effects of pressure and pore size on plant growth [15,34,3]. In addition, as important tools, the PTNDS were used to evaluate the response of plants to varying degrees of water, nutrient stress and to investigate the hydrotropic response of roots orientation to moisture gradients under microgravity [14,18,38]. Furthermore, Cao and Tibbitts [7] compared biomass production and gas exchange of potato (*Solanum tuberosum* L.) grown in a microporous tube irrigation system containing isolite (a porous ceramic aggregate) with nutrient film technique. However, to date, not much attention has been paid to the study about plant nutrient absorption and nutritional quality in PTNDS.

Our objective was to investigate whether the differences in nutrient status between PTNDS and hydroponic culture affect the growth and yield of *G. bicolor*. In particular, we focused on characterizing the ions uptake and nutritional quality of *G. bicolor*, developing the components of insoluble dietary fiber and examining the effects of antioxidant defense in both hydroponic system and PTNDS.

2. Material and methods

2.1. Water and nutrient delivery system

G. bicolor was cultivated in a controlled growth chamber in traditional hydroponic growth system (HGS) and Porous-tube Nutrient Delivery System (PTNDS) respectively, with implementing water supply on demand. The chambers were divided into two equal parts. Each half contained three replicates of the two culture systems. The experimental growth systems of PTNDS equipped with titanium porous tubes (diameter: length $=5$ cm $\times$ 50 cm) slight negative (suction) pressure (500 Pa) implementing water supply on demand under controlled environmental conditions. Storage tanks attached lowly (5 cm) to the center of tubes created a very small negative pressure within the tube, which only allowed water flow from the tube if the plants could transport water against pressure gradient [21]. Furthermore, the slight suction pressure within the porous distribution system is intended to ensure that the root zone is not flooded. The water was then absorbed by plant roots through the pores of the tubes [21]. The total cultivated area of *G. bicolor* was 0.75 m^2 for each treatment. The planting density was 100 plants per m^2.

2.2. Environmental conditions

Light systems were provided with mixtures of red plus white LEDs (R:W $=1:1$) at a photosynthetic photon flux (PPF) of 300 ± 10 mmol $m^{-2}\,s^{-1}$ at the top of canopy. Light period was continuous (24/0 h light/dark) for both treatments. Temperature was 22 ± 1.5 °C, with relative humidity of 70% $\pm$ 3.6%. CO_2 levels were about 350–380 μmol mol^{-1} via gas chromatography (GC), using a TCD detector (Tianmei, GC-7890-II, ShangHai, China).

A modified half-strength Hoagland solution was used as nutrient solution including [NH_4^+] 9.0 mg/L, [Ca^{2+}] 80.1 mg/L; [K^+] 117.2 mg/L; [Mg^{2+}] 24.05 mg/L, [NO_3^-] 310.4 mg/L; [$H_2PO_4^-$] 48.5 mg/L and [SO_4^-] 96.2 mg/L [47]. The pH of solution was maintained at 5.8 using 0.1 M HNO_3 with a Mettler Toledo pH meter. Electrical conductivity (EC) of the solution was kept at 2.0 dS m^{-1} as determined by a Mettler-Toledo conductivity meter. The nutrient solution was replaced once during the first 7 days, when a 100 mL of liquid was sampled and saved at 4 °C for ions concentration analyses.