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Study on O_2 generation and CO_2 absorption capability of four co-cultured salad plants in an enclosed system

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Abstract

The ability to generate O_2 and absorb CO_2 of several co-cultured vegetable plants in an enclosed system was studied to provide theoretical reference for the future man-plant integrated tests. Four kinds of salad plants (*Lactuca sativa* L. var. Dasusheng, *Lactuca sativa* L. var. Youmaicai, *Gynura bicolor* and *Cichorium endivia L.*) were grown in the CELSS Integration Test Platform (CITP). The environmental factors including O_2 and CO_2 concentration were continuously monitored on-line and the plant biomass was measured at the end of the test. The changing rules of O_2 and CO_2 concentration in the system were basically understood and it was found that the O_2 generated by the plants could satisfy the respiratory needs of 1.75 persons by calculation. It was also found that the plants could absorb the CO_2 breathed out by 2 persons when the light intensity was raised to 550 mmol m^{-2} s^{-1} PPF. The results showed that the co-cultured plants hold good compatibility and excellent O_2-generating and CO_2-absorbing capability. They could also supply some fresh edible vegetable for a 2-person crew.

Keywords: CELSS; Enclosed environment; Plant growth; Photosynthetic rate; O_2-generating; CO_2-absorbing ability

1. Introduction

It is widely accepted that the Controlled Ecological Life Support System (CELSS) is quite necessary for the long-term manned space exploration, extraterrestrial living, as well as space technology development. It can provide the basic living supplies for the crew such as food, oxygen and water with limited resources in situ (Sirko et al., 1994; Tibbits and Alford, 1982; Wheeler et al., 1996, 2003; Cope and Bugbee, 2013). Therefore, many research programs on CELSS have been implemented in the United States, Russia, ESA, Japan and Canada etc., and one of the most prominent work is about CELSS integration technology (Barta and Henninger, 1994; Albiol et. al., 2000; Berkovich et al., 1998; Gitelson and Okladnikov, 1994; Barta and Henderson, 1998; Wheeler et al., 2008). The research in CELSS has been carried out in China for nearly 20 years, but the main work has been focused on the development of single key technologies (Guo et al., 2008, 2009; Tang et al., 2010; Cheng et al., 2013), and the study on man-plant CELSS integrating test has never been conducted. Therefore, a CELSS Integration Test Platform (CITP) was constructed recently for carrying out multi-day and multi-person CELSS integration researches in China. On the basis of the first plant selection and co-culture research (Guo et al., 2013), a second co-culture test of plants was carried out to study the effects of increased light intensity on O_2-generating and CO_2-absorbing capability

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of plants, so as to accumulate experience for the up-coming human-rated CELSS integration test.

2. Materials and methods

2.1. Test conditions

The test was conducted in the newly-built CELSS Integration Test Platform (CITP) (Fig. 1). The platform consists of a plant cabin and a crew cabin and is fully enclosed with metal and polyurethane insulation material (its inner and outer layers are steel plates with insulation materials inside). The environmental parameters such as the atmospheric temperature and relative humidity, as well as the light intensity and nutrient composition, can all be automatically monitored in the plant cabin. The test conditions of the co-cultured plants are shown in Table 1.

2.2. Plant species

Four salad vegetables were selected as the test plants: *Lactuca sativa* L. var. Dasusheng, *Lactuca sativa* L. var. Youmaicai, *Gynura bicolor* and *Cichorium endivia* L.

2.3. Generation of oxygen and absorption of carbon dioxide

During the test, CO_2 and O_2 concentrations were under monitoring. According to the changing trend of the concentrations, the O_2 generation ability and CO_2 absorption ability were able to be analyzed with the change value of the concentrations (see Fig. 2).

The average daily oxygen production capacity was calculated according to the following formula:

$$M = V \times D \times \mu^{-1} \times m \quad (1)$$

Here, M: oxygen generation within a day, $g \cdot d^{-1}$;

V: effective volume of the two cabins, 246.4 m^3 (the estimated volume of all facilities within the two cabins were subtracted);

D: daily average net increase of oxygen concentration, %;

μ: standard molar gas volume, 24.5 $L \cdot mol^{-1}$ (25 °C);

m: molecular mass of oxygen, 32 $g \cdot mol^{-1}$.

The daily absorbed carbon dioxide was measured by means of weighting the mass of high-pressured CO_2 bottle outside the plant cabin.

2.4. Observation and analysis of the plant growth

The growth conditions of the co-cultured plants were shown in Figs. 3 and 4. During the previous test, it is found that some plant leaves withered and central leaves turned decayed, which might be caused by the higher electrical conductivity (EC) in the nutrition solution (2.5–2.9 $mS \cdot cm^{-1}$) (Guo et al., 2013). Therefore, the EC was adjusted to about 1.8–2.2 $mS \cdot cm^{-1}$ in this test and the plants grew better, which indicated that the modified EC was suitable for the plant growth. At the later stage, some leaves in the lower part of the plants began to rot, which might be due to the higher planting density. So if the plants have appropriate planting density and be harvested timely, this phenomenon might be avoided.

3. Results and discussion

3.1. Oxygen generation efficiency

The oxygen concentration in the closed system didn't exceed 20.9% during the earlier stage of the trial due to cultivation management and equipment operations by researchers' getting in and out occasionally. During the later stage of the test, the door of the CITP was completely sealed and the oxygen concentration started to climb steadily. During this period, the cabin door had to be opened four times for various reasons as shown in Table 2. From the 24th day to 34th day, the oxygen concentration increased from 20.9% to 26.0% steadily (Fig. 5) and the average increasing rate of O_2 concentration was about 0.51% per day. Comparing with the previous co-cultured

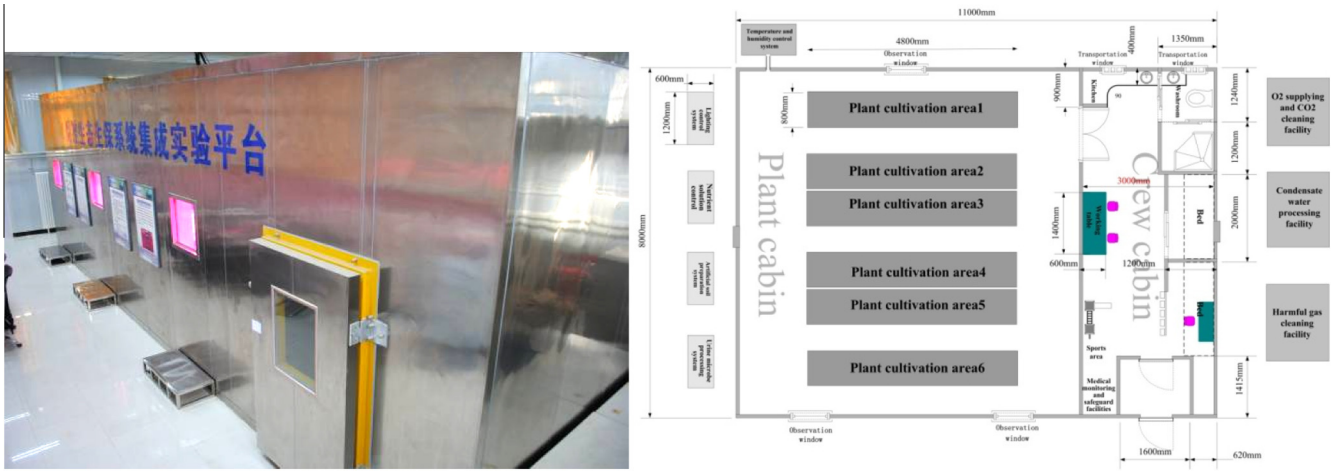

Fig. 1. The external view of CELSS Integration Test Platform (left) and its internal structure(right).