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Evaluation of wheat growth, morphological characteristics, biomass yield and quality in Lunar Palace-1, plant factory, green house and field systems

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ABSTRACT

Wheat (*Triticum aestivum* L.) is one of the most important agricultural crops in both space such as Bioregenerative Life Support Systems (BLSS) and urban agriculture fields, and its cultivation is affected by several environmental factors. The objective of this study was to investigate the influences of different environmental conditions (BLSS, plant factory, green house and field) on the wheat growth, thousand kernel weight (TKW), harvest index (HI), biomass yield and quality during their life cycle. The results showed that plant height partially influenced by the interaction effects with environment, and this influence decreased gradually with the plant development. It was found that there was no significant difference between the BLSS and plant factory treatments on yields per square, but the yield of green house and field treatments were both lower. TKW and HI in BLSS and plant factory were larger than those in the green house and field. However, grain protein concentration can be inversely correlated with grain yield. Grain protein concentrations decreased under elevate CO_2 condition and the magnitude of the reductions depended on the prevailing environmental condition. Conditional interaction effects with environment also influenced the components of straw during the mature stage. It indicated that CO_2 enriched environment to some extent was better for inedible biomass degradation and had a significant effect on "source–sink flow" at grain filling stage, which was more beneficial to recycle substances in the processes of the environment regeneration.

1. Introduction

Bioregenerative Life Support System (BLSS) is an artificial ecosystem consisting of many complex symbiotic relationships among higher plants, animals, and microorganisms [1,2]. As a consequence of the increasing importance of crop in BLSS, wheat (*Triticum aestivum* L.) plants can provide human beings with fresh air, clean drinking water, nutrient-rich food and necessary spiritual consolation, which are essential for long-term manned space missions [3,4]. Improvement of the crop yield and quality by biotechnology and

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engineering control technologies is therefore a matter of interest for researchers in both space [5] and unban agriculture fields [6]. In addition, what differences of wheat yield and quality in different cultivation environment should be investigated to identify the mechanisms of plant adaptation. Once these mechanisms are identified, decision support tools for growing plants can be optimized. These tools will be critical for developing a sustainable advance life support system for space exploration.

Plant factories are artificially controlled environment systems which are able to stably produce high-quality crops with less water, nutrition, pesticides, and labor consumption. The systems control lighting, temperature, humidity, water, the concentration of carbon dioxide, etc. in order to create an artificial and efficient cultivation environment in an indoor space [7,8]. Plant factory systems are emerging plant production industry in the future. In Asia, plant factory systems in Taiwan, Japan, and China already cultivated high-profit seedlings, herbs, fruits, and vegetables for consumers. However, previous studies focused on controlling technologies and strategies of plant factories [9] or production of leaf vegetables [10,11], a few of them concerned yield and quality of wheat plants in the plant factories.

In a smaller scale, an agricultural greenhouse is constructed to provide appropriate microclimate conditions for plant growth and crop production. The greenhouses are normally covered with transparent materials to the solar radiation such as glass or plastic film [12,13]. The temperature inside a greenhouse is increased due to two main physical reasons. The first reason is called the "heat trapping" which is basically the trapping of infrared radiation by the greenhouse covering material. For this reason, the heat is built up inside the greenhouse system by what it is called "greenhouse effect" [14]. The second cause is that the greenhouse structure is an "enclosed" space [15]. The greenhouse is constructed to be an enclosure that helps to inhibit the convective heat loss by the outer ambient environment. This may bring many benefits to the growth and development of crops compared with planting in the field.

In the growth and development processes, plants are usually subjected to environmental changes, which influence not only many biochemical processes, but also yield and quality of food crops such as wheat plants [16,17]. The cultivation of plants in space (closed environment) or in the field depends on different environmental factors [18,19]. Although available information on different cultivation environments resulted in small differences in leaf vegetables [20], very little work has been carried out on the significance of wheat output, quality and the component of inedible biomass of the edible biomass in BLSS, plant factory, agricultural greenhouse and the field systems. In this study, we investigate the influences of different cultivation environments on the wheat growth, thousand kernel weight (TKW), harvest index (HI), biomass yield and quality during their life cycle.

2. Materials and methods

2.1. Test conditions

2.1.1. BLSS-Lunar Palace 1 (LP1)

Lunar Palace 1 is like a micro-biosphere, which could provide astronauts with basic living requirements. Oxygen, water and food regenerate through biotechnology, making it possible for astronauts to live in space for long periods. Lunar Palace 1 now has one plant cabin and one comprehensive cabin. The plant cabin provides different environments for a variety of plants to grow. It consists of two planting rooms to cultivate high yielding crop plants. The experimental plant was dwarf spring wheat (*T. aestivum* L.). All wheat plants were cultivated in the bigger room. Planting area for spring wheat was 40 m^2. 10 batches of wheat plants with 7-day growth interval were cultivated hydroponically. Every batch was 4 m^2 and the growth period was about 70 days. The wheat planting density was 1000 seeds per m^2. Photosynthetic photon flux density (PPFD) levels were measured daily at the top of plant canopy with a quantum sensor (Li-250A, Li-Cor, USA). Previous study has shown that although wheat is not sensitive to the blue light dose induction [21,22], the combination of red–white LED spectra can improve its output and photosynthetic rate [16]. The parameters for wheat cultivation in different treatments are listed in Table 1. The modified Hoagland nutrient solution [23] was the basic culture medium (Table 2).

Table 1
The parameters for wheat cultivation in different treatments.

No.	Parameters	LP1	Plant factory	Green house	Field
1	Temperature (°C)	21 ± 1.3	21 ± 1.8	13.5–33.4	11.6–29.5
2	Relative humidity (%)	55 ± 4.6	55 ± 5.3	55 ± 8.9	37.5–52.4
3	CO_2 concentration (μmol mol^{-1})	1000–3000 (most time)	400 ± 30	400–1200	400 ± 30
4	Lighting system	Light emitting diodes (LEDs, red light covers 80% and white covers 20%); photosynthetic photon flux density (PPFD) is 500 μmol m^{-2} s^{-1}. (PPFD, light source is at 20 cm above)	Light emitting diodes (LEDs, red light covers 80% and white covers 20%); photosynthetic photon flux density (PPFD) is 500 μmol m^{-2} s^{-1}. (PPFD, light source is at 20 cm above)	Sunlight	Sunlight
5	Lighting time (light/dark)	24 h/0 h	24 h /0 h	11–14 h /13–10 h	11–14 h /13–10 h