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# Photosynthetic characteristics, antioxidant capacity and biomass yield of wheat exposed to intermittent light irradiation with millisecond-scale periods

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ABSTRACT

Energy consumption and output are two very important standards for evaluating the reliability of electric light sources when plants are grown in a controlled environment. As a primary source of energy, light is one of the most important environmental factors for wheat growth. The objective of this study was to investigate the influences of light/dark cycle operation with millisecond-scale period on the growth of wheat, photosynthetic characteristics, antioxidant capacity and biomass yield and quality during their life cycle. Four types of intermittent lighting with the same intensity were employed: a light/dark (0.5/0.5 ms) light (50%), a light/dark (0.7/0.3 ms) light (70%), a light/dark (0.8/0.2 ms) light (80%) and a continuous light (100%). The results showed that the wheat cultivated in the 80% light was characterized by highest photosynthetic rate and lowest lignin in inedible biomass, which was more beneficial to recycle substances in the processes of the environment regeneration. The data were comparable to those under continuous light condition in terms of chlorophyll concentration, antioxidant capacity, harvest index (HI) and thousand kernel weight (TKW). Wheat was sensitive to intermittent illumination which significantly affected those indices of growth and physiology, especially at heading and flowering stages.


## 1. Introduction

Sustained human presence in space requires the development of new technologies to maintain environment control, to provide water, oxygen, food and to keep the astronauts healthy and psychologically fit (Liu et al., 2008; Nelson et al., 2005). Bioregenerative Life Support Systems (BLSS) in conjunction with in-situ resource utilization will initially reduce and ultimately eliminate consumables from the logistics chain (Hu et al., 2012; Tikhomirov et al., 2003). As a primary source of energy, light is one of the most important environmental factors for plant growth (Dong et al., 2014b; Hu et al., 2014). In particular, wheat (*Triticum aestivum* L.), which is a core crop in BLSS and urban vertical farms (Despommier, 2009, 2013), is often restricted in growth by inappropriate artificial light, higher planting density, and skeletal structure shading. Thus, enhancing the crop yield and energy saving is a matter of interest for researchers in both space and urban agriculture settings.

The structure of plants is regulated, in part, by light signals from the environment (Goins et al., 1997; Shao et al., 2015). Light-enhanced production involves photosensory/photoregulation systems. The photoreceptors are light responsive switches for controlling the expression of specific genes involved with growth, developmental processes and secondary metabolism in plants (Furuya, 1989; Jenkins et al., 1995). Intermittent illumination with a second-scale period produces the same amount of anthocyanin as continuous light (Kurata et al., 2000). In order to adjust to various light environments, plants have evolved many mechanisms, including morphological and physiological changes at the levels of the leaf (Zhang et al., 2003). That adaptation maximizes the capture of the available light, which meets the demand for photosynthesis (Steinger et al., 2003).

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Previous research mainly focused on the impacts of different light intensities/qualities on the growth and development of plants in the natural sunlight (Chaturvedi and Ingram, 1989; Flore, 1980; Osaki et al., 1995). However, little is known about the effects of different intermittent illumination on the growth and development of plants under light-emitting diodes (LEDs). Responses of higher plants to intermittent lighting have been reviewed by Sager and Giger (Sager and Giger, 1980), but much still remains unknown. What effects will different artificial light/dark cycles, especially those of combined red and white light, have on the growth and development of plants? And which period under intermittent illumination will be not only suitable to the culture of plants, but also beneficial to energy saving? We find that light/dark cycle operation with millisecond-scale period presents a novel method that optimizes production with respect to light energy.

## 2. Materials and methods

### 2.1. Plant material and growth conditions

Spring wheat plants (*Triticum aestivum* L. cv. 'Dwarf') were planted in plant cabin of Lunar Palace-1 (Dong et al., 2015). 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. The wheat planting density was 1000 seeds per $m^2$. The growth period of the wheat was 70 days. For all treatments, lighting was continuous (24/0 h light/dark). The relative humidity (RH) was maintained at 55 ± 4.6%, with a 24 h photoperiod and a temperature of 21 ± 1.3 °C during daytime and night. The modified Hoagland nutrient solution was the basic culture medium (Dong et al., 2014a; Hoagland and Arnon, 1950).

**Table 1**
Output voltage and output current of the different treatments.

| | 50% | 70% | 80% | 100% |
|---|---|---|---|---|
| Output voltage | 64 V | 64 V | 64 V | 64 V |
| Output current | 2250 mA | 3150 mA | 3600 mA | 4500 mA |

### 2.2. LEDs devices with different intermittent light

All of the combined LEDs had the uniform spectra of red and white, and were designed by Beihang University, China (Dong et al., 2014a). The spectral distribution of the red (peak at 658 nm) and white (from 350 nm to 750 nm) light were measured using a spectroradiometer (Avaspec-2048-UA, Avantes B.V., Netherlands) (Dong et al., 2014c). A pulse width modulation (PWM) current driver and peripheral circuits were designed as a control unit for the LEDs for plant cultivation (Shimada and Taniguchi, 2011). The parameters of the light/dark cycle in each treatment were measured with a fast digital oscilloscope Tektronix TBS 1104 and they are shown in Fig. 1. The nominal power of the fixture is 300 watts (W). There are 20 × 16 = 320 individual LEDs in one light fixture (Fig 2A). Output voltage and output current of the different treatments were measured with Fluke 77 mm (Fluke, Inc., Everett, WA) when the anode and cathode were connected directly through the multimeter (Table 1). One fixture can cover 0.5 $m^2$ growing area due to the light fixture area. Moreover, the dimensions of the light fixture are shown in Fig. 2B.

Because the growth period of spring wheat plants was about 70 days, the distance between light sources and wheat canopy was regulated approximately 30 days. After heading stage, the light intensity ($\mu mol\ m^{-2}\ s^{-1}$) should never have to be adjusted again. The light intensity ($\mu mol\ m^{-2}\ s^{-1}$) was measured every 3 days using a quantum sensor and light meter (LI-250A and LI-190,

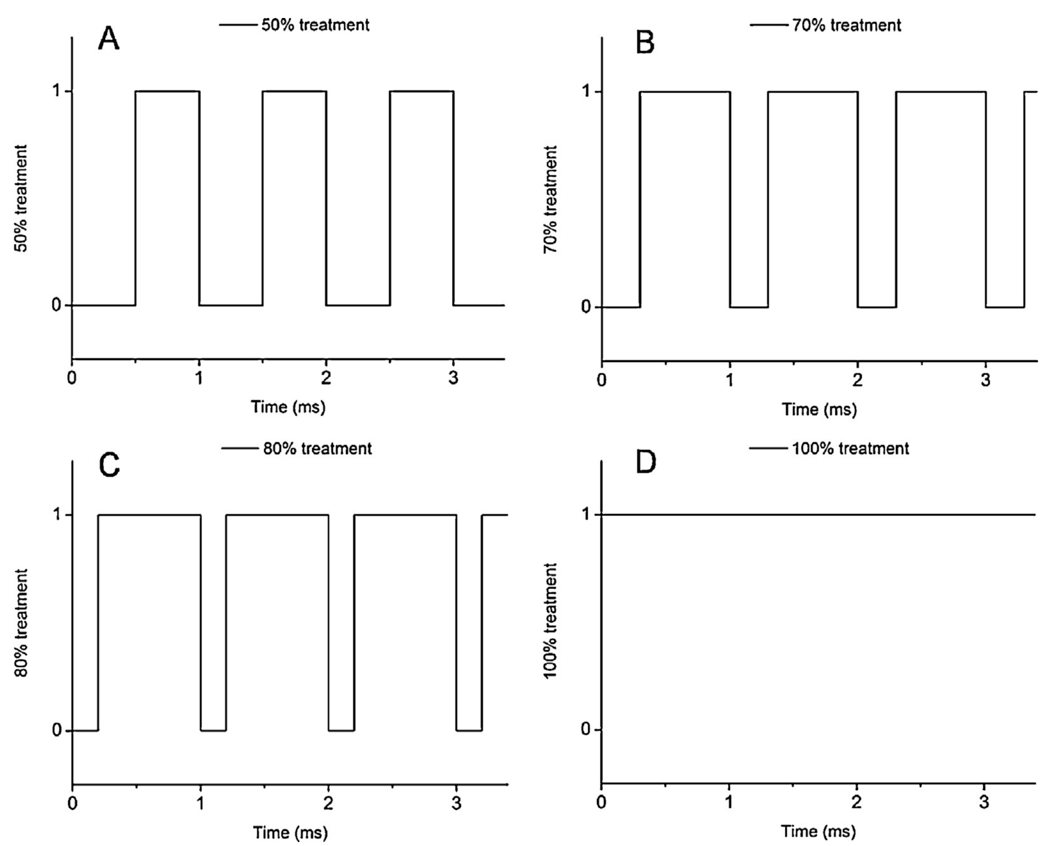


**Fig. 1.** Different light frequencies and treatments applied to wheat plants. "1": Light. "0": Dark.