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# Performance of Light Sources for Plants under Altered Gravity Conditions in Parabolic Airplane Flights

Hiroaki HIRAI [1], Yoshiaki KITAYA [1] and Takehiro HIRAI [2]

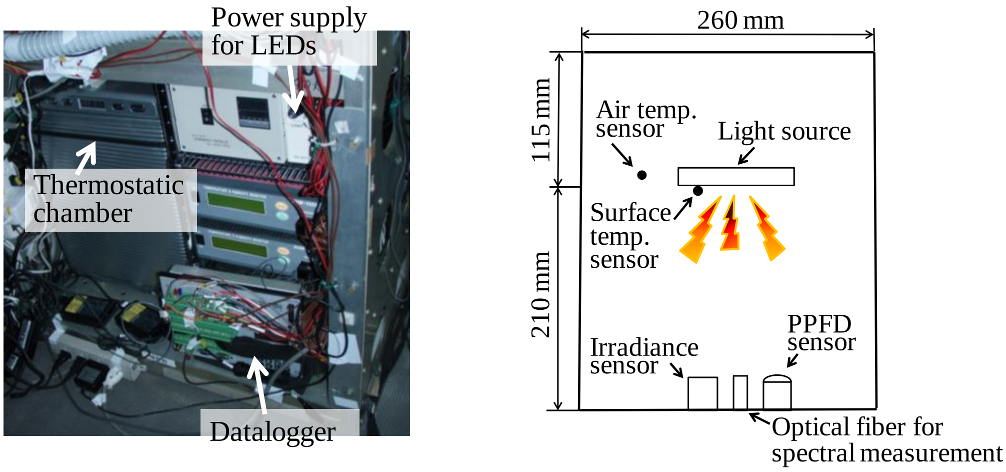
## Abstract

Performances of light sources, a halogen lamp, a fluorescent lamp and light emitting diodes (LEDs), commonly used for plant culture were examined under altered gravity conditions created during parabolic airplane flights. The surface temperatures of the light sources, irradiances, photosynthetic photon flux densities (PPFDs) and spectral distributions of radiation from the light sources were measured at the gravity levels of 0.01, 1.0 and 1.8 G for 20 s each during parabolic airplane flights. As a result, the surface temperature of the halogen lamp bulb increased most rapidly and the irradiance increased most remarkably among the three light sources at 0.01 G. On the contrary, the surface temperatures and light intensities of LEDs were most stable followed by the florescent lamp with gravity change. These characteristics of LEDs would be suitable for plant experiments and plant culture in space.

**Keyword(s):** LED, light, microgravity, wavelength

## 1. Introduction

A bioregenerative life support system (BLSS) in space has received increasing attention since a long-term manned space flight has become possible. Feasibility of achieving long-term manned space missions is dependent on how we secure the sufficient BLSS that controls food production, $CO_2/O_2$ conversion, and water purification[1-3]. Scheduling crop production is important in order to obtain high yields with a rapid turnover rate in space farming as part of the BLSS. Space faming will be anticipated to use in closed plant culture facilities. In such facilities, adequate air circulation would be important, which minimizes the resistance to gas diffusion in the leaf boundary layer. Inadequate air circulation limits photosynthesis and transpiration of plants[4-8] and, in consequence, plant growth and development would be suppressed.



(a) Photo of the front view. (b) Schematic diagram of the inside view of the thermostatic chamber.

**Fig. 1** Experimental setup in the airplane.

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1 Graduate School of Life and Environmental Sciences, Osaka Prefecture University, 1-1 Gakuen-cho, Naka-ku, Sakai, Osaka 599-8531, Japan
2 Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan
(E-mail: hirai@envi.osakafu-u.ac.jp)

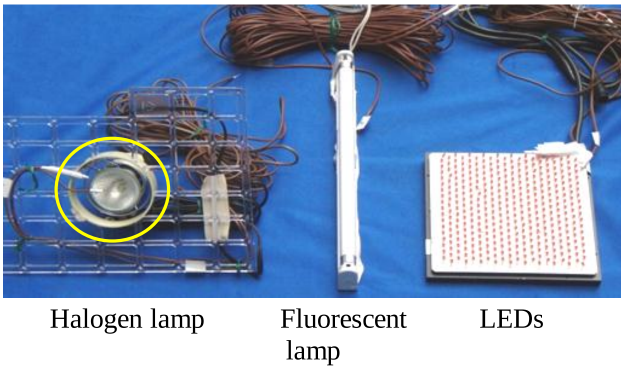

**Fig.2** Light sources used in the experiment.

Such a closed environment also makes it difficult to establish lighting systems suitable for plant culture in space. Lack of air movement under low or no gravity conditions would increase the temperature of light sources and thus alter radiant intensities, which may affect the growth and development of plants and the lifetime of themselves. However, few experiments have been attempted to investigate the performances of light sources under microgravity conditions. In this study, effects of microgravity on surface temperatures and spectral distributions of radiation from light sources were investigated in order to find appropriate light sources for space farming. Altered gravity conditions were created during parabolic airplane flights.

## 2. Materials and methods

Components of the experimental system were installed in a frame structure in an airplane (**Fig. 1a**). Three types of light sources commonly used for plant factory systems on the earth were selected in this experiment: a halogen lamp (Clip light JDR 50W, Ohm Electric Inc., Yoshikawa, Japan), a fluorescent lamp (Five eco 8W, Ohm Electric Inc., Japan), and red LEDs (Compact LED light units for Plant Research, CCS Inc., Kyoto, Japan) (**Fig. 2**). Irradiances as radiant intensities were measured with a pyranometer (Li-200SL, LI-COR, Lincoln, NE, USA). Photon numbers in a wavelength range between 400 and 700 nm as PPFD were measured with a quantum sensor (QSO-E, Apogee Co., Logan, UT, USA). Spectral distributions in a wavelength range between 180 and 890 nm were measured at every 0.2 nm wavelengths with a spectrometer (USB4000, Ocean Optics Inc., Dunedin, FL, USA). Three types of light sensors mentioned above were attached under each light source in a thermostatic chamber (ACW-610, Apix International Co. Ltd., Iwakura, Japan) (**Fig. 1b**). The halogen lamp was placed 200 mm, and the fluorescent lamp and LEDs were placed 160 mm above the light sensors.

Temperatures, irradiances, PPFDs and spectral distributions of light sources were monitored at gravity levels of 0.01, 1.0 and 1.8 G for 20 s each created sequentially in the parabolic airplane flight. The surface temperatures of the light sources were measured with thermocouples that were attached on the halogen lamp bulb, the fluorescent lamp tube and the covering acrylic material of LEDs. These output signals were recorded every 0.5 s with a datalogger (CR3000, Campbell Scientific Inc., Logan, UT, USA). Air temperatures were measured using a thermistor thermometer (TR-72U; T&D Co., Matsumoto, Japan). Thermometer sensors were placed under shading to avoid the additional radiation heat load from light sources. Air circulation was controlled with a fan. Parabolic airplane flights were carried out 9-20 times in a day and repeated 182 times for 13 days in total.

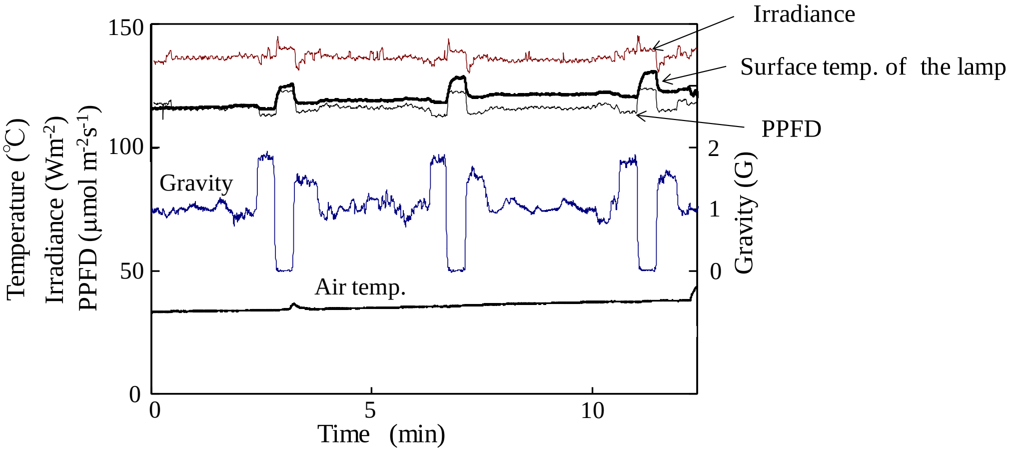

**Fig. 3** Typical time courses of the gravity, the surface temperature of the halogen lamp bulb, the irradiance, PPFD and the air temperature, when an air circulation fan was switched off.

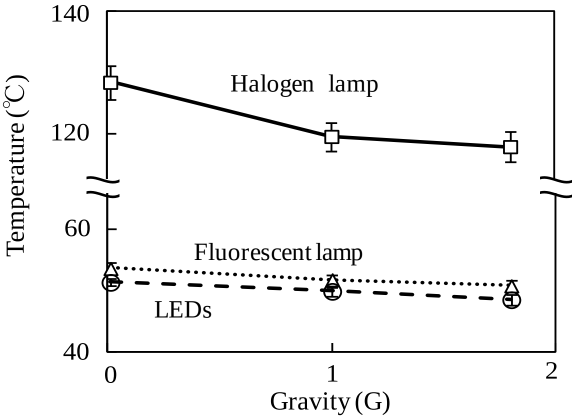

**Fig. 4** Effect of the gravity on surface temperatures of light sources, when the air circulation fan was switched off. Vertical bars indicate standard deviations (n=3).

## 3. Results

**Figure 3** shows time courses of the surface temperature of the halogen lamp bulb, the irradiance and PPFD of the halogen lamp and the air temperature corresponding to the gravity change. Altered gravity conditions of 1.8 and 0.01 G were created sequentially and maintained for 20 s each during the parabolic airplane flight. The gravity was 1.0 G when the airplane flew horizontally before and after each parabolic flight. When the fan was switched off and air circulation was stopped, the surface temperature of the halogen lamp bulb decreased after the gravity increased from 1.0 to 1.8 G and increased after the gravity decreased from 1.8 to 0.01 G. The irradiance and PPFD decreased after the gravity increased from 1.0 to 1.8 G and increased after the gravity decreased from 1.8 to 0.01 G. The irradiance and PPFD increased by 3 % and 6 %, respectively, when the gravity decreased from 1.0 to 0.01 G.

The surface temperature of the halogen lamp bulb increased by 8.8 $^{o}$C, when the gravity decreased from 1.0 to 0.01 G as shown in **Fig. 4**. The surface temperatures of the fluorescent lamp tube and covering materials of LEDs showed the similar tendency to the halogen lamp bulb. The surface temperatures increased from 51.7 to 53.6 $^{o}$C for the fluorescent lamp, and from 49.8 to 51.3 $^{o}$C for LEDs when the gravity decreased from 1.0 to 0.01 G.

**Figure 5** shows time courses of the gravity change and the surface temperature of the halogen lamp bulb with or without the air circulation. The surface temperature became stable, when the fan was switched on and the air was circulated under fluctuated gravity conditions.

**Figure 6** shows spectral distributions of three light sources corresponding to the gravity change. For the halogen lamp (**Fig. 6a**), the highest peak was shown at the wavelength of 639 nm. Shapes of the spectral distributions under different gravity conditions were mostly similar, although the total irradiance of the lamp increased with decreasing gravity levels. The irradiance increased by about 10 % at the peak, when the gravity decreased from 1.0 to 0.01 G. The irradiance fluctuated most largely among the three light sources.

For the fluorescent lamp (**Fig. 6b**), two high and one middle

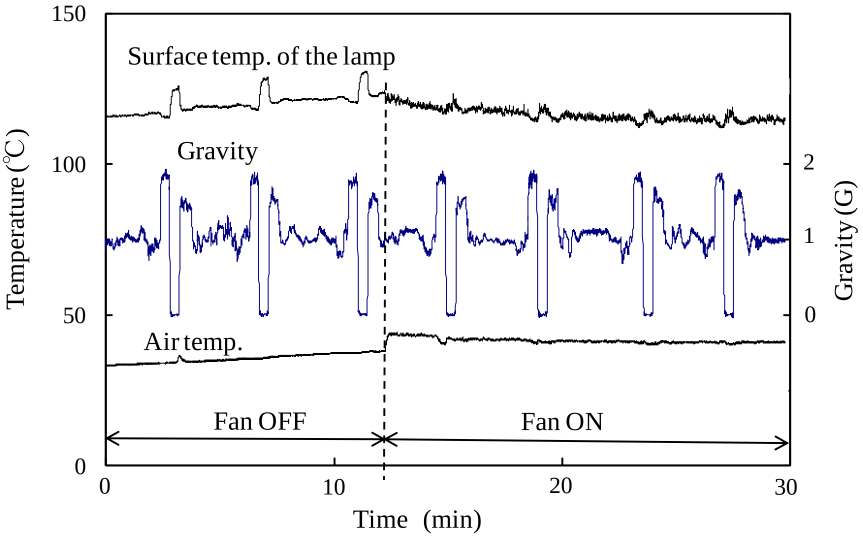

**Fig. 5** Time courses of the gravity, the surface temperature of the halogen lamp bulb and the air temperature.

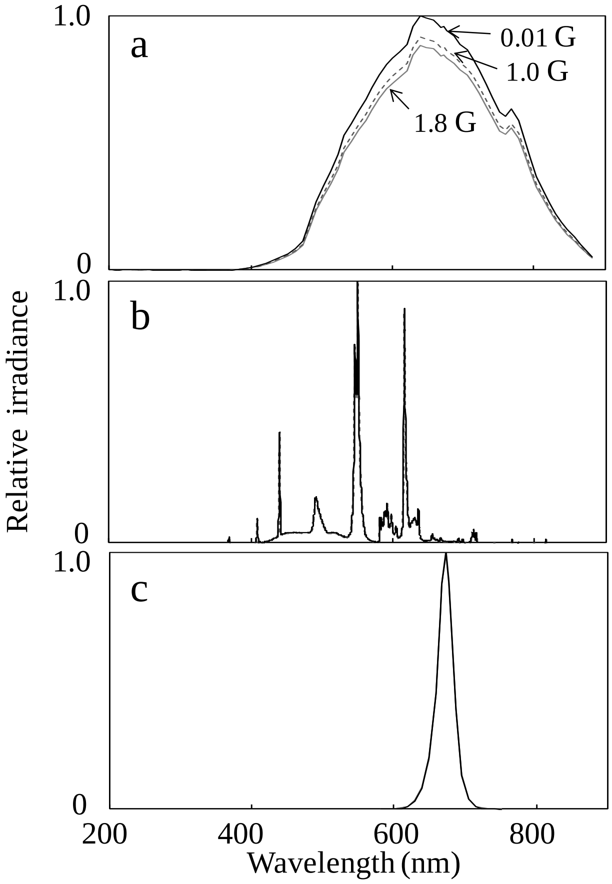

**Fig. 6** Spectral distributions from the halogen lamp (a), the fluorescent lamp (b) and LEDs (c) at different gravity levels. Carves at three gravity conditions were mostly overlapped for the fluorescent lamp and LEDs.

peaks appeared at wavelengths of 551 nm (green), 616 nm (red) and 440 nm (blue), respectively. The irradiances increased by 1.0 %, 1.6 % and 0.2 % at the green, red and blue peaks, respectively, when the gravity decreased from 1.0 to 0.01 G.

For the red LEDs (**Fig. 6c**), a single peak was shown at the wavelength of 672 nm. The irradiance of the red LEDs was stable regardless of the gravity change.

## 4. Discussion

In this study, performances of three types of light sources commonly used as artificial lights for plant culture on the earth were compared under different gravity conditions in order to examine their usability for plant experiment and for space agriculture. As a result, light sources with luminescent filaments like halogen lamps would be unsuitable for space farming because surface temperatures of the bulb rose to more than 100 $^{o}$C, which was two times those of the other two light sources examined in this study and furthermore, increased under microgravity conditions.

As for the fluorescent lamp, the surface temperature of the lamp tube was much lower than the halogen lamp and slightly higher than that of the LEDs. Irradiance from the fluorescent lamp also slightly increased under the microgravity condition.

On the other hand, the surface temperature of LEDs was lowest and the irradiance was most stable under altered gravity conditions. Besides these characteristics, LEDs emit the selectable narrow-waveband radiation that can be matched to the absorption spectra of plant pigments for promoting photosynthetic activity [9, 10].

Halogen lamp bulbs and fluorescent lamp tubes were made with fragile materials such as glass and would be easily broken. In addition, both light sources contains hazardous gases and materials. On the other hand, plastic materials covering LED tips are not easily broken and LED contain no hazardous gas materials. The lifetime of LEDs is longer than other two light sources. Therefore, LEDs would be promising light sources for plant culture in the future BLSS in space.

Since restricted free air convection under microgravity conditions in space would raise the surface temperature of the light sources and possibly alter light emission, the selection of light sources that are stable under altered gravity conditions is crucial. At the same time, considerable efforts must be directed toward the development of an adequate air circulation system not only for creating a comfortable environment for plant growth but also cooling light sources.

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