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A Novel Cropping Method for Production of High Functioning Crops by Utilizing On-site Solar Energy

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Abstract

The utilization efficiency of solar energy through photosynthesis by crops is only a few percent at most. Therefore, most solar energy in the field (on-site) remains unused. Plants are, however, able to use certain types of monochromatic light as an environmental signal, and they exhibit various physiological responses to even small amounts of the light. In particular, the significant induction of secondary metabolite production by blue light is well documented. Here, we propose a novel cropping method where unused solar energy is captured on-site by solar cells and converted to monochromatic light by using LEDs. The crops are then irradiated to stimulate enhanced production of secondary metabolites, thus improving crop function without the need for an external energy source. In this study, the effect of blue light on the production of functional secondary metabolites was evaluated in perilla (*Perilla frutescens* var. *crispa f. purpurea*), a traditional medicinal crop in Japan. Perilla leaves contain several functional substances such as perillaldehyde, rosmarinic acid, and anthocyanins, which have notable stomachic, antipyretic, detoxification, sedation, and diuretic efficacy. Plants were grown under natural daylight supplemented with blue light irradiation (460 nm, approx. 10 μmol/m²/s, 24 h) for 108 days before harvest. Control plants were grown without supplemental lighting. The content ratio of perillaldehyde in plants grown with blue light was 60% higher at harvest than in the controls. Moreover, in the vegetative growth stage, the perillaldehyde content increased significantly after only three days of blue light irradiation. These findings suggest that the present approach will benefit agricultural practices in developing countries through more efficient usage of on-site solar energy.

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Keywords: on-site solar energy; perilla; monochromatic lighting; high functioning crop
1. Introduction

Crops such as vegetables and cereals produce leaves and fruits by converting solar energy into chemical energy during photosynthesis. However, the efficiency of solar energy use by plants is a few percent at most [1], leaving a large amount of unused solar energy in crop fields. Consequently, there has been much discussion about the utilization of unused on-site solar energy in the form of solar cells and heat collection. Both systems, however, require large effort to maintain their renewable energy infrastructure.

We therefore investigated whether unused solar energy can be harnessed on-site for the improved production of crops. Although the use of solar energy to facilitate photosynthesis and thus enhance crop production might be the first choice, this idea was rejected because crops already have an ample supply of solar energy. We therefore decided to exploit unused solar energy to improve the quality and marketability of crops. When irradiated with light of a specific wavelength, for example, blue light at 460 nm, red light at 660 nm, and far-red light at 730 nm, plants perceive light stimuli as environmental signals and consequently adapt their morphology, which alters their nutritional value. Compared with the amount of light energy used in photosynthesis, very little light energy is needed to generate an environmental signal sufficient to trigger a physiological reaction in plants [2]. In particular, blue light is known to upregulate the production of secondary metabolites [3], suggesting that the light may also enhance the production of various functional ingredients (physiologically active components) in crops.

In this study, to develop a novel cropping method that utilizes monochromatic light, we designed a stand-alone supplemental lighting device that works autonomously without the need for an external power supply in ordinary outdoor crop fields, and we assessed the performance of a prototype. We also investigated the effect of blue-light supplementation on the production of functional ingredients in perilla herb, a traditional Japanese medicinal plant.

2. Stand-alone supplemental lighting device

Fig. 1 provides an overview of the stand-alone supplemental lighting device and appearance of a prototype device. The prototype, which is powered by two solar cells and backed-up by two lead-acid batteries, consists of a solar charge controller, a lighting control unit (also provided with a GPS and a radio clock for calculating the time of sunrise and sunset), and an light emitting diode (LED) unit. Because the solar cell supplies 36 W and the LED unit consumes 26 W, power for lighting is well provided by the solar cell at least for a few hours. The luminous intensity distribution of the prototype device is shown in Fig. 2. The highest photon flux density was observed 2 m from the point directly under the LED unit located at the top of the device (2 m from the ground level). Photon flux density rapidly decreased in line with increased distance from the 2-m point.

Crops responded to supplemental lighting with both a threshold response and dose-dependent response. Therefore, to illuminate crops in the testing field equally, we made a miniature model, one-quarter the size of the original, with a curved mirror to reflect the LED light. Fig. 3 shows the alteration of the light distribution by a curved mirror. The relationship between the amount of light and the distance from the light source was compared between the LED unit alone (Fig. 3, solid line) and with a curved mirror (Fig. 3, dashed line). The results demonstrated that light distribution was similar in the area 60–140 cm from the point directly under the LED unit, which was equivalent to 2.4–5.6 m with the original full-size device.
Fig. 1. Overview of the stand-alone supplemental lighting device (a) and appearance of a prototype (b).

Fig. 2. The luminous intensity distribution of the prototype device.
3. Functional improvement of perilla herb by monochromatic light supplementation

Perilla (*Perilla frutescens* Britton) contains several functional ingredients (perillaldehyde, rosmarinic acid, anthocyanin, etc.), and the herbal extract has notable stomachic, antipyretic, detoxification, sedative, and diuretic efficacy. In this study, two red perilla varieties, ‘Kishu-zairai’ (a medicinal red perilla native to Wakayama, Japan) and ‘Aka-chirimen-shiso’ (a commercial cultivar of red crape-shaped perilla), were used to investigate the effect of blue LED light on the content of perillaldehyde in harvested leaves. We made two experimental plots, one for supplemental lighting and another as a control, in a glasshouse under natural light conditions. Red perilla in the supplemental-lighting plot received blue LED light (460 nm) at 10 μmol/m²/s for 24 h in addition to natural light. Leaves were harvested after 108 days of cultivation, dried, and powdered, from which soluble components were extracted with methanol for capillary gas-liquid chromatography. The amount of perillaldehyde in 1 g of dried leaf is shown in Fig. 4. Blue LED light increased the levels of perillaldehyde in ‘Kishu-zairai’ and ‘Aka-chirimen-shiso’, which were originally different, by approximately 60% in both varieties.

In addition, we conducted similar supplemental lighting test to ‘Kishu-zairai’ plants of about 70 days after sowing and measured the amount of perillaldehyde in leaves harvested periodically. Fig. 5 shows the change of the content ratio of perillaldehyde in leaves harvested. An increase in perillaldehyde reached a significant point after just 3 days of light supplementation. The results of this study clearly show that supplemental blue light increases the content of the functional aromatic component in red perilla.
Fig. 4. The effect of supplemental blue lighting on the content ratio of perillaldehyde in dried leaves of two kind of perilla.

Open bar: control plot (without supplemental lighting)
Solid bar: continuous supplemental lighting plot

Fig. 5. Effect of the supplemental lighting on the content ratio of perillaldehyde in dried leaves

Solid line: under the supplemental lighting
Dashed line: control
4. Conclusion

The proposed cropping method uses on-site solar energy to improve the commercial value of crops. Although we present an increase in the active perilla ingredient in this study, we have also reported the hastening of flowering time in peas (*Pisum sativum* L.) [4] and color alteration in *Chrysanthemum morifolium* Ramat. [5] in previous studies using the same technique. We developed this technology for use in rural areas, where an external power supply is not always available. In particular, developing countries can produce highly marketable crops using this technique to utilize freely available solar energy.

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