Spectrum conversion film for regulation of plant growth

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Spectrum Conversion Film for Regulation of Plant Growth

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In order to regulate the plant growth, we newly developed the spectrum conversion films (red film and blue film). The red film can convert the blue–green light (450–550 nm) into the red light (600–700 nm), and the blue film can convert the ultraviolet (UV)–violet light (350–450 nm) into the blue–green light. The effect of covering plants with these films on leaf photosynthesis, plant growth and seed germination were examined in three species of plants under the natural light. Leaf photosynthesis of radish was slightly accelerated in the red film. Fresh and dry weights of root of radish were higher in the red film, and were up to 1.5 times higher than that in the blue and clear films. Therefore, the acceleration of root growth through the activation of leaf photosynthesis was observed in the red film. Fresh and dry weights of shoot of Welsh onion were also higher in the red film. On the other hand, leaf elongation was accelerated in the blue film, and this was observed in radish and Welsh onion. The seed germination of Blue Star (*Oxypetalum caeruleum*) was accelerated under the red film, and reached to 98%. From these results, the red film enables the accelerations of leaf photosynthesis and seed germination, and the blue film accelerates the leaf elongation. Therefore, the spectrum conversion films are applicable to regulate the plant growth in plant productions.

Keywords: growth regulation, photomorphogenesis, photosynthesis, seed germination, spectrum conversion film

INTRODUCTION

In plant productions, the regulation of plant growth is much required for high yield, high quality and labor-saving. Light quality is one of major factors to affect the plant growth, and the effects of light quality on plant growth have been studied for more than 50 years (Goto, 2003). According to previous studies (Frank and Bakx, 1997; Hanyu and Shoji, 2000; Inada, 1976; Islam *et al*., 1999; Morgan and Smith, 1976; Smith, 2000), it is confirmed that the plant growth (photosynthesis, photomorphogenesis, seed germination, stomatal movement, flower bud, etc.) is affected by the characteristics of wavelength such as red and far–red light ratio (R:FR), blue and red light ratio (R:B) and the amount of ultraviolet (UV), and the photoreceptors such as phytochrome, cryptochrome and phototropin play the key role in these physiological processes. In order to regulate the plant growth, many types of artificial lamps and covering materials have been developed (Goto, 2003; Murakami *et al*., 1995). However, these were necessary to improve more effectively and simply.

Aiming at the regulation of plant growth, we newly developed the spectrum conversion films (red film and blue film), which can convert the wavelength of the absorbed light into the other wavelength. In this study, the characteristics of the newly developed films and its covering effect on leaf photosynthesis, plant growth and seed germination were examined in some species of plants under the natural light.

MATERIALS AND METHODS

Characteristics of spectrum conversion film

Figure 1a shows the photograph of the spectrum conversion films (red film: ID–EVA, blue film: BB–EVA). These films were made by mixing the solid luminescent pigments of red (IAQ–DAS) and blue (BFO–BUT) into ethylene–vinyl acetate copolymer film. The red luminescent pigment can convert the wavelength of the blue–green light (450–550 nm) into the red light (600–700 nm), and the blue luminescent pigment can convert the wavelength of the UV–violet light (350–450 nm) into the blue–green light (Ooyama *et al*., 2006).

As the preliminary examination, spectral compositions of natural lights under the red and blue films were measured with a spectrometer (Otsuka Electronics Co, Ltd., Osaka, Japan). **Figure 1b** and **1c** shows the spectral compositions of natural light, natural light under the red film and natural light under the blue film. The red film absorbed the blue–green light and emitted the red light, and resultantly the red light, which plays a very important role in photosynthesis and photomorphogenesis, was increased as compared with that in the natural

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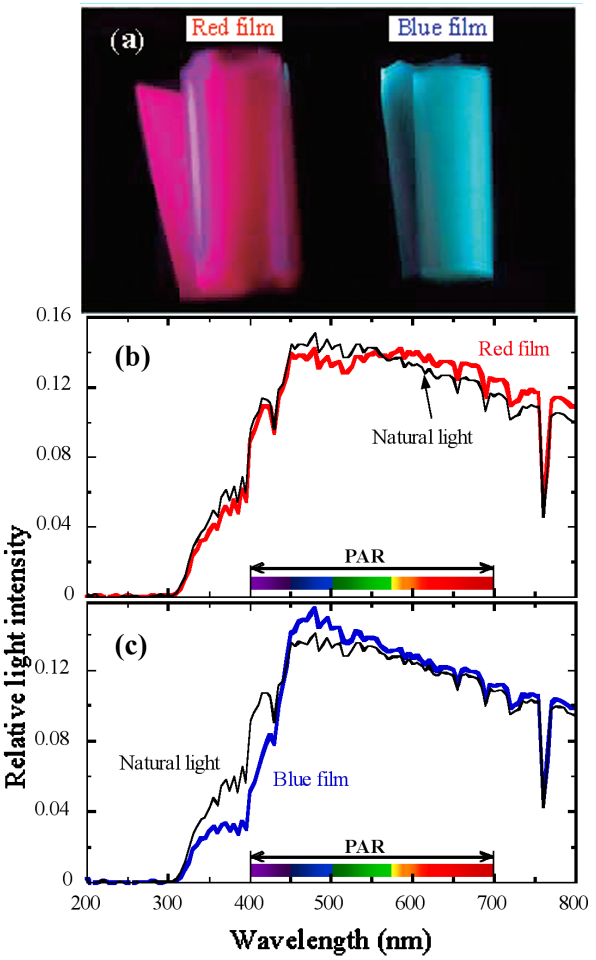

Fig. 1. Photograph of the spectrum conversion films (red film and blue film: a), and spectral compositions of natural light, natural light under the red film (b) and natural light under the blue film (c). The red film can convert the wavelength of the blue–green light (450–550 nm) into the red light (600–700 nm), and the blue film can convert the wavelength of the ultraviolet–violet light (350–450 nm) into the blue–green light.

light. On the other hand, the blue film absorbed the UV–violet light and emitted the blue–green light, and resultantly the UV light was decreased and the blue light, which plays a very important role in photosynthesis, photomorphogenesis and stomatal movement, was increased as compared with that in the natural light.

Growth experiment

To investigate the effect of covering treatment of the spectrum conversion films on plant growth, the growth experiments were conducted in a phytotron glass room in Kochi University. Seeds of radish (*Raphanus sativus* var. *radicula*) and Welsh onion (*Allium fistulosum* L. cv. Koutou) were sown in 6 L pots filled with vermiculites, and were grown for seven weeks in the phytotron glass room at the day/night air temperatures of 23/18 °C.

During four weeks before the harvest, respective 10 plants of radish and Welsh onion were covered with the red, blue and clear films, where the clear film was used as a control. Plants were irrigated everyday with 1 L of the nutrient solution (NO_3^-, 15.2; NH_4^+, 1.6; $H_2PO_4^-$, 1.6; K^+, 1.8; Ca^{2+}, 3.6 mmol L^{-1}) of OTSUKA HOUSE (Ostsuka Chemical Co. Ltd., Osaka, Japan) at an electrical conductivity (*EC*) of 1.0 dS m^{-1}.

At seven weeks after sowing, 10 plants of radish and Welsh onion were sampled and their leaf length and fresh and dry weights of shoot and root were measured.

Data are presented as mean ± standard error, and were analyzed by the analysis of variance (ANOVA) to test the significance of the observed differences. When the ANOVA was significant at $P \leq 0.05$, mean differences were statistically assessed at $P \leq 0.05$ by Fisher's PLSD test.

Measurement of leaf photosynthesis

To investigate the effect of covering treatment of the spectrum conversion films on leaf photosynthesis, the diurnal change in photosynthetic rate in a leaf of radish covered with the red, blue and clear films was measured under the natural light by using a leaf chamber system (LI–6400, LI–COR Inc., USA). Intact leaves of radish (six weeks old) grown for the growth experiments were used. Measurement was conducted from 8:30 to 17:30 in a phytotron glass room at an air temperature of 23 °C on sunny day. An air in a leaf chamber was supplied inside of the phytotron glass room, and an air temperature and CO_2 concentration in the leaf chamber were controlled at 23 °C and 370 μmol mol^{-1}, respectively. Furthermore, the diurnal change in photosynthetic photon flux density (*PPFD*) was also measured with a quantum sensor (LI–190SL, LI–COR Inc., USA).

Seed germination test

The effect of covering treatment of the spectrum conversion films on seed germination was investigated in a phytotron glass room. Seeds of Blue Star (*Oxypetalum caeruleum*) were soaked in a distilled water for 15 hours, and then were placed on filter paper moistened with distilled water in petri dishes at the day and night air temperature of 25 °C. Just after sowing, 50 seeds were covered with the red, blue and clear films for two weeks. The number of germinated seeds was measured during two weeks after sowing.

RESULTS AND DISCUSSION

Figure 2 shows the diurnal changes in photosynthetic photon flux density (*PPFD*) and photosynthetic rate in a leaf of radish covered with the red, blue and clear films. Photosynthetic rate in the respective treatments changed with *PPFD*. In the treatments of the red and blue films, photosynthetic rate was slightly higher than that in the clear film only during 8:30 to 9:30, but thereafter the values in the respective treatments was almost same. It is known that the photosynthetic activity depends on the spectrum, and Inada (1976) reported that the leaf photosynthesis was accelerated in the blue and red lights in radish plants. This suggests that the slight acceleration of photosynthetic rate in the red and blue films was caused by the enhancement of the red and blue lights through the spectrum conversion of the

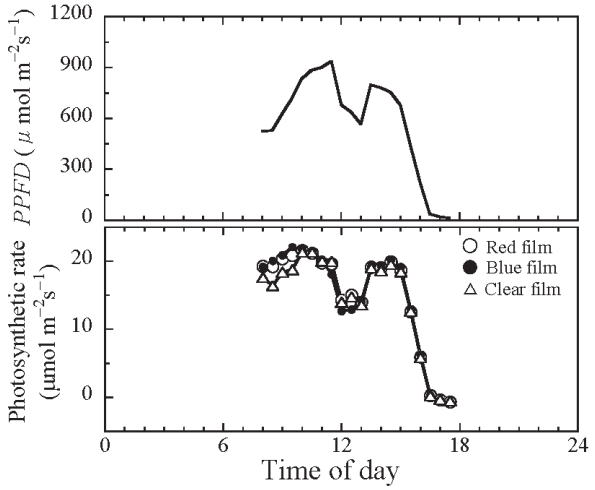

Fig. 2. Diurnal changes in photosynthetic photon flux density (*PPFD*) and photosynthetic rate in a leaf of radish covered with the red, blue and clear films at a CO_2 concentration of 370 μmol mol^{-1}. Measurement was conducted in a phytotron glass room at an air temperature of 23 °C.

red and blue films.

Figure 3 shows the photograph of harvested radish plants covered with the red, blue and clear films, and their leaf length, shoot dry weight and fresh and dry weights of root. Leaf length in the blue film was significantly higher than those in the red and clear films, and the values in the red and clear films were almost same. Shoot fresh weight in the red, blue and clear films were almost same. According to Smith (2000), plant can sense the light quality by using signal–transducing photoreceptors such as phytochrome, cryptochrome and phototropin. Phytochrome controls the elongation of plants by detecting the R:FR, and cryptochrome, which is photoreceptor of blue light, also controls the elongation. Barnes and Bugbee (1992) reported that the stem elongation of wheat plants was accelerated at higher blue light levels. Furthermore, the acceleration of the stem elongation in the low UV was observed in eggplants (Kittas *et al*., 2006). Thus, it can be considered that the acceleration of leaf elongation in the blue film was caused by the activation of cryptochrom through increase in the blue light, and by decrease in the UV light.

Root fresh weight was extremely increased in the red film, and this value was up to 1.5 times higher than those in the blue and clear films. Root dry weight showed the same pattern as seen in the root fresh weight. These results agreed with the findings of McCree (1971), who reported that rice plants exposed to red light accumulated more carbohydrate and therefore more dry matter. Frank and Bakx (1997) reported that the red light is more effective in stimulating the import of photoassimilates. In our result, the acceleration of photosynthesis under the red film was small. But, it can be considered that the time integration of slightly higher photosynthesis brings high accumulation of carbohydrates. And further, translocation of photoassimilates from the source to the sink becomes a major factor in the photosynthetic activity of plants (Habeshaw, 1973). In the red film, the

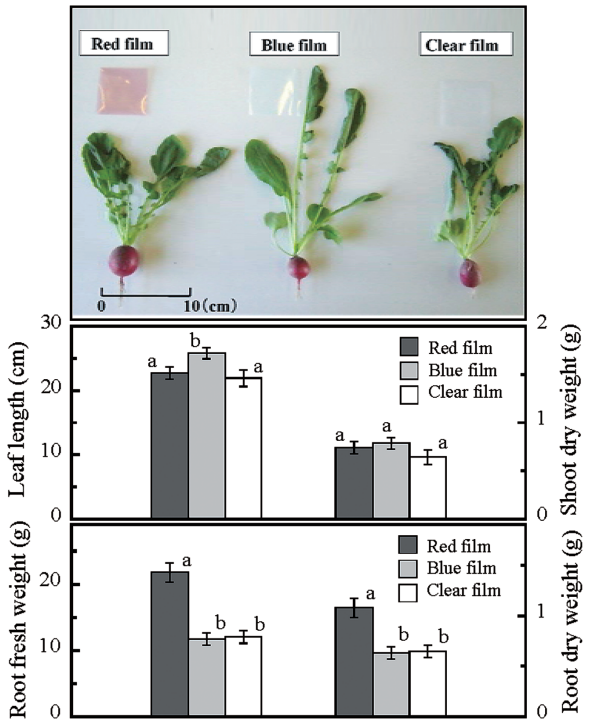

Fig. 3. Photograph of harvested radish plants covered with the red, blue and clear films, and their leaf length, shoot dry weight and fresh and dry weights of root. Plants were grown in a phytotron glass room at the day/night air temperature of 23/18 °C, and the film treatment was conducted during four weeks before the harvest. Error bars represent SE with n=10. Different letters indicate significant difference by Fisher's PLSD test at $P \leq 0.05$.

distance between the sink (root) and the source (leaf) was shorter than that in the blue film, and this can be expected that the acceleration of the translocation from the source to the sink. These results suggest that the growth enhancement of roots in the red film can be attributed to the interaction of the accelerations of the leaf photosynthesis and the translocation by increase in the red light.

Figure 4 shows the photograph of harvested Welsh onion covered with the red, blue and clear films, and their leaf length, fresh and dry weights of shoot. Leaf length in the blue film was significantly higher than those in the red and clear films, and the value in the red film was lower than that in the clear film. It can be considered that the acceleration of leaf elongation in the blue film was caused by the activation of cryptochrom through increase in the blue light, and by decrease in the UV light as shown in the result of radish.

Shoot fresh weight in the red and blue films were higher than that in the clear film but the significant difference between the red film and the blue film was not observed. Shoot dry weight in the red and blue films were higher than that in the clear film, and the value in the red film was higher than that in the blue film. It can be considered that the growth enhancement of shoot in the red film was caused by the accelerations of the leaf photosynthesis thorough increase in the red light.

Figure 5 shows the time course of seed germination

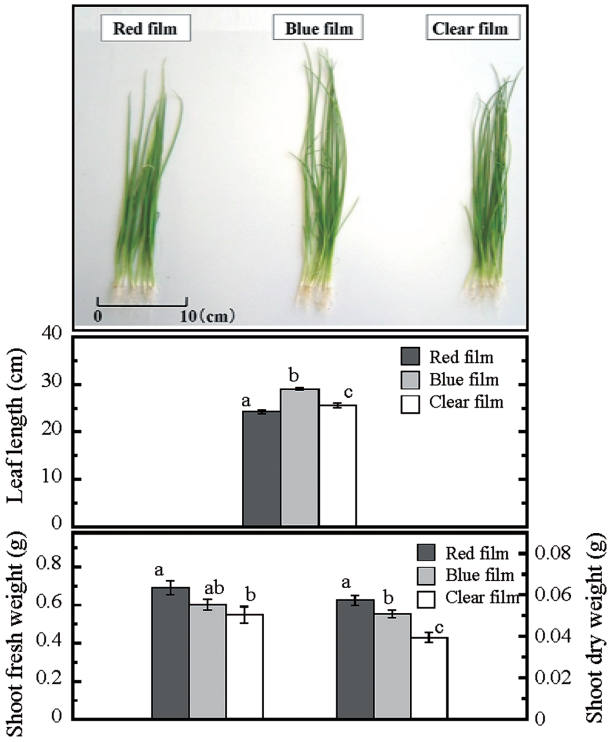

Fig. 4. Photograph of harvested Welsh onion covered with the red, blue and clear films, and their leaf length and fresh and dry weights of shoot. Plants were grown in a phytotron glass room at the day/night air temperature of 23/18 ˚C, and the film treatment was conducted during four weeks before the harvest. Error bars represent SE with n=10. Different letters indicate significant difference by Fisher's PLSD test at $P \leq 0.05$.

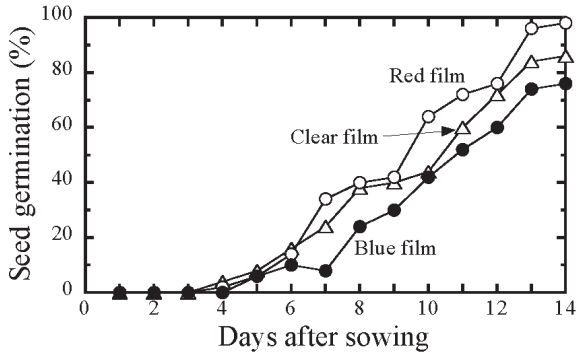

Fig. 5. Time course of seed germination of Blue Star (*Oxypetalum caeruleum*) covered with the red, blue and clear films. Seeds germination test was conducted during two weeks after sowing in a phytotron glass room at the day and night air temperature of 25 ˚C, and 50 seeds were used in the respective treatments.

of Blue Star covered with the red, blue and clear films. In the red film, the seed germination rate was significantly faster than those in the blue and clear films but in the blue film, it was inhibited. The seed germination at two weeks after sowing was higher in the red film, and reached to 98%. The failure of germination was higher in the blue film. It was reported that the red light induces the acceleration of seed germination (Islam *et al.*, 1999). Under the red light, phytochrome accelerates the seed germination by enhancement of the gibberellin in the seed (Toyomasu, 2005). Therefore, it can be considered that the acceleration of seed germination in the red film was caused by the enhancement of the gebberellin in the seed throughout increase in the red light.

From these results, the red film enables the accelerations of leaf photosynthesis and seed germination, and the blue film accelerates the leaf elongation. Therefore, the spectrum conversion films are applicable to regulate the plant growth in plant productions.

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