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토마토 숙도 조절을 위한 광 처리 효과

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Effects of Light Treatment on Controlling Tomato Ripening

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Abstract

This study was carried out to investigate the effects of red and far-red light (R and FR) treatments on stimulating or delaying the ripening of harvested tomatoes. Also, the reversible effects of light treatments on tomato ripening were examined with treating FR immediately after R treatment or with applying R after FR irradiation. The results showed that the development of tomato color was stimulated by R treatment and delayed by FR treatment. The effect of R irradiation on stimulating the development of tomato color was suppressed by FR treatment. The development of tomato color suppressed by FR treatment was stimulated by R irradiation. Therefore, it was considered that the development of tomato color is well mediated through a photoreversible pigment, phytochrome. The effect of light treatment on controlling tomato ripening was great when light irradiation was applied on tomatoes at the maturity state of mature-green rather than breakers stage.

Key words: Light, Tomato, Postharvest Ripening, Phytochrome, Color Development

Introduction

In photomorphogenesis, many aspects of the growth, development and differentiation processes in plants are often mediated through photoreversible pigment, phytochrome. The reversible effects of red and far-red lights on seed germination (Borthwick *et al.*, 1952) and plant flowering are well-established facts. Phytochrome, a single pigment exists in two interconvertable forms, Pr with an absorption maximum near 660 nm and Pfr, active form, with an absorption maximum near 730 nm (Borthwick *et al.*, 1952; Borthwick, 1972):

$$P_r \underset{\text{Far-red light (730 nm)}}{\overset{\text{Red light (660 nm)}}{\rightleftharpoons}} P_{fr}$$

After plants have been irradiated with red light, the P_{fr} form of phytochrome exhibits absorption in far-red region. This form is reversible to another form of P_r, which absorbs in the red region when irradiated with far-red light. Even a one minute light exposure is effective, and the reversibility is observed according to the last exposure (Khudairi, 1972).

Cohen and Goodwin (1962) indicated that a brief exposure to red light stimulated carotenoid synthesis in etiolated maize seedling, and the reversal of this effect by far-red light showed that it was a phytochrome-mediated reaction. Butler *et al.* (1963) found that phytochrome in dark-grown seedling was present entirely as P_r. They demonstrated that P_{fr} reverted to P_r in the dark following a single brief irradiation with red light which converted the P_r to P_{fr}.

According to previous study (Khudairi, 1972), the carotenoid biosynthesis of tomatoes is mediated by phytochrome. Thus, the influence of light on ripening of fruits has been the subject of a number of investigations. During ripening the color of tomato is changed to green, white, yellow, pink, and then red. The change from green to white involves

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chlorophyll degradation, and from white to red involves carotenoid biosynthesis. The red color of the tomatoes is due to its major carotene, lycopene, which is found at levels up to 90% of the total carotenoids (Gross, 1991). Smith (1936) found that the carotenoid content was reduced, when light was excluded during the development and maturity. He also observed that the carotenoid content of both the skin and the flesh of fruits ripened under the light was higher than that of fruits ripened in the dark. Denisen (1951), McCollum (1954), and Nettles *et al.*, (1955) also made the studies showing a significant increase in red color and higher carotenoid level in fruit exposed to light.

Several kinds of fluorescent and incandescent lamps are available as the light sources. Shewfelt and Halpin (1967) reported that Standard Gro-Lux or Wide Spectrum Gro-Lux fluorescent light was more effective than cool white fluorescent light in tomato ripening. Shewfelt (1970) showed that Standard Gro-Lux lamps produced the predominant radiant energy in the region of 650 nm and had a significant effect on ripening of fruits. Furthermore, the technique of artificial irradiation has been applied to apples for improving the red pigmentation (Saks *et al.*, 1990). Special light quality can be obtained from the light source with the use of color filter. Campbell *et al.* (1975) provided the information for the electrical, photometric, and radiometric properties of lamps, which were commercially available for plant lighting. Dobrowolski *et al.* (1977) examined the specifications of about eight-hundred colored glass filters made by thirteen manufactures.

With the use of increased mechanical harvesters and the development of cultivars adapted for machine harvesting, there is an added interest in controlling the ripening of detached tomatoes.

The objectives of present study were to:

- Evaluate the effects of red and far-red lights on the color development of tomatoes.
- Determine whether the phenomenon of the reversal of R effect by FR irradiation and FR effect by R irradiation on the color development of tomatoes is possible.
- Investigate which stage of maturity is well affected by light treatment on the color development of tomatoes.

Materials and Methods

Tomatoes

In the first experiment, the maturity state of tomatoes obtained from field was at mature-green. Then, tomatoes were ripened to maturity state of the breakers in room temperature. These tomatoes at maturity of the breakers stage were used in the first experiment. Tomatoes for experiment were sorted for uniformity of maturity and size and absence of physical defects. In the second experiment, mature-green tomatoes which were obtained from the field were used as experimental materials. Tomatoes for this experiment were also sorted for uniform maturity and size and absence of physical defects.

Light Treatments

In the experiment, a group of tomatoes were composed of five selected at random. For each light treatment, tomatoes were placed, blossom end up, in the irradiation chamber (Fig. 1). A group of tomatoes were kept in darkness for control. The group of tomatoes was exposed to red light (R), far-red light (FR), FR followed immediately by R (FR/R), and R followed immediately by FR treatment (R/FR). The R and FR treatments were applied for 5 minutes per a day respectively in an ir-

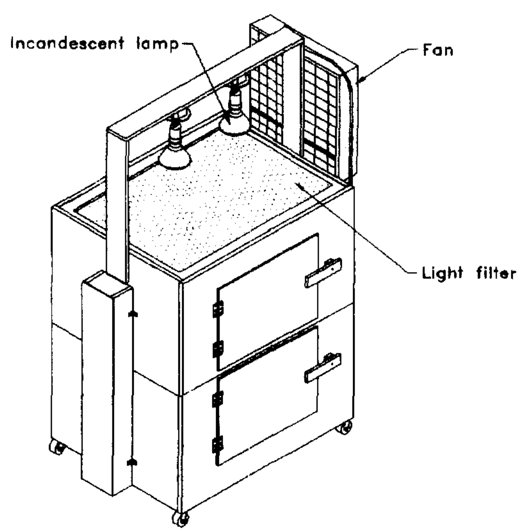

Fig. 1. Light irradiation chamber for red light (lower section) and far-red light (upper section).

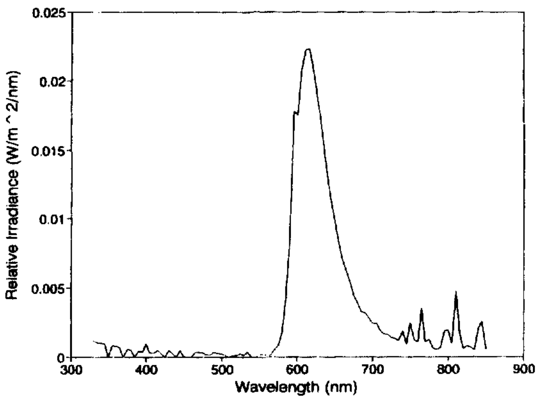

Fig. 2. Spectral irradiance distribution in filtered red light.

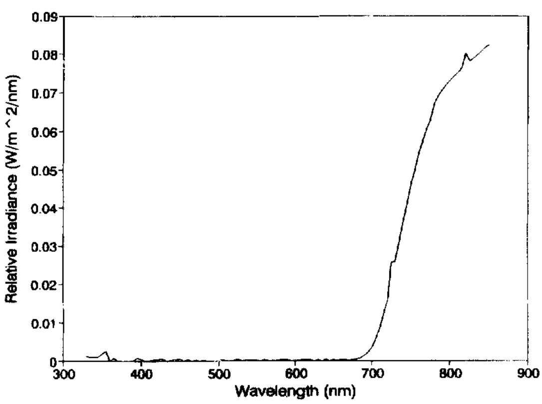

Fig. 3. Spectral irradiance distribution in filtered far-red light.

radiation chamber. The FR/R and R/FR treatments were applied for 5 minutes for R and 5 minutes for FR daily. After light treatment was completed, tomatoes were kept in darkness immediately.

In the first experiment, light treatment was continued for five days, because the light treatment of five days was sufficient for color development of tomatoes at maturity of the breakers stage. In the second experiment, light was successively treated for eight days since the initial maturity of tomatoes for experiment was at the stage of mature-green.

Tomatoes for R (1.136 W/m^2 in 600 to 700 nm, λ_{max}=615 nm, Fig. 2) treatment were placed in the lower section of the chamber and exposed to red light produced by six cool-white fluorescent bulbs and filtered through Roscolux #19 acetate (Rosco Inc., Port Chester, NY). FR (2.819 W/m^2 in 700 to 780 nm, λ_{max}=780 nm, Fig. 3) treatment was performed in the upper section of light irradiation chamber. The far-red light was obtained by filtering radiation from two 120 W incandescent lamps through a polyacrylic sheet of cast acrylic #2711 dark red (Rohm and Haas, Bristol, Pa).

Color Determination

There are six stages of maturity used to grade fresh tomatoes according to color classification requirements of the U. S. Department of Agriculture (USDA, 1975):

1) "Green" means that the surface of the tomato is completely green in color. The shade of green color may vary from light to dark.

2) "Breakers" means that there is a definite break in color from green to tannish-yellow, pink or red on not more than 10 percent of the surface.

3) "Turning" means that more than 10 percent but not more than 30 percent of the surface, in the aggregate, shows a definite change in color from green to tannish-yellow, pink, red or a combination thereof.

4) "Pink" means that more than 30 percent but not more than 60 percent of the surface, in the aggregate, shows pink, or red color.

5) "Light Red" means that more than 60 percent of the surface, in the aggregate, shows pinkish-red or red: Provided, that not more than 90 percent of the surface is red color.

6) "Red" means that more than 90 percent of the surface, in the aggregate, shows red color.

Each of six categories (Green, Breakers, Turning, Pink, Light Red, Red) were assigned a value (1, 2, 3, 4, 5, 6 respectively) and tomatoes were visually evaluated using a standard color chart (USDA, 1975). After last light treatment, daily checks for color development were made for tomatoes of each group from 6th to 9th day in the first experiment and from 9th to 14th day in the second experiment.

Statistical Analysis

Duncan's multiple range test (SAS Institute, Inc., 1991) was used to determine significant difference of tomato color among treatments during storage days after light irradiation.

Results and Discussion

With using tomatoes at maturity state of the breakers as the first experimental materials, the results of experiment which investigates light irradiation effects on color development were presented in Figs. 4 and 5. Fig. 4 shows that the red color development of tomatoes treated by R and FR and kept in darkness was continuously increased everyday during the period of storage after light treatment. However, the color score of tomatoes treated by R irradiation was significantly higher than that of tomatoes treated by FR irradiation and kept in darkness from 6th to 9th day of storage. For tomatoes treated by FR irradiation and held in darkness, red color development was not significantly different during the period of storage from 6 to 9 days. Tomatoes treated by R irradiation was reached to maturity state of "Light Red" at 7th day of storage after light treatment. However, tomatoes treated by FR irradiation did not reached to maturity state of "Light Red" until 9 days of storage after light treatment. Thus, it is confirmed that the red color development of tomatoes was stimulated by R irradiation and delayed by FR irradiation.

Fig. 5 presents that the color scores of tomatoes treated by FR/R and R/FR and kept in darkness were compared during the storage period from 6 to 9 days. The color score of tomatoes treated by FR/R was significantly higher than that of tomatoes treated by R/FR and held in the dark. However, the color scores of tomatoes treated by R/FR and kept in the dark were not significantly different. This results suggest that inhibitory effect on color development by FR irradiation was reversed by R irradiation, and stimulating effect on color development by R irradiation was also reversed by FR irradiation. Thus, it is suggested that color development of tomatoes is meditated by phytochrome.

The results of the second experiment which examine light irradiation effects on color development with using mature-green tomatoes were presented in Fig. 6 and Fig. 7. Fig. 6 presents that the red color development of tomatoes treated by R and FR and kept in darkness was continuously increased everyday during the period of storage after light treatment. However, the color score of tomatoes treated by R was significantly higher than that of tomatoes treated by FR irradiation and kept in darkness from 9th to 14th day of storage. Moreover, the color score of tomatoes treated by FR was significantly lower than that of tomatoes kept in darkness during the period of storage from 9 to 14 days. These results suggest that the color development of tomatoes is well regulated when tomatoes at ma-

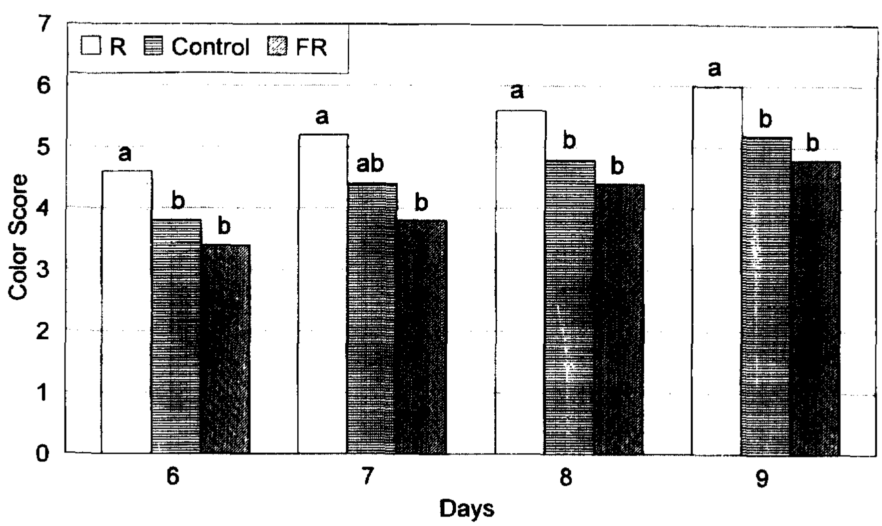

Fig. 4. Mean color scores of tomatoes irradiated with light (R, FR) and stored in darkness with using "Breakers" tomatoes as experimental materials. Bars within a group not labeled with the same letter are significantly different at 5% level.

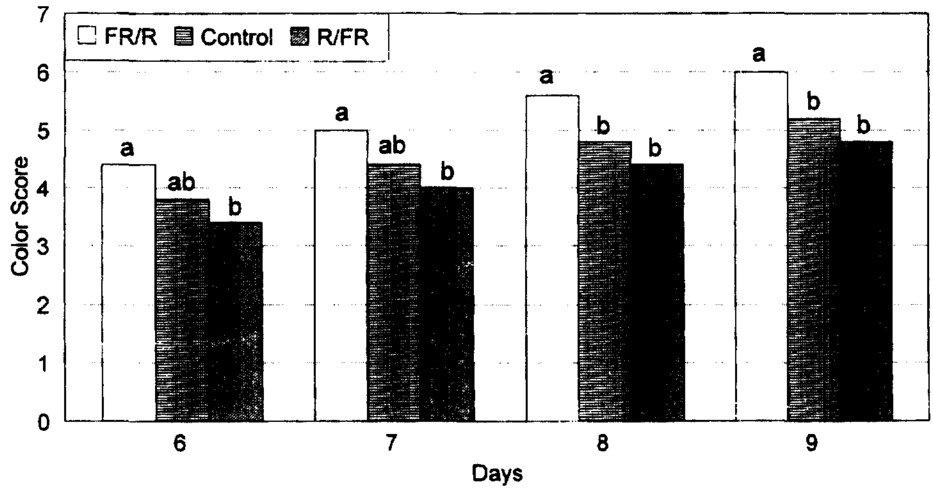

Fig. 5. Mean color scores of tomatoes irradiated with light (FR/R, R/FR) and stored in darkness with using "Breakers" tomatoes as experimental materials. Bars within a group not labeled with the same letter are significantly different at 5% level.

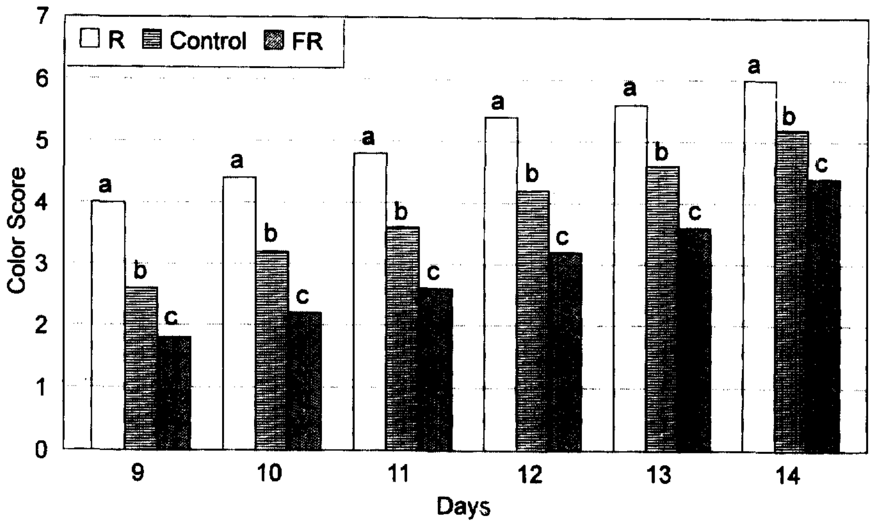

Fig. 6. Mean color scores of tomatoes irradiated with light (R, FR) and stored in darkness with using "Green" tomatoes as experimental materials. Bars within a group not labeled with the same letter are significantly different at 5% level.

turity state of mature-green are treated with light. Tomatoes treated by R irradiation was reached to maturity stage of light red after 12th day of storage after light treatment. However, tomatoes treated by FR irradiation did not reached to maturity stage of light red until 14 days of storage after light treatment.

Fig. 7 shows that color scores of tomatoes treated by FR/R and R/FR and kept in darkness were compared from 9th to 14th day of storage after light treatment. The color score of tomatoes treated by FR/R was significantly higher than that of tomatoes treated by R/FR and held in the dark. Also, the color scores of tomatoes treated by R/FR was significantly lower than that of tomatoes kept in the dark. This results suggest that inhibitory effect on color development by FR irradiation was reversed by R irradiation, and stimulating effect on

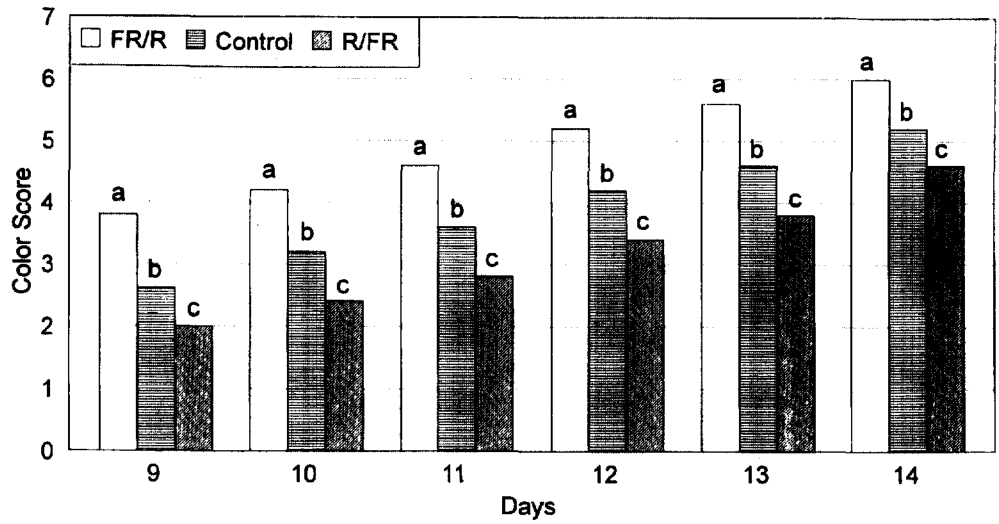

Fig. 7. Mean color scores of tomatoes irradiated with light (FR/R, R/FR) and stored in darkness with using "Green" tomatoes as experimental materials. Bars within a group not labeled with the same letter are significantly different at 5% level.

color development by R irradiation was also reversed by FR irradiation. Thus, it was confirmed that color development of tomatoes was meditated by phytochrome. Regulatory effect by phytochrome on the color development of tomato was great, when mature-green tomatoes were used as experimental materials.

Conclusions

This study was performed to investigate the light effects on the development of tomato color and wether the phenomenon of the reversal of R effect by FR irradiation and FR effect by R irradiation on color development of tomato is possible. Also, it was investigated that which stage of maturity is well affected by light treatment on the color development of tomatoes. The maturity stages of tomatoes used in the experiment were "Turning" and "Green". The group of tomatoes was exposed to red light (R), far-red light (FR), FR followed immediately by R (FR/R), and R followed immediately by FR treatment (R/FR). From this study, the following conclusions were reached:

1. When tomatoes at maturity state of breaker were used as experimental materials, the color score of tomatoes treated by R irradiation was significantly higher than that of tomatoes treated by FR irradiation and kept in darkness from 6th to 9th day of storage. For tomatoes treated by FR irradiation and held in darkness, red color development was not significantly different during the period of storage from 6 to 9 days after light treatment. The color score of tomatoes treated by FR/R was significantly higher than that of tomatoes treated by R/FR and held in the dark.

2. When tomatoes at maturity state of mature-green were used as experimental materials, the color score of tomatoes treated by R was significantly higher than that of tomatoes treated by FR irradiation and kept in darkness from 9th to 14th day of storage. The color score of tomatoes treated by FR/R was significantly higher than that of tomatoes treated by R/FR and held in the dark. Also, the color scores of tomatoes treated by R/FR was significantly lower than that of tomatoes kept in the dark.

3. The phenomenon of the reversal of R effect by FR irradiation and FR effect by R irradiation on color development of tomato was observed. It was concluded that the red color development of tomatoes was mediated by phytochrome.

4. The red color development of tomatoes was well regulated by light treatment, when tomatoes at maturity stage of mature-green were used as experimental materials.

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