

Research Article



CrossMark

Open Access

Photoreversibility of Fruiting and Growth in Oriental Melon (*Cucumis melo* L.)

Sung-Chang Hong*, Jin-Ho Kim, So-Jin Yeob, Min-Wook Kim, Sae-Nun Song,
Gyu-Hyun Lee, Kyeong-Sik Kim and Seon-Young Yu

Climate Change and Agroecology Division, Department of Agricultural Environment, National Institute of Agricultural Sciences, Rural Development Administration, Wanju 55365, Korea

Received: 8 August 2020/ Revised: 21 September 2020/ Accepted: 30 October 2020

Copyright © 2020 The Korean Society of Environmental Agriculture

This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

ORCID

Sung-Chang Hong
<https://orcid.org/0000-0002-9042-1284>

Jin-Ho Kim
<https://orcid.org/0000-0002-5266-1586>

So-Jin Yeob
<https://orcid.org/0000-0002-4732-6273>

Min-Wook Kim
<https://orcid.org/0000-0001-8262-5909>

Sae-Nun Song
<https://orcid.org/0000-0003-0617-339X>

Kyeong-Sik Kim
<https://orcid.org/0000-0002-1463-8617>

Gyu-Hyun Lee
<https://orcid.org/0000-0003-1872-427X>

Seon-Young Yu
<https://orcid.org/0000-0002-8514-1712>

Abstract

BACKGROUND: Photoreversibility, a reversion of the inductive effect of a brief red light pulse by a subsequent far red light pulse, is a property of photo responses regulated by the plant photoreceptor phytochrome B. Plants use photoreceptors to sense photo signal and to adapt and modify their morphological and physiological properties. Phytochrome recognizes red light and far red light and plays an important role in regulating plant growth and development. **METHODS AND RESULTS:** The reversal responses of growth and fruiting characteristics were investigated to increase the yield of oriental melon (*Cucumis Melo* L. var. Kumsargakieuncheon) by means of controlling light quality in a plastic house. Red (R:660nm) and far red (FR:730nm)

lights were subsequently irradiated on the whole stems and leaves of the oriental melon plant during growing periods, using red and far red LEDs as light sources, from 9:00 PM daily for 15 minutes. The intensities of R and FR light were 0.322-0.430 $\mu\text{mol m}^{-2}\text{s}^{-1}$ and 0.250-0.366 $\mu\text{mol m}^{-2}\text{s}^{-1}$, respectively. Compared to R light irradiation, combination of R and FR light irradiation increased the length of internode, number of axillary stems, number of female flowers, and fruit number of oriental melons. The results of treatment with R were similar to R-FR-R light irradiation in terms of length of internode, number of axillary stems, number of female flowers, and number of fruits. When FR treatment was considered, R-FR and R-FR-R-FR light irradiation had similarities in responses. These reversal responses revealed that oriental melon showed a photoreversibility of growth characteristics, flowering, and fruiting.

CONCLUSION: These results suggested the possibility of phytochrome regulation of female flower formation and

*Corresponding author: Sung-Chang Hong
Phone: +82-63-238-2501; Fax: +82-63-238-3825;
E-mail: schongcb@naver.com

fruiting in oriental melon. The fruit weight of the oriental melon was the heaviest with the R light irradiation, while the number of fruits was the highest with the FR light. With the FR light irradiation, the fruit weight was not significantly higher compared to that of the control. Meanwhile, the yield of oriental melon fruits increased by 28-36% according to the intensities of the FR light due to the increases of the number of fruits.

Key words: Far Red Light, Fruiting, Oriental Melon, Photoreversibility, Red Light

Introduction

Light is an energy source for the photosynthesis of green plants and a source of information for daylength effect, photoperiodism, and photomorphogenesis [1]. In plants, phytochrome senses the red light and far red light and mediates the important role of detecting light wavelength, light intensity, light direction, and light irradiation time throughout the development of plants [2]. Phytochrome is the most distinctive plant photoreceptor. The red light absorbing P_r -type phytochrome, among the phytochromes, is formed in the dark. P_r -type phytochrome, after absorbing the red light, can be converted into a far red light absorbing type P_{fr} [3]. In addition, phytochrome (phy) is adapted to detect red light, as well as far red light [4]. Photoreversibility, which is a reaction induced by the irradiation of a short red light and which becomes nullified by successive irradiation of far red light, is a photoreaction by the plant photoreceptor phytochrome B (phyB). Plants use photoreceptors to sense photo signal and to adapt and modify their morphological and physiological properties [1]. Phytochrome recognizes red light and far red light and plays an important role in regulating plant growth and development [5,6].

Phytochrome is a reversible photochromic biliprotein and exists in the form of the biologically inactive red light absorbing type P_r and the biologically active far red light absorbing type P_{fr} . The equilibrium between these P_r - and P_{fr} -type phytochromes drastically changes and is strongly related with the R:FR ratio [7]. The red light and far red light enable plants to adapt to the environment for survival through the phytochrome regulation system. The anatomical properties of leaves, photosynthetic efficiency, and distribution of carbon assimilation products affect the developmental process of leaves, especially after sunset, by the ratio of red

light and far red light [8]. Plants sense the changes of the red light of 660nm and far red light of 730 nm by the photo-receptable protein phytochrome. The wavelength and daylength of the light regulate numerous developments of the plants such as seed germination, stem elongation, and flowering. Far red light irradiated for a short duration of 5 to 10 minutes at the end-of-day (EOD) increases bioactive GA contents of the cowpea coleoptile through the action of PHY genes [9]. P_{fr} -type phytochrome acts as an effective active form in a phytochrome mediated reaction; therefore, it can act like a photoreversible light switch of the red light versus far red light in light treatment for an extremely short period [4,2,10,11,17]. The phytochrome, which is a photoreceptor protein of plants, exists in the form of inactive P_r -type and is converted into active P_{fr} -type by the red light to induce biological reaction and then converted again into an inactive P_r -type by far red light. The reaction, which is made possible through the red light is nullified by the far red light. These reactions are repeated and are called photoreversibility [19].

Typical photoreversible reactions of the higher plants known to date include germination of lettuce seeds, de-etiolation of oat cotyledons, leaf primordia formation, and development of the main leaves of mustard seedlings, formation of anthocyanins, internode elongation of soybeans, and chlorophyll content of pine leaves [12].

Oriental melons (*Cucumis Melo* L.) are growing in the field area of 145 ha and in facilities of 3,469 ha where they are mainly cultivated inside the plastic houses in Korea.

Therefore, this study was conducted to investigate the fruiting and growth responses of the oriental melon by way of controlling the red light and far red light, with the help of LED, and to develop a technology to increase production.

Materials and Methods

Alternative red and far-red light treatment

Oriental melons (*Cucumis Melo* L. var. kumsargakieuncheon) of uniform seedlings with leaf aged six were used for the experiment. They were planted one each in a 1/2,500 a Wagner pot on the 10th of June, arranged as three replications, and then cultivated until September 30th. The sandy loam upland soil and commercial horticultural seedling

mixes were formulated to (v/v) 5:5 and filled into the pot. Fertilizers N, P, and K were applied in the ratio of 190, 60, and 110 kg ha⁻¹ according to standard fertilization. The drip-irrigation nozzles were installed in each pot to maintain moisture uniformly throughout the growth period of the oriental melons.

The central wavelength of 660 nm for red LED and 730 nm for far red LED were applied for the experiment. Lighting treatment was applied by installing the red LED luminaries (200 cm × 6 cm × 3 cm) fabricated in-house at 40 cm of the pot top.

Light intensity was set to 0.330 μmol m⁻²s⁻¹ for the red light and 0.264 μmol m⁻²s⁻¹ for the far red light. Oriental melons were irradiated sequentially throughout the growing period by using an electronic timer from 9:00 pm (Table 1).

The intensity of red light and far red light were measured by means of light sensor SKP-215 (Skye Instruments, UK). After 60 days of light treatment, leaf area, internode length, number of axillary stems, number of female flowers, and number of fruits of oriental melon were examined.

Treatment with far-red light intensity

The oriental melons (*Cucumis Melo* L. var. kumsargakieuncheon) were cultivated in the plastic house at the local farm. Uniform seedlings with a leaf age of six were used in the experiment. Fertilizers N, P, and K were applied in the ratio of 190, 60, and 110 kg ha⁻¹ according to standard fertilization. After tillage operation and soil preparation, soil surface was covered with black vinyl mulching. The field was prepared with the rotary tillage operation and then the melon seedlings were planted on the 20th of March and cultivated till harvest on the 30th of September. The lighting treatment devices were installed at 2 meters-high from the canopies of the melons. Far red light having a wavelength in the range of 680 nm-760 nm with a center peak wavelength of

730 nm was applied to the plants. The intensities of far red light were 0.305 μmol m⁻²s⁻¹, 0.430 μmol m⁻²s⁻¹, and 0.754 μmol m⁻²s⁻¹, respectively. The control was set without lighting treatment based on conventional practice. The light was irradiated from 9 pm to 10 pm for one hour. As the growth of the oriental melons was advanced, the number of fruits, fresh weight of fruit, and yield were measured ten times at a regular interval.

Statistical processing of the data

The growth data of the oriental melon were processed with the least significant difference test (LSDT) using the statistical package R.

Results and Discussion

Photoreversibility of the growth and fruiting

The photoreversibility of the growth and fruiting of the oriental melon after sequentially treating it with the red light and far red light are shown in Fig. 1. Just after treating the plant with the red light, the leaf areas, number of axillary stems, internode length, number of female flowers, and number of fruits increase if the far red light is applied. Meanwhile, the sequential treatment of red light and far red light promotes the increases of leaf areas, number of axillary stems, internode length, number of female flowers, and number of fruit, along with similar trends by the treatment effect of red light, far red light, red light, and far red light.

Since P_{fr}-type phytochrome can act as an effective form in the phytochrome-mediated reaction, it can work like a photoreversible light switch of far red light compared to that of molecular red light with an extremely short light treatment [2,4,10,11]. [7] reported that the reaction of phytochrome was nullified by the far red light treated successively and the reaction was determined by the light that was treated lastly.

The number of axillary stems, number of female flowers,

Table 1. Red and far-red light treatment on growing oriental melon

Light treatment	Time
R	15 minutes
R, FR	15 minutes, 15 minutes
R, FR, R	15 minutes, 15 minutes, 15 minutes
R, FR, R, FR	15 minutes, 15 minutes, 15 minutes, 15 minutes

R: red light (660 nm), FR: far red light (730 nm)

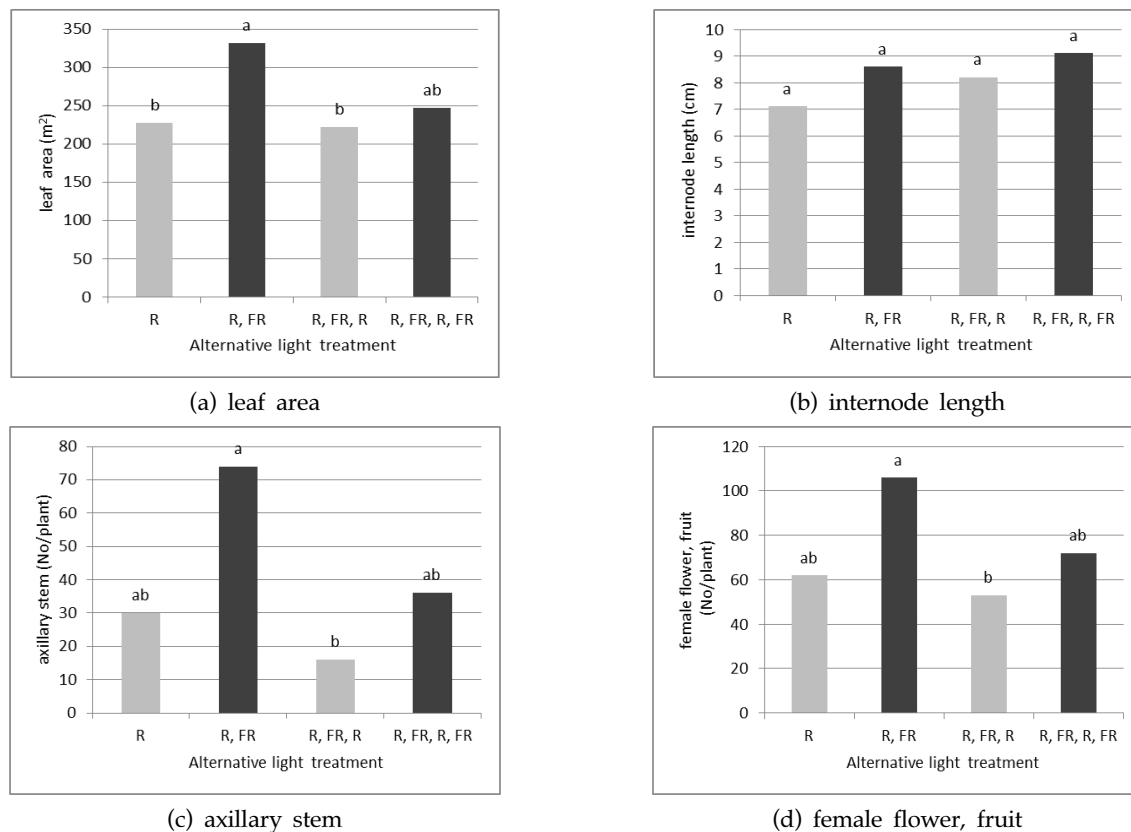


Fig. 1. Red and far-red lights induced photoreversible responses of growing oriental melon.

The common letters on the columns mean no significant difference at 5% probability level by Duncan's multiple range test.

and number of set fruits showed photoreversibility, which might be due to increases of the number of axillary stems by treatment with far red light.

Far red light, applied at the end-of-date, promoted 2nd and 4th internode elongation in the soybean, but the internode length was again reduced by the succeeding red light, indicating that the soybean internode length showed a photoreversibility by the red light and far red light [8].

The internode length of the oriental melon also increased by means of the far red light, decreased by the successively applied red light, and then the internode length was determined by the light which was treated lastly as shown in Fig. 1.

This photoreversibility of oriental melon growth by far red and red light corresponds to the Low Fluence Response (LFR). The intensities of light treatment in this study were $0.330 \mu\text{mol m}^{-2}\text{s}^{-1}$ for the red light and $0.264 \mu\text{mol m}^{-2}\text{s}^{-1}$ for the far red light.

[5] reported that the LFR was caused by PHYB, PHYD, and PHYE, and it was a reaction by the red light and far red light, a photoreversible reaction,

and it was induced by a light intensity higher than $1 \mu\text{mol m}^{-2}\text{s}^{-1}$.

Yield by the intensity of far-red light

The total yield of the oriental melon from planting in the plastic house till harvest and upon treatment with far red light is shown in Table 2. Fig. 2 is a view of growing oriental melon treated with far red light in a green house. The fruit weight was not significantly different from the fruits receiving far red light treatment. However, the yields were increased with far red light intensities of $0.305 \mu\text{mol m}^{-2}\text{s}^{-1}$, $0.430 \mu\text{mol m}^{-2}\text{s}^{-1}$, and $0.754 \mu\text{mol m}^{-2}\text{s}^{-1}$ by 28%, 35%, and 36%, respectively, due to the increases of number of fruits by far red light treatment.

The number of axillary stems was increased by the treatment with the far red light as shown in Fig. 1. The results are different from the report that the number of tillers in wheat decreased due to far red light treatment at the end-of-day [13]. [13] reported that the rates of tillers, leaf length, and fresh weights of stems and roots of wheat, which were reduced

Table 2. Effects of far-red light treatment on fruit characteristics and production in oriental melon

Light treatment ($\mu\text{mol m}^{-2}\text{s}^{-1}$)	Fruit number (no./plant)	Fruit weight (g/fruit)	Solid sugar (Brix $^{\circ}$)	Production (kg/plant)
Control (no light)	11.6 b	307 a	15.7 a	3.57 b
0.305	15.2 a	308 a	15.4 a	4.68 a
0.430	15.8 a	307 a	15.9 a	4.86 a
0.754	16.2 a	302 a	15.2 a	4.89 a
LSD	2.97	30.0	2.5	0.96

The common letters within a column mean no significant difference at 5% probability level by Least Significance Difference test.



Fig. 2. Scene of alternative red and far-red light treatment (left) and far-red light treatment on growing oriental melon (light).

after treatment with far red light, increased from the treatment with red light. In addition, the tillers, leaf length, and fresh weights of stems and roots of wheat showed photoreversibility due to the red and far red lights. In this study, the experimental subject, oriental melons, were dicotyledons, while the subject in the experiment of [13] was wheat, which was monocotyledon. The emerging patterns between the tillers of monocotyledon and axillary stems of the oriental melon, which is a dicotyledon, were also different. Kasperbauer [8,14] reported that the short red light irradiated on the beans for a few minutes at the end-of-day resulted in the relatively large and thick leaves, short stems, and large fresh weight of the roots. On the contrary, the far red light treatment on the beans for a short time at the end-of-day showed thin leaves, high plant height, heavy stems, and relatively small roots. In addition, Kasperbauer [8] reported that the increased dry weights of the leaves and petioles of beans after treatment with the far red light were reduced by the red light treatment. Furthermore, the reduced dry weights of roots and

nodules by treatment of far red light were increased by the treatment of red light; thereby, the dry weights of the leaves, petioles, roots, and nodules of beans exhibited photoreversible responses by means of red light and far red light.

There was no significant difference in the sugar content of oriental melon by far-red light treatment (Table 2). [18], it was reported that adding far-red light either during the day or at end-of-day resulted in significantly higher soluble sugar content.

The flowering of oriental melon and melon, in general, is an andromonoecious type in which male flower and androgyne are set from different nodes in one plant. The melon cultivar Kumsargakieuncheon, which recently has been widely cultivated, is a monoecious type in which male flower and female flower are set at different nodes. In some oriental melons and wild melons, hermaphroditic types are available where only androgynes are set in all the nodes regardless of main branch and axillary branches [15].

In the melon, the secondary stems normally

emerge from the 4th to 5th nodes at the main stem, while the androgyne (female flower) is set at the first node of the secondary stem. Unlike melon, female flowers in the oriental melon are almost not set in the main stem, as well as secondary stems, but they are set in the first node of the third stem [15].

The gender in the flower of the oriental melons is not determined from the beginning, but it is determined during growth and development under the influence of genetic predisposition and environment. Short day, low temperature, amount of sunshine, and nutrition are related to the differentiation of the female flower; specifically, the night-temperature affects the fruit more since night temperatures of 21°C instead of 25°C and 17°C instead of 21°C promote female flower settings more, as well as increase their number. There is no effect based on low night temperature just after the cotyledon's opening, but temperature effect becomes significant after 1-2 leaves, especially with two leaves and when the appearance of a female flower is less under the hot temperature. Furthermore, if support is provided, the number of female flowers increases and, according to the environmental condition, the development of stamens is sometimes poor and ovary growth is not substantial, resulting in the appearance of a flower whose gender is difficult to distinguish [15].

When "ethrel" application effect was examined for the oriental melon, there was no female flower setting in the main stem with no ethrel, while sound female flowers appeared and normally developed between 7-12th nodes when treated with ethrel during 4 leaf stages. The treatment with ethrel could be used as one method for the difficult fruit setting period or for the purpose of early fruiting [15].

Meanwhile, Hong et al. stated that the flowering responses of the perilla [16] were photoreversible. With the supplement of red-light at 0.5 $\mu\text{mol m}^{-2}\text{s}^{-1}$, the fresh leaf weight of perilla was increased by 21%, while chrysanthemum had its product quality improved with the fresh weight increment by 36% and with the red-lighting at 1.0 $\mu\text{mol m}^{-2}\text{s}^{-1}$. Meanwhile, the long-day plant strawberries had their production increased by 8.5%, with the supplementary lighting of red LED.

Therefore, the far red light treatment at the end-of-day might have contributed to the increase in number of fruits and production of oriental melon by way of increasing the number of female flowers. The production of oriental melon can be secured when the

female flowers appear to have more fruit settings. During the early growth of oriental melon, fruit setting is induced at the secondary axillary stem and, as it grows, leaves and stems become lush, making accurate vine management difficult. Therefore, in general, the increases of female flowers and fruit setting by treatment with far red light might be due to increases of the 3rd axillary stems by the action of far red light.

As mentioned above, the amount of oriental melon fruit was increased by far-red light treatment, but there was no significant difference in sugar content. Therefore, it is judged that the development of technology related to the control of the amount of the oriental melon fertilization and irrigation suitable for far-red light treatment is necessary in the future.

As a conclusion, the fruit setting of the oriental melon exhibited the photoreversibility by the red and far red light. The far red light might have induced an increase in the production of oriental melons by increasing the female flowers. Therefore, it was judged that the action of far red light induces the phytochrome responses and that the development of the technology of the far red light for various crop usages is beneficial in the agricultural sites.

Note

The authors declare no conflict of interest.

Acknowledgement

This study was carried out with the support of the "Research Program for Agricultural Science and Technology Development" (Project No. PJ003961) of the National Institute of Agricultural Sciences, Rural Development Administration, Republic of Korea.

References

1. Smith H (1982) Light quality, photoperception, and plant strategy. *Annual Review of Plant Physiology*, 33(1), 481-518.
2. Quail PH, Boylan MI, Parks BM, Short TW, Xu Y, Wagner D (1995) Phytochromes: photosensory perception and signal transduction. *Science*, 268(5211), 675-680. <https://doi.org/10.1126/science.7732376>.
3. Furuya M, Song PS (1994) Assembly and properties of holophytochrome, in: Kendrick RE, Kronenberg

- GHM, In *Photomorphogenesis in Plants*. pp. 105-134, Springer, Dordrecht.
https://doi.org/10.1007/978-94-011-1884-2_6.
4. Furuya M, Schafer E (1996) Photoperception and signaling of induction reactions by different phytochromes. *Trends in Plant Science*, 1(9), 301-307.
[https://doi.org/10.1016/S1360-1385\(96\)88176-0](https://doi.org/10.1016/S1360-1385(96)88176-0).
 5. Smith H (2000) Phytochromes and light signal perception by plants and emerging synthesis. *Nature*, 407(6804), 585-591. <https://doi.org/10.1038/35036500>.
 6. Viczián A, Klose C, Ádám É, Nagy F (2017) New insights of red light-induced development. *Plant, Cell & Environment*, 40(11), 2457-2468.
<https://doi.org/10.1111/pce.12880>.
 7. Franklin KA (2008) Shade avoidance. *New Phytologist*, 179(4), 930-944.
<https://doi.org/10.1111/j.1469-8137.2008.02507.x>.
 8. Kasperbauer MJ (1987) Far-red light reflection from green leaves and effects on phytochrome-mediated assimilate partitioning under field conditions. *Plant Physiology*, 85(2), 350-354.
<https://doi.org/10.1104/pp.85.2.350>.
 9. Martínez-García JF, Santes CM, García-Martínez JL (2000) The end-of-day far-red irradiation increases gibberellin A1 content in cowpea (*Vigna sinensis*) epicotyls by reducing its inactivation. *Physiologia Plantarum*, 108(4), 426-434.
<https://doi.org/10.1034/j.1399-3054.2000.t01-1-100413.x>.
 10. Smith H (1995) Physiological and ecological function within the phytochrome family. *Annual Review of Plant Physiology and Plant Molecular Biology*, 46(1), 289-315.
<https://doi.org/10.1146/annurev.pp.46.060195.001445>.
 11. Whitelam GC, Devlin PF (1997) Roles of different phytochromes in *Arabidopsis* photomorphogenesis. *Plant, Cell & Environment*, 20(6), 752-758.
<https://doi.org/10.1046/j.1365-3040.1997.d01-100.x>.
 12. Taiz L, Zeiger E (2006) *Plant physiology*, pp. 655-656, 4rd edition, Sinauer Associates Inc., USA.
 13. Kasperbauer MJ, Karlen DL (1986) Light-mediated bioregulation of tillering and photosynthate partitioning in wheat. *Physiologia Plantarum*, 66(1), 159-163.
<https://doi.org/10.1111/j.1399-3054.1986.tb01250.x>.
 14. Kasperbauer MJ, Hunt PG, Sojka RE (1984) Photosynthate partitioning and nodule formation in soybean plants that received red or far-red light at the end of the photosynthetic period. *Physiologia Plantarum*, 61(4), 549-554.
<https://doi.org/10.1111/j.1399-3054.1984.tb05168.x>.
 15. JT Yeon (2005) *Handbook of melon cultivation*, pp 43-45, Gyeongsangbuk-do Agricultural Research & Extension Services.
 16. Hong SC, Kwon SI, Kim MK, Chae MJ, Jung GB, Kang KK (2012) Flowering control by using red light of *Perilla*. *Korean Journal of Environmental Agriculture*, 31(3), 224-228.
<https://doi.org/10.5338/KJEA.2012.31.3.224>.
 17. Smith H, Whitelam GC (1997) The shade avoidance syndrome: multiple responses mediated by multiple phytochromes. *Plant, Cell & Environment*, 20(6), 840-844.
<https://doi.org/10.1046/j.1365-3040.1997.d01-104.x>.
 18. Zou J, Zhang Y, Zhang Y, Bian Z, Fanourakis D, Yang Q, Li T (2019) Morphological and physiological properties of indoor cultivated lettuce in response to additional far-red light. *Scientia Horticulturae*, 257, 108725. <https://doi.org/10.1016/j.scienta.2019.108725>.