Effect of Far-red Light on Saffron (*Crocus sativus* L.) Growth and Crocin Yields

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This study investigated the effect of the red (R) to far-red (FR) photon flux density ratio on the growth and crocin yields of 64 saffron (*Crocus sativus* L.) corms that were hydroponically cultivated in closed chambers. The life cycle of saffron can be divided into four stages: formation of the flower buds, flowering, formation of the daughter corms (FD) and development of the daughter corms (DD). During the DD stage, the corms were cultivated under the same environmental conditions except for the light quality, which was applied at an R/FR ratio of 15.8 (FL treatment) or 1.8 (FR treatment). There was no significant difference between treatments in the shoot length, or the maximum diameter, weight and stigma weight of the daughter corms. However, there was a significant difference in the absorbance of crocin solutions. Although the cause of FR-induced increase in crocin was not elucidated, it was presumed that a low R/FR ratio during the DD stage accelerates the translocation of photosynthetic products from the leaves to the corms to generate carbohydrate-enriched corms. This might result from increased sink strength, which is associated with phytochrome equilibrium.

Keywords: crocin, phytochrome, R/FR ratio, saffron corm, translocation

INTRODUCTION

The production of plants in plant factories supplies stable and very safe products regardless of the weather conditions, but is also associated with significant costs in terms of both the initial investment and ongoing electricity expenses. Therefore, to compensate for these high production costs, it is necessary to produce crops with a high unit price. This research focussed on production of medicinal plant saffron (*Crocus sativus* L.), which is considered an expensive spice globally. This bulbous plant of the genus *Crocus* (family Iridaceae) is traditionally cultivated in Iran, where 93.7 % of the world’s total production is grown (Ghorbani, 2008). The basic component of commercial saffron is the stigma, which contains the yellow-red carotenoid pigment crocin (C_{15}H_{26}O_{9}). Crocin has a wide variety of applications not only in the food industry and as a colourant, but also in medicine (Gazerani et al., 2013), with several reports demonstrating its pharmacological activity, including anti-tumour properties and improved outcomes for alcoholic memory disorder (Shoyama, 2009).

The life cycle of saffron can be divided into four stages: formation of the flower buds, flowering, formation of the daughter corms (FD) and development of the daughter corms (DD) (Miyagawa et al., 2015). Traditionally, saffron corms start to produce flowers in autumn following transplantation into the field in late summer. The plants’ leaves continue to grow from summer to winter, with two daughter corms usually forming and enlarging at the base of the shoot on their mother corm at low temperatures in winter. At the beginning of spring, the leaves begin to wither and the enlarged daughter corms are harvested and stored while dormant, during which time they undergo flower bud formation. It is well known that the bulbous plant stores a large quantity of carbohydrates in the bulb, which support root growth, nutrient absorption and differentiation of the flower buds, stems and leaves during its underground life (Ohyama et al., 1986). Consequently, since these carbohydrates may make a large contribution to flowering energy, saffron corms that contain a large amount of photosynthetic products are expected to have higher stigma yields, as indicated by the extremely strong correlation between flowering rate and corm weight (Pharmaceutical Affairs Bureau, 1995).

In recent years, light quality (i.e. the spectral composition of light) has been identified as an important environmental factor for plant growth and quality improvement. Photosynthesis occurs under photoinhibition conditions that span a particular range of photosynthetically active radiation (PAR), from approximately 400 nm to 700 nm. Far-red radiation, which is the outside part of the PAR spectrum, is not directly involved in photosynthesis but does induce photomorphogenesis in plants via changes in phytochrome equilibrium. For instance, Lercari (1982) found that far-red light irradiation induced the translocation of carbohydrates from the leaves to the bulb in onion (*Allium cepa*) plants and concluded that carbohydrate accumulation in onions is a phytochrome-mediated response; and Terabun (1978) discovered that there was an interaction between red and far-red light in the enlargement of onion, wakegi onion and garlic (*A. sativum*) bulbs.
However, the effect of light quality on saffron growth has not been examined previously.

It is generally accepted that plants respond to a complex combination of environmental factors. In terms of light quality, it was hypothesised that the far-red light component during the DD stage would promote carbohydrate accumulation within saffron corms via the interaction with phytochrome, and increase stigma yields and crocin contents. Therefore, this study investigated the effect of light with a far-red component during the DD stage on the growth of saffron daughter corms and crocin yields to establish an optimal cultivation strategy for saffron production in plant factories.

MATERIALS AND METHODS

Tested samples

The experiment was conducted in two closed chambers (LPH-410SPC; Nippon Medical & Chemical Instruments Co., Osaka, Japan) at The Center for Collaborative Research and Technology Development of Kobe University, Hyogo Prefecture, Japan, using 64 saffron corms that had been hydroponically cultivated in closed chambers during the previous year. Since the corms did not have the same harvest date due to differences in growth, early-harvested corms were stored in a closed chamber at 18/15°C (light/dark period) until all the corms had been harvested. All the corms were then placed in an incubator (MIR-154; Panasonic, Osaka, Japan) at 25°C for 90 d to promote flower bud formation.

Experimental treatments

The corms were separated into two equal-sized experimental treatment groups, according to the type of light source that was used during the DD stage: normal fluorescent light (FL) or fluorescent light with high far-red light (FR). The R/FR ratio, which is defined as the ratio of the total photon flux density of red light (600–700 nm) to that of far-red light (700–800 nm), was 15.8 in the FL treatment and 1.8 in the FR treatment. Thirty-two corms were hydroponically cultivated in each treatment. The corms were allocated to each group in such a way that there was no significant difference in corm weight between the two treatments.

Cultivation methods

Hydroponic cultivation was carried out using a nutrient solution that consisted of half-strength Otsuka-A prescription (OAT House No. 1 and No. 2; OAT Agrio, Tokyo, Japan), which was exchanged once per week. The pH (pH Interface ACQ210N-PH, pH Electrode ACQ310-PH; Aquatronica Co., Tokyo, Japan), electrical conductivity (Low Range Conductivity Interface ACQ210N-MS, Electro Conductivity Electrode ACQ310-MS; Aquatronica Co., Tokyo, Japan) and temperature (Temperature & Level Interface ACQ210NL-TL, Temperature Sensor ACQ001S; Aquatronica Co., Tokyo, Japan) of the nutrient solution were measured every min. Air was supplied to the roots by bubbling (HIBLOW Air Pump GP-30; Techno Takatsuki Co., Osaka, Japan) during cultivation. Eight black acrylic plates (ACRYSUNDAY EX plate, 440 mm × 278 mm; Acrysunday Co., Osaka, Japan) each containing eight 60-mm-diameter holes were prepared to plant the saffron corms. A piece of net was attached to the underside of each plate and adjusted to the correct tension to fix the bottom position of the planted corms. A corm was placed on the net at the centre of each hole, with eight corms being planted on each acrylic plate. Each acrylic plate was then placed in a solution container (sun box #7; Sanko Co., Tokyo, Japan) that was filled with 5 L of the nutrient solution. The inside space of each chamber was divided into upper and lower parts and two solution containers were placed in each, giving a total of eight containers used in the experiment.

Cultivation environment

The day of planting was defined as cultivation day 0. The temperature was set to promote flowering, in accordance with a previous study (Miyagawa et al., 2015), and

Table 1 Environmental conditions in each growing stage in the normal fluorescent light (FL) and fluorescent light with high far-red light (FR) treatment groups.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growing stage</td>
<td>Flowering</td>
</tr>
<tr>
<td>Cultivation day (d)</td>
<td>FL</td>
</tr>
<tr>
<td>0–85</td>
<td>85–112</td>
</tr>
<tr>
<td>R/FR ratio (−)</td>
<td>15.8</td>
</tr>
<tr>
<td>Humidity (%)</td>
<td>85</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>Light/dark</td>
</tr>
<tr>
<td>Light/dark</td>
<td>17/17</td>
</tr>
<tr>
<td>Light/dark</td>
<td>10/14</td>
</tr>
<tr>
<td>Light/dark</td>
<td>8/16</td>
</tr>
<tr>
<td>Light/dark</td>
<td></td>
</tr>
</tbody>
</table>

FD: Formation of the daughter corms.
DD: Development of the daughter corms.
* Light source was replaced on cultivation day 119.
* Temperature at the FD stage was changed from 17/17°C to 15/6°C on cultivation day 91.
* Temperature at the DD stage was changed from 18/15°C to 15/7°C on cultivation day 121.
* PPFD: Photosynthetic photon flux density.
* PPFD at the FD stage was not measured based on assumption that it remained unchanged.
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the photoperiod and humidity were made to match that of Taketa city, which is a top saffron-producing area in Japan. Table 1 shows the environmental conditions that were used at each growing stage. The relative humidity, air temperature and CO2 concentration were controlled throughout the cultivation period. The light sources were fluorescent lamps (FHF32EX-N-HX-S and FL20SEX-N-HG; NEC Co., Tokyo, Japan) with an R/FR ratio of 15.8 at a photosynthetic photon flux density (PPFD) of 225.8 ± 10.5 μmol m⁻² s⁻¹ (mean ± standard deviation) in the FL treatment and fluorescent lamps with high far-red components (FL40S • FR • P and FL20S • FR • P; Panasonic Co., Osaka, Japan) with an R/FR ratio of 1.8 at a PPFD of 225.8 ± 9.82 μmol m⁻² s⁻¹ in the FR treatment. The PPFD was measured at eight transplanting points on the tray using a quantum metre (metre: Light Meter LI-250; sensor: LI-190SA; LI-COR, Lincoln, NE, USA).

The growth condition was shifted to the set value for the FD stage on cultivation day 85, at which time the end of flowering was confirmed in both treatments. Miyagawa et al. (2015) previously showed that a temperature of 15/6°C (light/dark) is more appropriate than 17/17°C for increasing the crocin concentration after the beginning of the FD stage. Therefore, the set temperature value was changed to 15/6°C on cultivation day 91. All axillary buds were removed to prevent the daughter corms from splitting into smaller corms and only two apical buds were left on the top of each corm.

Once bulb formation had been confirmed in both treatments on cultivation day 112, the growth condition was shifted to that of the DD stage. The bulbing ratio, which is the ratio of the basal-portion diameter of a shoot to the daughter corm diameter (Le et al., 2002), was used to indicate formation of the daughter corm, with a ratio >1.5 indicating the completion of formation of the daughter corm. It was initially intended that the light source in the FR treatment would be exchanged to fluorescent lamps with an R/FR ratio of 1.8 on cultivation day 112; however, this actually occurred on cultivation day 119 due to a delay in the arrival of the fluorescent lamps. The same fluorescent lamps as had been used during the flowering and FD stages continued to be used in the FL treatment. The relative values of the photon flux density of the two types of light sources are shown in Fig. 1 and were calculated by the following equation (Takatsuji, 2010):

\[
PFD = \frac{X \times \lambda}{PFD_{\text{max}}}\]

where \(PFD\) is the relative value of the photon flux density at wavelength \(\lambda\); \(PFD_{\text{max}}\) is the maximum value of \(X\), multiplied by \(\lambda\); and \(X\) is the spectral radiant energy at wavelength \(\lambda\) measured by a spectral radiometer (S-2630; Somaopt. Co., Tokyo, Japan). The PPFDs in the FL and FR treatments were adjusted at 162.3 ± 8.11 μmol m⁻² s⁻¹ and 151.1 ± 11.7 μmol m⁻² s⁻¹, respectively, to ensure that there was no significant difference between the two treatments. However, there was a concern that the decrease in PPFD might lead to a lower photosynthesis rate and hinder corm enlargement. Therefore, since Miyagawa et al. (2015) previously demonstrated that a low temperature condition (15/7°C) at the DD stage results in saffron corms having a higher sink capacity and thus avoids any halt in cell growth and corm enlargement, the set temperature value was changed from 18/15°C to 15/7°C on cultivation day 121 to promote corm enlargement even under a low PPFD condition.

The daughter corms were harvested at cultivation day 227 when half the length of the leaves of all eight corms on a single black acrylic plate had withered. All corms were then stored in an incubator (MIR-154; Panasonic, Japan) at 25°C for 108 d to promote flower bud formation. Following storage, 32 corms were selected from each treatment group (ensuring that there was no significant difference in corm weight between treatments) and used in the flowering experiment to examine the effect of the light environment at the DD stage on stigma yield and crocin content. Since some of the adjacent corms had pushed against each other on the same mother corm and consequently fallen away during the DD stage in the initial experiment, the method of planting the saffron corms on the acrylic plate needed to be improved to support the daughter corms. Therefore, all pieces of net were removed from the underside of the black plates and instead a sponge was wound around the corms to fix them to the hole of the plate at the flowering stage. The fluorescent lamps were exchanged with new ones (FHF32EX-N-HX-S and FL20SEX-N-HG; NEC Co., Tokyo, Japan) with an R/FR ratio of 15.8 and PPFDs of 249.6 ± 11.7 μmol m⁻² s⁻¹ in the FL treatment and 248.4 ± 11.4 μmol m⁻² s⁻¹ in the FR treatment to prevent any decrease in the amount of light.

Measurements

As temporal growth indices, the shoot length and maximum diameter of the corms were measured once per week using a tape measure or calliper (Vernier Caliper; Mitutoyo Co., Kanagawa, Japan). Shoot length was defined as the length from the base of the stem to the tip of the longest bud or leaf during the cultivation period and the maximum diameter of the corms was measured from the beginning of the DD stage. Corm weight was measured by
an electric balance (AJII-220; SHINKO DENSHI CO., Tokyo, Japan) just before transplanting for the flowering experiment.

In regard to flowering, it is of extreme importance that the stigmas are harvested at an appropriate time because the crocin content reaches its peak at the time of full bloom and subsequently decreases over time by oxidation and hydrolysis in the presence of oxygen, light and moisture (Shoyama, 2009). Thus, the diameter of the flower and the maximum interval between edges of the petals that face each other when looking at the flower from anterior view were measured. “Full bloom” was defined when the ratio between them became 1.0 (Fig. 2) and the flowers and stigmas were measured. “Full bloom” was defined when the ratio between them became 1.0 (Fig. 2) and the flowers and stigmas were measured. “Full bloom” was defined when the ratio between them became 1.0 (Fig. 2) and the flowers and stigmas were measured. “Full bloom” was defined when the ratio between them became 1.0 (Fig. 2) and the flowers and stigmas were measured. “Full bloom” was defined when the ratio between them became 1.0 (Fig. 2) and the flowers and stigmas were measured. “Full bloom” was defined when the ratio between them became 1.0 (Fig. 2) and the flowers and stigmas were measured.

The criterion for determining harvest time of flowers was relatively evaluated by comparing absorbance of each sample solution.

Fig. 2 The criterion for determining harvest time of flowers and stigmas. Solid arrow and dashed arrow represent the diameter of the flower and the maximum interval between edges of the petals that face each other, respectively. Flowers were judged to be in full bloom and harvested when both the arrows were equal in length. A: Not full bloom; B: Full bloom

The absorbance of crocin solution extracted from the stigmas was measured by colorimetric analysis with reference to the Japanese Pharmacopoeia (Ministry of Health, Labour and Welfare, 2016). While 0.100 g of dried stigmas is required for absorbance measurement according to the Japanese Pharmacopoeia, the weight of dried stigmas harvested from one corm in the flowering experiment was less than 0.100 g. Therefore, dried stigmas harvested from the different corms were needed to be mixed. Since 0.373 g and 0.360 g of dried stigmas were obtained in the FL and FR treatments respectively, three sample solutions were prepared for each treatment. To do this, the dried stigmas were ground into a fine powder using a pestle and mortar, 0.100 g of which was weighed and collected as one sample. Then, 150 mL of warm water was added and the mixture was shaken for 30 min at 70°C and 120 min -1 using a water bath shaker (Personal-11; TAITEC Co., Saitama, Japan), cooled to room temperature and filtered through quantitative philtre paper (No131; Advantec Toyo Kaisha Co., Tokyo, Japan). The filtrate (1 mL) was then transferred to a volumetric flask and diluted with distilled water to make up a constant volume (10 mL) of sample solution for absorbance measurement. A Carbazochrome Sodium Sulfonate Trihydrate (CSST) solution, which has similar characteristics to crocin solution in an aspect of their colour, was used as a standard (Ministry of Health, Labour and Welfare, 2016). This was prepared by mixing 0.0980 g of CSST with distilled water to make up 100 mL and then correctly diluting 5 mL of this solution to 100 mL in a volumetric flask by adding distilled water, in the same way as the sample solutions were prepared. After the above pre-processing steps, the absorbance of each solution was measured at a wavelength of 438 nm and compared with distilled water using an ultraviolet and visible spectrophotometer (UV-160A; SHIMADZU Co., Kyoto, Japan). The absorbance was measured four times for each sample solution and the standard solution, respectively. According to the Japanese Pharmacopoeia, the standard for medicine is satisfied when the absorbance of a sample solution exceeds that of the standard solution. The absorbance of a sample solution was used as an index for crocin concentration after confirming whether the standard is satisfied. Thus, the difference of crocin concentrations between the treatments was relatively evaluated by comparing absorbance of each sample solution.

Statistical analysis

Non-parametric analyses of variance (ANOVA) prevents the premise of normality of measurement data, were conducted to test whether there were any significant differences in mean values between treatments. The Wilcoxon test was applied to compare two groups, and the Kruskal-Wallis test and a multiple comparison by S method were applied to compare more than two groups (Shirahata, 1987). However, it was impossible to evaluate differences in the absorbance of sample solutions by the Wilcoxon test with a significance level of less than 10% under the condition that the number of samples was three in both treatments. Then, a t-test was also performed to consider differences in the absorbance of sample solutions in the treatments under the assumption that crocin concentration data follows a normal distribution.

RESULTS AND DISCUSSION

Shoot length and maximum diameter

Weekly transition in the average shoot length with respect to the cultivation period and increment of the shoot length from the start of the DD stage (cultivation day 112) for both treatments are shown in Fig. 3, while time course of the mean maximum diameters of the daughter corms is shown in Fig. 4. Since it has previously been demonstrated that there is a correlation between the maximum diameter and weight of the daughter corms (Hassan-Beygi et al., 2010), use of the maximum diameter as an index for enlargement of the daughter corm was assumed to be highly reliable.

It was originally assumed that each treatment group would produce 64 daughter corms (i.e. two daughter corms per mother corm multiplied by 32 mother corms). However, only 41 and 45 daughter corms were produced in the FL and FR treatments, respectively, due to some of...
them being pushed against each other and thus separated from the mother corm midway through the DD stage. Consequently, it was considered that the tensile forces, compressive forces and torques that occurred at the junctions between the mother and daughter corms as a result of their own weight were greater than the strength of the junctions. Samples in which at least one daughter corm had separated were excluded from measurement due to the possibility of this affecting the distribution of nutrients between the two daughter corms.

In both treatments, shoot length increased greatly in the initial cultivation period, but the rate of change then gradually decreased to reach almost zero just before harvesting. By contrast, the maximum diameter of the daughter corms increased in an almost linear fashion during the cultivation period. No significant difference was found in either of these growth indices between the two treatments, although there was a tendency for plants in the FR treatment group to have longer shoots than those in the FL treatment group (Fig. 3). These findings suggest that a low R/FR ratio does not make a large contribution towards promoting shoot extension and enlarging the daughter corms, although the irradiation period of light with a low R/FR ratio might not have been long enough to have a significant effect on saffron growth. In this study, the timing of transition to the DD stage was exactly the same for each corm, but the period to complete formation of the daughter corms was different due to the different cultivation histories of the plants and the divergence of morphological changes among the corms. Several corms that had relatively slow growth rates were moved to the DD growth conditions just after completion of their formation. However, such corms were found in both the treatments. Therefore, the finding that both shoot length and the maximum diameter of the daughter corms tended to be higher in the FR treatment group than in the FL treatment group suggests that a low R/FR ratio just after the completion of daughter corm formation may promote saffron growth.

Weight of daughter corms and dry stigmas, and crocin concentrations

The results of the flowering experiment are shown in Table 2. There was no significant difference between treatments in the daughter corm weights or the numbers of flowers produced. Furthermore, although the fresh stigma weight per flower was slightly higher in the FR treatment group than in the FL treatment group, the mean dry stigma weight and the dry stigma weight per daughter corm were the same in both treatments. Thus, light with a far-red component had no effect on corm weight and stigma yields in this experiment.

The absorbance of sample solutions in each treatment group and a standard solution are shown in Table 3. The stigmas obtained in this experiment met the Japanese
that more photosynthesis products were delivered to the daughter corms to yield higher carbohydrate contents in the FR treatment group, despite little difference in corm weight being observed between treatments. This is probably because the carbohydrate contents are explained not only by corm weight but also by carbohydrate concentration. Though the carbohydrate contents of the corms could not be measured due to the necessity to test the corms for the flowering experiment, it was estimated that carbohydrate accumulation would be accelerated under light conditions with a low R/FR ratio during the DD stage and was probably associated with the equilibrium state of phytochrome.

The most characteristic feature of a phytochrome molecule is its ability to convert between two kinds of three-dimensional structures: the red absorbing form of the phytochrome protein Pr converts to Pfr when it absorbs red light; and the far-red absorbing form of the phytochrome protein Pfr converts back to Pr when it absorbs far-red light (Matsushita, 2008). It has been shown that the Pfr/P ratio (where P is the sum of Pfr and Pr) is strongly dependent on the R/FR ratio of irradiating light (Hanyu et al., 1996). Therefore, it is reasonable to assume that the decrease in R/FR ratio from 15.8 to 1.8 moved the phytochrome equilibrium in the direction of a lower Pfr/P ratio in saffron.

Although the mechanism of signal transduction from phytochrome is not yet clear, the acceleration of carbohydrate translocation into the corms will have resulted from an increased sink strength. Ranwala et al. (2002) showed that sucrose is utilised for metabolic and synthetic activities of the sink tissues, and suggested that an increased activity of the sucrose hydrolysing enzymes, which are regulated by phytochrome, may result in more reducing sugars being carried to sink tissues, increasing the sink strength. Keiller and Smith (1989) also demonstrated that the activities of the enzymes of sucrose biosynthesis and degradation change in a manner that is consistent with the observed changes in carbohydrate status. Consequently, the observed increase in crocin concentration in the stigmas of saffron corms that were irradiated by light with a low R/FR ratio is presumed to have been caused by an action of the phytochrome, which altered the enzyme activity involved in sucrose biosynthesis or degradation and thereby sink metabolism.

CONCLUSIONS

The present study examined the effect of light with a far-red component during the period of development of the daughter corms (DD) on saffron growth and crocin yields. This light quality did not have any growth promoting effect on shoot length, maximum diameter of the daughter corms, weight of the daughter corms or dry stigma weight per

Table 2: Comparison of the plant yield in the normal fluorescent light (FL) and high far-red light (FR) treatment groups.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Daughter corm weight (g)</th>
<th>Number of flowers</th>
<th>Stigma weight per flower (mg)</th>
<th>Dry stigma weight per daughter corm (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL</td>
<td>20.155 ± 6.192</td>
<td>52</td>
<td>37 ± 15</td>
<td>7.2 ± 1.6</td>
</tr>
<tr>
<td>FR</td>
<td>19.997 ± 5.335</td>
<td>50</td>
<td>44 ± 12</td>
<td>7.2 ± 1.4</td>
</tr>
</tbody>
</table>

*Mean ± standard deviation.

Table 3: Comparison of the absorbance of crocin solutions in the normal fluorescent light (FL) and high far-red light (FR) treatment groups.

<table>
<thead>
<tr>
<th>Treatment (Standard)</th>
<th>Absorbance (−)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FL</td>
<td>0.951 ± 0.034</td>
</tr>
<tr>
<td>FR</td>
<td>1.24 ± 0.08</td>
</tr>
</tbody>
</table>

*Mean ± standard deviation, n = 3. They reflect the absorbance of crocin solutions extracted from 0.100 g of dry weight of stigma, which was used as an index for crocin concentrations. The values in the table were calculated from the absorbance of three crocin solutions, which was calculated by averaging the absorbance measured with four iterations. Different letters (a and b) indicate a significant difference between the two treatments at a 10% significance level in the Wilcoxon test and a 1% level in the t-test.

*It reflects the absorbance of a standard solution calculated by averaging the absorbance measured with four iterations for one sample.
daughter corm. However, it did significantly affect the crocin concentration in the stigmas. Thus, a light environment with a low R/FR ratio during the DD stage may accelerate the translocation of photosynthetic products from the leaves to the corms to produce carbohydrate-enriched corms, which are considered to have a superior capacity for producing crocin. Since maximising crocin yields is of primary importance for the commercial production of saffron in plant factories, the use of a light source with a low R/FR ratio during the DD stage would be a valid approach for obtaining high-quality corms, which are expected to produce a large amount of crocin during flowering. Additional studies are required to thoroughly investigate the translocation-promoting action that is related to the equilibrium states of phytochrome and to develop a more effective cultivation strategy for saffron production, including optimisation of the light environment.

REFERENCES


