Effects of the red:far-red light ratio on photosynthetic characteristics of greenhouse cut *Chrysanthemum* – Short communication

Z.Q. Yang[1,2], Y.X. Li[1,2], J.B. Zhang[2], J. Zhang[2], J. Zhu[2], L.L. Gu[2], B. Zhang[2]

[1]*Jiangsu Key Laboratory of Agricultural Meteorology, Nanjing University of Information Science & Technology, Nanjing, China*
[2]*College of Applied Meteorology, Nanjing University of Information Science & Technology, Nanjing, China*

Abstract

Yang Z.Q., Li Y.X, Zhang J.B., Zhang J., Zhu J., Gu L.L., Zhang B., 2013. **Effects of the red:far-red light ratio on photosynthetic characteristics of greenhouse cut *Chrysanthemum* – Short communication**. Hort. Sci. (Prague), *40*: 40–43.

For the use of LED as a light source to regulate the photosynthesis of chrysanthemum leaves under greenhouse conditions, the effects of different red (660 ± 30 nm) to far-red (730 ± 30 nm) radiation ratios (R:FR) on the photosynthetic characteristics and chlorophyll fluorescence parameters of chrysanthemum leaves were studied. Red and far-red LED light sources were combined in different proportions to produce four R:FR ratio treatments: 0.5, 2.5, 4.5 and 6.5. The chlorophyll *a* content, SPAD value, net photosynthetic rate, light-saturated maximum photosynthetic rate, CO_2-saturated carboxylation rate, apparent quantum efficiency and carboxylation efficiency were all the highest under the R:FR ratio of 2.5, followed by the R:FR ratio of 4.5. Potential photochemical efficiency of photosystem II, photochemical quenching and electron transport rate for the R:FR ratios of 2.5 and 4.5 were markedly higher than those for 0.5 and 6.5, however, those parameters did not differ significantly between the R:FR ratios of 2.5 and 4.5.

Keywords: chrysanthemum; R:FR; LED; photosynthesis; chlorophyll fluorescence

Studies on the use of light quality to regulate crop growth and development in greenhouses have attracted extensive attention. Phytochrome is most sensitive to red (R) and far-red (FR) light (Batschauer 1998). Li and Kubot (2009) demonstrated that the anthocyanin, carotenoid and chlorophyll contents in lettuce decreased with an increase of the FR component in light. Heraut et al. (1999) showed that red light could promote the chlorophyll content in plants. Yamazaki (2010) considered that FR light significantly lowered the chlorophyll content and the ratio of chlorophyll *a* to chlorophyll *b*. It was confirmed that an increase of the R:FR ratio could promote the photosynthetic rate of leaves (Robin et al. 1994; Ni et al. 2009).

Chrysanthemum is one of the four most popular cut flowers worldwide. Many studies were conducted on the effects of light quality on the photosynthetic characteristics of chrysanthemum leaves (Kim et al. 2004), but few of these studies use LEDs

Supported by the National Natural Science Foundation Item, Grant No. 41075087; the National special Public Sector Research, Grants No. GYHY(QX) 200906023, GYHY(QX) 201006028, and Priority Academic Program Development of Jiangsu Higher Education Institutions.

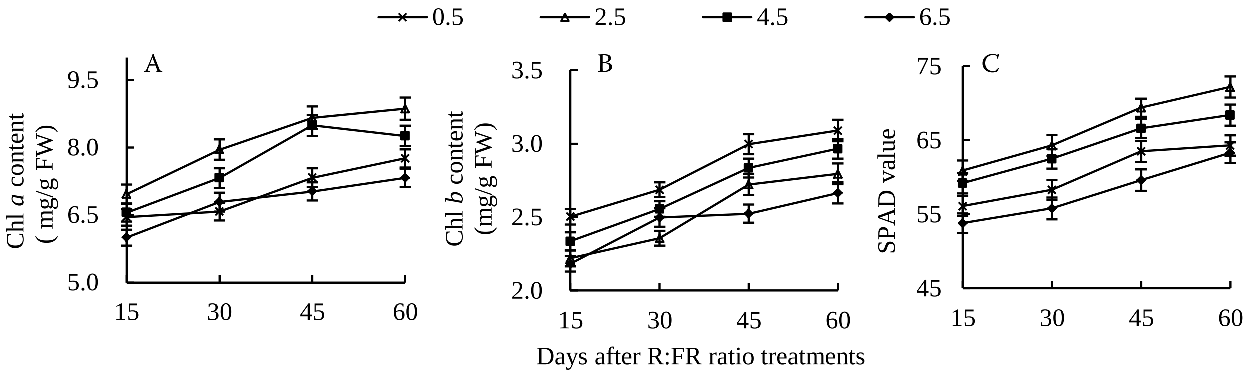

Fig. 1. Effects of R:FR ratios on the chlorophyll contents of chrysanthemum leaves

as the light sources to yield accurate R:FR ratio gradients. Leuchner et al. (2007) found that the photosynthetic rate showed a non-linear increase with R:FR ratios. Thus, it is necessary to study the effects of a wide range of R:FR ratios on the photosynthetic characteristics of chrysanthemum leaves. The present study may provide a scientific basis for the use of LED as a light source to regulate the photosynthesis of chrysanthemum leaves under greenhouse conditions.

MATERIAL AND METHODS

The experimental chrysanthemum (*Chrysanthemum × grandiflorum* Tzvelv cv. Jingba) was planted in four cultivation pools (3.0 × 1.0 m) on October 6, 2010 with a spacing of 20 × 20 cm. A vermiculite and perlite mixture with a volume ratio of 2:1 was pasteurized and used as the culture substrate. All plants were irrigated with nutrient solution that had a conductivity of 1.5 ms/cm (200 ppm N; 80 ppm P; 170 ppm K). When the plant height reached 50 cm, the natural light was shaded using the black plastic film and LED light sources with different R:FR ratios were used to produce short-day treatments (08:00–17:00). The R to FR energy ratios of the four experimental treatments were 0.5, 2.5, 4.5 and 6.5. Plants irradiated with natural light (R:FR = 1.02) served as the control. The photosynthetically active radiation (PAR) in all of the treatments was regulated to be 500 μmol/m^2/s at the top of the canopy. Each treatment comprised 30 chrysanthemum plants. Three plants in each treatment were selected and the 4th–5th function leaves from the top of plants were measured to determine the chlorophyll content, photosynthetic and chlorophyll fluorescence parameters.

To determine the SPAD value, ten plants in each treatment were selected and the 4th–5th function leaves from the top of plants were measured using a chlorophyll meter (SPAD502, Konica Minolta, Tokyo, Japan). The chlorophyll *a* (Chl *a*) and chlorophyll *b* (Chl *b*) contents were determined using the colorimetric method. The light-response curve, CO_2-response curve, net photosynthetic rate

Table 1. The light-response and CO_2-response parameters for different R:FR ratio treatments

Development stages	R:FR	P_{max} (μmol/m^2/s)	A_q	A_{max} (μmol/m^2/s)	C_e
Squaring stage	0.5	19.185 ± 0.523^{b}*	0.042 ± 0.003^{c}	23.524 ± 1.145^{b}	0.040 ± 0.003^{c}
	2.5	22.128 ± 0.716^{a}	0.091 ± 0.006^{a}	26.188 ± 1.367^{a}	0.078 ± 0.005^{a}
	4.5	20.925 ± 0.587^{b}	0.061 ± 0.005^{b}	22.280 ± 1.213^{b}	0.064 ± 0.004^{b}
	6.5	17.859 ± 0.507^{c}	0.030 ± 0.003^{c}	22.835 ± 1.278^{b}	0.034 ± 0.002^{c}
Flowering stage	0.5	18.164 ± 0.367^{b}	0.024 ± 0.002^{c}	24.096 ± 1.306^{c}	0.044 ± 0.003^{c}
	2.5	21.375 ± 0.647^{a}	0.062 ± 0.004^{a}	33.129 ± 1.423^{a}	0.070 ± 0.004^{a}
	4.5	20.147 ± 0.618^{a}	0.048 ± 0.003^{b}	29.295 ± 1.461^{b}	0.057 ± 0.003^{b}
	6.5	18.853 ± 0.476^{b}	0.036 ± 0.003^{b}	27.947 ± 1.365^{b}	0.050 ± 0.003^{c}

*different letters ($P < 0.05$) indicate significant differences within each column according to the Duncan's Multiple Range test; P_{max} – light-saturated maximum phorate; A_{max} – CO_2-saturated maximum asrate; A_q – apparent quantum efficiency; C_e – carboxylation efficiency

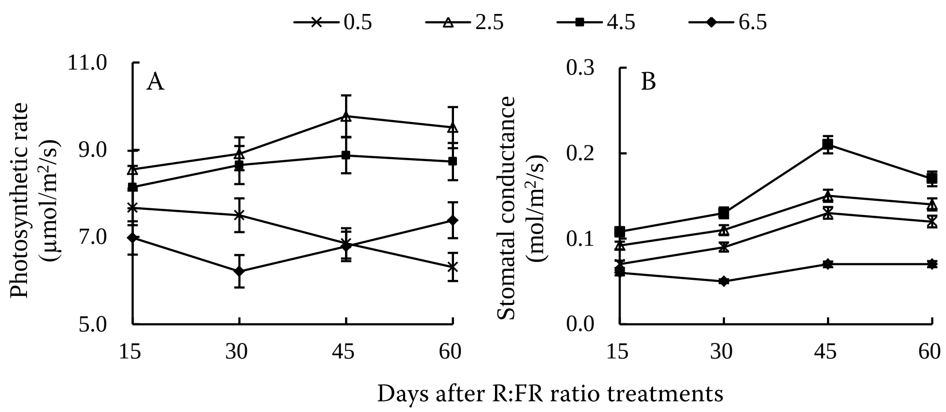

Fig. 2. Effects of R:FR ratios on the net photosynthetic rate and stomatal conductance of chrysanthemum leaves

and stomatal conductance were measured using LI-6400 photosynthesis system (LI-COR Inc, Lincoln, USA). The light-response and CO_2-response curves were fitted using the rectangular hyperbolic model to obtain the light-saturated maximum photosynthetic rate (P_{max}), CO_2-saturated maximum assimilation rate (A_{max}), apparent quantum efficiency (A_q) and carboxylation efficiency (C_e). Curve fitting was performed using the SPSS 15.0 (SPSS Science Inc., Chicago, USA). The maximum quantum efficiency (F_v/F_m) of PSII, photochemical quenching (qP) and electron transfer efficiency (ETR) were measured using 6400-40 Fluorescent Leaf Chamber (LI-COR Inc, Lincoln, USA).

RESULTS AND DISCUSSION

The Chl *a* contents and SPAD values of chrysanthemum leaves under four R:FR ratio treatments were, from high to low, 2.5, 4.5, 0.5 and 6.5, whereas the order was 0.5, 4.5, 2.5, 6.5 from high to low for the Chl *b* content (Fig. 1). Heraut et al. (1999) reported that red light could promote the chlorophyll content, whereas Bach and Krol (2001) found that red light reduced the chlorophyll content; Yamazaki (2010) found that the chlorophyll content and Chl *a*/*b* of rice was reduced under FR light. Our research indicated that the optimal R:FR ratio for the development of chloroplasts was 2.5 and an excessively high R:FR ratio (6.5) reduced the Chl *a* content and Chl *a*/*b* value.

Ni et al. (2009) recognised that an increase in the red light component could promote crop photosynthetic, stomatal conductance and transpiration rates. Leuchner et al. (2007) further confirmed that the changing trend of the photosynthetic rate over the R:FR ratio was nonlinear. The present study showed that, the P_{max}, A_q, A_{max} and C_e of the chrysanthemum leaves under the R:FR ratio of 2.5 was

Table 2. The chlorophyll fluorescence parameters of chrysanthemum leaves under different R:FR ratio treatments

Chlorophyll fluorescence parameters	R:FR	Treatment days			
		15	30	45	60
F_v/F_m	0.5	0.786 ± 0.008[b]	0.804 ± 0.007[b]	0.797 ± 0.011[b]	0.782 ± 0.006[c]
	2.5	0.814 ± 0.005[a]	0.827 ± 0.006[a]	0.834 ± 0.008[a]	0.832 ± 0.005[a]
	4.5	0.808 ± 0.007[a]	0.825 ± 0.008[a]	0.828 ± 0.003[a]	0.812 ± 0.007[b]
	6.5	0.777 ± 0.005[b]	0.781 ± 0.003[b]	0.788 ± 0.008[b]	0.783 ± 0.004[c]
qP	0.5	0.647 ± 0.009[b]	0.657 ± 0.007[b]	0.654 ± 0.007[b]	0.649 ± 0.010[b]
	2.5	0.756 ± 0.005[a]	0.773 ± 0.004[a]	0.781 ± 0.006[a]	0.753 ± 0.006[a]
	4.5	0.749 ± 0.007[a]	0.754 ± 0.008[a]	0.762 ± 0.009[a]	0.743 ± 0.008[a]
	6.5	0.627 ± 0.005[b]	0.628 ± 0.005[b]	0.634 ± 0.005[b]	0.632 ± 0.005[b]
ETR	0.5	59.3 ± 1.21[b]	65.5 ± 1.44[b]	64.7 ± 1.19[b]	61.4 ± 2.12[b]
	2.5	68.4 ± 1.35[a]	74.1 ± 1.93[a]	80.5 ± 1.28[a]	77.1 ± 1.57[a]
	4.5	67.8 ± 1.17[a]	75.4 ± 1.65[a]	77.8 ± 1.30[a]	74.9 ± 1.15[a]
	6.5	57.3 ± 1.53[b]	56.4 ± 1.16[c]	63.5 ± 1.02[b]	58.1 ± 1.07[b]

F_v/F_m – maximum quantum of PSII; qP – photochemical quenching; ETR – electron transfer efficiency the highest during both the squaring and flowering stages, followed by the R:FR ratio of 4.5 (Table 1).

During the entire treatment period, the net photosynthetic rate for the R:FR ratio of 2.5 was always higher than those of the other treatments and was followed by the 4.5 R:FR ratio (Fig. 2). The stomatal conductance for the R:FR ratio of 4.5 was higher than those for the other treatments over the entire experimental period; the R:FR ratio of 2.5 resulted in the next highest values, and the R:FR ratio of 6.5 consistently produced the lowest values. Wang et al. (2009) found that light quality affected photosynthesis by affecting the activity of the photosynthetic apparatus and the expression and activity of the enzymes in the Calvin-Benson cycle. In the present study, the chlorophyll content was the highest at an R:FR ratio of 2.5, which was consistent with the photosynthetic rate. Thus, it can be inferred that the R:FR ratio affects photosynthesis in chrysanthemum leaves mainly through the regulation of non-stomatal factors.

Fv/Fm, qP and ETR values of the chrysanthemum leaves did not differ significantly between the R:FR ratios of 2.5 and 4.5, with the exception of Fv/Fm on day 60, and the values for the R:FR ratios of 2.5 and 4.5 were markedly higher than those for 0.5 and 6.5 (Table 2). Yamazaki (2010) found that FR light caused a lag of Fv/Fm in rice. We found that the chlorophyll fluorescence parameters of the chrysanthemum leaves were not linearly correlated with the R:FR ratios. The effects of R:FR ratios on the fluorescence parameters may be related to the balance between PSI and PSII (Sood et al. 2004).

References

Bach A., Krol A., 2001. Effect of light quality on somatic embryo genesis in *Hyacinthus orientalis L.* Delft's blue. Biological Bulletin of Poznan, *38*: 103–107.

Batschauer A., 1998. Photoreceptors of higher plants. Planta, *206*: 479–492.

Heraut B.V., Robin C., Varlet G.C., Afif D., Guckert A., 1999. Light quality (red:far-red ratio): Does it affect photosynthetic activity, net CO_2 assimilation, and morphology of young white clover leaves? Canadian Journal of Botany, *77*: 1425–1431.

Kim S.J., Hahn E.J., Heo J.W., Paek K.Y., 2004. Effects of LEDs on net photosynthetic rate, growth and leaf stomata of chrysanthemum plantlets *in vitro*. Scientia Horticulturae, *101*: 143–151.

Leuchner M., Menzel A., Werner H., 2007. Quantifying the relationship between light quality and light availability at different phenological stages within a mature mixed forest. Agricultural and Forest Meteorology, *142*: 35–44.

Li Q., Kubot C., 2009. Effects of supplemental light quality on growth and phytochemicals of baby leaf lettuce. Environmental and Experimental Botany, *67*: 59–64.

Ni J.H., Chen X.H., Chen C.H., Xu Q., 2009. Effects of supplemental different light qualities on growth, photosynthesis, biomass partition and early yield of greenhouse cucumber. Scientia Agricultura Sinica, *42*: 2615–2623.

Robin C., Hay M.J.M., Newton R.C.D., 1994. Effect of light quality (red:far-red ratio) and defoliation treatments applied at a single phytomer on axillary bud outgrowth in *Trifolium repens* L. Oecologia, *100*: 236–242.

Sood S., Tyagi A.K., Tripathy B.C., 2004. Inhibition of Photosystem I and Photosystem II in wheat seedlings with their root-shoot transition zones exposed to red light. Photosynthesis Research, *81*: 31–40.

Wang H., Gu M., Cui J., Shi K., Zhou Y., Yu J., 2009. Effects of light quality on CO_2 assimilation, chlorophyll-fluorescence quenching, expression of Calvin cycle genes and carbohydrate accumulation in *Cucumis sativus*. Journal of Photochemistry and Photobiology B, *96*: 30–37.

Yamazaki J.Y., 2010. Is light quality involved in the regulation of the photosynthetic apparatus in attached rice leaves? Photosynthesis Research, *105*: 63–71.

Received for publication February 2, 2012
Accepted after corrections September 9, 2012

Corresponding author:

Dr. Yongxiu Li, Nanjing University of Information Science & Technology,
Jiangsu Key Laboratory of Agricultural Meteorology, Nanjing, China
phone/fax: + 86 25 587 311 65, e-mail: lyxsha@nuist.edu.cn