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Effect of Low Light Intensity on Longevity of Flowering on Bedding Plants Targeted for Indoor Use

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Abstract

The adaptability of nine bedding plants to low light intensity was evaluated for their indoor use. Based on the duration of flowering under indoor low light intensity [1,000 lx, 16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux density (PPFD)], the plants' adaptability was classified into three groups. In group 1, the effect of low light intensity was unclear due to short flowering longevity irrespective of light intensity; this group included *Helianthus*. Group 2 included species not adaptable to indoor low light intensity, under which the duration of flowering indoors was less than three weeks; this group included *Petunia Salvia*, and *Verbena*. Group 3 included species adaptable to indoor conditions, under which the duration of flowering was longer than three weeks; this group included *Catharanthus, Impatiens, Tagetes, Torenia* and *Zinnia*. The effect of low light intensity on shoot growth did not appear as a reduction in plant width, but did appear in plant height and length of the longest lateral stem. The leaf color of most species was darkened by low light intensity. Even *Catharanthus*, *Torenia* and *Zinnia*, which showed the highest adaptability to low light intensity, could not maintain sufficient ornamental quality under 8.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD. The duration of flowering became longer as light intensity increased, although the response differed among species. In *Torenia* and *Zinnia*, the duration of flowering was extended under 2,500 lx (42.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD), indicating that long-term use was possible under bright indoor conditions, including at such locations as windowsills and showcases.

Discipline: Horticulture
Additional key words: flower diameter, indoor environment, number of flowers, weak light

Introduction

Bedding plants are mainly used to improve the landscape quality at public facilities, such as park and streets, as well as in private gardens. Although the production of bedding plants accounts for only 5% of Japan's total domestic flower production, bedding plants are a key item in suburban horticulture as their compactness enables intensive production on small farms (MAFF 2014). However, due to the decreasing trend in gardening, lower sales attributed to an economic slump, and more people intending to live in an apartment building rather than a detached house, the consumption of bedding plants in Japan decreased by more than 20% in 2012 as compared to 2002 (MAFF 2013).

In order to stop this decrease, we developed a new culture system to facilitate the indoor use of bedding plants. This system uses an organic culture medium (a mixture of coconut coir and peat moss) wrapped with discarded school uniform material, which has a neat appearance and can be discarded as burnable garbage after use (Okazawa et al. 2016).

In this system, indoor low light intensity is clearly the main limiting factor for plant longevity. In such potted flowers as *Cyclamen* and *Delphinium*, low light intensity (11.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD and 7.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, respectively) reduced plant longevity due to decreasing light intensity (Komagata et al. 2002, Tanase et al. 2005). In *Cyclamen*, the decrease in longevity appeared as a lower flower number and a reduced depth of flower color.

Under low light intensity, *Ficus benjamin*a, an ornamental foliage plant, exhibited faded leaf color and

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accelerated internode elongation (Chen et al. 2005). However, there is no information about the longevity of bedding plants under indoor low light intensity conditions, although the effect of light intensity on bedding plants growing in an open field and a greenhouse has been reported (Niu et al. 2000, Cerny et al. 2003, Moccaldi & Runkle 2007).

Light intensity also differs significantly depending on the indoor location, such as a windowsill or back of the room. According to Japanese Industrial Standards (JIS Z 9110, JIS Handbook (2010)), the appropriate illumination level is 500 lx (8.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD) for a conference room and 750 lx (12.6 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD) for an office. For households, reading and handicraft require illuminations of 500 lx and 1000 lx (16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD), respectively. Thus, different light intensities according to light installation locations give us different plant growth responses. In fact, potted carnations placed under 9.8 $\mu molm^{-2}s^{-1}$ PPFD exhibit severe leaf yellowing and leaf death, with lost aesthetic value; however, a higher light intensity (51.6 and 274.2 $\mu molm^{-2}s^{-1}$ PPFD) improves the quality of such plants (Komagata et al. 2005).

In the present study, we investigated the effect of indoor low light intensity on the growth and flowering of bedding plants, and screened species suitable for indoor use. We also investigated the effects of different light intensities on screened species by simulating various indoor locations. Based on the results, the appropriate indoor management of those species is discussed.

Materials and Methods

1. Plant material and growth conditions

Table 1 lists the nine species of bedding plants used in experiment 1. These species are identified by genus name in the following text, table and figures. Three species (i.e., *Catharanthus*, *Torenia*, *Zinnia*) that showed high adaptability for indoor conditions in experiment 1 were used in experiment 2. Seeds were sown in a 288-cell plug tray filled with a commercial medium (TM-2; Takii Seed. Co., Ltd., Kanagawa, Japan).

Plants were grown using the cloth container culture system (Okazawa et al. 2016). In brief, the cloth container was sewn into a flat and square envelop measuring 10 cm per side using a discarded school uniform (Tombo Co., Ltd., Okayama, Japan). This envelope was filled with a lightweight organic culture medium, a 200-mL mixture of coco peat (Coco-yuki; DIA Co., Ltd., Kanagawa, Japan) and peat moss (Main River; Oji Forest & Products Co., Ltd., Tokyo, Japan, 1:1 in volume). For basal fertilizer, 81 g N, 237 g P_2O_5 and 81 g K_2O were added per 100 L of medium. A seedling was transplanted to a container when 2-4 leaves opened, and then to a glasshouse under natural sunlight. The ventilation and heating temperatures were 25°C and 13°C, respectively.

2. Light treatment

As soon as all plants within an experimental plot bore an open flower, they were transferred to an incubator simulating indoor light conditions (hereinafter referred to as 'indoor treatment'). In experiment 1, which was conducted to screen species highly tolerant to low light intensity, plants were illuminated by fluorescent lamps (FHF32EX-N-HN; Panasonic Co., Ltd., Tokyo, Japan) for 12 h/day from 5:00 to 17:00 in experiment 1. Light intensity at the plant top level was 1,000 lx [photosynthetic photon flux density (PPFD) of 16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$], one of the indoor light levels recommended by the JIS Z 9110 illumination standard mentioned above.

Table 1. Bedding plants used in this study.

Species	Cultivar	Start of treatment
Catharanthus roseus	Titan Rose	1 Aug
Helianthus annus	Konatsu	27 Sep
Impatiens walleriana	Super Elphin XP Rose	27 May
Petunia hybrida	Rondo Rose	1 Aug
Salvia splendens	Red Hot Sally	28 May
Tagetes patula	Safari Yellow	5 Aug
Torenia fournieri	Kauai Rose	28 May
Verbena hybrida	Obsession White	28 May
Zinnia elegans × *Z. angustifolia*	Profusion Yellow	1 Aug

All experiments were conducted in 2014.

Temperature was maintained at 20°C. Control plants were grown in the greenhouse as described above (hereinafter referred to as 'greenhouse treatment'). The treatment was conducted for four weeks. The plant width, plant height, length of the longest leaf, length of the longest lateral stem, number of opened flowers (flower number), and flower diameter were measured every week. The color of the largest leaf was measured using a chlorophyll meter (SPAD-502; Konica Minolta Co., Ltd., Tokyo, Japan). Each plant was measured three times, and the average was used as an individual datum. We used 10 plants per experimental plot.

In experiment 2, plants were subjected to the same treatment as in experiment 1, although under different light intensities of 500 lx (8.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD), 1,000 lx (16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD), and 2,500 lx (42.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD). These light intensities were set according to JIS Z 9110, which recommends light intensities for interior spaces. Thus, the appropriate illumination level is 500 lx for a conference room, 1,000 lx for a typical office, and 2,500 lx for displays in supermarkets. The treatment was conducted for six weeks. The number of opened flowers were measured every week.

3. Statistical analysis

Data were analysed based on Tukey's multiple range tests.

Results

1. Screening of bedding plants highly tolerant to indoor conditions

In the greenhouse treatment, all species tested exhibited normal flowering (Fig. 1). The plants flowered vigorously throughout the treatment although treatment was suspended when the number of flowers under indoor treatment reached zero. In contrast, the indoor treatment affected flowering differently among species.

In *Helianthus*, which bears only one capitulum, both the duration of flowering (defined as the period during which the plant had opened flowers) and flower diameter did not differ significantly between indoor and greenhouse treatments (Fig. 1).

The duration of flowering was less than three weeks for *Petunia*, *Salvia and Verbena* receiving indoor treatment. *Verbena* exhibited a very short flowering duration of only two weeks. In *Petunia*, the flower diameter decreased by 29.5% in indoor treatment compared with that in greenhouse treatment after two weeks of treatment.

In contrast, *Catharanthus*, *Impatiens*, *Tagetes*, *Torenia and Zinnia* flowered for more than three weeks with the indoor treatment. Low light intensity began to reduce the flower diameter after one week of treatment in *Catharanthus* and *Zinnia*, and after two weeks of treatment in *Impatiens*, *Tagetes* and *Torenia*. After three weeks of indoor treatment, the decrease in flower diameter compared with that in greenhouse treatment was relatively small in *Tagetes* and *Torenia* (i.e., non-significant and 12.4% decrease, respectively), while it was 31.9%, 20.8% and 20.9% in *Catharanthus*, *Impatiens* and *Zinnia*, respectively.

Indoor treatment reduced the plant width in *Petunia*, *Verbena* and *Zinnia* compared with greenhouse treatment, whereas indoor treatment caused no significant effect on *Catharanthus*, *Impatiens*, *Salvia*, *Tagetes* and *Torenia* (Table 2 and Fig. 2). Indoor treatment reduced both the plant height and length of the longest lateral stem in most species tested. In contrast, indoor treatment increased the SPAD value (index of relative chlorophyll content), except for *Verbena* and *Zinnia*. The length of the largest leaf length was almost the same between indoor and greenhouse treatments, except in *Impatiens*, which had significantly greater leaf length with indoor treatment.

When the effect of indoor treatment was characterized based on the changes during treatment, the plant height increased slightly in *Catharanthus*, *Verbena* and *Zinnia*, whereas it increased remarkably by 28.7% in *Impatiens* and by 40.8% in *Torenia* (data not shown). Leaf color was slightly faded in *Tagetes* and *Verbena*, unchanged in *Catharanthus*, *Petunia*, *Salvia*, *Torenia* and *Zinnia*, and darkened in *Helianthus* (data not shown).

2. Effects of various light intensities (simulating indoor conditions) on growth and flowering

Flowering response to different light intensities simulating various indoor conditions was investigated for species highly tolerant to low light intensity, specifically *Catharanthus*, *Torenia* and *Zinnia* (Figs. 1 and 3). In *Catharanthus*, the duration of flowering became longer as light intensity increased: three weeks under 8.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, four weeks under 16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, and five weeks under 42.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD.

Torenia showed a distinct response to different light intensities after two weeks of treatment. Higher light intensity resulted in a larger flower number. The large difference in the number of flowers, which was seen in *Catharanthus* and *Zinnia* between 16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and 42.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, was not detected in *Torenia*; 8.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD light did not reduce the flower number to zero even after five weeks. However, the flower number became zero after six weeks of treatment, irrespective of the light conditions examined.

Zinnia showed a reduced flower number under 16.8

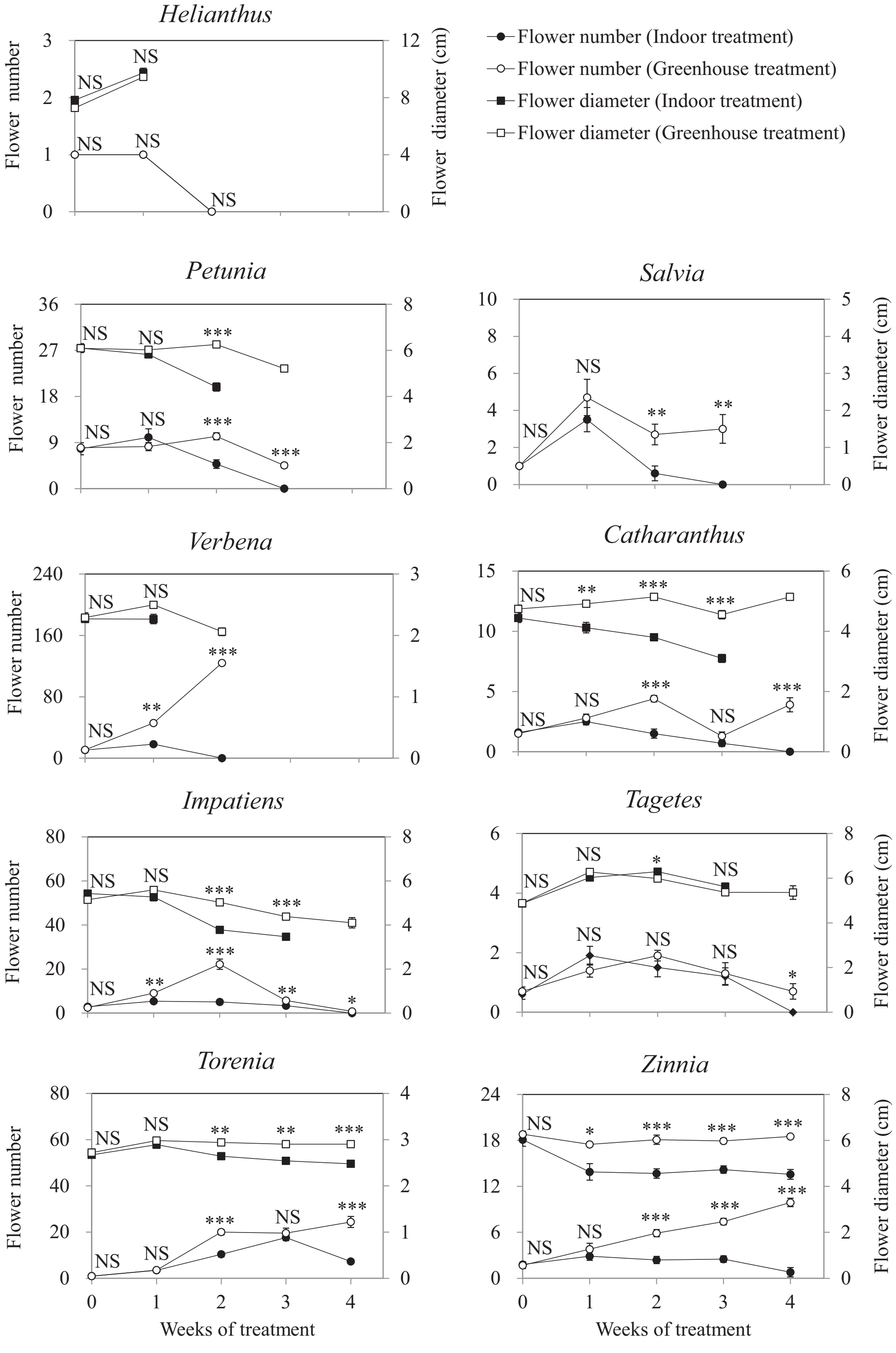

Fig. 1. Effect of low light intensity on flower number and diameter.
Vertical bars represent ± SE. NS, *, ** and *** indicate t-test evaluation of non-significant and significant differences at P = 0.05, 0.01 and 0.001, respectively, from the control plants grown in a greenhouse. *Helianthus* bore only one flower in both indoor and greenhouse treatments.

Table 2. Effect of indoor low light intensity on the growth of bedding plants.

Species	Growing condition	Plant width (cm)	Plant height (cm)	Length of the longest lateral stem (cm)	Length of the largest leaf length (cm)	Leaf color (SPAD)
Catharanthus roseus	greenhouse	16.1[y]	21.7	6.1	7.9	31.7
	indoor	15.5	15.5	3.6	8.0	39.0
	t-test[x]	NS	**	**	NS	*
Helianthus annus	greenhouse	18.7	17.6	ND[Z]	ND	29.1
	indoor	19.8	17.7	ND	ND	29.2
	t-test	NS	NS	ND	ND	NS
Impatiens walleriana	greenhouse	23.2	12.8	11.0	5.7	34.0
	indoor	22.2	12.1	9.3	6.3	40.3
	t-test	NS	**	**	**	**
Petunia hybrida	greenhouse	23.2	12.9	13.0	5.8	32.4
	indoor	17.9	11.3	9.3	6.2	38.6
	t-test	**	*	**	NS	*
Salvia splendens	greenhouse	16.5	24.4	9.5	11.3	34.1
	indoor	18.5	19.4	3.4	11.4	54.2
	t-test	NS	**	**	NS	**
Tagetes patula	greenhouse	21.3	31.1	17.2	8.5	33.4
	indoor	21.6	24.6	10.6	8.3	42.5
	t-test	NS	**	**	NS	**
Torenia fournieri	greenhouse	26.4	17.6	15.4	8.2	32.0
	indoor	26.4	17.6	14.0	7.8	37.3
	t-test	NS	NS	NS	NS	**
Verbena hybrida	greenhouse	26.0	16.2	17.4	5.0	37.1
	indoor	21.7	12.8	14.2	5.2	36.3
	t-test	**	**	**	NS	NS
Zinnia elegans × *Z. angustifolia*	greenhouse	26.6	35.3	27.4	6.4	30.5
	indoor	23.3	27.6	21.1	6.8	30.2
	t-test	*	**	**	NS	NS

[x]NS, * and ** indicate *t*-test evaluation of non-significant and significant differences at $P = 0.05$ and $P = 0.01$, respectively.
[y]Data were collected after three weeks of treatment, except for *Helianthus annus* and *Verbena hybrida*, which were measured after one and two weeks of treatment, respectively, when the flower number reached zero. Values show the mean (n = 10).
[z]ND: no data.

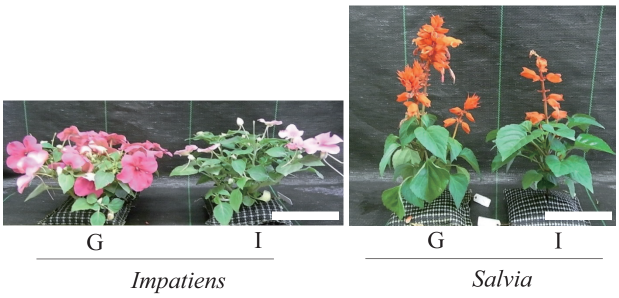

Fig. 2. Effect of low light intensity on plant shape in *Impatiens* and *Salvia*.
These photographs were taken three weeks (*Impatiens*) and two weeks (*Salvia*) after light treatment. G: greenhouse treatment (control), I: indoor treatment. Scale bars indicate 10 cm.

μmol·m^{-2}·s^{-1} PPFD and reached near zero after six weeks of treatment. Weaker light intensity at 8.4 μmol·m^{-2}·s^{-1} PPFD also reduced the number of flowers within two weeks of treatment. The plants had no flowers after three weeks of treatment. In contrast, the number of flowers increased continuously during treatment under 42.0 μmol·m^{-2}·s^{-1} PPFD.

Discussion

As bedding plants are not assumed to be used indoors, their propagation is usually targeted for outdoor use. On the other hand, the adaptability to indoor conditions has been evaluated in indoor plants. For

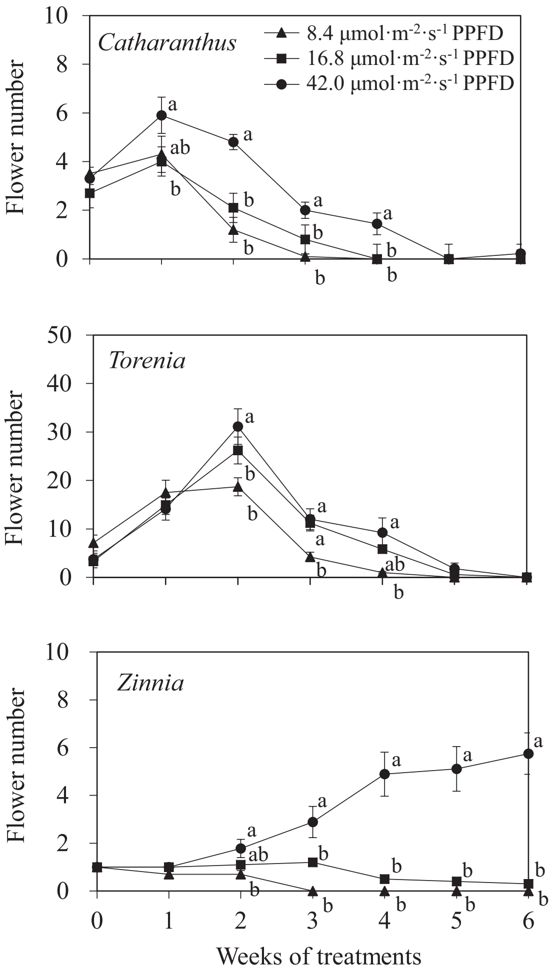

Fig. 3. Effect of light intensity on flower number. Data represents the mean ± SE (n = 10).
The same letters indicate non-significant differences among the treatments at P value < 0.05 by Tukey's test.

example, in potted cyclamen (Komagata et al. 2002) and *Dieffenbachia* (Conover & Poole 1981), the minimum illumination level necessary to maintain sufficient quality was 2,000 lx (= 33.6 µmol·m^{-2}·s^{-1} PPFD) and 12 µmol·m^{-2}·s^{-1} PPFD, respectively. In the present study, we intended to identify bedding plants highly tolerant to indoor low light intensity.

According to a questionnaire survey (MPS Japan 2008), most consumers requested a cut flower longevity as long as one week. Given this result, the sufficient longevity for our cloth container system was set as three weeks because we felt that consumers would naturally expect a much longer longevity for intact plants than cut flowers. Based on the duration of flowering under indoor low light intensity (16.8 µmol·m^{-2}·s^{-1} PPFD), the adaptability of bedding plants to indoor conditions was classified into three groups (Fig. 1).

In group 1, the effect of low light intensity is unclear given the short flower longevity irrespective of light intensity. This group includes *Helianthus*, which has only one capitulum. Group 2 includes species not adaptable to indoor low light intensity. In this group, the duration of flowering under indoor conditions was less than three weeks. This group includes *Petunia*, *Salvia* and *Verbena*. Group 3 includes species adaptable to indoor conditions. In this group, the duration of flowering was longer than three weeks. This group includes *Catharanthus*, *Impatiens*, *Tagetes*, *Torenia* and *Zinnia*. These findings clearly show that the minimum light intensity to confer sufficient quality maintenance varies among species. Meanwhile, *Impatiens* and *Petunia* are quantitative long-day plants, while *Salvia*, *Tagetes*, *Torenia* and *Zinnia* are quantitative short-day plants, and *Cataranthus* and *Helianthus* are day-neutral plants (Editorial Committee of Manual for Flowering Regulation 1995). In this study, the illumination period was fixed to 12 hours. Thus, whether the length of day in indoor treatment affected the flowering of long- or short-day plants cannot be ruled out.

In order to obtain sufficient quality for indoor use, plants require not only light intensity at the light compensation point (Eugene et al. 1975) but also extra light to produce photosynthates to maintain continuous flowering. The plants classified in group 3 described above grew and flowered well under the low light intensity, whereas those in group 2 grew very slowly with poor flowering (Fig. 1, data not shown for vegetative growth). Thus, species highly adaptable to low light intensity may have not only a low light compensation point but also a low lighting requirement to obtain continuous flowering.

Faust et al. (2005) reported that the photosynthetic daily light integral (DLI) enabling sufficient growth was lower in *Begonia* and *Impatiens*, and higher in *Catharanthus*, *Petunia*, *Tagetes* and *Zinnia* when tested in natural sunlight with shading materials, where light intensity was much higher than that employed in our indoor conditions. Our results coincided with their results with respect to *Impatiens* and *Petunia*. However, *Catharanthus*, *Tagetes* and *Zinnia* were highly adaptable to indoor conditions (Fig. 1). These results suggest that the effect of high light intensities on plant growth and flowering does not necessarily correlate with adaptability to low light intensity.

Low light intensity is one of the major factors reducing plant quality. For example, the flower diameter of potted carnations was significantly smaller at 9.8 and 51.6 µmol·m^{-2}·s^{-1} PPFD than at 274.2 µmol·m^{-2}·s^{-1} PPFD (Komagata et al. 2005). A reduction in flower size was also observed in the present study, although it varied among species (Fig. 1); for example, *Tagetes* and *Torenia* showed a relatively small reduction in flower size. A reduction in flower size is clearly an adaptive response to low light intensity, which enables a preferential distribution of photosynthates to photosynthetic organs (leaves) rather than flowers. Therefore, it was assumed that the small reduction in flower diameter possibly indicates a low light compensation point and/or small demand for photosynthates to produce a sufficient size of flower.

Meanwhile, shoot growth was greatly reduced by low light intensity (Table 2). It should be noted that low light intensity preferentially retards upright growth, which did not appear as a reduction in plant width but instead as greater height and length of the plant's longest lateral stem. Another characteristic effect of low light intensity on shoots was dark leaf color, which is a common adaptive response to low light intensity (Di Benedetto & Garcia, 1992).

Catharanthus, *Torenia* and *Zinnia* all showed high adaptability to low light intensity, but only *Torenia* showed continuous flowering under an extremely low light intensity (500 lx, 8.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD), which is necessary for a conference room. However, it was difficult to obtain flowers of sufficient ornamental quality. Based on these results, we concluded that no species tested can maintain sufficient ornamental quality under 8.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD.

In contrast, under 16.8 and 42.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, the duration of flowering lasted more than three weeks in these three species. Thus, said species are suitable under light conditions used for such detailed work as design and component assembly (JIS Z 9110, i.e., 16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD) or for displays in supermarkets and such shops as fashion outlets (i.e., 42.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD). In addition, PPFD at the window without direct sunlight is about 2,000 lx (33.6 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD) (Kajikawa 2011).

In *Torenia*, no extension of flowering duration was observed at 42.0 compared with 16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD. However, even after six weeks of indoor conditions under 16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, *Torenia* plants continued forming and growing new flower buds. Based on these results, flowering in *Torenia* may occur intermittently under low light intensities. Therefore, *Torenia* can be grown for a long period under light intensity greater than 16.8$\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, provided that intermittent flowering is tolerated.

In *Zinnia*, the flower number continuously increased under 42.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD, thus suggesting that this light intensity is comparable to outdoor conditions in terms of flowering.

In conclusion, several species of bedding plants such as *Catharanthus*, *Torenia* and *Zinnia* are available for indoor use. Our results showed that light brighter than that for a typical office (16.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$) was required for indoor use, whereas the brightness of a conference room (8.4 $\mu mol \cdot m^{-2} \cdot s^{-1}$) was insufficient. The effect of higher light intensity obtained near a window is yet to be elucidated, as we are awaiting more species for analyses.

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