Temperature and Day Length Affect Time to Flowering and Abnormal Capitulum Formation in Summer-to-Autumn Flowering Cultivars of *Chrysanthemum morifolium* Ramat.

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Factors involved in delayed flowering and the formation of abnormal capitula in four summer-to-autumn flowering cultivars of *Chrysanthemum morifolium* Ramat. were investigated. Anomalous involucre bracts, i.e. bracts formed among ray and disc florets within the capitulum, were more frequent in ‘Floral Yuka’ plants grown at day/night temperatures of 20/12.5°C than at 20/20°C under a 12 h day length or natural day length of 14–15 h. The number of involucre bracts in the capitulum of plants grown at either 35/25°C or 25/15°C increased compared with that of plants grown at 30/20°C under a 12 h day length. A natural long day length suppressed flower bud development and promoted the formation of many involucre bracts in the capitulum, compared with inflorescences of plants grown under a 12 h day length. Long day length of 14–15 h induced anomalous involucre bract formation in ‘Floral Yuka’ and ‘Iwa no Hakusen’. In contrast, high temperature promoted involucre bract formation in the capitulum, primarily in ‘Seiun’, and neither day length nor temperature affected involucre bract formation in ‘Natsubiyori’.

Key Words: abnormal capitulum, anomalous involucre bracts, chrysanthemum, flower bud development.

Introduction

Okada (1963) distinguished summer (June to July), August, and September flowering cultivars of Japanese *Chrysanthemum morifolium* from autumn- and winter-flowering types on the basis that flower bud initiation in the former groups was not affected by the photoperiod. Kawata and Toyoda (1982) subsequently clarified that most July, August, and September flowering cultivars are qualitative short-day plants. They can flower at high temperatures in summer and collectively have been termed ‘summer-to-autumn flowering cultivars’ (Kawata, 1987). Kawata et al. (1987) showed that their flowering time is controllable by long-day treatments in the greenhouse and that they can flower outdoors in long days in summer.

The major summer-to-autumn flowering cultivars of

standard chrysanthemums in Japan are ‘Seiun’, ‘Iwa no Hakusen’, and ‘Floral Yuka’, which are produced from June to September without short-day treatment in greenhouses; however, the flowering time and occurrence and the frequency of abnormal inflorescences, e.g. capitula in which anomalous involucre bracts are formed among ray and disc florets (Fig. 1), vary from year to year, probably reflecting the effects of temperature and

Fig. 1. Normal and abnormal capitulum produced in a summer-to-autumn flowering *Chrysanthemum morifolium* ‘Floral Yuka’. Left, normal flower (normal ray florets are formed in the capitulum); Right, abnormal capitulum with anomalous involucre bracts formed in the center of the capitulum.

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day-length conditions in summer and early autumn.

Ito et al. (1996) reported that the main factor promoting abnormal capitulum development in ‘Seiun’ was high day temperature rather than high night temperature. Tanigawa et al. (2009) subsequently proved that abnormal capitula increased in frequency either at a high day or night temperature, and that the period from late involucre formation or early floret formation to early petal formation was most affected by high temperatures in ‘Seiun’. Similarly, Sasaki et al. (2000) suggested that the flower bud developmental stage from late involucre formation to early petal formation was most affected by high day temperatures in ‘Tenju’ with regard to the frequency of abnormal capitula.

However, when cut flowers of ‘Floral Yuka’ are produced both from mid-May to June and from late-August to September, flowering is delayed and many of the plants form abnormal capitula. Chrysanthemum growers report that ‘Floral Yuka’ plants form abnormal capitula more frequently under natural temperature and daylight conditions than in a heated greenhouse and under short-day conditions using blackouts from mid-May to June. These observations indicate that environmental factors other than high temperature may be involved in the delay of flowering and inducing the formation of abnormal capitula.

Few studies have investigated the relationship between low temperature or day length and the formation of anomalous involucre bracts in the capitulum. Determining which factors affect involucre bract formation will enable the improvement of cut-flower quality and will help to achieve year-round cut-flower production of chrysanthemums. Therefore, in this study we investigated the effects of temperature and day length on time to flowering and the formation of abnormal capitula in summer-to-autumn flowering chrysanthemum cultivars.

Materials and Methods

Plant materials and culture conditions

Mother plants of four standard summer-to-autumn flowering cultivars of *C. morifolium*, namely ‘Floral Yuka’ (for Experiments 1–3) and ‘Iwa no Hakusen’, ‘Natsubiyori’, and ‘Seiun’ (for Experiment 3 only), were planted in a greenhouse on October 20, 2007, and grown in long days, achieved by night-break treatment with incandescent lamps from 22:00 to 2:00 to maintain vegetative growth. The plants were trimmed at a height of 20 cm. Top cuttings (5–7 cm stem length with three leaves) from newly developed lateral vegetative shoots were taken from the mother plants on February 22, 2008 in Experiment 1, on February 27, 2008 in Experiment 2, and on May 20, 2008 in Experiment 3. They were rooted in volcanic soils (Bora-soil) with mist-spraying in a greenhouse. After 14 days, 10 rooted cuttings were planted in a plant box (60 cm long × 18 cm wide × 15 cm deep) filled with a medium comprised of a 5 : 2 : 2 : 1 ratio of paddy soil, Metro-mix 350 (Sun Gro Horticulture

Distribution, Inc., Bellevue, USA), leaf mold (Hayashi Engei Shizai Co., Okayama, Japan), and volcanic soil, respectively. Each plant box contained 30 g slow-release fertilizer (N : P₂O₅ : K₂O = 13 : 16 : 10, Long Total Kaki No. 1, 100-day-type, Chisso Asahi Fertilizer Co., Tokyo, Japan). The plant boxes were placed in a greenhouse and watered every morning until the start of each experiment with night-break treatment. There were three replicates in each treatment. Days to flowering after the end of night-break treatment, increase in leaf number (ILN) in short days, and the number of involucre bracts among ray or disc florets in the capitulum were recorded.

Experiment 1. Effects of temperature and short days after the end of long days

The rooted cuttings were placed in phytotron rooms on April 17 and grown at either 20°C (6:00–18:00)/20°C (18:00–6:00) or 20°C/12.5°C under a natural or 12 h day length (short day obtained using blackout). Natural day length of approximately 14 h at the start of the treatment increased linearly by 1 h until late-May with a gradual increase to the peak day length in late-June (Fig. 2).

Experiment 2. Effects of day/night temperature after the end of long days

The cuttings were grown at 25/15°C, 30/20°C or 35/25°C under a 12 h day length in the phytotron rooms from April 21.

Experiment 3. Effects of short days after the end of long days at natural high temperatures

From July 4, the cuttings of four cultivars were grown under either: (1) a constant 12 h day length, (2) a 12 h day length for the first three days and then with day length increasing by 15 min/3 days to a maximum 14 h day length (12–14 h), or (3) a 14 h day length for the first three days followed by day length decreasing by

Fig. 2. Maximum natural day length during the term from Experiment 1, 2, and 3 in Fukuoka region and the day-length treatments in Exp. 3 where the summer-to-autumn flowering chrysanthemums were grown.

15 min/3 days to a minimum 12 h day length (14–12 h). The control cuttings were grown under a natural day length, and all treatment conditions were maintained until flowering. Maximum and minimum temperatures in the greenhouse at the start of short days and from mid-July to mid-August are shown in Figure 3.

Fig. 3. Maximum and minimum air temperatures at 5-day intervals during the Experiment 3 in the greenhouse in which the summer-to-autumn flowering chrysanthemums were grown at natural temperature and daylight conditions.

Results

Experiment 1. Effects of temperature and short days after the end of long days

The earliest flowering was observed in plants grown at 20/20°C under a 12 h day length (Table 1). At the same temperature, 12 h day length led to earlier flowering than natural day length, and 20/20°C induced earlier flowering than 20/12.5°C under the same day length. The increase in leaf number (ILN) was lowest in plants grown at 20/20°C with 12 h day length, and was highest at 20/12.5°C with natural day length. Plants grown at 20/20°C with 12 h day length did not form abnormal capitula and formed fewer involucre bracts in the capitulum than those grown in other conditions. Low temperature (20/12.5°C) or long day length (natural day length) accelerated involucre bract development.

Experiment 2. Effects of day/night temperature after the end of long days

Days to flowering were longer and ILN was higher in plants grown at 35/25°C than in those grown at 30/20°C or 25/15°C (Table 2). Number of involucre bracts in the capitulum was greater in plants grown at 25/15°C or 35/25°C than at 30/20°C.

Table 1. Effects of short-day and temperature treatments applied after the end of long-day treatment (April 17) on flowering and capitulum characteristics in the summer-to-autumn flowering *Chrysanthemum morifolium* 'Floral Yuka'.

Short-day treatment ^z	Temperature treatment (6:00–18:00/18:00–6:00)	Flowering date (Day/Month)	Days to flowering in short days	Increase in leaf number in short days	Number of involucre bracts in the capitulum
12 h	20/12.5°C	12/Jun	56.3 b ^y	27.3 b	38.5 c
	20/20°C	28/May	40.7 d	25.2 c	10.0 d
Natural	20/12.5°C	15/Jun	59.2 a	29.3 a	93.4 a
	20/20°C	4/Jun	49.7 c	27.8 b	42.7 b
Analysis of variance ^x	Day length (a)		**	**	**
	Temp. treatment (b)		**	**	**
	a × b		**	NS	**

^z 12 h, plants were grown in daylight-type phytotron room with short-day treatment (12 h day/12 h night, controlled by blackouts); Natural, plants were grown in phytotron room under natural daylight conditions.

^y Mean separation within the column by Tukey's HSD test, 5% level of significance.

^x NS and ** indicate non-significance and significance of differences at $P < 0.01$, respectively.

Table 2. Effects of temperature treatments applied after the end of long-day treatment (April 21) on flowering and capitulum characteristics in the summer-to-autumn flowering *Chrysanthemum morifolium* 'Floral Yuka'.

Temperature treatment ^z (6:00–18:00/18:00–6:00)	Days to flowering in short days	Increase in leaf number in short days	Number of involucre bracts in the capitulum
25/15°C	47.4 c ^y	27.6 c	18.1 b
30/20°C	53.8 b	29.2 b	4.9 c
35/25°C	69.2 a	34.4 a	93.8 a
Analysis of variance ^x	**	**	**

^z Plants were grown in daylight-type phytotron room under 12 h short days (daylight from 6:00 to 18:00, controlled by blackout).

^y Mean separation within the column by Tukey's HSD test, 5% level of significance.

^x ** indicates a significant difference at $P < 0.01$.

Table 3. Effects of day-length treatment after the end of long-day treatment (July 4) on flowering and capitulum characteristics in the four summer-to-autumn flowering *Chrysanthemum morifolium* cultivars.

Cultivar	Day-length treatment ^z	Flowering date (Day/Month)	Days to flowering in short days	Increase in leaf number in short days	Number of involucre bracts in the capitulum
Floral Yuka	12 h	24/Aug	51.3 c ^y	26.4 c	3.5 c
	12–14 h	25/Aug	52.3 c	25.2 c	8.2 c
	14–12 h	5/Sep	63.0 b	28.7 b	25.1 b
	Natural	14/Sep	72.3 a	32.4 a	46.5 a
Iwa no Hakusen	12 h	27/Aug	53.7 c	27.5 a	0.1 b
	12–14 h	26/Aug	53.0 c	27.5 a	0.1 b
	14–12 h	31/Aug	58.0 b	28.3 a	0.4 b
	Natural	9/Sep	67.0 a	28.3 a	16.6 a
Natsubiyori	12 h	1/Sep	59.3 c	25.6 c	0.3 a
	12–14 h	1/Sep	59.0 c	27.0 b	0.3 a
	14–12 h	9/Sep	67.0 b	26.5 b	0.3 a
	Natural	21/Sep	78.7 a	30.6 a	0.0 a
Seiun	12 h	21/Aug	47.7 c	26.6 b	54.5 b
	12–14 h	21/Aug	48.0 c	27.3 ab	44.7 b
	14–12 h	29/Aug	56.0 b	27.0 ab	67.5 b
	Natural	6/Sep	64.3 a	27.7 a	170.4 a
Analysis of variance ^x	Cultivar (a)		**	**	**
	Day length treatment (b)		**	**	**
	a × b		**	**	**

^z 12 h, plants were grown under 12 h short days (SD), controlled by blackouts; 12–14 h, plants were grown under 12 h SD for the first three days and then the day length was extended by 15 min every three days to a maximum day length of 14 h, which was maintained until flowering; 14–12 h, plants were grown under 14 h SD for the first three days and then the day length was shortened by 15 min every three days to a minimum day length of 12 h, which was maintained until flowering; Natural, plants were grown under natural day length in the same greenhouse.

^y Mean separation within the column by Tukey's HSD test, 5% level of significance in each cultivar.

^x ** indicates a significant difference at $P < 0.01$.

Experiment 3. Effects of short days after the end of long days at natural high temperatures

All cultivars flowered earlier under a 12 or 12–14 h day length than 14–12 h and natural day lengths (Table 3). The 14–12 h day length was more effective than natural day length for promoting early flowering.

The ILN was lower under a 12 or 12–14 h day length than 14–12 h and natural day lengths in 'Floral Yuka', did not differ significantly among all treatments in 'Iwa no Hakusen', was lowest under a 12 h day length and highest with natural day length in 'Natsubiyori', and was lower under a 12 h day length than natural day length in 'Seiun'.

Involucre bract formation was suppressed by a 12 h or 12–14 h day length in 'Floral Yuka' when compared with that under a 14–12 h day length. It was not affected by any treatment in 'Iwa no Hakusen' and 'Natsubiyori', and was particularly low in 'Natsubiyori'. 'Seiun' formed the highest number of involucre bracts under a natural day length with no significant differences among the 12 h, 12–14 h, and 14–12 h day lengths.

Discussion

High daily temperatures and night-break treatments result in delayed flowering and poor-quality flowers in *Chrysanthemum* cultivars grown for summer and early

autumn cut-flower production (Kawata, 1978). High night temperatures (>22°C) delay flowering and induce abnormal inflorescence development by suppressing flower bud initiation and/or development (Cathey, 1954; Cockshull, 1979; Cockshull and Kofraneck, 1994; Whealy et al., 1987). However, the flowering of mid-May to June crops of standard summer-to-autumn flowering cultivars, such as 'Floral Yuka', is often delayed markedly and many anomalous involucre bracts develop in the capitulum. Thus, we hypothesized that the formation of abnormal capitula occurs after exposure to low temperatures, or when the day length exceeds 14 h, rather than exposure to high temperatures.

Flowering of 'Floral Yuka' under a natural day length exceeding 14 h was, as expected, delayed, with many abnormal capitula formed regardless of the temperature, and many anomalous involucre bracts developed under a 12 h day length at low or high temperature. These results indicate that long day length or low temperature induce anomalous involucre bract formation similar to the effect of high day or night temperature. De Jong (1978) reported that the delay of flowering at high temperature correlated with a similar delay at low temperature in many cultivars. Our results also show that a natural long day length suppresses flower bud development and retards flowering. Therefore, for cut-

flower production of 'Floral Yuka' from mid-May to June, plants must be grown at a night temperature of about 20°C and under 12 h short-day conditions. This novel finding is of considerable horticultural importance.

In Experiment 3, the 12 h day length reduced the number of days to flowering and the production of abnormal capitula in 'Floral Yuka' and 'Iwa no Hakusen'. The number of anomalous involucre bracts formed in 'Seiun' with a 12 h day length was reduced by one-third of that in natural day length. In contrast, in 'Natsubiyori' very few anomalous involucre bracts developed with a long day length or high temperature.

After floral initiation, chrysanthemum inflorescences develop acropetally, i.e. ray florets are produced distal to the involucre, which is composed of bracts surrounding the whole inflorescence (Harris et al., 1991; Popham and Chan, 1952). Because the ILN in 'Floral Yuka', 'Natsubiyori', and 'Seiun' was notably higher in natural long days, it is considered that the transition from vegetative growth to reproductive growth could not have occurred smoothly. This might have contributed to the increased involucre bract number in 'Floral Yuka' and 'Seiun'.

Consequently, the summer-to-autumn flowering cultivars used in these experiments can be classified into three types based on the main factor inducing abnormal capitulum development. First, a long day length is the main factor inducing the formation of anomalous involucre bracts within the capitulum in 'Floral Yuka' and 'Iwa no Hakusen'. Second, high temperature is the main factor in 'Seiun'. Third, abnormal capitula are not induced by either long days or high temperature in 'Natsubiyori'. Further investigation is necessary to clarify the main factors causing anomalous involucre bract development in other summer-to-autumn flowering cultivars.

The 12–14 h day length treatment decreased anomalous involucre bract number to a greater extent than natural day length in 'Floral Yuka', 'Iwa no Hakusen', and 'Seiun'; however, the difference in the effects of the 12–14 h and 12 h day length treatment was not significant in all the cultivars studied, indicating that increasing day length may not affect abnormal capitula formation.

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