EFFECT OF PHOTOPERIOD, TEMPERATURE AND CARBON DIOXIDE ON FLOWERING

OF CHRYSANTHEMUM (Chrysanthemum morifolium Ramat.)

by

OMAR MANSOUR EL-SHEIBANY

B.S., Cairo University, 1969

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1977

Approved by:

Steven M Steil
Major Professor

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INTRODUCTION

The florist's chrysanthemum (Chrysanthemum morifolium Ramat.) is a short-day plant that initiates flower primordia when the dark period is uninterrupted for 12 hours (5-6 weeks in length). American commercial cultivars do not naturally initiate their flower buds in the southern states until mid-August, and a few days later in the northern states, and will not naturally develop buds until early September. This broad classification does not include the garden cultivars, which are not sensitive to photoperiod, but require cold treatment of three to four weeks at a temperature of approximately $1°$ C (vernalization) before flowering occurs.

Traditional greenhouse practices have evolved because of the above lighting requirements. With simple and inexpensive techniques of lighting the plants for a short period each night during natural short days and of lengthening the dark period by covering them with black cloth during natural long days, and controlling the temperature (15-16°C night temperature), the plants may be kept vegetative on one hand and may be caused to initiate and develop their flower buds on the other.

A study of the effects of photoperiod, temperature and carbon dioxide will serve to explain the reasons behind the greenhouse techniques presently used.

The objectives of this study are to:

1. To review important studies investigating photoperiodism in general and chrysanthemums in particular.

2. To show practical application of different conditions of temperature, lighting, shading and carbon dioxide.

EFFECT OF LIGHTING ON FLOWERING RESPONSE

A. Photoperiodism

The concept that flowering might be controlled by a hormonal stimulus was first proposed by Sachs (63), and supported more recently by findings of Tokimato (69).

Mobility of the stimulus became clear after discovery of the effects of day length on flowering of certain varieties of tobacco (Nicotiana tabacum) and soybean (Glycine max) (28).

Previous study (24,27,53,70) established three photoperiod response types:

1. Short-day plants (SDP) require a certain minimum number of hours of uninterrupted darkness in order to initiate flowers which differs with different species. Chrysanthemum sp. have a critical uninterrupted dark period of 12 hours while tobacco (Maryland Mammoth), has a critical dark period of 10 hours (Fig. 1).

2. Long-day plants (LDP) require a certain minimum number of hours of light in order to initiate flowers which also differs with different species. Henbane (Hyoscyamus niger) has a critical day length of more than 10 hours of light, while bentgrass (Agrostis palustris), has a critical day length of more than 16 hours of light (Fig. 1). Lang and Melchers (39) demonstrated the importance of the dark period in the flowering of long-day plants with henbane. Long dark periods had an inhibitory rather than a stimulatory role because henbane is a long day plant.

3. Day-neutral plants flower after a certain period of vegetative growth because their flower initiation is determined exclusively by genotype regardless of photoperiod. Tomato

	Short day Plants	Long day Plants
A	Vegetative	Flowering
B	Vegetative	Flowering
C	Flowering	Vegetativ
D	Vegetative	Flowering
E	Vegetative	Flowering

0   6   12   18   24 hours

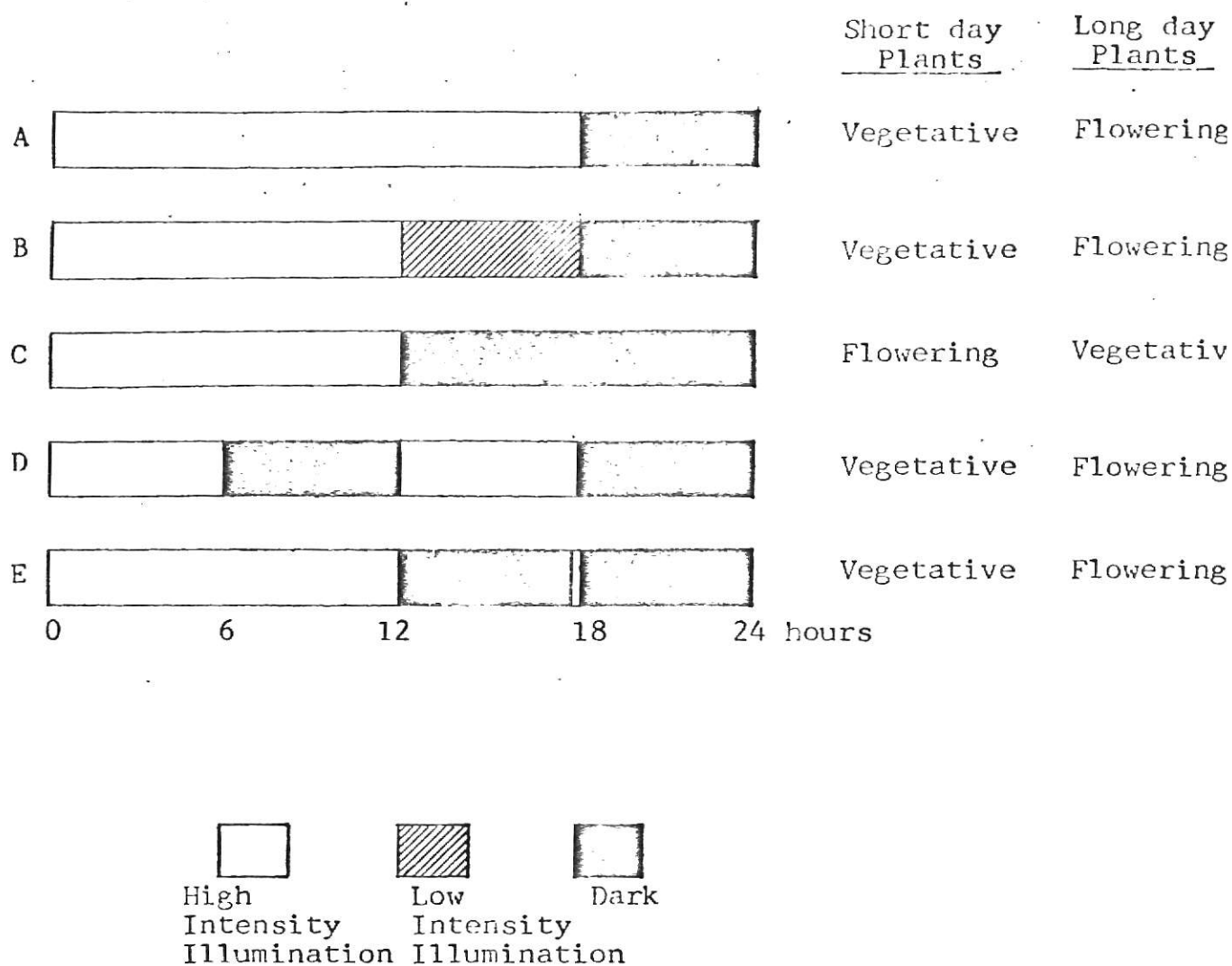High Intensity Illumination   Low Intensity Illumination   Dark

Figure 1.   Summary of responses of short-day plants and long-day plant to various photoperiodic regimes.

(Lycopersicon esculentum) and cucumber (Cucumis sativus) are examples of these types. There are a small number of species that require exposure first to long days then to short days for flower initiation to occur and hence are called "long-short-day" plants (LSDP); examples of this type of response are Kalanchoe (Kalanchoe laxiflora) and night jessamine (Cestrum nocturnum). Other species, such as white clover (Trifolium repens) and canterburybells (Campanula medium), require exposure first to short days and then to long days, and hence are called "short-long-day" plants (SLDP).

Borthwick and Parker (4) illustrated that exposure to a single prolonged dark period was insufficient for soybean flower induction and for a long night to be effective the plants had to be previously subjected to a period of light. They found that the required light duration depended on the number of short day cycles and on the light intensity (5).

It has also been shown by Schawbe (65) that inflorescence buds of chrysanthemum produced under long days will complete development if they are transferred to short-day, while inflorescence buds produced under short-day conditions were inhibited from completing their development by transferring them to long-day.

B. Site and Nature of the Photoperiodic Stimulus

The site of preception of the photoperiodic stimulus has conclusively been found to be the leaf (29,37). It was demonstrated in both long and short-day plants that if only the leaves were exposed to the proper inductive day length conditions, while the remainder of the plant remained in a noninductive photoperiod,

flowers would be initiated. The most striking case of this phenomenon was demonstrated in perilla (<u>Perilla</u> <u>frutescens</u>). Noninduced perilla plants flowered when leaves were excised from induced perilla plants and then grafted to the noninduced plants. When this procedure was performed with noninduced leaves on non-induced plants (3,43,71) flowering did not occur.

Hamner and Bonner (29) illustrated that (<u>Xanthium pennsyl-</u><u>vanicum</u>) remained vegetative if young leaves were continually removed as they began to expand. Nayler, (49) in studying the critical day length of individual leaves of cocklebur, reported that young, fully expanded leaves had a critical day length of 9 hours, whereas in older leaves it was increased from 10.5 to 15 hours. Later it became apparent that the half expanded leaf was most sensitive to photoperiod (64). Thus, the photoperiodic sensitivity of leaves varies considerably with their age.

C. Floral Hormone

Though the leaves perceive the photoperiodic stimulus, it is the shoot apex which ultimately responds to the inductive day length by differentiating flower primordia. This phenomenon led Chailahjan (20), to propose the existence of a floral hor-mone which he called florigen. He used the chrysanthemum as experimental material. A number of similar plants with a ter-minal bushy habit were taken and all the leaves were removed from the upper half of the plants. These plants were then divided into four sets (Fig. 2). The first set was left to grow in long summer days with the result that no flowers were formed at the top of the plant. In the second set, the lower halves with the intact leaves were covered each afternoon with a light-tight box,
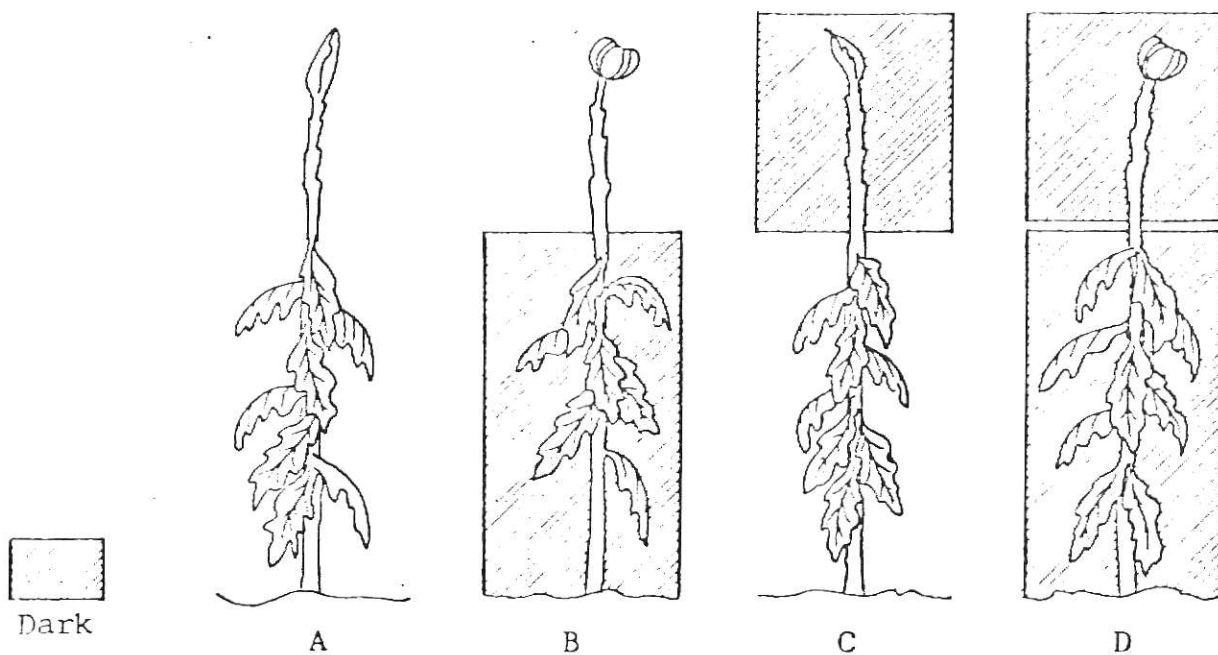
Figure 2. Flowering occurs in chrysanthemum when the leaves are exposed to short days (B and D), irrespective of whether the shoot apex is exposed to long days (B) or short days (D).

so that this part of the plant received short days and the upper
leafless part received long days. All these plants produced
flowers at the top of the leafless branches. In the third set,
the tops were provided with boxes and given short days, and the
leafy lower parts received normal long days, but no flowering
resulted. The fourth set, in which the whole plants had short
days, flowered as did the second set. Obviously, the stimulus
of short days was received only by the leafy basal part of the
plant and this stimulus was transmitted, presumably by means of
a hormone, to the upper defoliated part where flowers were in-
duced to form. The upper part, having no leaves, could not re-
ceive the stimulus.

Initial support for this concept was gained through grafting
experiments (21,38). Additional evidence for a floral hormone
came from experiments when donors of one daylength response type
induced flowering in receptors of a different daylength response
type (22). Chailahjan (22) induced flowering in a short-day
plant. Jerusalem artichoke (Helianthus tuberosus) grown under long
day conditions flowered when grafting to a day neutral donor plant,
sunflower (Helianthus annuus).

Moshkov (46) induced flowering in the short-day tobacco
(Maryland Mammoth) grown under long days by grafting it to the
long-day plant (Nicotiana sylvestris). These experiments not
only provided strong evidence for the existence of a floral hor-
mone, but also suggested that the hormone was common to both long
and short-day plants.

Chailahjan's first experiment (20) did not rule out the
possibility that the influence transmitted from leaves to apical

meristem might be the spread of some vital change in the living protoplasm in the intervening tissues. The stimulus will not pass through a portion of stem on which there are mature leaves subjected to a daylength unsuitable for flowering. This suggests that such leaves actually produce a substance which may destroy the hormone or prevent its movement. The stimulus will pass through a graft union and this has been shown in the tobacco varieties previously mentioned (46). Although this hormone has eluded all attempts to extract it, some progress has been made in this direction and Lincoln, et al. (42) have suggested that the substance be called Florigenic Acid.

More recently Hodson and Hamner (30) were able to extract a flower inducing substance from cocklebur when grown under inductive conditions. With the addition of gibberellic acid to the extract they were able to induce flowering in noninduced cocklebur. Neither gibberellic acid nor the extract alone was capable of inducing flowering in noninduced plants.

D. Phytochrome Action

Parker, et al. (51) constructed a spectrograph to study inhibition of flowering by interrupting the dark period. They found that the wave length-dependence of the light break effect in soybean was very similar to that of cocklebur. It was found that the action spectra for light breaks promoting flowering of long-day plants, such as barley (Hordeum vulgare) and henbane were similar to the action spectra in short-day plants such as chrysanthemum, although the effect was in the opposite direction. Brothwick, et al (6), and Parker, et al, (52) implied that one pigment mediated the photoperiodic process of both long and short

day plants. The pigment was later found to exist in two forms:
red light with an absorption peak in the red region, 660 nm,
(Pr) and far-red, probably a biological active form with a
peak absorption in the far-red region, 735 nm, (Pfr) (7). The
pigment was isolated in 1959 and given the name phytochrome (10).

Borthwick, et al. (8) found that the inhibitory effect of
light break in cocklebur was reversible by subsequent exposure
to far-red light. The dark period needed for flowering was short-
ened when the cocklebur plants were given brief exposure to far-
red light at the end of the main light period, while exposure to
red light increased it. These results were interpreted to mean
that the pigment was predominately in the active form (wave
length 735 nm, (Pfr) at the end of the light period and this re-
verted to the Pr form and thereby shortened the length of the
dark period required for flowering in cocklebur.

E.   The Role of Phytochrome

Illumination of chrysanthemum for up to five hours near the
middle of each night during natural short days induces vegetative
growth. Cathey and Borthwick (18) found that the cycles of the
dark and light given during a 4-hour period in the middle of the
night delayed flowering as well as continuous light throughout
the 4 hours. At 20 ft. c., light-dark cycles of 30 minutes or less
were effective as long as the radiant energy was given for 5% of
the cycle (3 seconds every minute and 90 seconds every 30 minutes
for 4 hours) in the middle of the dark period (Table 1). The
short periods of irradiation adequate to prevent flowering of
some other plants, e.g. cocklebur and soybean, are completely

Table 1. Hours of interrupted lighting needed each
          night to maintain chrysanthemum in a vegetative
          state.
          (Latitude 35-40°).*

June 15-July 15	0
July 15-July 30	2
August 1-August 31	3
September 1-March 31	4
April 1-May 15	3
May 15-June 15	2

*(Cited in the Ball Red Book, 13th Edition, 1975).

inadequate for chrysanthemum.

Cathey and Borthwick (19) have shown that the above results, gained when incandescent-filament lamps were used, were due to the degree of conversion of phytochrome in the plants.

Phytochrome, a blue, photoreversible pigment, is thought to be present in all plants. Phytochrome is an active agent in controlling photomorphogenesis in plants. Visible radiant energy triggers the action of phytochrome in processes such as seed germination, stem elongation, leaf expansion, flowering, fruiting, and coloration.

Results presented by Cathey and Borthwick (19) on effects of fluorescent light show evidence that flowering of chrysanthemum can be fully inhibited by just one minute of fluorescent light (600 ft-c.) each night. This level is many times greater than that demanded to inhibit flowering in cocklebur or soybean. The fact that an individual minute of illumination is inhibitory, even though a high intensity is needed, shows that the phytochrome is converted from the red-absorbing 660 nm, (Pr) form to the far-red-absorbing 735nm, (Pfr) form. This minute is enough to inhibit completely the flowering reaction before the far-red (Pfr) reverts to the inactive form. The flower inhibiting reaction caused by Pfr is not particularly different in chrysanthemum. These results seem to dispute an earlier statement (9) that flowering of chrysanthemum is not inhibited by a single conversion of phytochrome. The contradiction comes from the fact that past outcomes were from experiments with incandescent-filament lamps (equal-red and far-red) and the present ones were with fluorescent lamps (red). Change of phytochrome in a chrysanthemum leaf by one minute lighting from an incandescent-filament light or the sun, regardless of the intensity, is never sufficient to inhibit flowering, but

one minute lighting from a fluorescent light is effective,
provided the intensity is high.

The differences between the actions of fluorescent and
incandescent-filament illuminations on chrysanthemums were
interpreted on the basis of differences between the two kinds
of illumination in the red and far-red parts of the spectrum,
coupled with conditions of leaf structure that might peculiarly
affect screening by chlorophyll of radiation absorbed by phyto-
chrome in the chrysanthemum plant.

F. Effect of Light Duration and Intensity on Flowering

Controlling the photoperiod has been found to affect the
flowering of chrysanthemum in different ways. Doorenbos and
Kofranek (23) illustrated that differences between early and
late cultivars are mainly due to the period required for flower
development rather than that required for flower initiation.
For example bud initiation in the early cultivar 'Gold Coast'
and the late cultivar 'Vibrant' takes 24 short-days. However,
the flower opens after 28 days with 'Gold Coast' and after 42
short days with 'Vibrant'. Both plants were grown under the
same conditions.

Bud initiation can be induced by very short photoperiods.
Post and Kamemoto (60) showed that one or two short days appar-
ently caused no change from vegetative growth, but the onset
of flowering was evident after three, four or five short days
depending on cultivars used. This only occurred when the short
days were given in succession since Post (59) failed to induce
initiation with six short days when no more than three of them
were in succession, whereas four consecutive short days caused
flower buds to be initiated.

Okada (50) also recorded varietal differences in this re-
spect, but gave his results as heights on which the plants
must grow before they become photoperiodically reactive. Using
early, mid-season and late cultivars he found that this amount
of growth varied between 18 and 20 cm, but the variation was
not connected with the normal season of maturity of the cultivars.

Kamemoto and Nakasone (35) suggested that the flowering
behavior of chrysanthemum in Hawaii can be explained by the
prevailing day-length conditions. The longest day, June 21st,
is 14 hours and 15 minutes, consequently, bud initiation takes
place throughout the year. During the summer, however, the
initiated buds fail to develop because the critical day-length
for flower bud development, which is around $13\frac{1}{2}$ hours, is not
reached until around August 21st.

In 1972, Sharova and Dovryaninova (67) showed that
short days induced flowering of chrysanthemum, but this affect
decreased with diminishing plant age. Longer periods of short-
days were necessary for initiation in younger than in older
plants although the treatment retarded vegetative growth.
Cathey (15) showed that shifting from high to lower temperatures
under a proper day length had a favorable effect on the flower-
ing of chrysanthemum.

In recent studies, the effects of supplementary light treat-
ment on the flowering of chrysanthemum were investigated by
several researchers (11,36,66). The results of these investi-
gations suggest that:

"1. Blooming of chrysanthemum could be expanded by con-
     trolling photoperiod and temperature.

2. Plants which received extra light immediately after
    planting were the earliest, had the tallest internodes

and flower stalks, produced the most flowers and had the longest flowering season.

3. The effect of supplementary light depends to a great extent upon the time of application."

Ranger (61) showed that the effect of night interruption with different light periods depends not only upon these light periods, but also upon the day light periods to which the plants were exposed.

Jaacov Ben-Jaacov (34), showed that if the short-day treatment was followed by long days, the development of the terminal flower bud was not affected, while lateral flower bud development was stopped. The reversal of the effects of the far-red light on bud development of chrysanthemum was reported by Reisch (62) who found development was partially negated.

Studies on the effects of photoperiodism on the flowering behavior of chrysanthemum revealed that these effects could be altered by other factors such as light intensity. Cathey and Borthwick (19), Hughes and Cockshull (31,32,33) and Love (44) have found that light intensity effects flowering response. Their conclusions are:

" 1. The flowering tendency was strongest under high light intensities of short days, although the light intensities did not influence the time required for flower initiation.

2. More advanced stages of floral ontogeny were found when the light intensity of the supplementary illumination was decreased from 10 to 2 ft. c., suggesting that a portion of flower initiation process can proceed under extremely low light intensity.

3. During day-time, supplementary fluorescent light was found to be ineffective and the unlighted treatments were comparable in quality to that of lighted ones.

4. There was no significant difference between plants grown under constant daily light intensity and

plants grown under gradually increasing illumination when the daily light total was the same in both ones.

5. High light intensity increased the dry weight of chrysanthemum only when applied to the plants during their later stages of growth. "

G. Importance of Different Photoperiodic Responses for Commercial Chrysanthemum Production

In 1928 and 1936 it was reported (1,40,54) that flowering of chrysanthemum varied according to daily exposure to light. For example, increasing the dark period on chrysanthemum, decreased the time required for flowering. These results were adapted to commercial use by using black cloth to enclose the plants. Post (55) found that black sateen cloth was more effective in providing the dark period, as compared to plain cloth.

Poesch (54) found that supplementary illumination during the dark period retard flower bud differentiation and delay flowering. His results indicated that a 15-hour light period was effective in retarding bud formation.

Post (58) proposed that 14-14.5 hour light was sufficient for bud initiation in chrysanthemum. On the other hand, Love (44), found that the optimum photoperiod for the greenhouse chryanthemum cultivars (8-week, 'White Pink Chief'; 9-week, 'Blue Chip'; 11-week; 'Venoga'; and 13-week, 'Acclaim') was 12 hours using incandescent at 2 or 10 ft. c.

Changing the blooming pattern in chrysanthemum by the interruption of the dark period has been studied (25,68). Results suggested that such treatment was effective in delaying the blooming of chrysanthemum without reductions in quality or quantity of flowers. This is of practical importance, since growers will be able to obtain flowers from their best cultivars over a longer period of time.

Effect of Temperature on Flowering Response

One cannot separate the effects of temperature from those of daylength in regulating the flowering of chrysanthemums. Temperature is the dominating factor in the summer-flowering cultivars while daylength dominates the responses of the autumn-flowering cultivars. From data presented by Mulford (48), it would appear that in some cultivars of chrysanthemum, there are factors other than photoperiod which are important in the control of time of bloom. For example, the fluctuation of temperature from year to year might affect the rates of development of the flower buds which had been already differentiated under specific photoperiodic conditions (which are almost constant from year to year). The night temperature was more critical than the day temperatures (26).

Post (56,57) and Furuta and Nelson (26) studied the effect of temperature on flowering of chrysanthemum. They found that low night temperature ($10°C$) prevented bud formation, delayed flowering and decreased the number of buds per stem. High night temperature above $26.7°C$ caused crown bud formation on pompon chrysanthemums compared with chrysanthemums grown under similar conditions at $15.6°C$ night temperature. Cathey (16) found that temperature had no effect on the critical photoperiod for flower bud initiation and development; plants at low night temperature ($10.5°C$) required shorter photoperiods than at $16°$ and $25.5°C$. Cathey (15) also found that flowering could either be accelerated or delayed by reduction in temperature, depending on cultivar and the amount and time of the reduction. Cathey (17) worked with 6,8,10,12 and 15 week cultivars, (i.e.

time from the start of short days to anthesis), which were
subjected to 7 photoperiod treatments ranging from 9 to 16
hours and to 3 minimum night temperatures (10, 15.6 and 26.7°C).
He found the temperature altered the critical photoperiod nec-
essary for flower initiation and development in all cultivars.
The longer the normal period needed to bring a given cultivar
to flower under autumn conditions the shorter was the photo-
period needed for flower bud formation and development. The
photoperiod required for inflorescence initiation was shortened
by lowering the temperature, whereas that required for flower
development was shortened by raising the temperature. At the
lowest temperature (10°C) there was no difference in the crit-
ical photoperiod for initiation and development of the flower;
when the flower buds were initiated they developed slowly.

Cathey (12,13,14) divided chrysanthemums into three groups
according to their response to temperature; namely:

1.   Thermozero cultivar Shasta:

'Shasta' (10 weeks to flower) has a wide temperature tol-
erance. It flowers in minimum time at 15.6°C. Flowering was
delayed about the same at 10 or 26.7°C, but the 26.7°C night
temperature compared with 10°C doubled the number of flowers
per spray. Low temperature (10°) during vegetative growth had
little effect on the flowering time. Continued low temperature
during bud initiation followed by 15.6° for bud development de-
layed flowering to almost the same extent as if the low temper-
ature had continued until flowering. Any shift from 15.6° to
10° delayed flowering and reduced the number of flowers.

2. Thermopositive cultivar Encore:

'Encore' (10 weeks to flower) flowered if the temperature was maintained at a minimum of 15.6° C. The minimum flowering time was at 15.6° C. Continuous low temperature (10°) prevented the buds from developing into open flowers. Continuous high temperature (26.7°) delayed flowering by 7 days compared with plants grown at 15.6° but had little effect on the number of flowers produced on each spray.

Plants shifted from 10° to 15.6° C were delayed or completely inhibited in flowering; this delay occurred due to the low temperature on the stock plants. The earlier the plants were shifted from 15.6° to 10°C, the greater the delay. Low temperature (10°C) in all cases increased the number of flowers due to the formation of crown sprays with elongated laterals. Buds initiated at 10°C were crown buds but no florets were initiated on the capitulums. Temperature had its primary effect on the initiation of flowers. Once flowers were initiated, development occurred over a wide range in temperature.

3. Thermonegative cultivar Defiance:

'Defiance' (13 weeks to flower) did not flower if the temperature was above 15.6°C. The minimum flowering time was at 15.6°C. Continuous low temperature (10°) delayed flowering and reduced the number of flowers per spray by half. Shifting from 15.6° to 10° or 10° to 15.6° at the various developmental stages had little effect on flowering time. At temperatures of 15.6° or below, florets were initiated but developed slowly. At a temperature above 15.6°, florets were initiated but they did not develop. Temperature had its primary effect on the development of the flower.

Carbon Dioxide

The application of additional carbon dioxide to the green-house atmosphere has a beneficial effect on chrysanthemum growth. Applications during October and March increase photosynthesis which leads to improved flower quality. During these months, when ventilators in heated houses are normally closed until mid or late morning, there is insufficient air exchange to insure adequate CO_2 for optimum growth, especially for a fast-growing crop.

When light conditions for growth are poor, it has been shown that low concentration of CO_2 is sufficient. As light conditions improve the plants respond to higher concentrations of CO_2 up to 1500 ppm.

The highest quality chrysanthemum pot plants have been grown in good light conditions of spring and summer using 900 to 1500 ppm CO_2 with day temperatures controlled at 18.5 C and night temperature at 14.5°C. If the day temperature is held at 18.5° in bright weather in summer without the use of ventilators, there is evidence that artificial enrichment of the CO_2 level in the greenhouse to 1500 ppm would be economically beneficial. Anon (2) showed in trials on 8 chrysanthemum cultivars, plants grown at 13.5° or 15.6°C with 750 ppm carbon dioxide were, in general, of higher quality and sometimes flowered earlier than plants given no additional carbon dioxide. Mowry et al (47) revealed that chrysanthemums sprayed with carbonated water were ready for cutting in 57 days compared to 71 days required for control plants. Mastalerz (45) reported that

the tallest and heaviest plants of 'Indianapolis White' and 'Mefo' chrysanthemum were produced when CO_2 was applied from planting until harvest. Plants with no extra CO_2 made the least growth. Lavsen (41) observed that the cultivars varied in their response to CO_2, although all responded favorably to extra CO_2 in the early spring. Hughes and Cockshull (31) stated that the pot chrysanthemum 'Bright Golden Anne' showed an increase in total dry-matter production with increasing light and CO_2, with small interaction between them. The effects of additional carbon dioxide were largely accounted for by increased photosynthesis. Flower weight increased with increasing light intensity and CO_2 concentration with a positive interaction between them.

In an experiment conducted by Hughes and Cockshull (32), plants planted in January and grown to April showed bigger final total dry weight, flower dry weight and larger leaf areas (than September-December plants) under higher light intensity and higher CO_2 concentration with a high positive interaction between them. However, plants planted in September and grown to December responded little to increased CO_2 concentration and there was only slight positive interaction with light intensity.

Conclusion

Chrysanthemum is a short-day plant, which will set and develop flower buds if it is exposed to an uninterrupted dark period of 12 hours and temperature of 15.6 - 17°C. This uninterrupted dark period can be created artificially through the use of good quality black sateen cloth.

Flowering of chrysanthemum is inhibited (to obtain vegetative growth) by a few hours (4 hours) of continuous or intermitted fluorescent or incandescent-filament illumination of low intensity (20 ft. c.) during the middle of uninterrupted dark period.

One cannot separate the effects of temperature from those of light duration in regulating the flowering of chrysanthemums. Temperature is the dominating factor in the summer-flowering cultivars while daylength dominates the response of the autumn-flowering cultivars.

High temperature (26.7°C) increases the number of buds per spray, but delays flowering in all cultivars, and inhibits flowering of the thermonegative cultivars. Plants grown from 26.7°C stock flower with much shorter stems than plants grown from stock at 10 or 15.6°C. The same number of days for vegetative growth in early summer and late summer do not produce the same length of stems because the high summer temperature on the stock plants reduces growth of the late summer planting.

Low temperature (10°C) delays the flowering slightly in the thermonegative cultivar. If a grower cannot accurately control his temperature, thermonegative cultivars would be less difficult to flower for fall and winter than thermopositive

cultivars. Also low temperature (10°C) inhibits the flowering of thermopositive cultivars. The temperature must be accurately controlled at a minimum of 15.6°C before flowering can be obtained. Continuous low temperature (10°C) reduces the number of flowers per spray on thermozero and thermonegative cultivars. Thermopositive cultivars do not flower at continuous 10 C.

Thermopositive cultivars have more flowers per spray when they are shifted from 10° to 15.6°C. On the other hand the thermozero cultivars flower in the range 10° to 26.7^{o}C. There is an equal delay at 10^{c} to 26.7^{c}C in the flowering when compared with the minimum flowering time at 15.6°C. Minimum flowering time is obtained with all cultivars when a night temperature of 15.6^{o}C was continued throughout the life cycle.

The application of carbon dioxide cannot be regarded as a substitute for light, temperature or any of the other basic culture requirements for chrysanthemum growth. The treatment will have a beneficial effect only if these other factors are in balance.

Daylight intensity during the winter months is not only poor, but also very variable from day to day and some method must be employed to ensure that the atmosphere is enriched when light intensity is such that the crop can take advantage of the additional carbon dioxide.

The relationship between day temperature, ventilation and carbon dioxide level is important.

ACKNOWLEDGMENTS

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EFFECT OF PHOTOPERIOD, TEMPERATURE AND

CARBON DIOXIDE ON FLOWERING OF

CHRYSANTHEMUM (Chrysanthemum morifolium Ramat.)

by

OMAR MANSOUR EL-SHEIBANY

B.S., Cairo University, 1969

AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1977

Chrysanthemum (Chrysanthemum morifolium Ramat.) is a short-day plant that initiates flower buds when the dark period is uninterrupted for 12 hours (5-6 weeks in length), but will not develop them when the light duration exceeds 13.5 hours. This uninterrupted dark period can be created artificially through the use of black sateen cloth.

To prevent flower bud initiation, the uninterrupted dark period is broken by a few hours (4 hours) of continuous or intermittent fluorescent or incandescent-filament illumination of low intensity during the middle of the dark period.

Most rapid flowering occurs when the night and day temperature is maintained constantly at 15.6 C. Night temperatures above or below this causes delay in flowering.

The application of carbon dioxide cannot be regarded as a substitute for light, temperature or any of the other basic cultural requirements for chrysanthemum growth. Under better conditions concentrations of up to 1500 ppm have given good results.