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EFFECT OF CONSTANT TEMPERATURES AND NATURAL DAYLENGTH ON FLOWERING TIME AND LEAF NUMBER OF *ANTIRRHINUM* USING THE PHOTO-THERMAL MODEL

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Abstract

After 80% seed germination plants of an early flowering cultivar Chimes White of *Antirrhinum* were subjected to five set-point temperature regimes (14, 18, 22, 26 and 30°C) for two consecutive years to observe their effects on the flowering time and leaf numbers using photo-thermal model. Findings revealed a curvilinear response of flowering time to temperatures that is plants flowered after 34 (31.8°C), 35 (25.3°C), 37 (23.1°C), 43 (19.5°C) and 68 days (14.6°C) of transplantation in 2002 whereas in 2003 flowering time was recorded as 30 (31.5°C), 29 (27.5°C), 34 (24°C), 39 (22.5°C) and 67 days (15.1°C). Similarly, rate of progress to flower per day was increased linearly up to plateau at 28°C set-point temperature, thereafter, no changes in rate of progress to flower is observed which indicated that 28°C is the ceiling temperature for the flower initiation and development of cultivar Chimes White. A three to six days difference in flowering time was observed below ceiling temperature which might be due to the difference between the light integrals (0.9 $\mathrm{MJ.m^{-2}.d^{-1}}$) in two years. Non-significant difference was observed regarding leaf numbers data in both years i.e. 9-10 leaves in 2002 and 8-9 leaves in 2003. Predicted data estimated from the photo-thermal model plotted against the actual data which showed a best fit, hence, the model application is validated which would assist growers to use it for plant scheduling.

Key words: Snapdragon, *Antirrhinum majus* L., Temperature, Daylength, Photo-thermal model, Flowering time, Leaf numbers.

Introduction

Environmental factors such as photoperiod, temperature and light integral determine the rate of growth and development in plants (Baloch *et al.,* 2011; Baloch *et al.,* 2014; Rasheed *et al.,* 2015). For optimized manipulation of these factors in production, a number of decision support systems have been developed such as yield forecast, policy analysis and management models which are now widely used in the horticultural industry. The prediction of flower development and its timing is important to allow growers to meet market requirements (Wurr *et al.,* 1990). For ornamental crops, prices of cut-flowers and pot plants are higher during specific, short periods of the year. For these reasons, various models have been developed to predict timing of production and other features to improve crop management and allow market demands to be met (Adams *et al.,* 1996).

Flowering of many plants including *Antirrhinum* (Snapdragon) is affected by temperature (Cremer *et al.,* 1998; Munir *et al.,* 2004). The rate of development to flower can be represented as the reciprocal of the time to flowering (Roberts & Summerfield, 1987; Baloch *et al.,* 2012). According to the following linear function the rate of flowering ($1/f$) can be related to the mean temperature (T) (Hadley *et al.,* 1984; Adams *et al.,* 1998):

$$1/f = a + b\,T \qquad \text{Eq. 1}$$

where a and b are constants

In most plants however, an optimum temperature (To) exists at which the flowering process occurs at its greatest rate (Ellis *et al.,* 1990; Adams *et al.,* 1998) but as temperature increases a ceiling temperature (Tc) is reached at which the rate of flowering approximates to zero. Pearson *et al.* (1993) reported that the optimum temperature can be estimated from the concept of effective temperature. This assumes that development increases with temperature at the same but opposite rate above and below the optimum temperature (To). For any value of optimum temperature (To) a supra-optimal temperature can then be converted into effective temperatures (Te) which represent the equivalent sub-optimal temperature response. It can be expressed in the following model:

$$Te = To - |\,To - Ta\,| \text{ and } Tb < Ta < Tc \qquad \text{Eq. 2}$$

where Ta represents the actual temperature and To, Tb and Tc are calculated. Tb is the base temperature at which the rate of progress to flowering is zero and can be estimated as:

$$Tb = -\,a / b \qquad \text{Eq. 3}$$

By considering effective temperature, equation 1 hence can be modified as:

$$1/f = a + b\,Te \qquad \text{Eq. 4}$$

Keeping in view the importance of above linear models for the prediction of flower and leaf development two experiments were conducted in two consecutive years to investigate the response of *Antirrhinum* cv. Chimes White to varied temperatures under natural daylength which was not previously studied.

Materials and Methods

The objective of this experiment was to determine the flowering and leaf number response of *Antirrhinum majus* L. cv. Chimes White, to five temperature regimes. Seeds were sown in June for two consecutive years. Seeds were sown into module trays (P135, volume per cell 20ml; Plantpak Ltd., Maldon, U.K.) containing SHL peat-based modular compost (William Sinclair Horticulture Ltd., Lincoln, U.K.). Seed trays for each experiment were placed in an environment-controlled growth room at 20 ± 2°C temperature providing lighting (72 µmol m^{-2} s^{-1} photosynthetic photon flux density-PPFD) using a mixture of warm white fluorescent and tungsten bulbs (6.3% tungsten calculated by nominal wattage) at plant height with a 16h.d^{-1} photoperiod. After 80% seed germination, plants were transplanted into 9cm pots containing a mixture of SHL peat-based compost and perlite (3:1 v/v) and were then transferred into five temperature-controlled glasshouse compartments, set to provide minimum temperatures of 14, 18, 22, 26, and 30°C, with ventilation at temperatures 4°C above these set points. The actual temperatures within each compartment were recorded every 15s using a data-logger (Datataker 500, Data Electronics, Letchworth Garden City, U.K.). The hourly average temperature was then calculated. Each temperature sensor was situated in an aspirated screen in the centre of each compartment. Tube solarimeters (in house manufacture, Szeicz *et al.,* 1964) were positioned about three meters above the ground in each temperature compartment to measure the light transmission (total solar radiation) into the glasshouse. In the 14°C compartments, temperature control was carried out by the use of air conditioning units. Actual average temperatures from the start of the experiment to flowering are mentioned in the Table. Experiments were laid out on Randomized Complete Design and six replicates were used for each treatment. Plant nutrients were given in the form of a soluble fertilizer, Sangral 111 (William Sinclair Horticulture Ltd., Lincoln, U.K.) at a conductivity of 1500 to 1600µS.cm^{-2} (182ppm N; 78ppm P; 150ppm K), at pH 5.7 to 5.8. To avoid *Pythium*, water was applied manually every two or three days as required. Plants in each treatment were observed daily until flower opening (corolla fully opened). Numbers of days to flowering from date of transfer to the glasshouse and the leaf numbers (below the inflorescence) were recorded at harvest. Data of these parameters were analyzed using Genstat-11 software, (Lawes Agricultural Trust, Rothamsted Experimental Station, U.K.).

Results

Figure 1 showed that time to first flower opening in plants from both sowing dates (June 2002 and June 2003) declined significantly with increased temperature ($p<0.05$). Plants sown in June 2002 and grown at the lowest temperature (14.6°C) flowered after 68 days, whereas plants grown at highest temperatures (25.3 and 31.8°C) flowered 35 and 34 days earlier respectively. Similarly, plants grown at 19.5 and 23.1°C flowered after 43 and 37 days respectively. Similar trend was observed during the June 2003 experiment, as plants at lowest temperature (15.1°C) flowered after 67 days followed by 39 (22.5°C), 34 (24°C), 29 (27.5°C) and 30 days (31.5°C). Although both experiments were conducted in the same month (June), however, a three to six days flowering time difference was observed which could be due to a slight difference in light integrals i.e. 8.1 (2002) and 9 MJ.m^{-2}.d^{-1} (2003). However, analysis of two years data showed statistically non-significant ($p>0.05$) difference in time to flowering between the individual means of two experiments. Data from both experiments were therefore combined in a further analysis using the following general photo-thermal model:

$$1 / f = a + bT$$

The best fitted model describing the effects of actual temperature (*T*) on the rate of progress to flowering (1/*f*) can be written as:

$$1 / f = bT$$

$$1 / f = 0.00111\ (\pm 3.755E\text{-}05)\ T$$

$$R^2 = 0.82,\ d.f.\ 9$$

N.B. The constant was not significantly different from zero.

The value shown in parenthesis is the standard error of the regression coefficient and the analysis showed that the rate of progress to flowering was linearly related to temperature (Fig. 2). Data derived from the actual rate of progress to flowering was plotted against the predicted data of rate of progress to flowering which was estimated through multi-linear photo-thermal model '$1 / f = a + bT + cT2$', where $T2$ is the square root of T (Fig. 3). By the look of Figure 3 it is apparent that the actual rate of flowering versus those fitted by the model are closely located near the line of identity which validated the predicted photo-thermal model. On the other hand, data regarding leaf number per plant was slightly but non-significantly affected by either sowing dates or temperatures, however, plants of all treatments produced 9-10 and 8-9 leaves in June 2002 and June 2003 experiments respectively (Fig. 4).

Table Temperature and daily light integral detail of glasshouse environment throughout growing season.

June 2002			**June 2003**		
Temperature		**Daily light integral MJ. m^{-2}.d^{-1}**	**Temperature**		**Daily light integral MJ. m^{-2}.d^{-1}**
Set-point °C	**Actual °C**		**Set-point °C**	**Actual °C**	
14	14.6	8.3	14	15.1	8.3
18	19.5	8.3	18	22.5	9.0
22	23.1	8.0	22	24.0	9.0
26	25.3	7.9	26	27.5	9.4
30	31.8	8.0	30	31.5	9.2
Average light integral		8.1	Average light integral		9.0

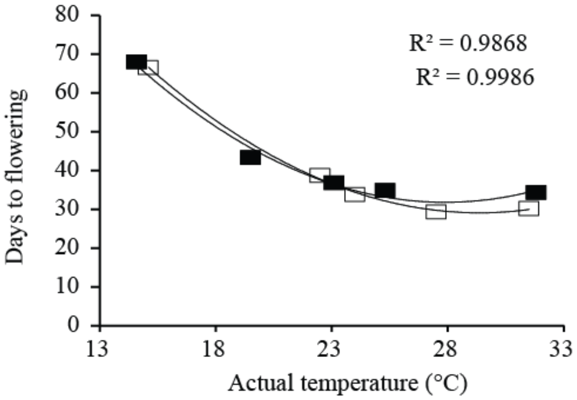

Fig. 1. The effect of temperature on time to flowering of *Antirrhinum majus* cv. Chimes White sown in June 2002 (■) and June 2003 (□). Each point represents the mean of 6 plants where negligible variability within replicates was observed due to controlled environment.

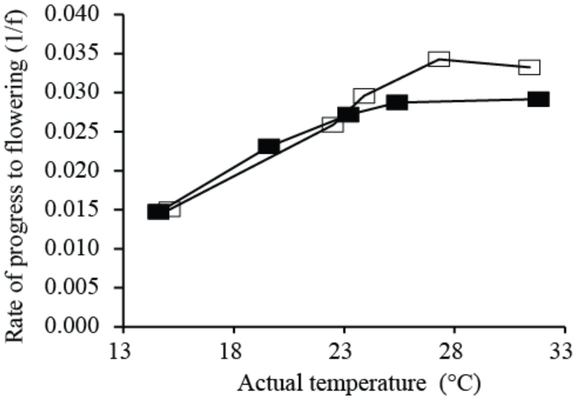

Fig. 2. The relationship between mean temperature and rate of progress to flowering of *Antirrhinum majus* cv. Chimes White, where each point represents the mean of six plants. $1/f = 0.00111$ (±3.755E-05) T, where T is the mean temperature of respective means. R^2 was 0.82 at 9 d.f.

Discussion

A number of studies has been carried out previously (Sanderson and Link, 1967; Edwards and Goldenberg, 1976; Munir *et al.,* 2004) on various *Antirrhinum* cultivars all showing that longer photoperiods and warmer temperatures hasten flowering but no attempt has been made to combine temperature, photoperiod and light integrals factors into a single model for a commercial cultivar until now. In this paper, the effects of constant temperatures and natural daylength on flowering time and leaf numbers were studied on the commercial early flowering *Antirrhinum* cv. Chimes White which is not reported previously. Five temperatures throughout development were studied at high light integrals (in the month of June). This experiment was repeated in the same month of the following year. Results showed that temperature affected the time to flowering and leaf numbers which could be due to the Mediterranean origin of *Antirrhinum*, as plants originating from this region prefer an open environment with ample sunshine (Summerfield *et al.,* 1997).

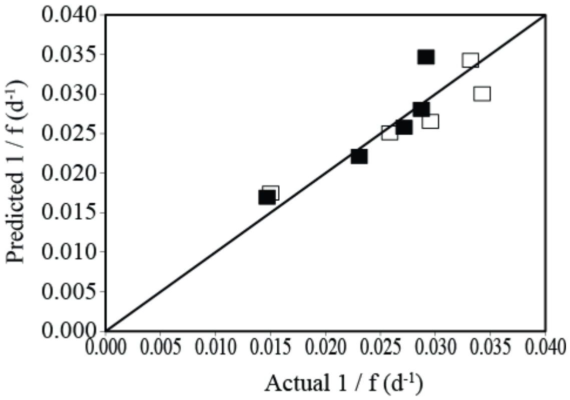

Fig. 3. The relationship between the actual rate of progress to flowering against those fitted by the flowering model ($1 / f = a + bT$) of *Antirrhinum majus* cv. Chimes White sown in June 2002 (□) and grown at 14.6, 19.5, 23.1, 25.3, and 31.8°C and sown in June 2003 (■) and grown at 15.1, 22.5, 24.0, 27.5, and 31.5°C under natural photoperiods. The solid line is the line of identity.

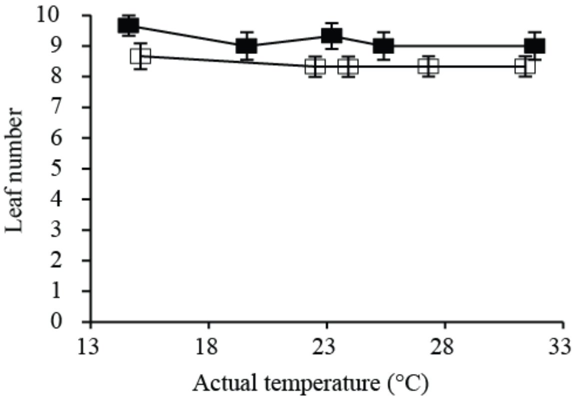

Fig. 4. The effect of temperature on leaf number of *Antirrhinum majus* cv. Chimes White sown in June 2002 (■) and June 2003 (□). Each point represents the mean of the 6 plants, vertical bars (where larger than the points) represent the standard errors.

It has been previously observed that *Antirrhinum* flowers earlier at higher temperatures (Edwards and Goldenberg, 1976). The response of cv. Chimes White clearly showed that the time of flowering decreased as temperature increased to 23-25°C. Miller (1962) also suggested that the optimum temperature for *Antirrhinum* varied with age of plant. He pointed out that a night temperature of 15-18°C for first 3-4 weeks resulted in optimum growth but crop quality was improved when the crop was finished at 10°C. In addition, *Antirrhinum* flowers later at lower temperatures, but has stronger and longer stems than if grown at higher temperatures. The present study also produced similar results (data not shown) confirming that flowering occurred earlier at higher temperatures but at the cost of plant quality.

Similarly, Cremer *et al.* (1998) studied the effect of temperature on flowering time under artificial daylength on *Antirrhinum* inbred lines Sippe-50 and S-412 and concluded that increasing temperature from 20 to 25°C hastened flowering and reduced leaf numbers of the two inbred lines. They also compared flowering time of two lower temperatures and observed that plants of both inbreds flowered earlier at 12°C than at 15°C and put this down to a vernalization effect. However, in present study, plants were exposed to natural daylength and an early flowering commercial cultivar was studied. The reason of growing plants under natural daylength was to minimize the wastage of resources as Cremer and co-workers grew plants under artificial light which eventually increase the cost of production. This probably explains the large differences in time to flowering and leaf numbers between the two experiments. Moreover, in present study no vernilization effect was observed because the lowest temperature used in present experiments was well above the range typically associated with vernalization treatments. Similarly, Cockshull (1985) also stated that no vernalization effect is known for *Antirrhinum*. Decreases in time to flowering with increase in temperature have been observed in a number of other species such as geranium (Khattak *et al.,* 2011), chrysanthemum (Hidén and Larsen, 1994), pansy and petunia (Adams *et al.,* 1997 and 1998), cauliflower (Rahman *et al.,* 2013). It is also revealed (Munir *et al.,* 2004) that temperature affects the rate of development, so that plants produce leaves more rapidly and progress to flowering more rapidly. Hence, temperature does not affect the number of leaves. The general photo-thermal model has been successfully applied to the flowering response of many crops species (Pearson *et al.,* 1993; Adams *et al.,* 1997 and 1998) and this model was also successfully applied on to *Antirrhinum*. However, this model assumed that the cv. Chimes White is equally sensitive to temperature which is going to be studied in the future experiments.

Conclusion

It is concluded from present study that flowering time and rate of progress to flower of *Antirrhinum* cv. Chimes White can be accelerated by subjecting them to high temperatures, and 28°C is appeared to be a ceiling temperature as above it (30°C) no supra-optimal effect of temperature was observed. Moreover, plants can be grown at lower temperatures (18 to 22°C) to enhance their quality and then moved to ceiling temperature to hasten flowering. These findings are useful for ornamental industry for the sturdily supply of plants to the market and would also save the wastage to resources.

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References

Adams, S.R., S. Pearson and P. Hadley. 1996. Modelling growth and development of Pansy cv. Universal Violet in response to photo-thermal environment: Application for decision support and scheduling. *Acta Hort.,* 417: 23-32.

Adams, S.R., S. Pearson and P. Hadley. 1997. The effects of temperature, photoperiod and light integral on the time to flowering of pansy cv. Universal Violet (*Viola* × *wittrockiana* Gams). *Ann, Bot.,* 80: 107-112.

Adams, S.R., P., Hadley and S. Pearson. 1998. The effects of temperature, photoperiod, and photosynthetic photon flux on the time to flowering of petunia 'Express Blush Pink'. *J. Amer. Soc. Hort. Sci.,* 123: 577-580.

Baloch, J.U.D., M. Munir, M. Abid and M. Iqbal. 2011. Effects of different photoperiods on flowering time of qualitative long day ornamental annuals. *Pak. J. Bot.,* 43: 1485-1490.

Baloch, J.U.D., M. Munir, M. Abid and M. Iqbal. 2012. Effects of varied irradiance on flowering time of facultative long-day ornamental annuals. *Pak. J. Bot.,* 44: 111-117.

Baloch, J.U.D., M. Munir and F. Bibi. 2014. Effects of supplementary irradiance on flowering time of obligate long day ornamental annuals under non-inductive environment. *Pak. J. Bot.,* 46: 1253-1259.

Cockshull, K.E. 1985. *Antirrhinum majus*. In: *CRC Handbook of Flowering*. Vol. I: A.H. Halevy (Ed.), CRC Press, Florida, U.S.A. pp. 476-481.

Cremer, F., A. Havelange, H. Saedler and P. Huijser. 1998. Environmental control of flowering time in *Antirrhinum majus*. *Physiol. Plant.,* 104: 345-350.

Edwards, K.J.R. and J.B. Goldenberg. 1976. A temperature effect on the expression of genotypic differences in flowering induction in *Antirrhinum majus*. *Ann. Bot.,* 40: 1277-1283.

Ellis, R.H., P. Hadley, E.H. Roberts and R.J. Summerfield. 1990. Quantitative relations between temperature and crop development and growth. In: *Climatic Change and Plant Genetic Resources*. (Eds.): Jackson, M.T., B.V. Ford-Lloyd and M.L. Parry. Belhaven Press, London, U.K. pp: 85-115.

Hadley, P., E.H. Roberts, R.J. Summerfield and F.R. Minchin. 1984. Effects of temperature and photoperiod on flowering in soya bean [*Glycine max* (L) Merrill] - a quantitative model. *Ann. Bot.,* 53: 669-681.

Hidén, C. and R.U. Larsen. 1994. Predicting flower development in greenhouse grown chrysanthemum. *Sci. Hort.,* 58: 123-138.

Khattak, A.M., S. Pearson, K. Nawab, M.A. Khan and K.B. Marwat. 2011. The effects of light quality and temperature on the growth and development of geraniums. *Pak. J. Bot.,* 43: 679-688.

Miller, R.O. 1962. Variations in optimum temperatures of snapdragons depending on plant size. *Proc. Amer. Soc. Hort. Sci.,* 81: 535-543.

Munir, M., M. Jamil, J.U.D. Baloch and K.R. Khattak. 2004. Growth and flowering of *Antirrhinum majus* L. under varying temperatures. *Int. J. Agri. Biol.,* 6: 173-178.

Pearson, S., P. Hadley and A.E. Wheldon. 1993. A reanalysis of the effects of temperature and irradiance on time to flowering in Chrysanthemum (*Dendranthema grandiflora*). *J. Hort. Sci.,* 68: 89-97.

Rahman, H.U., P. Hadley, S. Pearson and M.J. Khan. 2013. Response of cauliflower (*Brassica oleracea* L. var. *Botrytis*) growth and development after curd initiation to different day and night temperatures. *Pak. J. Bot.,* 45: 411-420.

Rasheed, A., A. Hameed, M.A. Khan and B. Gul. 2015. Effects of salinity, temperature, light and dormancy regulating chemicals on seed germination of *Salsola drummondii* ULBR. *Pak. J. Bot.,* 47: 11-19.

Roberts, E.H. and R.J. Summerfield. 1987. Measurement and prediction of flowering in annual crops. In: *Manipulation of Flowering*. (Ed.): Atherton, J.G. Butterworths, London, U.K. pp: 17-50.

Sanderson, K.C. and C.B. Link. 1967. The influence of temperature and photoperiod on the growth and quality of a winter and summer cultivar of snapdragon, *Antirrhinum majus* L. *Proc. Amer. Soc. Hort. Sci.,* 91: 598-611.

Summerfield, R.J., R.H. Ellis, P.Q. Craufurd, Q. Aiming, E.H. Roberts and T.R. Wheeler. 1997. Environmental and genetic regulation of flowering of tropical annual crops. *Euphytica,* 96: 83-91.

Szeicz, G., J.L. Monteith and J.M. dos Santos. 1964. A tube solarimeter to measure radiation among plants. *J. Appl. Eco.,* 1: 169-174.

Wurr, D.C.E., J.R. Fellows, R.A. Sutherland and E.D. Elphinstone. 1990. A model of cauliflower curd growth to predict when curd reach a specific size. *J. Hort. Sci.,* 65: 555-564.

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