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Light quality and temperature effects on antirrhinum growth and development

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Abstract: An experiment was carried out to examine the effects of light quality on the growth and development of antirrhinum under three different temperatures 19 °C, 24 °C and 27 °C in glasshouses. Five different colour filters (i.e. 'Red absorbing', 'Blue absorbing', 'Blue and Red absorbing' and two 'partially Blue absorbing' materials) were tested, with one clear polythene as a control. Plant height, internode length and leaf area were significantly affected by the spectral filters as well as the temperature. Analysis of color filter's effect on presumed photoreceptors to exist indicated that antirrhinum plant height was regulated by the action of a blue acting photoreceptor (BAP) and not the phytochrome. There was no evidence for an effect of phytochrome or BAP on time to flowering, however, increasing temperature levels effectively decreased the time to flowering. To predict the effects of different spectral qualities and temperature, simple models were created from data on plant height, internode length and time to flowering. These models were then applied to simulate the potential benefits of spectral filters and temperature in manipulation of growth control and flowering in antirrhinum.

Key words: Antirrhinum, Light quality, Temperature, Spectral filters, Photoreceptors
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INTRODUCTION

Much interest has been shown in non-chemical means of plants growth control during the past decade. Manipulation of temperature, light quality and quantity, have been proposed as methods of plant height control (Mortensen and Stromme, 1987; Heins and Erwin, 1990; McMahon and Kelly, 1990). Considerable previous research focused on the manipulation of day/night temperatures for growth control (Erwin *et al*., 1989; Moe *et al*., 1995). In many plants, height was reduced when they were grown with higher night than day temperature, but leaf chlorosis, and delayed flowering has limited the use of temperature manipulation for plant growth regulation (Karlsson *et al*., 1989). A number of studies have examined whether the manipulation of spectral quality has potential for growth control in a range of ornamental plants (Mortensen and Stromme, 1987; Mortensen, 1990; McMahon *et al*., 1991; Rajapakse and Kelly, 1992; Rajapakse *et al*., 1993; Rajapakse and Kelly, 1995; Van Haeringen *et al*., 1998).

Light quality has been demonstrated to influence many aspects of plant growth and morphology (Smith, 1982; 1995). It has been suggested that rigid or flexible plastic greenhouse covers with specific spectral qualities, would enable growers to use light quality to regulate the growth of greenhouse crops (Rajapkse and Kelly, 1993).

Khattak and Pearson (1997) showed that spectral filters had remarkable effects on chrysanthemum growth and flowering. However, it was observed that most previous work on spectral filters was conducted on chrysanthemum, which is a short day plant (McMahon *et al*., 1991; Rajapakse and Kelly, 1991; 1992; Rajapakse *et al*., 1992; 1993; Rajapakse and Kelly, 1995). Mortensen and Stromme (1987) studied light quality effects on vegetables (tomato and let-

tuce), but little work seems to have been done on antirrhinum under natural light conditions. Responses of long day plants such as antirrhinum have also been rarely studied under different temperature regimes.

Here the responses of antirrhinum, a long day plant, to spectral filters were studied under condition similar to those of chrysanthemums (Khattak and Pearson, 1997) so that their growth and development could be compared.

MATERIAL AND METHODS

Plant material and treatments

The experiment was conducted in the School of Plant Sciences, University of Reading, UK. *Antirrhinum majis* (Cv. Coronatte yellow) seeds were purchased from Colgrave Seeds and sown in module trays having SHL (Sinclair Horticulture Ltd., Lincoln, UK) seed and modular compost on July 18, 1996. The seeds were covered with a thin layer of vermiculite, watered and put in a growth room set at 15 °C and lit at 100 μmol/(m^2·s) with white fluorescent tubes for 16 h/d. The trays were kept moist until germination. The seeds germinated on July 26, 1996 and the seedlings were watered at two or three days intervals (as needed). Twenty days later, the seedling trays were moved from the nursery room to an oriented southward glasshouse (5 m×8 m×4 m high) set at 15 °C. The next day, the seedlings were put in 9 cm pots containing a mixture of 75% potting compost and 25% perlite. Three days later, the plants were transferred to one of three identical (adjacent, similar in size and shape, with same light intensity) glasshouse compartments set at three different temperatures i.e. 15 °C, 20 °C and 25 °C (thermostatically controlled heating and cooling). However, the actual temperatures recorded were 19 °C, 24 °C and 27 °C respectively. In each compartment there were six different spectral filters replicated twice (Khattak and Pearson, 1997). The filters were wrapped on wooden frames making chambers of 30 cm width, 60 cm length and 60 cm height. Four plants were placed in each filter-covered chamber. At flowering, the plants were harvested and measured for final plant height, stem fresh and dry weight, leaf area, leaf fresh and dry weight, number of flowers, flower fresh and dry weights, etc.

Spectral filters

Six different solid spectral filters were used, 5 obtained from Lee Filters Ltd., Andover, UK (filters 088, 101, 109, 110, 117), and 150 μm clear low density polyethylene (LDPE) was used as a control. The filters were selected so that the analysis could test for independent effects of a Blue Acting Photoreceptor (BAP) using the light equivalence principle described by Schafer *et al.*(1981), such that they would provide the same overall Photosynthetically Active Radiation (PAR) transmission and phytochrome photoequilibrium (φ; phi), but have different 'blue' transmissions. Other claddings were chosen that gave different phytochrome photoequilibria. The actual spectral transmissions of 300 to 800 nm for each of the materials were measured on an optical bench using a Bentham Instruments spectroradiometer (M3000EA monochromator), as described by Pearson *et al.*(1995), and are shown in Fig.1. The R (red):FR (far-red), B (blue):R and B:FR ratios were then calculated assuming a narrow band absorption (1 nm) for each wavelength. Phytochrome photoequilibria (φ) constants were estimated using the model of Hayward (1984). Table 1 gives a summary of the transmissions recorded for all the spectral materials.

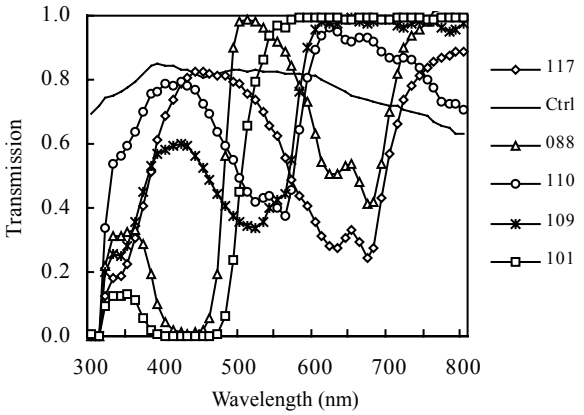

Fig.1 Transmission of different filters used in the experiment

Data collection and analysis

Temperatures inside each glasshouse compartment were recorded using a Campbell CR 7 data logger via aspirated K type thermocouples. In order to measure air temperature and protect them from direct sunlight, the sensors were fixed in the middle of pipes (40 cm long×8 cm diameter) with small fans fixed to one end which would blow air into the pipe from

outside. The average temperatures recorded over the duration of the experiment were 19 °C, 24 °C and 27 °C. The daily PAR light integral received outside the greenhouse (measured with a Kipp solarimeter) averaged over the duration of the experiment was 12.15 MJ/(m^2·d), which was further reduced 20% by the greenhouse cladding. Different plant growth and development parameters were measured including plant height, internode length, leaf number, area and weight, stem weight and flowering. All the data taken were subjected to analysis of variance (2 factor) or multiple linear regression analysis. MSTATC software (Michigan State University, USA) was used for computing analysis of variance and least significant difference (LSD) tests, and MS Excel for regression analysis.

RESULTS

Effects of spectral filters and temperature

A detailed comparison of the effects of spectral filters and temperature on the growth and development of antirrhinum is given in Table 2.

Significant differences ($P \leq 0.001$) were found in plant height measured at flowering. There was a strong effect of blue light on antirrhinum plant height (PH in Table 2). Plant height decreased with the increase in blue light. However, there was no indication of an effect of φ on plant height. The 117, control and 110 materials had the lowest plant heights of 38.7, 38.9 and 39.9 cm, respectively. These materials had relatively high blue transmission (24.0%, 21.9% and 18.3% respectively) but different φ. The tallest

Table 1 A summary of the transmission of the spectral filters used in the experiment

Filters	PAR[1] Transmission (%)		R:FR (660:730)	B:R (450:660)	B:FR (450:730)	Phi (φ)	Blue[4] (400–500 nm) (%)	Absorption
	A[2]	B[3]						
Control	63.9	n/a[5]	1.38	0.78	1.08	0.73	30.1	Neutral
088	52.4	54.4	0.57	0.00	0.00	0.66	13.8	Blue and red absorbing
101	63.1	64.9	1.14	0.00	0.00	0.73	03.3	Blue absorbing
109	59.9	63.3	1.15	0.36	0.41	0.72	19.8	Partially Blue absorbing
110	63.1	65.4	1.17	0.51	0.60	0.72	25.9	Partially blue absorbing
117	57.4	58.2	0.43	2.02	0.88	0.60	42.1	Red absorbing

[1]Photosynthetically Active Radiation (400–700 nm); [2]Calculated using a Li-Cor quantum sensor; [3]Calculated as the transmission of quanta assuming a standard solar spectral distribution (Pearson *et al*., 1995); [4]Calculated as the proportion of blue quanta transmitted relative to the total PAR quanta incident above the cladding; [5]n/a: not available

Table 2 Main effects of light quality and temperature on antirrhinum

	PH (cm)	*IL* (cm)	*NL*	*LA* (cm^2)	*LFW* (g)	*LDW* (g)	*SLW* (mg/cm^2)	*SFW* (g)	*SDW* (g)	*DF* (d)
Filters										
Control	38.9	1.82	21.4	568.9	16.35	1.58	2.76	7.39	1.02	65.7
88	45.3	2.01	22.7	500.3	12.82	1.26	2.45	7.35	1.01	68.6
101	50.0	2.26	22.2	553.7	14.29	1.44	2.59	9.05	1.22	66.4
109	42.4	1.93	22.0	509.3	14.46	1.38	2.68	7.08	1.07	67.3
110	39.9	1.83	21.8	485.7	13.85	1.39	2.79	6.96	0.94	66.2
117	38.7	1.84	21.0	396.6	11.22	1.07	2.69	5.17	0.71	66.7
Significance	***	***	***	*	**	*	NS	***	***	NS
LSD values	3.95	0.21	0.88	89.33	3.14	0.30		1.82	0.24	
Temperature										
19 °C	47.6	2.23	21.3	679.8	20.33	1.95	2.90	12.62	1.66	72.5
24 °C	42.3	1.92	22.1	462.7	12.04	1.23	2.67	5.74	0.86	66.5
27 °C	37.6	1.70	22.1	364.7	9.12	0.88	2.41	3.13	0.46	61.5
Significance	***	***	**	***	***	***	**	***	***	***
LSD values	2.8	0.15	0.6	86.8	2.22	0.29	0.42	1.29	0.17	1.9
Interaction										
F×*T*	NS	NS	NS	NS	NS	NS	NS	*	NS	NS

PH: Plant height; *IL*: Internode length; *NL*: Number of leaves; *LA*: Leaf area; *LFW*: Leaf fresh weight; *LDW*: Leaf dry weight; *SLW*: Specific leaf weight; *SFW*: Stem fresh weight; *SDW*: Stem dry weight; *DF*: Days to flowering; *F*: Filter; *T*: temperature; NS: Non significant; *: Significant at $P \leq 0.05$; **: Significant at $P \leq 0.01$; ***: Significant at $P \leq 0.001$

(50.0 cm) plants were produced by the 101 material, which had high φ, but the lowest blue (3.3%) transmission. Thus, the data suggested that there was evidence for the action of a blue photoreceptor, since materials with relatively higher blue transmission had significantly ($P\leq0.001$) shorter plants than those with low blue transmission independent of φ. Variations in temperature also resulted in significantly different heights. The tallest (47.6 cm) plants were produced at the lowest temperature (19 °C), followed by 24 °C (42.3 cm) and the lowest height (37.6 cm) was recorded for the plants grown under the highest temperature (27 °C). This was because plants grown under the highest temperature flowered about a week earlier than those of other temperatures.

Spectral filters significantly ($P\leq0.001$) affected internode length (IL in Table 2). The material with the lowest blue transmission (101) had the longest (2.26 cm) internodes compared to the rest of the materials. The other materials behaved similarly, although there were slight differences, depending on the amount of blue light present. The effect of temperature on internode length was almost identical to that on plant height. The lowest temperature (19 °C) produced the longest (2.23 cm) internodes whose length decreased ($P\leq0.001$) with the increase in temperature i.e. 1.92 cm at 24 °C and 1.70 cm at 27 °C. However, the plants under the higher temperatures flowered earlier than the plant under lower temperature.

The leaf number (NL in Table 2) was also affected significantly ($P\leq0.01$) by the spectral filters. But the differences in leaf number were small, with the difference between the highest and lowest NL being 1.7 leaves. The lowest leaf number was produced by the 117 and Control materials, which had different φ but relatively high blue transmission. This shows that φ had little effect on leaf number, while blue light or a blue photoreceptor (BAP) may reduce the number of leaves in antirrhinum. The effect of temperature was obvious and the leaf number was affected significantly ($P\leq0.01$), where the lowest (19 °C) temperature led to the lowest number of leaves.

In terms of leaf area (LA in Table 2), there was no evidence for an effect of a blue photoreceptor, since the control, 110, 109 and 101 filters (same φ but different levels of blue) had similar leaf areas. There was a suggestion that low φ led to a reduced leaf area, since the 117 filter (low φ, but high blue transmission) led to the lowest ($P\leq0.05$) leaf area (30.3% lower than the control). The plants grown at the highest (27 °C) temperature had the smallest ($P\leq0.001$) leaf area, which increased as temperature decreased, with the lowest (19 °C) temperature leading to the largest leaf area (679.8 cm^2).

Spectral filters significantly affected the leaf fresh ($P\leq0.01$) and dry ($P\leq0.05$) weights. The control material (high φ) produced the highest leaf fresh and dry weights (LFW and LDW in Table 2), whereas 117 (low φ, high blue) and 088 (low φ, low blue) produced the lowest weights (the 088 material weighed 21% and 117 weighed 31% lower than the control). These results show that blue light had no effect, but that φ apparently had effect, since the materials with the same high φ but different blue (i.e. control, 101, 109, 110) had similar but higher leaf fresh and dry weights compared to those with low φ. Like leaf area, temperature variation greatly affected LFW and LDW. The highest weights ($P\leq0.001$) were recorded for the lowest temperature (19 °C) and the weights decreased as temperature increased, with the highest temperature (27 °C) producing the lowest leaf weights.

Specific leaf weight is the leaf dry weight per unit leaf area, and represents the thickness of the leaf. The data recorded (SLW in Table 2) showed that the spectral materials had no significant effect on specific leaf weight. Different temperatures, on the other hand, significantly ($P\leq0.01$) affected the specific leaf weight. The lowest temperature (19 °C) led to the highest (2.90 mg/cm^2) SLW but the highest temperature (27 °C) led to the lowest (2.41 mg/cm^2) SLW. Thus, low temperature produced thicker leaves while high temperature led to thinner leaves.

Both the stem fresh and dry weights (SFW and SDW in Table 2) were significantly ($P\leq0.001$) affected by the spectral filters. It seems that stem dry weight was affected by a BAP, since the weight was inversely related to the proportion of blue light transmitted by the materials. The materials with the lowest blue transmission (101) had the highest (1.22 g) stem dry weight, while the material with highest blue transmission (117) had the lowest (0.71 g) stem dry weight. However, in case of stem fresh weight, significant ($P\leq0.05$) interaction was observed between temperature and spectral filters. At the lowest temperature (19 °C), filter 101 produced the highest SFW,

followed by 088, while the control and 110 produced similar SFW. The 117 filter behaved consistently at all temperatures producing the lowest LFW. At 24 °C, the filters 101, 109 and control produced higher SFW than the rest, whereas, at 27 °C, filter 109 produced the highest SFW. Temperature regimes significantly ($P \leq 0.001$) affected stem dry weight. Plants grown at 19 °C had the highest dry weights (1.66 g), and the weight decreased as the temperature increased.

The variation in spectral quality had no significant effect on time to flowering in antirrhinum. However, the data (DF in Table 2) show that minimum DF (65.7) were found in the control (high φ and high blue), and maximum (68.6) DF were noted under the 088 filter (low φ and low blue). Temperature showed strong effects on time to flowering. Plants grown at the highest temperature (27 °C) were the earliest to flower. Flowering delayed by 5 and 11 d as the temperature was decreased to 24 °C and 19 °C, respectively.

Simulation of the effects of spectral filters and temperature

The data were also analysed using multiple regression analysis to develop simple quantitative relationships, which could be used to model plant height, internode length and time to flowering for plants grown under any spectral filter.

Antirrhinum plant height (PH) was found to be a function of the amount of blue light (B) in the incident radiation (MJ/(m^2·d); 400–500 nm) and temperature (T, °C), so that

$$PH=63.05\pm3.66-12.72\pm1.70B-0.67\pm0.15T$$
$$(r^2=0.83,\ 15\ \text{d.f.})$$

Like the Analysis of variance (ANOVA), φ had no significant effect on PH.

For internode length as well, the amount of blue light and temperature both had significant effects, but φ had no effect;

$$IL=3.03\pm0.17-0.45\pm0.08B-0.04\pm0.007T$$
$$(r^2=0.81,\ 15\ \text{d.f.})$$

Time to flowering (DF) in antirrhinum was found to be a function of the prevailing temperature only, and was not affected by amount of blue light present or the phytochrome photoequilibrium, so that

$$DF=98.41\pm2.74-1.35\pm0.12T$$
$$(r^2=0.89,\ 16\ \text{d.f.})$$

DISCUSSION

The data presented here show clearly that spectral quality has substantial effect on the growth and development of antirrhinum. There was a strong effect of blue light on plant height confirming the presence of a photoreceptor acting in the blue region of the spectrum. Significant reductions were found in the plant height with the increase in blue transmission confirming previous studies on other species (Mortensen and Stromme, 1987; Thomas and Dickinson, 1979; Young, 1981; Mortensen, 1990). However, it was surprising that phytochrome photoequilibrium (φ) did not appear to have any effect on the plant height. These results are in contrast to results reported in Khattak and Pearson (1997) where the chrysanthemum plant height was strongly affected by φ as well as blue light. This might be due to species sensitivity because, according to Casal (1994), some plants are more sensitive to blue, some to φ, while for some there is an interaction between blue and φ. The 088 and 117 materials (having low φ) produced the smallest leaf areas and leaf fresh and dry weights. The same effects were found for chrysanthemum (Khattak and Pearson, 1997). This confirms that the effect was due to phytochrome.

Variation in temperature greatly affects plant growth and flowering. The plant height and internode length increased as the temperature increased above 19 °C. These results are in consistence with results of Mortensen and Larsen (1989), who observed a decrease in shoot length at high temperature (above 22 °C) for some plants.

The interactions between light quality and temperature were largely not significant, suggesting that the spectral filters operate effectively over a wide range of temperatures.

The data on time to flowering showed that light quality had no effect on flowering time. This might be that antirrhinum is a long day plant (LDP) and the experiment was carried out during long days when the plants flowered rapidly before the light quality had effect. Furthermore, in LDP far red is known to be required for flowering and in antirrhinum Van Haer-

ingen *et al*.(1998) showed that removal of FR delayed flowering. This is quite different from a red far-red (R-FR) response and more like high irradiance (HI) response where intensity of FR is important (Carr-Smith *et al*., 1989). In such instances φ will not therefore indicate the level of response. Here all the filters changed the φ, but did not affect FR transmission. This and the Van Haeringen's study therefore suggests an independent effect of FR on flowering of antirrhinum, which is not modulated by a classical R-FR reversal mechanism.

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