Combined Effects of Light and Temperature on Product Quality of *Kalanchoe blossfeldiana*

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Abstract

A study with a comprehensive range of four constant photosynthetic photon flux densities (PPFD = 60, 90, 140 and 200 µmol $m^{-2}s^{-1}$) combined with four constant temperatures (18, 21, 23 and 26°C; equal day and night temperature) was conducted in growth chambers using the pot plant *Kalanchoe blossfeldiana*. The current work allows for establishing relationships between these two climatic factors and product quality (plant height, number of flowering shoots, inflorescence size and inflorescence position) and cropping duration. From the studied product quality attributes, temperature and PPFD only showed a marked interaction on number of flowering shoots and on inflorescence size. The huge increase observed on the number of flowering shoots (from 4.6 to 20.5) was a response to higher PPFD, whereas temperature had only a minor effect. Inflorescence size was also enhanced at higher PPFD (especially at lower temperatures) but in contrast with the number of flowering shoots, inflorescence size was drastically reduced at higher temperatures. Plant height varied between 13.5 and 21.6 cm and was strongly influenced by temperature, whereas influence of PPFD was only marginal. Time to flowering decreased quadratically with temperature and with PPFD, and no interaction between these climatic factors was found. The fastest treatment (26°C combined with 200 µmol $m^{-2}s^{-1}$) was 30 days earlier than the slowest one (18°C combined with 60 µmol $m^{-2}s^{-1}$). Different possibilities for reducing the cropping duration are proposed, taking product quality into account.

INTRODUCTION

Supplementary lighting is increasingly used in greenhouse horticulture in areas where in part of the year natural light level is not sufficient for acceptable yield and product quality (Marcelis et al., 2002). Particularly in greenhouse ornamental production, supplementary light is a prerequisite to allow a year-round production (e.g. photoperiodic treatments for flowering control) and to reduce the variation in product quality throughout the year (e.g. increasing the autumn and winter quality). For optimal use of supplementary lighting a good understanding of the effects of light and possible interactions with other climatic factors on crop growth, development, yield and product quality is necessary.

Explanatory simulation models are known to be powerful tools to analyse quantitatively the effects of supplementary lighting on crop growth (Marcelis et al., 2002) and this analysis can be further extended to several external quality attributes (e.g. Carvalho and Heuvelink, 2004). Kalanchoe growers aim at producing a compact plant, with richly flowering umbels and one to three open flowers at commercial harvest, in the shortest time as possible. In a previous study a conceptual dynamic model for predicting plant height and number of flower heads in *Kalanchoe blossfeldiana* was developed (Eveleens-Clark et al., 2004). In order to use this conceptual model as a decision support system for year-round kalanchoe production, it needs to be further extended, parameterised and calibrated for different seasons. Therefore, information is needed on the effects of photosynthetic photon flux density (PPFD) and temperature on product quality and cropping duration.

The present works aims at quantifying the separate effects of PPFD and temperature and investigate possible interactive effects between these two climatic conditions on several external quality attributes and on cropping duration. Since this information cannot be obtained from commercial data sets nor from a greenhouse experiment (where it is not possible to clearly distinguish the effects of PPFD from the ones of temperature (Carvalho et al., 2005)), this research was carried out in growth chambers using a broad range of PPFD and temperatures.

MATERIALS AND METHODS

Experimental Set-up

Unrooted cuttings of *Kalanchoe blossfeldiana* 'Anatole' (Kwekerij Blommendale, Middelburg, The Netherlands) were planted on the 8th July 2004 in 10.5 cm pots filled with peat-based commercial potting compost (PG mix, EGO, Bleiswijk, The Netherlands). During the rooting period (14 days) plants were placed in a greenhouse compartment from a multispan Venlo-type glasshouse (Wageningen, The Netherlands, lat. 52°N) at a density of 99 plants m^{-2} on ebb and flood benches, under constant environment (20°C; natural photoperiod ≈ 17h; ambient CO_2 and 85% relative humidity). After rooting, plants were distributed over four artificially lit growth chambers (l × w × h = 3.50 m × 2.50 m × 2.50 m). Sixteen treatments were applied resulting from all combinations of four constant PPFD (59 ± 2; 88 ± 1; 136 ± 2; and 200 ± 2 μmol $m^{-2}s^{-1}$) and four constant temperatures (18.0 ± 0.1; 21.2 ± 0.2; 23.0 ± 0.1; and 26.1 ± 0.1°C). Each chamber had an equal day and night temperature and all the chambers had a common vapour pressure deficit set point (0.6 kPa). Air temperature at crop level varied between 0.3–0.6°C, when comparing the extreme light treatments Within each chamber the light treatments were achieved by the use of shade screens with different light transmissivity (30%, 45%, 68% and a control with no screen: XLS-17, XLS-14, and XLS-10 respectively; Ludvig Svensson, Kinna, Sweden).

Once in the growth chamber plants were initially subjected to long-day (LD) conditions for another 14 days, using fluorescence tubes that were continuously on for 18 hours day^{-1} (Philips TL 50W, colour 84). From the start of the short-day (SD) period onwards, lamps were only on for 10 hours day^{-1} in order to promote flower induction and plants were spaced out from 99 to 42 plants m^{-2}. Plants were irrigated as required with a standard nutrient solution, adjusted to the cultivation phase and no growth regulators were applied. Temperature and relative humidity were automatically recorded each 15 min. Daily incident PAR was measured at crop level (resulting in an incident photosynthetic active radiation of: 17.6, 7.2 and 10.4 mol $m^{-2}d^{-1}$ when averaged over the LD period, SD period and whole cultivation period of the control treatment, respectively). A total of 160 plants (i.e. ten plants per treatment, obtained from two blocks consisting of five plants each) where destructively harvested at flowering stage. Final plant height, number of flowering shoots, inflorescence dry mass (excluding apical inflorescence) and inflorescence position were measured on each plant when three flowers were fully open (i.e. flowering stage; stage 10 LetsGrow.com). The reaction time per plant was also recorded.

Statistical Design and Analysis

The experimental set-up was a split-plot design with two blocks. Temperature was the main factor and light was the split factor. Analysis of variance was conducted, and treatment effects were tested at the 5% probability level. The statistical software package Genstat 7 (VSN International Ltd., Herts, UK) was used.

RESULTS AND DISCUSSION

Plant Height

Total plant height increased linearly with both PPFD ($P<0.001$) and temperature

(P<0.001) (Fig. 1). This positive response of plant height to PPFD and temperature is in agreement with the findings of Carvalho et al. (2005). These authors observed that in spring the stem elongation rate was higher as compared to autumn, but they could not separate the effects of light from the effects of temperature. However, from these results it is possible to observe that plant height responds more strongly to temperature increase. For instance, plants grown at 26°C were 60% taller than plants grown at 18°C, whereas plants grown at a PPFD of 200 μmol $m^{-2}s^{-1}$ were only 12% longer than plants grown at the lowest light levels.

Flower Characteristics

1. Number of Flowering Shoots. The number of flowering shoots (emerging from the axillary buds on the main stem) varied between 4.6 and 20.5 and was significantly influenced by the interaction between PPFD and temperature (P=0.041), though PPFD had a much stronger effect (Fig. 2A). At the same temperature treatments, number of flowering shoots increased by 2 to 4 fold when PPFD increased from 60 to 200 μmol $m^{-2}s^{-1}$. In contrast, the largest temperature effect was observed at the lowest PPFD, where the number of flowering shoots decreased by 40% with increasing temperature from 18°C to 26°C. This large increase in the number of flowering shoots at higher PPFD is closely related to the higher availability of photoassimilates as previously described for chrysanthemum (Carvalho and Heuvelink, 2003).

2. Average Inflorescence Size. Inflorescence size was studied based on the average inflorescence dry mass excluding the apical inflorescence (i.e. the ratio between side inflorescences dry mass and number of flowering shoots) and it gives an indication on the amount of flowers present in each shoot. Similarly to the number of flowering shoots, inflorescence size was significantly affected by the interaction between PPFD and temperature (P=0.010) (Fig. 2B). In general, higher light levels enhanced the number of flowers per shoot, specially at lower temperatures: plants grown at 18°C and receiving 200 μmol $m^{-2}s^{-1}$ had inflorescences that were on average more than two times heavier than the ones from plants receiving 60 μmol $m^{-2}s^{-1}$. However, increasing temperature strongly reduced the average flower dry mass. This is possibly due to the fact that plants grown at higher temperatures have a shorter cropping duration and, therefore, less assimilates are available also for the flowers.

3. Average Inflorescence Position. The average inflorescence position, measured as the vertical distance between the apical inflorescence and the inflorescence plateau (i.e. level where the top of most inflorescences is located) was significantly affected by PPFD (P=0.032) and temperature (P=0.018) (Fig. 3). In spite of the significant quadratic effect of PPFD the variation observed in this attribute was rather small (Fig. 3A). Temperature effect on the inflorescence distance was more pronounced and it promoted a 'triangular' shape (Fig. 3B). For instance, plants grown at 26°C had an inflorescence plateau located at 4.7 cm distance from the apical inflorescence, whereas this distance was 1.8 cm shorter in plants grown at 18°C.

Total Dry Mass

Total dry mass per plant (TDM) was significantly influenced by PPFD (P<0.001) and temperature (P=0.036). PPFD had a very strong effect on TDM: 1% more light increased plant growth rate by 0.60 to 0.86% (data not shown). In contrast, a significant temperature effect on TDM was only observed in plants grown at 26°C that were 10% lighter than plants grown at other temperatures.

Time to Flowering

Since the number of long-days given to each treatment was the same, time to flowering (i.e. time from planting until flowering) was only dependent on the response of the reaction time (i.e. time from the start of the SD period until flowering) to the studied climatic factors. Both PPFD (P<0.001) and temperature (P<0.001) had a significant quadratic effect on reaction time. Plants grown at a PPFD of 200 μmol $m^{-2}s^{-1}$ flowered 12

days earlier than plants grown at 60 μmol $m^{-2}s^{-1}$ (Fig. 4A). However, the effectiveness of reducing the reaction time declines as PPFD increases, due to a light saturation process. Increasing temperature from 18°C up to a maximum value of 24.4°C would drastically reduce the reaction time (from 82 days to 63 days). Nevertheless, a further temperature increase to 26°C results in longer reaction time (Fig. 4B). Similar effects of PPFD and temperature, to the ones above described for kalanchoe, were previously reported for chrysanthemum (Karlsson et al., 1989).

CONCLUDING REMARKS

Light and temperature are two climatic factors of utmost importance for quality and cropping duration control in kalanchoe. Based on these results, to reduce the kalanchoe cultivation period and, therefore, increase the annual yield two approaches are possible: increase PPFD (especially in autumn and winter crops) and/or increase temperature. However, this work clearly shows that the first strategy is more advantageous since increasing PPFD also enhances plant quality (strong increase in the number of flowering shoots and flower size, with only a marginal enlargement of plant height). In contrast, by increasing temperature this would shorten the reaction time but the plants would be drastically taller, with the same number of flowering shoots but with smaller inflorescences. The quantitative relationships presented in this paper give a good basis for extending, parameterize and calibrate the conceptual model developed by Eveleens-Clark et al. (2004). This will allow future simulations, for instance on the evaluation of the profitability of using assimilation light in kalanchoe production during the dark periods of the year.

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Figures

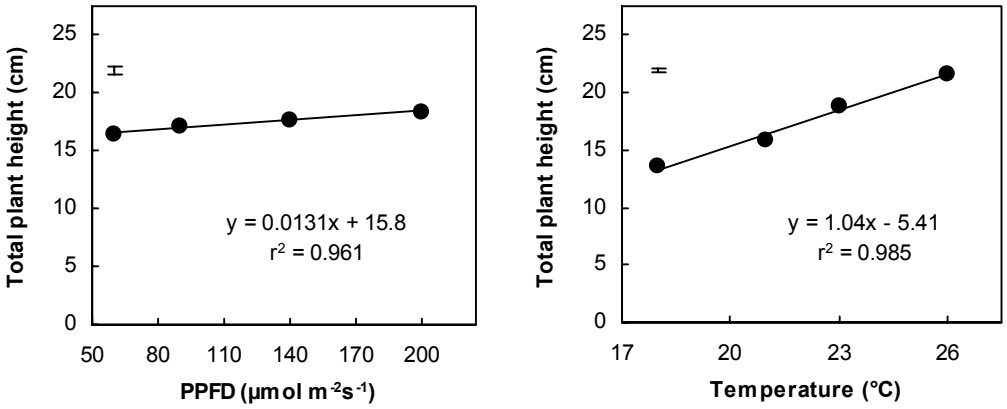


Fig. 1. Effect of photosynthetic photon flux density (A) and temperature (B) on total plant height of *Kalanchoe blossfeldiana* 'Anatole' at flowering. Lines represent linear regression. Vertical bars indicate LSD = 0.596 (A) and LSD = 0.345 (B).

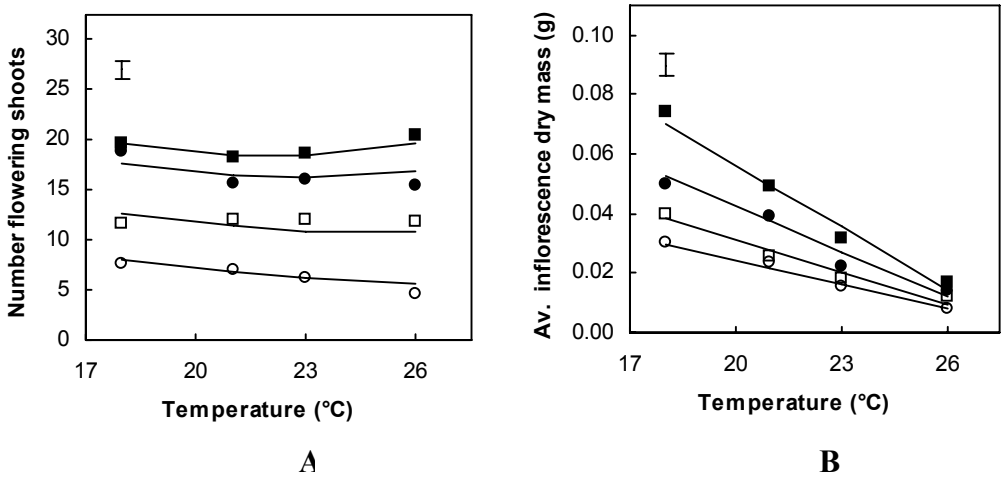
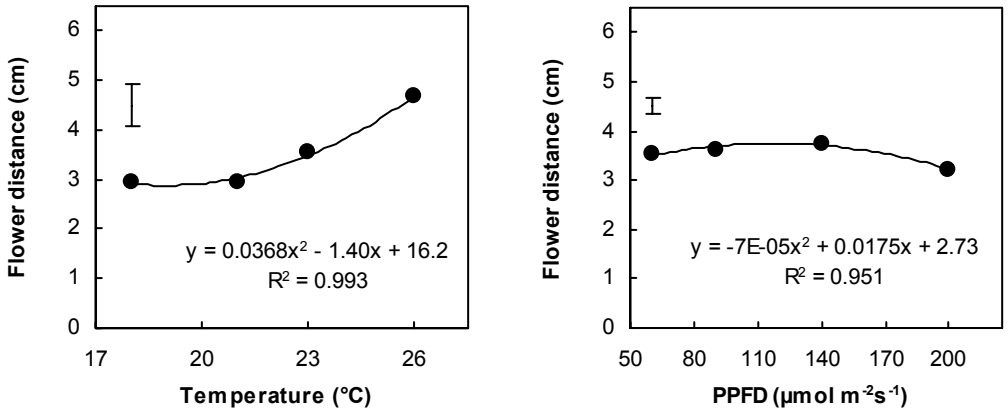
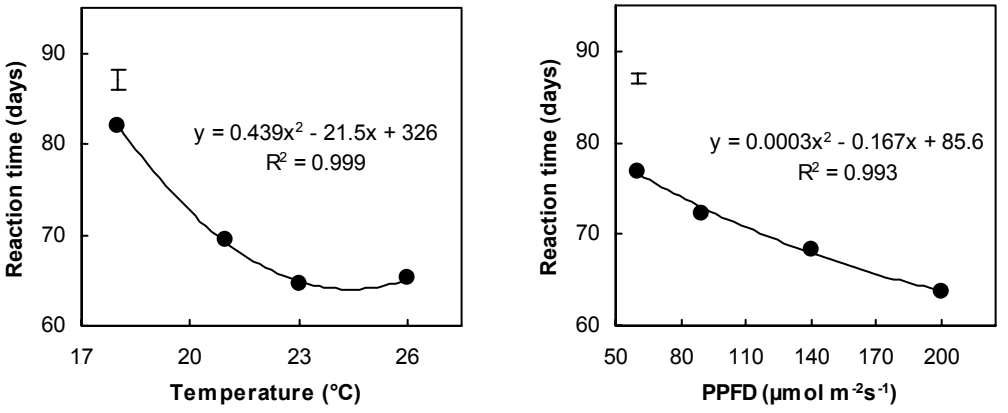


Fig. 2. Number of flowering shoots (A) and average inflorescence dry mass excluding the apical inflorescence (B) at flowering as a function of the interaction between photosynthetic photon flux density and temperature: ○ 60 µmol $m^{-2}s^{-1}$, □ 90 µmol $m^{-2}s^{-1}$, ● 140 µmol $m^{-2}s^{-1}$ and ■ 200 µmol $m^{-2}s^{-1}$. Lines represent regression model. Vertical bars indicate LSD = 1.87 (A) and LSD = 0.0093 (B).



A **B**

Fig. 3. Effect of photosynthetic photon flux density (A) and temperature (B) on average inflorescence position of *Kalanchoe blossfeldiana* 'Anatole' at flowering. Lines represent linear regression. Vertical bars indicate LSD = 0.342 (A) and LSD = 0.830 (B).



A **B**

Fig. 4. Effect of photosynthetic photon flux density (A) and temperature (B) on reaction time of *Kalanchoe blossfeldiana* 'Anatole'. Lines represent linear regression. Vertical bars indicate LSD = 1.16 (A) and LSD = 2.23 (B).