Improving Product Quality and Timing of Kalanchoe: Model Development and Validation

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Abstract

Predicting and controlling the visual product quality and the cropping duration is of utmost importance in year-round flowering pot plant production. Explanatory crop growth and quality models are valuable tools for scenario studies and dynamic crop control. A dynamic model was developed, calibrated and validated for plant height and cropping duration of *Kalanchoe blossfeldiana*. Data from a previously published study conducted in climate chambers with cultivar 'Anatole', under all combinations of four constant temperatures (18, 21, 23 and 26°C, equal day and night) with four photosynthetic photon flux densities (PPFD, 60, 90, 140 and 200 µmol m^{-2} s^{-1}), were used for model development and parameter estimation (calibration). Plant height was modelled taking into account the vegetative internode appearance rate (optimum response to both temperature and light) and the individual vegetative internode length against time, described by a Richards function. The asymptotic maximum (*A*) in this function increased linearly with light and quadratically with temperature. Added to this vegetative length is the generative length. The starting date of generative elongation quadratically decreased with temperature and light and generative elongation rate showed a linear increase with temperature and light. Cropping duration was predicted using the rate of flower development (inverse of reaction time, i.e. the time from start of short day until harvest stage), which increased quadratically with temperature and with light (no interaction). These modules were validated, with an independent data set collected at a commercial greenhouse in two growth seasons (winter and summer). Cropping duration was predicted well, but plant height was underestimated. The achievements and limitations of modelling dynamically the plant height and the cropping duration in year-round kalanchoe production are discussed.

INTRODUCTION

Kalanchoe production in The Netherlands is very capital-intensive and highly mechanized. Automated plant handling equipment and the use of colour cameras with image processing software and hardware for sorting out the plants would allow that pots can be transferred efficiently between glasshouse compartments that have an optimal environment for each specified stage of development. To make full use of these technologies by providing the desired environment for a target product quality and delivery date, crop models are essential.

Crop height and a predetermined delivery date are important quality parameters for all pot plants in a demand-driven market (Dijkshoorn-Dekker, 2002). Kalanchoe growers aim at producing a compact plant, with richly flowering umbels and one to three open flowers at harvest, grown in the shortest time 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 in a decision support system, it needs to be extended with a time to flower module, parameterised (calibrated) and validated. Carvalho et al. (2006) conducted

a climate room experiment to quantify the separate effects of photosynthetic photon flux density (PPFD) and temperature and their possible interactions on several external quality attributes and on cropping duration.

The present work aims at developing, calibrating and validating a dynamic model for plant height, and time to flowering for kalanchoe 'Anatole'. Development and calibretion is based on the conceptual model described by Eveleens-Clark et al. (2004) and the data from Carvalho et al. (2006). For validation independent data for a winter and a summer crop are collected in a commercial greenhouse. The model will provide insight into the development of height and into the planning of crop production.

MATERIALS AND METHODS

Experimental Set-up

The data used for the development of a dynamic model and parameter estimation were collected in a previous study conducted in climate chambers using *Kalanchoe blossfeldiana* 'Anatole' grown in 10.5 cm pots under all combinations of four constant temperatures (18, 21, 23 and 26°C, equal day and night) with four photosynthetic photon flux densities (PPFD, 60, 90, 140 and 200 μmol m^{-2} s^{-1}) (Carvalho et al., 2006). The implementation of the model for plant height and time to flowering was carried out in the dynamic simulation software package Powersim (www.powersim.com).

Both modules were validated with an independent data set. Model input is daily light sum and 24 h average temperature. These validation experiments were carried out on a commercial nursery in Middelburg, The Netherlands (Lat. 52°N) between December 2004 and August 2005 (Table 1). In both experiments unrooted cuttings of *Kalanchoe blossfeldiana* 'Anatole' with 3 leaf pairs were planted in 10.5 cm pots (filled with peat-based commercial potting compost). Plants were initially subjected to long-day conditions (LD, i.e. vegetative phase) with a maximum day-length of 13.5 h (SON-T lamps, 30.2 μmol m^{2} s^{-1} photosynthetic active radiation, PAR). For the induction of flowering, the compartment was blacked-out completely for 14 hours a day. At the start of short day (SD) period, the plants were spaced out from 92 plants m^{-2} to 45 plants m^{-2}. Plants were irrigated as required with a standard nutrient solution, adjusted to the cultivation phase and no chemical growth retardants were applied. Average daily temperature, light intensity, daily average CO_2 level, timing of screens (open/closed) and timing of lamps (on/off) were automatically recorded. Daily incident PAR reaching the crop was calculated in both experiments taking screening (shade screen and blackout screen) and assimilation lighting into account, and additionally it was measured at crop level in experiment 2. Details on achieved climate are presented in Table 1.

Every 2-3 weeks total plant height, vegetative and generative length and number of internodes (vegetative and generative) were determined. Final harvest was conducted when 1 to 3 flowers were fully open.

RESULTS AND DISCUSSION

Reaction Time

The reaction time of the crop is defined as the number of days from start of short day (SD) to harvest stage (1 to 3 open flowers) (Carvalho et al., 2006). Development rate, i.e. the inverse of the reaction time, is used in the model to calculate the development stage (0 = start of SD, 1 = harvest stage) and it was obtained under constant climate conditions in the calibration experiment. This rate showed an optimum response to temperature, and increased quadratically with light. No interaction between these climatic factors was found.

Reaction time was predicted accurately for the 16 calibration treatments. Reaction time varied between 58 and 86 days, was on average overestimated by 3% and the difference between measured and predicted reaction time was at most 4 days. Also for the validation experiments, reaction time was predicted very well. For the winter experiment

both measured and predicted reaction time was 69 days, whereas for the summer experiment this was 57 and 59, respectively.

Plant Height

Plant height is defined as the sum of vegetative length and generative length (Carvalho et al., 2005) and it also includes the apical inflorescence length, which starts to develop from visible flower bud stage (Fig. 1). The apical inflorescence length is about 2-3 cm when plants are harvest-ready, independently of temperature and light (data not shown). Note that this fixed value is not included in plant length mentioned further on in this paper. The vegetative length results from the number of internodes and internode elongation.

1. Vegetative Length: Internode Appearance Rate. Internode appearance rate (IAR) increased quadratically with both temperature and light (Fig. 2), without interaction. IAR was calculated from the slope of the linear part of the relationship between number of vegetative internodes and time (Fig. 3). The LD period in which these internodes were formed was relatively short (14 days) when compared to the total growth period of up to 103 days for the lowest light treatment at 18°C. The macroscopic appearance and elongation of internodes formed in the LD does continue into the SD period. On average 3 to 4 more internodes became visible after the start of SD (Fig. 3). This was also observed by Eveleens-Clark et al. (2003). The IAR ranged from 0.15 at 18°C to 0.19 internodes per day at 23°C or 26°C (Fig. 2). This means that 2.1 and 2.7 internodes were formed respectively during 14 LD's. Prediction of the number of internodes in time, based on the regression formula for IAR from Fig. 2, gave accurate results (Fig. 3). Note that this is a calibration, not an independent validation. Fig. 3 shows the most extreme treatments, all other treatments were in between. Predicted final internode number plotted against measured final internode number showed only a 2% underestimation on average. The difference between predicted and measured final internode number was less than 1, except for 3 treatments where the final internode number was overestimated by 1.5 or underestimated by 1 or 1.9 internodes. This was partly caused by the fact that the model only predicts integer node numbers.

2. Vegetative Length: Internode Elongation Rate. Internode elongation rate was taken as the derivative of a Richards function. Based on the previous finding that vegetative internodes on the same plant have a very homogeneous final length (Carvalho et al., 2005; Fig. 1), it was assumed that all vegetative internodes follow the same elongation curve and that treatment would only influence the asymptotic maximum of the Richards function (*A*). Based on the observed number of internodes in time and taking into account that some internodes were already partly elongated at the start of the treatments, the Richards function could be calibrated for each of the 16 treatments. *A* increased linearly with light and quadratically with temperature. Observed final internode length varied between 0.65 cm (18°C at 60 µmol m^2 s^{-1}) and 1.05 cm (26°C at 200 µmol m^2 s^{-1}).

3. Total Vegetative Length. For simulation of vegetative length the initially present internodes were given a starting value, e.g. one could be halfway its final elongation based on IAR at that specific treatment. With a time step of one day average light and average temperature received so far by a specific internode, is calculated. To avoid changes in final internode length for internodes that had already (almost) finished their elongation, *A* for a specific internode was fixed as soon as the length of that internode reached 90% of *A*. In this way an accurate dynamic pattern in time for vegetative length could be obtained for the calibration data (Fig. 4). The vegetative length increased almost linearly in time until a plateau was reached.

In a previous paper (Carvalho et al., 2004) we proposed to model the dynamic increase in vegetative length based on the number of internodes and an average internode length. This appeared to be impossible, as such average internode length could not be deduced from the data. Every time when a new internode appears, there is a sudden drop in average internode length. Using the final average internode length would lead to an overestimation of the length during stem elongation. At the start of the cultivation many

internodes are still expanding, whereas towards the end of the cultivation the number of expanding internodes decreases. Therefore, the daily increase in vegetative length had to be modelled for each internode separately.

4. Generative Length. The generative length was calculated as a whole using only the total generative elongation rate (GER) since modelling individual internodes and an IAR was too erratic (data not shown). By extrapolating the dynamic measurements of generative length, the starting time of the generative elongation could be determined for each of the 16 treatments (Fig. 5). Generative elongation does not start at the beginning of the SD (day 14) but only occurs from day 40 (23°C at 200 µmol m^2 s^{-1}) up to day 51 (26°C at 60 µmol m^2 s^{-1}) onwards. The starting date represents the time when the first generative internode (i.e. internode significantly longer than the vegetative internodes; Carvalho et al., 2005; Fig. 1) becomes macroscopically visible. This starting date decreased quadratically with temperature and light (no interaction), whereas GER is simulated as a linear positive function of temperature and light (no interaction).

5. Total Length. Final length varied between 9.9 and 20.0 cm depending on the treatment (Fig. 6). Predicted values were very close to the measured ones (Fig. 6), with on average only 1% overestimation for the 16 treatments used for model development and calibration. However, the model underestimated the final length by 2.4 and 6.7 cm for the winter and summer validation experiment, respectively. The number of internodes was predicted correctly. It appeared that in the greenhouse (validation) average final internode length was substantially higher than in the climate rooms (calibration). Data also gave the impression that internode elongation in the greenhouse continued for a longer period than in the climate rooms. There is no clear explanation for these differences, but light spectrum is known to influence elongation (e.g. Moe et al., 1991; Kim et al., 2004) and this may play a role here. The light spectrum in the climate rooms (white fluorescent tubes, Philips TL 50W, colour 84) is different from the solar spectrum (+ SON-T lamps in winter) in the greenhouse.

CONCLUDING REMARKS

A flexible, explanatory model for plant height patterns in time has been developed, calibrated and validated for one cultivar (‘Anatole’) and one pot size (10.5 cm). This model is an essential tool for production planning, optimal greenhouse climate control and scenario studies. Because the model is explanatory, we expect that it can be rather easily adapted for other cultivars and pot sizes. The main effects of pot size are closely related to the cultivation practices and can be easily included in the model as they correspond to normal input data (e.g. lower initial number of internodes and reduced LD period for smaller pot sizes). Pot size is not expected to influence reaction time. Important information needed to adapt the model for other cultivars would be their reaction time, final average vegetative internode length and final generative length under one specific condition. From these values a relative increase or decrease compared to ‘Anatole’ can be deduced. As a first approximation it would be reasonable to assume that responses to temperature and light are the same as for ‘Anatole’. Nevertheless, an experiment with several cultivars and further validation would be needed.

Plant height and timing are important quality parameters. The value of the model would increase if also the number of flower heads would be predicted. Based on our previous papers (Eveleens-Clark et al., 2004; Carvalho et al., 2005; Carvalho et al., 2006) it is expected that this extension is possible by simulating the total biomass production, as a close positive relationship between number of flower heads and total plant biomass exists.

ACKNOWLEDGEMENTS

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Tables

Table 1. Planting and harvest dates of *Kalanchoe blossfeldiana* 'Anatole' and climate data for the two validation experiments in a commercial greenhouse.

Expt.	Planting date	Harvest date	No. of LD[w]	Temperature[y] (°C)	Outside global radiation[y] (mol $m^{-2}d^{-1}$)	Total incident PAR[y] (mol $m^{-2}d^{-1}$)	CO_2-level[z] (ppm)
1	8 December	15-22 March	31	20.8/20.4/20.5	9.4/30.2/24.8	3.9/5.9/5.4	595
2	1 April	20-25 June	25	21.8/22.7/22.5	60.0/91.0/82.8	23.8/14.0/16.4	478

[w] Including rooting period of approx. 2 weeks

[y] Average over: long-day (LD) period / short-day period / whole cultivation period

[z] Average over the whole cultivation period

Figures

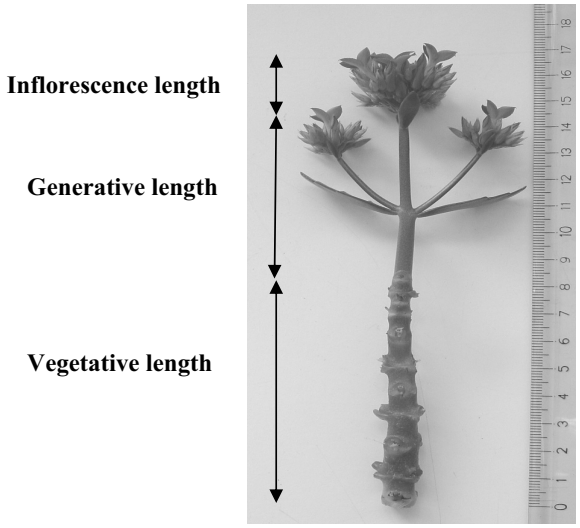

Fig. 1. Different components of plant height in *Kalanchoe blossfeldiana*.

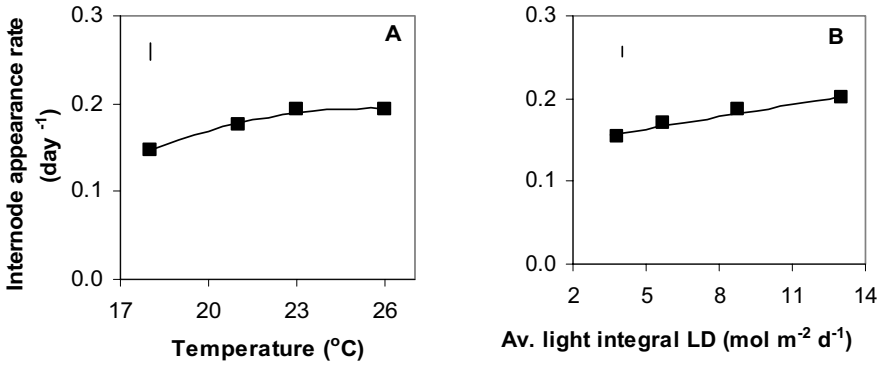

Fig. 2. Vegetative internode appearance rate as a function of the average temperature (A) and average light integral during long-day period (B). Curves represent the regression model. Vertical bars indicate LSD = 0.0191 (A), LSD = 0.0130 (B).

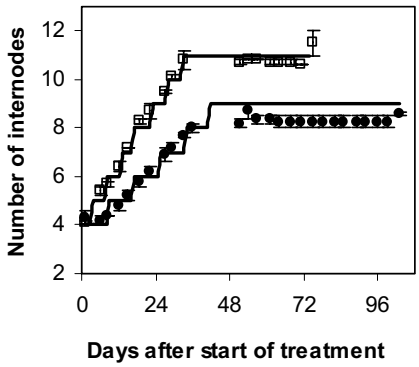

Fig. 3. Number of vegetative internodes in time at the two extreme PPFD/temperature combinations: (●) 60 µmol m^{-2} s^{-1} at 18°C and (□) 200 µmol m^{-2} s^{-1} at 26°C. Lines represent prediction by the calibrated model. Vertical bars indicate SE_{mean}. From 14 days after start of treatment onwards plants received SD, until then this was LD.

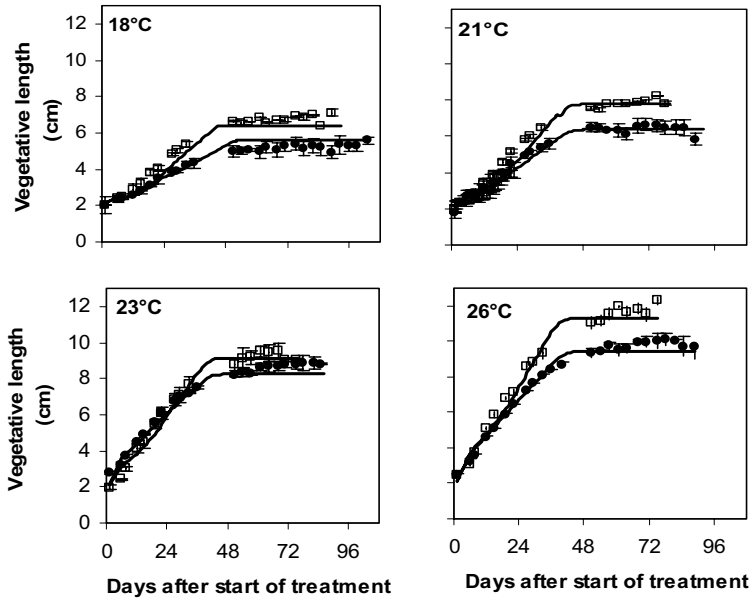

Fig. 4. Effect of temperature on time patterns of vegetative length of *Kalanchoe blossfeldiana* 'Anatole' at 60 µmol m^{-2} s^{-1} (●) and 200 µmol m^{-2} s^{-1} (□). Curves represent predicted patterns by the calibrated model. Vertical bars indicate SE_{mean}. From 14 days after start of treatment plants received SD, until then this was LD.

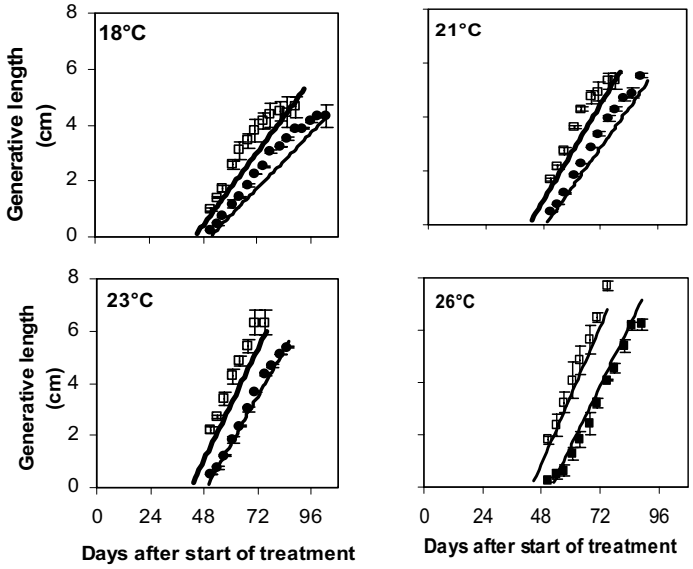

Fig. 5. Effect of temperature on time patterns of generative length of *Kalanchoe blossfeldiana* 'Anatole' at 60 µmol $m^{-2}s^{-1}$ (●) and 200 µmol m^{-2} s^{-1} (□). Lines represent predicted patterns by the calibrated model. Vertical bars indicate SE_{mean}. From 14 days after start of treatment plants received SD, until then this was LD.

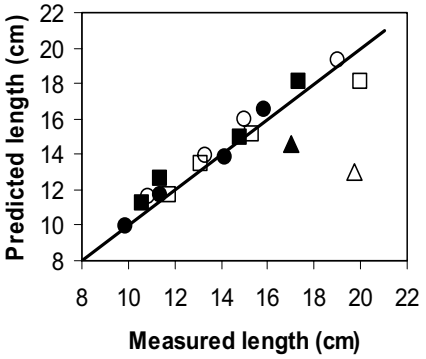

Fig. 6. Predicted final length (calibrated model) for the 16 treatments: ● 60, ■ 90, ○ 140 and □ 200 µmol m^{-2} s^{-1}, each at 4 temperatures, plotted against measured final length. Line shows x=y. Final length for both experiments at the commercial greenhouse are also included (▲ winter, Δ summer).