Modelling Visual Quality of *Kalanchoe blossfeldiana*: Influence of Cultivar and Pot Size

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Abstract

An explanatory model for predicting kalanchoe plant height and cropping duration has been developed for one cultivar and one pot size, as described in earlier papers. In two experiments (winter and summer) seven contrasting cultivars (‘Anatole’, ‘Debbie’, ‘Delia’, ‘Mie’, ‘Pandora’, ‘Tenorio’ and ‘Toleda’) and two pot sizes (7 and 10.5 cm) were analysed to make this model more generally applicable. The studied cultivars showed a strong variation in plant height (10.2 to 29.2 cm) and reaction time (55 to 64 days, from start of short-day period until harvest) when grown under the same conditions (values provided are for summer cultivation in 10.5 cm pots). The effect of pot size on plant height was closely related to the cultivation practices, which already corresponded to model input parameters. For instance, smaller pots resulted in shorter plants but this was due to a lower initial number of internodes and a reduced duration of long-day period. Additionally, growing plants in smaller pots resulted in a longer reaction time especially during winter (on average 8 days delay). The framework of the explanatory model previously developed for ‘Anatole’ grown in 10.5 cm pots was successfully adapted to other kalanchoe cultivars and pot sizes. It was concluded that when implementing this dynamic model to predict plant height and reaction time for different cultivars in different climate conditions, only few parameters have to be quantified and compared to the reference cultivar at one light and temperature condition.

INTRODUCTION

Predicting and controlling the visual product quality and cropping duration is of utmost importance in year-round flowering pot plant production (Eveleens-Clark et al., 2004; Carvalho et al., 2006b). Explanatory models are key tools for optimal greenhouse control, production planning and scenario studies in modern on-demand ornamental production. However, only a limited number of models for ornamental product quality exist (Heuvelink et al., 2004) and they have been mostly developed for cut flowers (Körner et al., 2006). Kalanchoe is an example of a flowering pot plant with a very capital-intensive, highly mechanised production system and with strict quality specifications (Eveleens-Clark et al., 2004; Carvalho et al., 2005). Therefore, this ornamental plant could clearly benefit from the implementation of explanatory models for assisting growers and consultants in their decision-making.

In a previous study a dynamic model for predicting plant height, number of flowering shoots and cropping duration was developed and validated for one kalanchoe cultivar (‘Anatole’) and one pot size (10.5 cm diameter) (Carvalho et al., 2006b). The data used for model development and parameter estimation were obtained in a climate chamber experiment, where plants were grown 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., 2006a). The model validation was further performed for a winter and a summer crop, using an independent data set that was collected in a commercial greenhouse (Carvalho et al., 2006b).

Cultivar differences must be taken into account when modelling plant height in kalanchoe (Carvalho et al., 2005). The effects of pot size on product quality and cropping duration have been poorly addressed. However, some studies show that larger pots resulted in taller plants both in alstroemeria and in chrysanthemum, but the effect on time to flower depended on the plant species (Healy and Klick, 1993; Brum et al., 2007). Therefore, before the reference explanatory model can be generally applied in year-round kalanchoe production it must be extended to other cultivars and pot sizes. The current study aims at quantifying and understanding the influence of cultivar and pot size on the visual quality and cropping duration of kalanchoe. The ultimate goal of this research is to use that information to extend the reference kalanchoe model.

MATERIALS AND METHODS

Experimental Set-Up

Two calibration experiments were carried out between December 2004 and August 2005 on a commercial nursery in Middelburg, The Netherlands (Lat.52^{o}N) (Table 1). In both experiments unrooted cuttings of seven *Kalanchoe blossfeldiana* cultivars (‘Anatole’, ‘Debbie’, ‘Delia’, ‘Mie’, ‘Pandora’, ‘Tenorio’ and ‘Toleda’) with an average of 3 or 4 leaf pairs were planted, respectively, in pots of 7 and 10.5 cm top diameter filled with peat-based commercial potting compost. These cultivars were selected based on their contrasting need of chemical growth retardants for controlling plant height. The pot sizes were chosen as together they represent around 80% of the total kalanchoe production in The Netherlands. Plants were initially subjected to long-day (LD) conditions. In winter a maximum day-length of 13.5 h was given to the plants, using supplementary lighting (SON-T lamps, 30.2 µmol m^{-2} s^{-1} photosynthetic active radiation, PAR). The duration of the LD period was predefined taking into account the pot size and planting date, as common practice in commercial production (Table 1). *Kalanchoe blossfeldiana* is a qualitative short-day (SD) plant, and SD was applied until harvest. At the start of SD period the compartments were blacked-out completely for 14 hours a day and the plants were spaced out from 92 plants m^{-2} to 45 plants m^{-2} (in 10.5 cm pots) and from 208 plants m^{-2} to 139 plants m^{-2} (in 7 cm pots). Plants were irrigated as required with a standard nutrient solution, adjusted to the cultivation phase and no chemical growth retardants were applied to the crop. Average daily temperature, outside global radiation, timing of screens (open/closed) and timing of lamps (on/off) were automatically recorded (Table 1). Daily incident PAR reaching the crop was calculated in both experiments taking screening (shade screen and blackout screen) and assimilation lighting into account. Additionally, these calculations were confirmed in Exp. 2 by measuring daily incident PAR at crop level (LI-COR, model LI-191SA; Lincoln, USA).

Vegetative length, generative length and number of vegetative internodes were determined every 2-3 weeks and at harvest stage (i.e. when one to three flowers per plant were fully open; Table 1). Details on the determination of the plant height characters are given in Carvalho et al. (2005). The reaction time per plant was also recorded.

Model Calibration

The parameters for the reaction time and for the plant height characters (i.e. vegetative internode appearance rate, average maximum vegetative internode length and total generative length) were determined in both calibration experiments, for the seven cultivars planted in 7 and 10.5 cm pots as described for ‘Anatole’ (Carvalho et al., 2006b). A factor representing the cultivar specific value of each of these parameters relative to the reference model (‘Anatole’ planted in 10.5 cm pots and grown in climate chamber) was given as model input (Table 2). For instance, if ‘Anatole’ (reference cultivar) has an observed reaction time of 69 days and another cultivar 66 days under the same growth conditions, the factor for reaction time of the new cultivar is 66/69. Response to temperature and light is assumed to be the same as for ‘Anatole’.

RESULTS AND DISCUSSION

Cultivar and Pot Size Effect

The studied cultivars grown under the same climate and the same cultivation conditions (i.e. pot size, plant density and duration of LD period) differed greatly in their visual quality and cropping duration. For instance, in the summer cultivation plants grown in 10.5 cm pots varied between 10.2 cm ('Delia') and 29.2 cm ('Tenorio') in final plant height (data not shown); had from 15 ('Anatole') up to 19 ('Debbie') flowering shoots (data not shown); and the reaction time was 55 ('Toleda') up to 64 ('Mie') days from start of short-day period until harvest stage (Table 2). These results are consistent with Carvalho et al. (2005) who conducted an in depth analysis of the final plant height formation of twenty kalanchoe cultivars and observed large variations between those cultivars when grown at the same climate conditions.

Concerning pot size most of the observed effects on the plant height components were closely related to the cultivation practices, as expected by Carvalho et al. (2006b). For instance, growing plants in smaller pots resulted in shorter plants, which is in agreement with previous findings in other ornamental plants (Healy and Klick, 1993; Brum et al., 2007). However, it was shown that in kalanchoe this reduction in plant height observed in smaller pots is due to lower initial number of internodes and reduced duration of long-day period, i.e. cultivation practices predefined by the grower. Since these cultivation practices already corresponded to standard data input into the reference model no adjustments needed to be made. Nevertheless, plants grown in smaller pots showed a longer reaction time (1 to 14 days, depending on cultivar), especially during winter (on average 8 days delay) (Fig. 1). In this study we could show that these results are possibly related to the lower initial leaf area (LA) present in smaller pots (on average 54% lower; Fig. 2). Thus, a higher initial LA results in a shorter reaction time, but the sensitivity of reaction time to the initial LA is cultivar dependent (e.g. reaction time in 'Pandora' was very sensitive to initial LA whereas in 'Anatole' this was only slightly affected; Fig. 2). This negative effect of initial LA on reaction time reflects the importance of the intercepted light integral in the reaction time, which was previously described in kalanchoe (Carvalho et al., 2006a). Therefore, increasing intercepted light integral by using cuttings with a higher initial LA could be an interesting solution for decreasing the reaction time in smaller pots.

Model Calibration

'Anatole' has developed an average of 0.14 internodes per day in both calibration experiments (Table 2). Since this value was 25% lower than that predicted by the reference model, IAR is given a factor 0.75. In contrast, the actual values of the parameter for the average maximum vegetative internode length were 1.3 in the winter and 1.6 in the summer. The relative values of this parameter (factors) and their actual values are similar because the predicted average maximum internode length of the reference cultivar when grown in the climate chamber varied between 0.9 and 1 cm. For reaction time, IAR and the generative length the cultivar-specific factor indicating the relative difference with 'Anatole' was similar in the summer and the winter (Table 2) and therefore for each cultivar only one factor was used for simplification.

The model predicted accurately the reaction time of different cultivars grown in 10.5 cm pots in both seasons, with only 1.4% overall overestimation (Fig. 1B). However, for 7 cm pot size the model was less accurate, resulting in an average underestimation of 7% (Fig. 1A). This underestimation is due to the above-described increase in reaction time at smaller pot size, which has not been included in the model. Concerning the plant height components, the explanatory model slightly underestimated the vegetative length for both pot sizes (Fig. 3A and 3C). The main reason for such underestimation is the shorter internodes found in the commercial greenhouse (calibration experiment) as compared to the climate chamber (model development experiment). Figure 4 shows the measured and predicted time patterns of the different plant height components. In

‘Tenorio’ it is clear that the underestimation of vegetative length is due to an underestimation of the maximum vegetative internode length and not due to an underestimation of the number of vegetative internodes, since the measured and predicted values of the latter had a good fit (Fig. 4C and 4D). Mortensen (1994) has shown that unlike many other plant species, in kalanchoe variations in the day and night temperature resulted in longer internodes as compared to plants grown at constant temperature conditions. Thus, we expect that these differences in vegetative internode length are due to the positive DIF (i.e. positive difference between day and night temperature) observed in the commercial greenhouse as compared to the zero DIF obtained in the climate chamber experiment. This also explains why the summer experiment (Exp. 2), where day temperatures were more difficult to control, had in general a higher maximum vegetative internode length as compared to the winter (Table 2). Predicted generative length was also underestimated, especially for plants grown in 10.5 cm pots (Fig. 3B and 3D) but the generative lengths were similar for both seasons. This is possibly due to the fact that a higher temperature in the summer increases the internode length but it shortens the reaction time, so there is less time for increasing the generative length that is still in its linear growth phase (Fig. 4A and 4C).

CONCLUDING REMARKS

In spite of the large differences in terms of visual quality and cropping duration encountered among cultivars grown under the same conditions (including pot size), the relative differences between the new cultivars and the reference cultivar are kept rather constant in the winter and summer experiment (i.e. factors are similar among experiments within each cultivar; Table 2). These findings confirmed our assumption that the responses to temperature and light are common to all cultivars (Fig. 1B). However, pot size has an effect on reaction time which is not included in the model (Fig. 1A). Therefore, when implementing the dynamic model developed for ‘Anatole’ grown at 10.5 cm (Carvalho et al., 2006b) to predict plant height for other kalanchoe cultivars in different climate conditions, only few parameters need to be quantified at one light and temperature condition and compared to the reference cultivar (i.e. average maximum vegetative internode length, internode appearance rate and generative length). Concerning cropping duration so far the model is limited to cultivars grown at the reference pot size (i.e. 10.5 cm). Moreover, we believe that this approach could be applied to other pot plant species bringing forward the possibility to find general processes in the field of predicting product quality and cropping duration of ornamentals. Those general processes are important for enhancing the development of quality models (Heuvelink et al., 2004), which could be further used as important components for establishing a guarantee label for keeping quality as proposed by Körner et al. (2006).

ACKNOWLEGDEMENTS

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Tables

Table 1. General information on two calibration experiments (winter and summer) conducted in a commercial greenhouse using seven cultivars of *Kalanchoe blossfeldiana* each planted in two pot sizes (7 and 10.5 cm diameter).

Exp	Pot size (cm)	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 $m^{-2}d^{-1}$)
1	7	29 Dec.	22 March – 6 April	24			
	10.5	8 Dec.	15 – 22 March	31	20.8 / 20.4 / 20.5	9.4 / 30.2 / 24.8	3.9 / 5.9 / 5.4
2	7	9 April	24 June – 8 July	20			
	10.5	1 April	21 June - 5 July	25	21.8 / 22.7 / 22.5	28.0 / 42.8 / 39.1	11.2 / 9.1/ 9.6

[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

Table 2. Actual plant parameters of seven cultivars of *Kalanchoe blossfeldiana* grown in a commercial greenhouse in winter (Exp. 1) and summer (Exp. 2) in 10.5 cm pots and their values relative to the reference cultivar 'Anatole' (i.e. factors) grown in the climate chamber experiment (= factor 1). Abbreviations: IAR = internode appearance rate; IN = internode.

Cultivar	Exp	Reaction time (days)	*Factor reaction time*	IAR (internode /day)	*Factor IAR*	Av. max. veg. IN length (cm)	*Factor av. max. veg. IN length*	Generative length (cm)	*Factor generative length*
Anatole	1	69	*1.00*	0.13	*0.75*	1.3	*1.3*	7.8	*1.00*
	2	57	*1.00*	0.14	*0.75*	1.6	*1.6*	7.2	*1.00*
Debbie	1	68	*0.99*	0.12	*0.69*	1.2	*1.2*	9.3	*1.19*
	2	54	*0.95*	0.15	*0.80*	1.7	*1.7*	9.2	*1.28*
Delia	1	68	*0.99*	0.09	*0.52*	0.9	*0.9*	3.3	*0.42*
	2	56	*0.98*	0.11	*0.59*	1.1	*1.1*	3.9	*0.55*
Mie	1	74	*1.07*	0.08	*0.46*	1.9	*1.9*	6.2	*1.26*
	2	64	*1.12*	0.07	*0.38*	1.7	*1.7*	6.7	*1.07*
Pandora	1	72	*1.04*	0.14	*0.81*	1.2	*1.2*	4.7	*0.60*
	2	59	*1.04*	0.16	*0.86*	1.1	*1.1*	4.2	*0.58*
Tenorio	1	72	*1.04*	0.12	*0.69*	1.9	*1.9*	9.2	*1.18*
	2	60	*1.05*	0.14	*0.75*	2.2	*2.2*	7.8	*1.08*
Toleda	1	66	*0.96*	0.11	*0.63*	1.6	*1.6*	12.9	*1.65*
	2	55	0.96	0.13	0.70	1.6	*1.6*	11.3	*1.57*

Figures

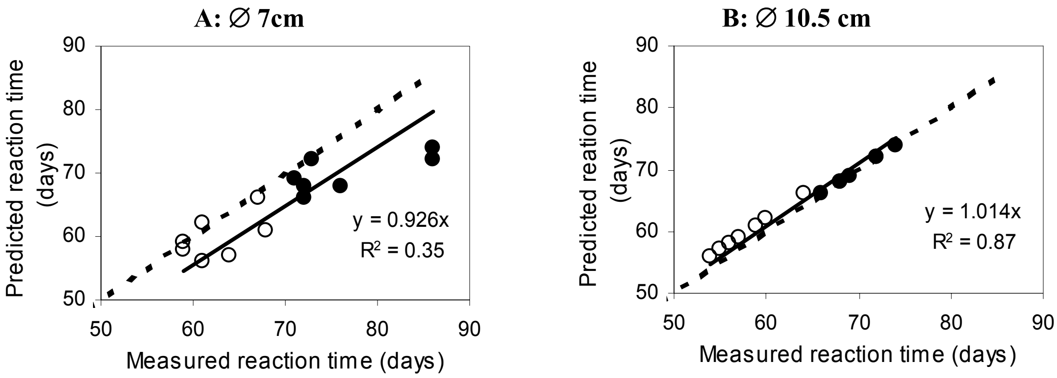

Fig. 1. Predicted reaction time plotted against measured reaction time for seven kalanchoe cultivars planted in pots with 7 cm (A) and 10.5 cm (B) diameter, during winter (●, Exp.1) and summer (○, Exp. 2). Solid line represents linear regression and dashed line represents 1:1 relationship.

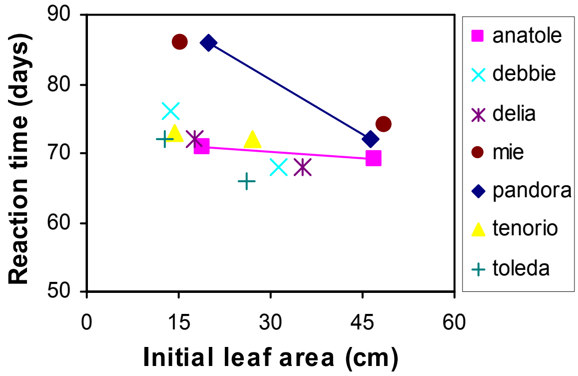

Fig. 2. Observed reaction time in winter as a function of the initial leaf area in seven kalanchoe cultivars planted in pots with 7 cm (higher reaction time values) and 10.5 cm (lower reaction time values) diameter. Lines illustrate cultivar differences in the sensitivity of reaction time to the inicial leaf area.

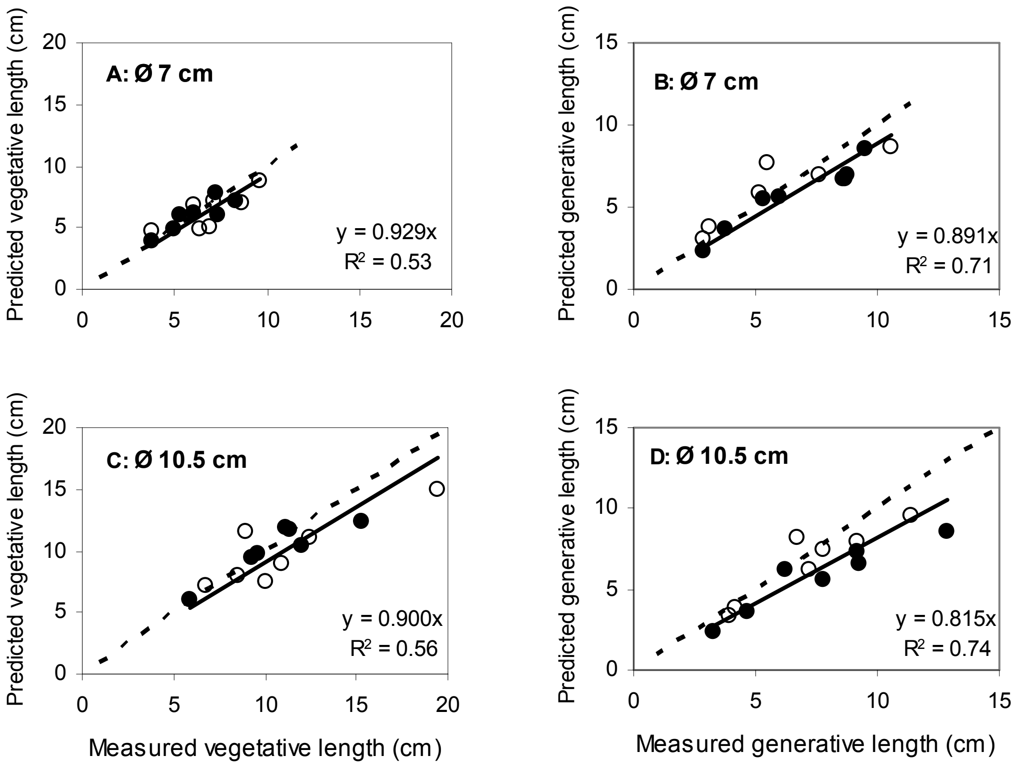

Fig. 3. Predicted and measured vegetative length (A and C) and generative length (B and D) at harvest of seven kalanchoe cultivars planted in 7 cm (A and B) and 10.5 cm (C and D) pots, during winter (●, Exp.1) and summer (○, Expt. 2). Solid line represents linear regression and dashed line represents 1:1 relationship.

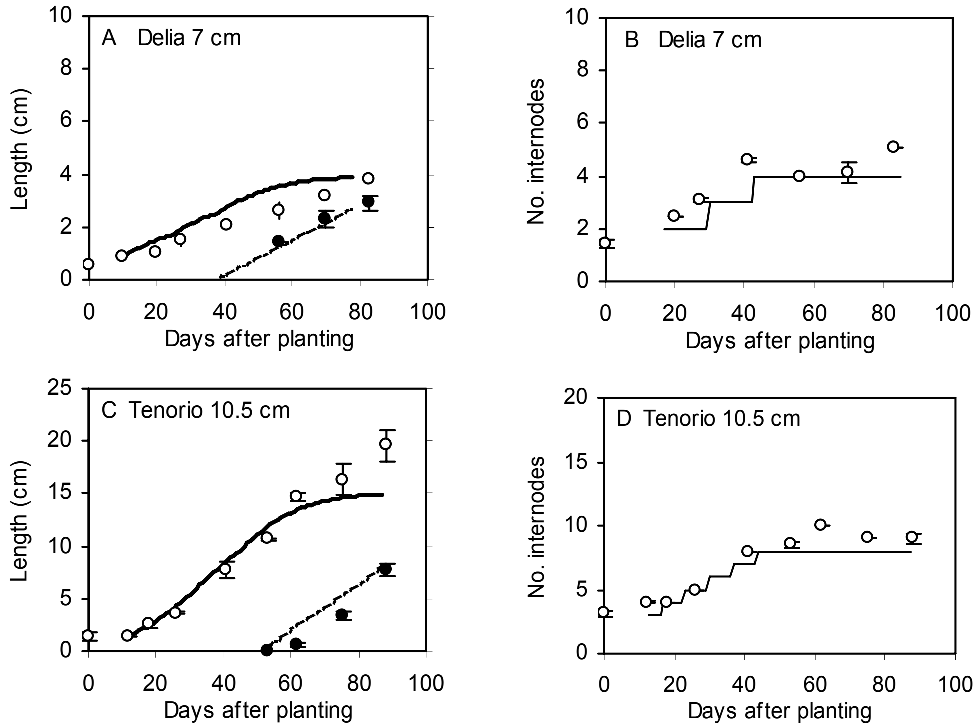

Fig. 4. Time patterns of vegetative length (○), generative length (●) (A and C) and number of vegetative internodes (B and D) in the two extreme combinations: shortest cultivar 'Delia', grown in 7 cm pots during winter (A and B) and tallest cultivar 'Tenorio' grown in 10.5 cm pots during summer. Symbols represent measured values and solid lines indicate predicted patterns.