Modelling External Quality of Cut Chrysanthemum: Achievements and Limitations

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Keywords: *Dendranthema grandiflorum*, flower area, flower number, flower size, simulation model, plant height, visual quality

Abstract

This paper provides an overview of the achievements and limitations of modelling external quality of cut chrysanthemum. A series of greenhouse experiments were conducted in different seasons to quantify the effects of the climate conditions and of the cultivation practices. This information was used as the basis for parameter selection and estimation, and for building the modules for plant height, number of flowers per plant and individual flower size. Increased assimilate availability by higher daily incident photosynthetic active radiation (PAR, 4.2 to 18.3 mol m^{-2} d^{-1}), higher CO_2 concentration (345 to 623 µmol mol^{-1}) and lower plant density (80 to 32 plants m^{-2}) hardly influenced stem length (maximum increase of 10%). Nevertheless, the duration of the long-day period (0 to 21 days) and temperature (16 to 28°C) are required inputs when predicting stem length, since these strongly enhanced the number of internodes and the average internode length. A module is developed for predicting number of flowers excluding flower buds (NF) based on the total aerial fresh mass per plant (TFM) (NF = 0.210TFM – 1.25). This relationship accurately described NF for highly diverse growth conditions (r^2 = 0.84). In contrast, individual flower size of the fully open flowers did not respond to the assimilate availability showing a rather constant value: 0.21 g flower^{-1}; 32 cm^2 flower^{-1}. However, when the incident PAR during the short-day period was under a threshold value (7 mol m^{-2} d^{-1}; i.e. autumn crops) individual flower size decreased linearly with decreasing PAR and higher temperatures resulted in smaller flowers. The practical application of these modules is discussed.

INTRODUCTION

The development of models on product quality has been an important and challenging issue in greenhouse crop simulation, over the last few years (Challa, 2002). Nevertheless, only few models for ornamental crops are available (Marcelis et al., 1998) and these are mainly focused on the growth and development, rather than on product quality (Gary et al., 1998). Lee (2002) developed and validated a photosynthesis-driven growth model, for the prediction of dry mass production in year-round cut chrysanthemum (CHRYSIMv1.0). Since the visual (external) quality aspects have a large influence on the selling price of chrysanthemum, this explanatory model could highly benefit from the incorporation of 'modules' to predict the main external quality aspects.

To predict the main external quality aspects of cut chrysanthemum a good quantification and understanding of the effects of the above-ground growth conditions is needed. Carvalho and Heuvelink (2001) made an attempt to integrate the available knowledge on this topic. From their literature study it became clear that quality aspects were rarely the focus in studies on chrysanthemum. The information was widely spread and often a clear understanding of the processes behind a quality aspect was lacking, and the results could not easily be generalised. Furthermore, some contradictions were also found when comparing different studies. Part of these contradictions was possibly related to the use of different cultivars in different studies, but others needed additional research.

Proc. Int'l. WS on Models Plant Growth &
Contr. Prod. Qual. in Hort. Prod.
Eds. M. Fink and C. Feller
Acta Hort. 654, ISHS 2004

For instance, the conflicting results about validity of the DIF concept (difference between day and night temperature) to predict internode length could be later clarified (Carvalho et al., 2002). Moreover, the physiological background of this concept also needed further investigation (Schouten et al., 2002). In contrast to the influence of temperature on stem length, only limited information is available on the flower characteristics, e.g. on number of flowers per plant and flower size of chrysanthemum. The effects of plant density and duration of the long-day (LD) period on various quality aspects is also a weak point in chrysanthemum research.

This paper is based on a large number of published and unpublished data from experiments conducted over two years. The effects of the climate conditions (temperature, light intensity and CO_2 concentration) and of the cultivation practices (duration of the LD period and plant density) on several external quality aspects of cut chrysanthemum were quantified and analysed. With these data important functional relationships were developed, which provides a basis for modelling several chrysanthemum external quality attributes. The aim of the present study is to give an overview of the achievements and limitations of modelling external quality of cut chrysanthemum and to propose how to combine that information into 'modules' to predict the main external quality aspects. Special attention is given to the prediction of plant height, number of flowers and flower size, since these are very important external quality attributes that needed further investigation.

MATERIAL AND METHODS

Several experiments were conducted between Sept. 1999 and Jul. 2001 in compartments (12.8 m × 12.0 m) from a multispan Venlo-type glasshouse (Wageningen University, The Netherlands, lat. 52°N) using *Chrysanthemum* 'Reagan Improved' (Fides Goldstock Breeding, Maasland, The Netherlands), planted in soil beds. The following growth conditions were analysed: temperature (16 to 28°C); daily incident PAR (4.2 to 18.3 mol m^{-2} d^{-1}); CO_2 concentration (345 to 623 µmol mol^{-1}); plant density (32 to 80 plants m^{-2}) and duration of the LD period (from 0 to 21 days). In each experiment, plants were harvested at a specific stage of development, i.e. when the first row of disc florets had reached anthesis in at least three inflorescences (flowers) per plant. Since within each experiment flower development rate slightly differed among the treatments, harvest was spread over a maximum of eight days. For details on the experimental set-up see Carvalho and Heuvelink (2003).

PREDICTING EXTERNAL QUALITY ASPECTS

Plant Height

In cut chrysanthemum plant height and stem length showed exactly the same results since the former was equal to the latter plus 8 to 11 cm from the length of the uppermost flower peduncle at harvest stage (data not shown). Therefore we refer to the plant height, which is most sound in terms of visual quality. The module, however, was build for stem length. A module for stem length could be based on the prediction of the number of internodes and the internode length (Fig. 1). Since chrysanthemum has a determinate growth pattern under SD conditions, new internodes are formed only until the start of flower initiation. The longer the duration of the LD period the taller the plants, as more time exists to form new internodes (Carvalho and Heuvelink, 2003; Carvalho et al., 2003). This explains the positive linear relationship between plant height and LD period observed by Carvalho et al. (2003). Temperature was also found to have a strong positive effect on the number of internodes, due to its effect on the internode appearance rate (IAR) (Carvalho et al., 2002). This relationship was described as a quadratic response of IAR to day temperature (DT), with an optimum at 25.7°C ($IAR = -0.0022DT^2 + 0.113DT - 0.75$; $R^2 = 0.88$). Concerning the final internode length, a positive linear relationship with DIF was observed [Final internode length (mm) = 0.547DIF + 16.57] (Carvalho et al., 2002).

Although several growth conditions have been described to affect chrysanthemum stem elongation (Carvalho and Heuvelink, 2001), only the temperature and the length of the LD period had a major influence on plant height. Increased assimilate availability by higher light intensity, higher CO_2 concentration and lower plant density only increased plant height with a maximum of 10% (Carvalho and Heuvelink, 2003). Hence, it can be concluded that stem elongation is not principally a matter of assimilate availability. As soon as a minimum requirement for assimilates is guaranteed, more assimilates do not enhance the elongation of the internodes (Schouten et al., 2002; Carvalho and Heuvelink, 2003). This conclusion is supported by the absence of a seasonal effect on stem length, even though incident photosynthetically active radiation (PAR) increased by more than a factor four from winter to summer crops (Carvalho and Heuvelink, 2003). Lee (2002) suggested that applying the concept of specific stem length (i.e. average stem length per g of stem dry mass, cm g^{-1}; e.g. Kropff and Van Laar, 1993) could be an interesting approach for modelling chrysanthemum stem length based on photosynthesis and dry mass partitioning into the stem. The major advantage of using such approach would be the possibility of directly including this information into a photosynthesis-driven model. Nevertheless, this approach is not interesting in the case of cut chrysanthemum as assimilate availability has only a minor effect on stem length. Stem length of cut chrysanthemum should be, therefore, modelled separately from crop photosynthesis.

Number of Flowers per Plant

A positive linear relationship between the number of flowers per plant, including flower buds (NF^+), and the total aerial plant dry mass (TDM) was found (Carvalho and Heuvelink, 2003; $NF^+ = 1.938TDM - 2.34$). This module adequately described NF^+, for highly diverse growth conditions, i.e. daily incident PAR (4.2 to 18.3 mol m^{-2} d^{-1}), CO_2 concentration (345 to 623 µmol mol^{-1}) and duration of the LD period (0 to 21 days). The variation in temperature was smaller, but still between 19.1 and 22.6°C (Carvalho and Heuvelink, 2003). This relationship was further validated using an independent data set (Carvalho et al., 2003). Simulated and measured TDM showed a good agreement for the nine studied combinations of LD period (2, 9 and 16 days) and plant densities (48, 64 and 80 plants m^{-2}), with an average underestimation of 4% only (Carvalho et al., 2003).

In contrast with stem length, and since NF^+ is closely related to the assimilate availability, a photosynthesis driven crop growth model to predict TDM (Lee, 2002) can be extended with this module for predicting NF^+. Moreover, since flower buds do not have a commercial value, because buds do not develop into flowers during vase life (data not shown), the above-referred relationship can be made more practical, from the viewpoint of product quality. This can be done when using total aerial fresh mass (TFM), instead of TDM, and by predicting the number of flowers per plant excluding flower buds (NF). Flower buds are defined as buds larger than 5 mm, but with the ray florets not yet separated from the inflorescence disc. Using the data from the same experiments as Carvalho and Heuvelink (2003), a similar positive linear relationship is observed when relating number of flowers including (Fig. 2a) or excluding (Fig. 2b) flower buds with TFM.

Attention should, however, be paid when using these modules for predicting the number of flowers at low light intensity combined with a relatively high temperature. For instance, Carvalho et al. (2004a) found that temperature had a strong positive effect on NF^+ but only a minor influence on TDM. When temperature increased from 17 to 21°C, plants showed 47% higher NF^+ whereas TDM only increased by 7%. For this reason the regression module from Carvalho and Heuvelink (2003) gave a good prediction for the 17°C temperature treatment (5% overestimation), but it underestimated NF^+ in the 21°C treatment with 23%. The reason for this discrepancy may be related to the different range of temperatures used in both studies. However, this is most likely due to an interaction between irradiance and temperature, as NF^+ is less temperature sensitive in plants grown under high light levels (Carvalho and Heuvelink, 2003). Several studies reported that increased photosynthetic photon flux can partly reduce the effect of high temperature conditions (e.g. Karlsson and Heins, 1986; Karlsson et al., 1989). Therefore, a significant positive effect of temperature on NF^+ at low light conditions should be included in the module, in particular for temperature in the last phase of the short-day (SD) period (i.e. from visible flower bud till harvest). Carvalho et al. (2004a) showed such a linear relationship between temperature and NF^+. However, to establish such function more accurately this interaction between light and temperature needs further investigation, using a wider range of light and temperatures.

Individual Flower Size

When plant assimilate status becomes more favourable (e.g. wider spacing and/or higher light intensity), chrysanthemum will react with producing more flowers and flower buds, rather than larger flowers (Carvalho and Heuvelink, 2003; Carvalho et al., 2004b). However, it has been clearly demonstrated that the reason for this response is not that flowers would not be able to grow bigger, as actual flower dry mass is only 42% of potential flower dry mass (Carvalho et al., 2004b). Therefore, for the prediction of the individual flower dry mass or individual flower area, light intensity does not need to be taken into account, unless incident PAR during the SD period is under a threshold value (Fig. 3). For light values below the threshold value (around 7 mol m^{-2} d^{-1} for 'Reagan Improved') a positive linear relationship between flower size and light level was observed, but above the threshold flower size remained constant: 0.21 g $flower^{-1}$; 32 cm^2 $flower^{-1}$ (Carvalho and Heuvelink, 2003). Temperature during the SD period is an important model input (Fig. 3). Carvalho et al. (2004a) developed a temperature regression model that includes the distinct effects of temperature, according to the phase of the SD period. Nevertheless, similarly to the above described interaction between the irradiation and temperature on NF^+, it was found that higher temperatures during the SD period had only a negative effect on flower size at low irradiance levels (Carvalho et al., 2004a). Further research is needed to find out if a threshold value for light exists, under which high temperatures have a negative effect.

When modelling flower size in spray-type cut chrysanthemum flower position was found to be irrelevant, except when comparing flowers located on the first and second order axillary shoots (Carvalho et al., 2004b). Although further research is needed to determine whether a constant ratio between size of first and second order flowers exists, it was observed that the latter had around 60% of the dry mass and area of the former (Carvalho et al., 2004b). If such constant ratio would be general, size of the second order flowers could be predicted from the size of the first order ones. Further investigation is also needed on the quantification of the effects of the growth conditions on the number of second order flowers. Light intensity and plant density certainly affect this aspect, as they are known to play an important role in chrysanthemum branching (Carvalho and Heuvelink, 2001).

PRACTICAL APPLICATION AND FUTURE RESEARCH

As the daily light integral plays an important role in several quality aspects, special attention should be paid to this factor. For instance, when chrysanthemum is planted in September (autumn crop) quality is drastically reduced in terms of TFM, NF and even a reduction in flower size is observed (Carvalho and Heuvelink, 2003; Carvalho et al., 2003). The use of supplementary assimilation lamps in the autumn and winter crops is, therefore, an important tool to enhance external quality. However, economic calculations are necessary to determine whether their use is profitable and which light intensity should be installed (e.g. Roelofs et al., 2001). An example of that, only focused on TFM, was given already by Lee et al. (2002). Carvalho et al. (2003) conducted also a case study to show that the use of an explanatory model that incorporates some quality aspects, is extremely valuable in terms of decision support as several options are possible to obtain a given quality and these options are very much dependent on the planting week. In their study a photosynthesis driven crop growth model for predicting total dry mass in cut chrysanthemum (Lee et al., 2002) was validated and further used to address some practical questions concerning the choice for the duration of the long-day period and plant density.

From this paper it is clear that external quality in cut chrysanthemum is a rather complex phenomenon as several growth conditions can affect many quality aspects. The use of simulation models, is therefore very helpful to define the 'optimum greenhouse climate' to reach a certain quality at harvest. Although this research was strongly based on one cultivar ('Reagan Improved'), it covers different seasons and a wide range of growth conditions within experiments. Thus, the results presented here are rather general and were to some extent also validated for cultivars very different from 'Reagan Improved' (e.g. 'santini' type cultivars) (Carvalho and Heuvelink, 2003). The model is explanatory and built up from individual modules, such that it is relatively easy to adapt it to other cultivars. Most likely, the model structure will not change, but several model parameters are certainly cultivar specific. These parameter values may be determined from a limited number of experiments. For example, considering that the relationship between TFM and NF is linear, only two extreme conditions, resulting in a low and in a high TFM are needed for each new cultivar to determine this relationship. The model could include cultivar correction factors, which are set to one for 'Reagan Improved' and adapted for other cultivars by calculating the ratio between a parameter for a given cultivar and for 'Reagan Improved'. The advantage of this approach is the limited number of experiments that it will require to adjust the modules to other cultivars.

In order to calculate an optimum greenhouse environmental strategy to minimise costs and to produce a plant of a certain quality (Karlsson et al., 1983), or to decide on certain investments (e.g. supplementary light), this study should be complemented with an economical analysis. This would allow quantifying the additional costs of producing a higher quality chrysanthemum. It would also be very interesting to analyse the postharvest performance (vase life) of a 'high external quality chrysanthemum' and relate it to its growth conditions. A detailed study using a large range of cultivars to calibrate and validate the current modules is particularly important because many new cultivars are introduced in the market every year. It is concluded that to prove the value of the present work for practice, extensive validation with commercial data is needed. After proven validity under commercial conditions, the present model can be included in a decision support system for chrysanthemum growers.

ACKNOWLEDGEMENTS

This research is part of a project financially supported by PRAXIS XXI-Ph.D. grant (fellowship BD16196/98), from Fundação para a Ciência e a Tecnologia, Portugal.

Literature Cited

Challa, H. 2002. Crop models for greenhouse production systems. Acta Hort. 593:47-53.

Carvalho, S.M.P. and Heuvelink, E. 2001. Influence of greenhouse climate and plant density on external quality of chrysanthemum (*Dendranthema grandiflorum* (Ramat.) Kitamura): first steps towards a quality model. J. Hort. Sci. & Biotech. 76:249-258.

Carvalho, S.M.P. and Heuvelink, E. 2003. Effect of assimilate availability on flower characteristics and plant height of cut chrysanthemum: an integrated study. J. Hort. Sci. & Biotech. 78:711-720.

Carvalho, S.M.P., Dhonukshe, V.B. and Heuvelink, E. 2003. Interactive effects of duration of long-day period and plant density on external quality of cut chrysanthemum. Acta Hort. 624:335-342.

Carvalho, S.M.P., Abi-Tarabay, H. and Heuvelink, E. 2004a. Temperature in three phases of the cultivation period influences chrysanthemum flower characteristics. *Submitted.*

Carvalho, S.M.P., Heuvelink, E., Harbinson, J. and Van Kooten, O. 2004b. Effect of sink-source ratio and flower position on chrysanthemum flower size. *Submitted.*

Carvalho, S.M.P., Heuvelink, E., Cascais, R. and Van Kooten, O. 2002. Effect of day and night temperature on internode and stem length in chrysanthemum: is everything explained by DIF? Ann. Bot. 90:111-118.

Gary, C., Jones, J.W. and Tchamitchian, M. 1998. Crop modelling in horticulture: state of the art. Sci. Hort. 74:3-20.
Karlsson, M.G. and Heins, R.D. 1986. Response surface analysis of flowering in chrysanthemum ‘Bright Golden Anne’. J. Amer. Soc. Hort. Sci. 111:253-259.
Karlsson, M., Heins, R.D. and Carlson, W.H. 1983. Development of environmental strategies based on plant growth models. Acta Hort. 147:153-160.
Karlsson, M.G., Heins, R.D., Erwin, J.E., Berghage, R.D., Carlson, W.H. and Biernbaum, J.A. 1989. Irradiance and temperature effects on time of development and flower size in chrysanthemum. Sci. Hort. 39:257-267.
Kropff, M.J. and Van Laar, H.H. 1993. Modelling crop-weed interactions. CAB Intl., Wallingford. 274p.
Lee, J.H. 2002. Analysis and simulation of growth and yield of cut chrysanthemum. PhD Dissertation, Wageningen Univ., The Netherlands. 120p.
Lee, J.H., Heuvelink, E. and Challa, H. 2002. A simulation study on the interactive effects of radiation and plant density on growth of cut chrysanthemum. Acta Hort. 593:151-157.
Marcelis, L.F.M., Heuvelink, E. and Goudriaan, J. 1998. Modelling biomass production and yield of horticultural crops: a review. Sci. Hort. 74:83-111.
Roelofs, T., Lee, J.H. and Heuvelink, E. 2001. Belichtingsniveau chrysant heeft optimum nog niet bereikt. [Assimilation light intensity applied in practice in cut chrysanthemum is still sub-optimal]. Vakblad voor de Bloemisterij 18:48-49.
Schouten, R.E., Carvalho, S.M.P., Heuvelink, E. and Van Kooten, O. 2002. Modelling of temperature-controlled internode elongation applied to chrysanthemum. Ann. Bot. 90:353-359.

Figures

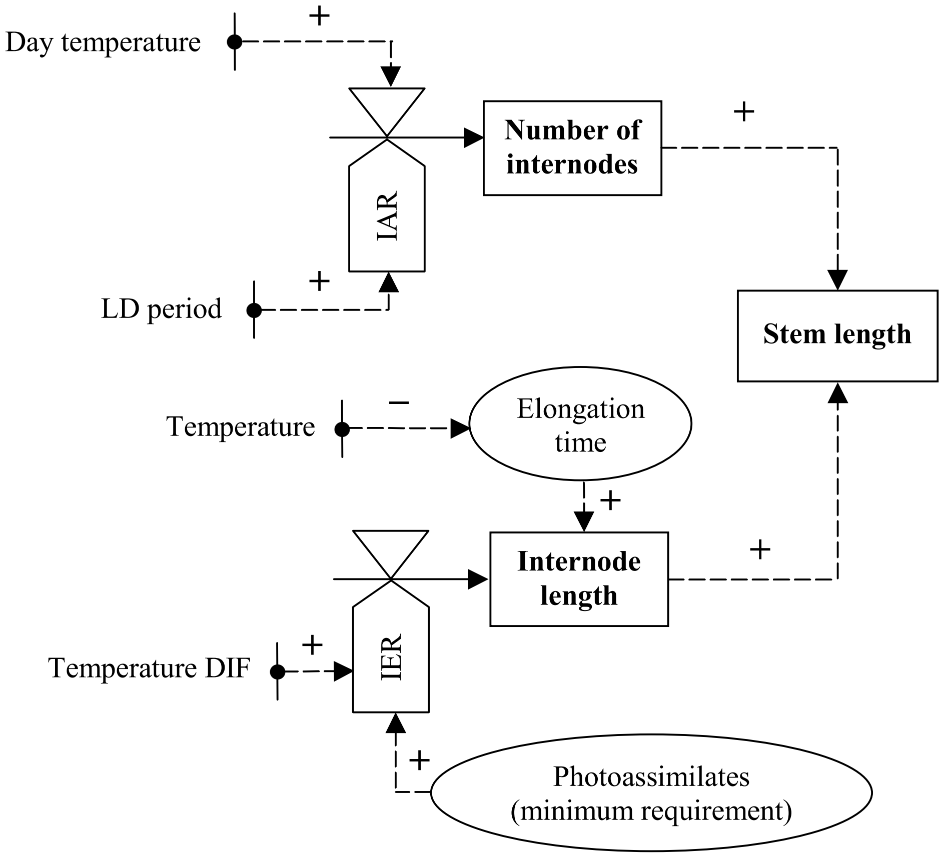

Fig. 1. Relational diagram for stem length in cut chrysanthemum. Boxes are state variables, ellipses are parameters and valves are rate variables. Dashed arrows represent information flow: (+) indicates positive influence, (–) indicates negative influence. Abbreviations: DIF = difference between day and night temperature; IAR = internode appearance rate; IER = internode elongation rate; LD = long-day.

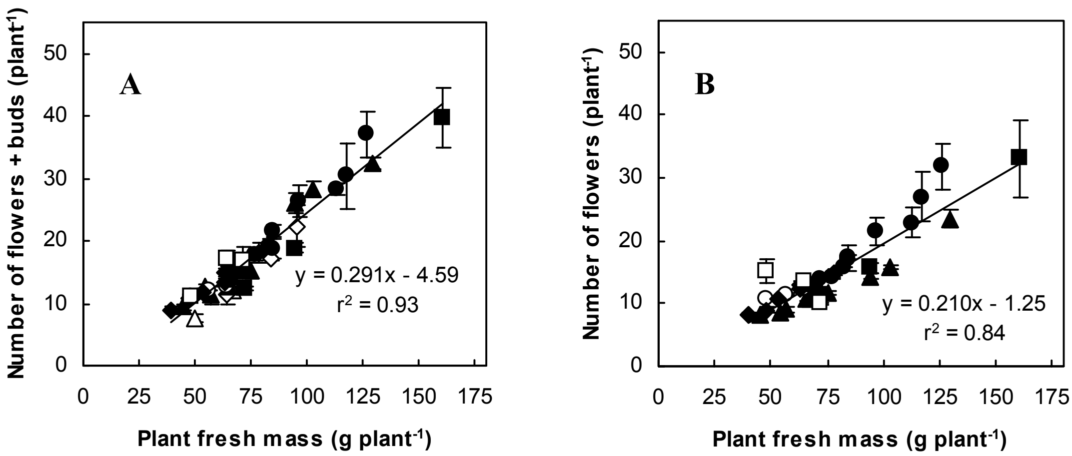

Fig. 2. Relationship between: (A) total number of flowers per plant, including buds, and total aerial fresh mass per plant; (B) number of flowers per plant, excluding flower buds, and total aerial fresh mass per plant at harvest of *Chrysanthemum* 'Reagan Improved'. Symbols represent: △ Exp. 1, ◊ Exp. 2, ○ Exp. 3, □ Exp. 4, ▲ Exp. 5, ♦ Exp. 6, ● Exp. 7, ■ Exp. 8; as presented by Carvalho and Heuvelink (2003). Line represents linear regression. Vertical bars indicate s.e.m. when larger than symbols.

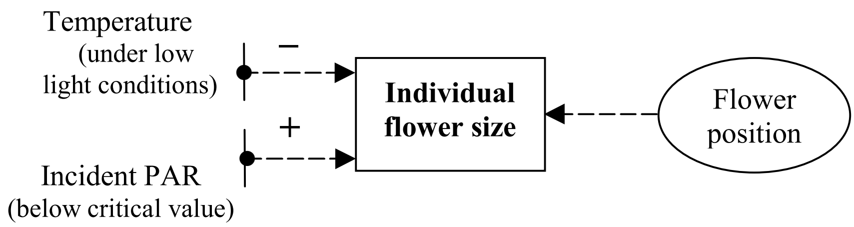

Fig. 3. Relational diagram of the individual flower size of a fully open flower of cut chrysanthemum. Boxes are state variables and ellipse is a parameter. Dashed arrows represent information flow: (+) indicates positive influence, (–) indicates negative influence. Abbreviations: PAR = photosynthetically active radiation.