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Modelling the quality of potted plants after dark storage

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Prolonged dark storage affects the quality of potted plants. A model was designed to quantify the effect of storage time and temperature on the display life of potted plants, such that logistics can be optimized, resulting in increased remaining quality and less rejected plants. Experiments were carried out with two *Phalaenopsis* cultivars, two *Anthurium* cultivars and two *Cyclamen* cultivars, the latter with two colour variants per cultivar. Plants were stored for different storage times at different temperatures. The aim of the chosen times and temperatures was to determine the quality effect of transport at optimal and suboptimal temperatures. After storage, plants were stored at 20 °C for 14 days, for simulating a display period. Different quality aspects were scored immediately after storage and after 7 and 14 days of display.

For each cultivar, a model was fitted consisting of a logistic function for representing the storage-time dependency of quality. In order to cope with both senescence symptoms at higher temperatures and chilling injury at lower temperatures, two non-interfering Arrhenius equations were incorporated. Because the effects of chilling exposure are commonly manifest only when the chilled plants are returned to ambient temperatures, the quality of *Phalaenopsis* and *Anthurium* plants measured immediately after storage at low temperatures was not taken into account. The behaviour of the *Phalaenopsis* and the *Anthurium* cultivars was well described by their models. The coefficients of determination based on the unexplained variation due to lack of fit were in the range of 0.89–0.99.

1. Introduction

Potted plants are increasingly transported over greater distances. Many pot plant species are from tropical and subtropical origin and may develop chilling injury symptoms at low temperatures. Storage and transport of such plants, generally takes place at relatively high temperatures (e.g. 12–15 °C) and, to avoid excessive desiccation, at high relative humidity. Such conditions favour fungal infection, stimulate etiolated growth (elongated light-green shoots) and stimulate senescence and abscission of leaves, flowers and flower buds (Reid and Jiang, 2012; Ferrante et al., 2012). The prolonged lack of light causes carbohydrate depletion and this may be the trigger for senescence processes. The lack of light may also trigger increased ethylene production and sensitivity leading to abscission of flower parts. When plants are stored at chilling temperatures an unfavourable oxidative status may lead to cell death, which may only become visible some time after transfer of the plants to ambient temperature (Einset et al., 2007). Both preharvest conditions and postharvest treatments may affect the response of plants to prolonged dark storage (Ferrante et al., 2012).

Being able to predict the quality after distribution (storage and transportation) may assist in decision making in the potted plant business. Actual technological developments are such that time–temperature data can be collected from sensor devices. Combining them with a quality decay model enables optimization of logistics, resulting in increased remaining quality and less rejected plants. Examples are described by Hertog et al. (2014) and Jedermann et al. (2014). These developments create a demand for models translating product history into reliable predictions of the product quality. The quality of potted plants depends, among other factors, on their postharvest treatments (e.g. Buck and Blessington, 1982; Poole et al., 1984; Sterling and Molenaar, 1985). Temperatures during storage and transportation are often too high or, for plants that are chilling-sensitive, sometimes too low. To allow the optimization of handling in the distribution chain and a reduction in the number of rejected plants, a model describing the quality of potted plants was developed. The model describes the quality of different potted plant cultivars based on temperature and time during storage and it accounts for stepwise changing storage

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temperatures. Beyond the scope of this paper was the possible effect of ethylene on the quality of potted plants, which may occur in practice (Woltering, 1987).

The modelling approach in this paper is in line with the commonly-accepted approach to model quality change of perishable products via first-order reaction kinetics or a logistic curve, with temperature dependency following Arrhenius (Tijskens and Polderdijk, 1996). In order to cope with the possibility of having chilling injury, a linear combination of two Arrhenius equations was applied. The study in this paper is comparable to the study about models that describe the effects of temperature and time on the acceptability of potted plants stored in darkness, performed by Tijskens et al. (1996). The two studies differ regarding the set of species that is covered. Moreover, models developed in this study describe the average quality, whereas the models of the latter study describe the acceptability in terms of the number of acceptable plants. Necessary information for the models of both studies is the initial quality of non-stored potted plants (Van Meeteren, 1998).

This paper is organized as follows. In Section 2, the setup of the experiment is described, including the way of quality scoring. In addition, the applied modelling approach is presented in a mathematical way, besides a description of how the model was fit and how the quality of this fit was analysed. In Section 3, both the experimental results and the fit results are presented, and these results are discussed in Section 4. The quality of the model fit is discussed by comparing the model predictions with the measurements from the experiment.

2. Material and methods

2.1. Experiment

Different potted plant species, and for each species two cultivars (*Phalaenopsis* ‘Tropic Snowball’, *Phalaenopsis* ‘Atlantis’, *Anthurium* ‘Chico Green’, *Anthurium* ‘Arion’, *Cyclamen* Super Series ‘Picasso’ and ‘Compact’) were used in the experiment. *Phalaenopsis* and *Anthurium* have a reputation as very sensitive to low temperatures. Recommended transport temperatures are 15–18 °C for *Phalaenopsis* and 10–15 °C for *Anthurium*. Recommended transport temperature for *Cyclamen* is 2–5 °C.

Plants with white flowers were recommended by the Dutch Federation of Agriculture and Horticulture (LTO Glaskracht Nederland), because of the supposed high sensitivity for transport of plants with white flowers, and because spots (caused by *Botrytis cinerea* or chilling) are noticed easier on white flowers. Per species two cultivars with different supposed transport sensitivity were chosen: *Phalaenopsis* ‘Tropic Snowball’ is more sensitive than ‘Atlantis’ and *Anthurium* ‘Chico Green’ is more sensitive than ‘Arion’.

The potted plants were obtained from commercial growers in the Netherlands in 2013. *Phalaenopsis* (July) and *Anthurium* (September) plants were delivered in 12-cm pots, *Cyclamen* (October) in 10-cm pots. The plant height of *Phalaenopsis* was approximately 60 cm, the plant height of *Anthurium* ‘Chico Green’ and ‘Arion’ were 45 and 50 cm, respectively, and the plant height of *Cyclamen* was approximately 15–20 cm. In the commercial harvesting stage, *Phaleanopsis* plants contained three flowering stems, each with 1–3 open flowers and a number of closed buds. Anthurium plants had on average four coloured spathes – *Cyclamen* plants had larger numbers of open flowers and flower buds.

Following harvest, the potted plants were transported within 2 h to the laboratory.

Here, first the plants were stored dry in the dark for different periods of time (*Phalaenopsis* for 6, 10, 15, 20 and 24 days at 10 °C, for 4, 5, 10, 16 and 20 days at 15 °C, for 3, 5, 10, 12 and 15 days at 20 °C and for 3, 4, 6, 8 and 12 days at 25 °C; *Anthurium* for 6, 12, 16, 24 and 30 days at 5 °C, for 3, 6, 8, 12, 15, 18 and 24 days at 10 °C, for 2, 4, 8, 10, 12 and 16 days at 15 °C and for 3, 4, 6, 9 and 12 days at 20 °C; *Cyclamen* for 10, 15 and 20 days at 2 °C, for 4, 6, 8, 12, 15 and 18 days at 5 °C, for 2, 3, 4, 6, 9 and 12 days at 10 °C and for 2, 4, 5, 6 and 8 days at 15 °C. The aim of the chosen times and temperatures was to determine the quality effect of transport at optimal and suboptimal temperatures. *Phalaenopsis* and *Anthurium* were stored at recommended temperatures and at higher and lower temperatures. *Cyclamen* was stored at recommended low temperatures and higher temperatures.

Relative humidity (RH) was different for each temperature: 79% at 2 °C, 83% at 5 °C, 88% at 10 °C, 91% at 15 °C, 94% at 20 °C and 95% at 25 °C. Combination of these temperatures and RH’s resulted in the same vapour pressure deficit (VPD), 140–160 Pa. The VPD is an important driving force for evaporation.

Immediately after storage, plants were watered, and stored for 7 days (*Phalaenopsis*) or 7 and 14 days (*Anthurium* and *Cyclamen*) to simulate a display period. The climate conditions during this storage were 20 °C and 60 ± 5% RH, 12 μmol m^{-2} s^{-1} light from fluorescent tubes for 12 h per day. During the display period the plants were watered once or twice a week.

For each combination of storage time and temperature, 8 plants (*Phalaenopsis* and *Anthurium*) or 10 or 20 plants (*Cyclamen*) were stored. For *Cyclamen*, two colour variants were used per cultivar, resulting into 5 or 10 plants per colour per case. As controls, 24 plants (*Phalaenopsis* and *Anthurium*) or 30 plants (*Cyclamen*) were immediately after transport, so without any dark storage, placed under the conditions for simulating a display period.

2.1.1. Quality scoring

The quality of the potted plants was measured both immediately after storage (so just before the display period), and after a display period of respectively 7 days (*Phalaenopsis*) or both 7 and 14 days (*Anthurium* and *Cyclamen*). A scale from 9 to 1 was applied (Table 1), according to which a physiological scientist scored the quality of the potted plants on indicators such as number of dried flowers, number of abscised flowers, fungal infection of flowers and foliage, leaf yellowing and chilling injury (dark spots on the foliage, developing in rotten leaves). The quality assessment was

Table 1
Rating scale for scoring the quality of potted plants.

Quality score	Description
9	Very good; no defects on foliage or flowers
8	Good; minor defects on foliage or flowers
7	Fairly ok; minor defects on foliage and flowers
6	Sufficient; some defects on foliage and/or flowers
5	Insufficient; defects on foliage and/or flowers, some dried – and/or abscised buds or – flowers
4	Bad; serious defects on foliage and/or flowers, dried buds, abscised flowers
≤3	Very bad; serious foliage yellowing, rotten foliage, serious bud – and/or flower abscission, rotten flowers