

Modelling the quality of potted plants after dark storage



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ABSTRACT

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.

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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 (Tijksens 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 Tijksens 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, *Phalaenopsis* 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

conducted by two physiological scientists, sometimes together to guarantee convergence of the assessments, mostly alone.

Phalaenopsis plants were scored based on the desiccation and abscission of buds and flowers, leaf yellowing and the occurrence of darkened areas on the leaves, later developing into water soaked areas as symptoms of chilling injury.

Anthurium plants were scored based on the quality of the leaves (yellowing, dark areas and dry leaf edges), the spathe (yellowing, dehydration, dullness) and the spadix (browning).

Two 'Super Series' *Cyclamen* cultivars were tested ('Compact' and 'Picasso') and for each cultivar two colour variants (a red/pink coloured one and a crème/white one) were tested. Quality was determined by a plethora of defects such as leaf yellowing, stem bending (stems of leaves and flowers), senescent leaves, leaf desiccation, flower wilting and flower discoloration (in the pink and red *Cyclamen*). A supplementary file is added, where for each species for some quality scores in Table 1 a photo is associated. The obtained measurement data are provided in a second supplementary file.

2.2. Modelling approach

The model describes the quality as a function of the storage time and storage temperature. Therefore it is composed of a so-called primary model and a secondary model. The purpose of the primary quality model is to describe the time dependency of quality. For perishable products, it is in general common to model quality change and predict the remaining keepability via first-order reaction kinetics or a logistic curve, with temperature dependency following Arrhenius (Tijksens and Polderdijk, 1996). Loss of perceived quality over time is the result of a cascade of biochemical reactions. Such cascades, which are mostly only poorly understood, can often be approximated by the sigmoid logistic curve (Tijksens et al., 1996). This logistic curve is described mathematically in Section 2.2.1.

The purpose of the secondary quality model is to describe the temperature dependency of quality. A common secondary model for describing the temperature dependency is an Arrhenius equation (Tijksens and Polderdijk, 1996). For example, Rijgersberg and Top (2006) have applied Arrhenius for modelling the temperature dependency of the quality of fresh-cut endive. Tromp et al. (2012) have shown that the temperature dependency of the quality of cut roses can be modelled according to Arrhenius.

In order to cope with the possibility of having chilling injury, a linear combination of two Arrhenius equations was applied. The same approach was followed for modelling the acceptability of potted plants by Tijksens et al. (1996). This approach suggests two processes, one which is particularly active at high temperatures and results in, for example, excessive water loss, and one which is particularly active at low temperatures and results in, for example membrane deterioration (Tijksens et al., 1994). Although it is not certain on forehand that chilling injury indeed is covered by an Arrhenius dependency, it is neither assumed to be impossible (Parkin et al., 1989). The mathematical details of this approach of two independent Arrhenius equations are described in Section 2.2.2.

2.2.1. Primary quality model

According to the logistic curve, the quality attribute q changes in time according to:

$$\frac{dq}{dt} = -k_T q \left(1 - \frac{q}{q_{-\text{inf}}} \right) \quad (1)$$

where k_T represents the temperature-dependent quality decay rate (d^{-1}), and $q_{-\text{inf}}$ is the higher asymptote (the lower asymptote equals 0). The solution of the differential Eq. (1) is a logistic curve:

$$q(t) = \frac{q_{-\text{inf}} q_0 e^{-k_T t}}{q_{-\text{inf}} + q_0 (e^{-k_T t} - 1)} \quad (2)$$

where q_0 is the initial value of the determining quality attribute (the value of non-stored potted plants).

The primary model Eq. (2) has a lower asymptote equal to 0. However, for quality scoring a scale from 9 to 1 was used. In order to have a lower asymptote equal to 1, Eq. (2) was adapted as follows:

$$q(t) = \frac{(q_{-\text{inf}} - 1)(q_0 - 1)e^{-k_T t}}{(q_{-\text{inf}} - 1) + (q_0 - 1)(e^{-k_T t} - 1)} + 1 \quad (3)$$

2.2.2. Secondary quality model

In order to cope with both chilling injury and senescence, two Arrhenius equations were applied simultaneously, according to the suggestion for modelling two non-interfering temperature-dependent processes by Tijksens and Polderdijk (1996). It followed that:

$$k_T = k_{T,\text{Cl}} + k_{T,\text{S}} \quad (4)$$

where $k_{T,\text{Cl}}$ is the temperature-dependent quality-decay rate for chilling injury (d^{-1}), and $k_{T,\text{S}}$ is the temperature-dependent quality-decay rate for senescence (d^{-1}).

When applying two non-interfering Arrhenius temperature dependencies, k_T is calculated as follows:

$$k_T = k_{\text{ref,Cl}} e^{B_{\text{Cl}}((1/T_{\text{ref}}) - (1/T))} + k_{\text{ref,S}} e^{B_{\text{S}}((1/T_{\text{ref}}) - (1/T))} \quad (5)$$

where B_{Cl} and B_{S} (K) are product-dependent parameters commonly known as $E_{a,\text{Cl}}/R$ and $E_{a,\text{S}}/R$. $E_{a,\text{Cl}}$ and $E_{a,\text{S}}$ (J/mol) represent activation energies and R is the universal gas constant (J/(K mol)). T is the temperature (K), and $k_{\text{ref,Cl}}$ and $k_{\text{ref,S}}$ are the quality-decay rates (d^{-1}) for respectively chilling injury and senescence at the reference temperature T_{ref} which is 293.15 K (=20 °C, temperature during display period).

2.3. Fitting approach

2.3.1. Data set

The model, being the combination of the primary model Eq. (3) and the secondary model Eq. (5), was fitted on the measurement data from the experiment (Supplementary material). However, *Anthurium* and *Phalaenopsis* are chilling-sensitive plants, and it is common knowledge that the effects of chilling exposure are commonly manifest only when the chilled plants are returned to ambient temperatures. Therefore, the quality immediately after storage at 5 °C and 10 °C was not taken into account for *Anthurium* and *Phalaenopsis*.

2.3.2. Fitting technique

Fitting the model took place using the function *lsqcurvefit* from the software Matlab (R2009a) for solving nonlinear curve-fitting (data-fitting) problems in least-squares sense.

Stepwise changing temperatures data were included in the model fitting. Quality was either evaluated immediately after storage (t_1 at the storage temperature T_1) or after a display period (t_2 at a reference temperature of 20 °C) following the initial storage period. The two sequential periods of constant temperatures were incorporated into a single model expression following Eq. (6):

$$q(t_1 + t_2) = \frac{(q_{-\text{inf}} - 1)(q(t_1) - 1)e^{-k_{\text{ref}} t_2}}{(q_{-\text{inf}} - 1) + (q(t_1) - 1)(e^{-k_{\text{ref}} t_2} - 1)} + 1 \quad (6)$$

where

$$q(t_1) = \frac{(q_{-\text{inf}} - 1)(q_0 - 1)e^{k_{r_1} t_1}}{(q_{-\text{inf}} - 1) + (q_0 - 1)(e^{k_{r_1} t_1} - 1)} + 1 \quad (7)$$

So the quality at the end of the storage time was taken as the initial quality for the display period.

A least-squares fit was performed with the storage times and temperatures according to the experimental settings (the set-point times and temperatures). Controls were included in the fit process.

2.4. Quality of fit

The coefficient of determination (R^2) was used as a measure for the explained variation. For each cultivar or colour variant, there were 8, 5 or 10 potted plants, which can be considered as replicates. Therefore, it was possible to partition the unexplained variation into a 'lack of fit' and a 'pure error':

$$R^2 = 1 - \frac{SS_{\text{res}}}{SS_{\text{tot}}} = 1 - \frac{S_{\text{lof}} + SS_{\text{pe}}}{SS_{\text{tot}}} \quad (8)$$

SS_{res} is the residual sum of squares (the unexplained variation) and SS_{tot} is the total sum of squares. S_{lof} is the unexplained variation due to a lack of fit, and SS_{pe} is the unexplained variation due to the so-called pure error. The lack of fit is a measure for the difference between the local average of the 5, 8 or 10 duplicates and the predicted value. The pure error is a measure for the difference between the observed values of each duplicate and the local average. It exists due to a biological variance between different potted plants of the same cultivar.

Based on this partition into lack of fit and pure error, the coefficient of determination was recalculated, but now on the basis of the unexplained variation due to lack of fit only:

$$R_{\text{fit}}^2 = 1 - \frac{SS_{\text{lof}}}{SS_{\text{tot}}} \quad (9)$$

In this way the impact of the biological variance on the quality of fit was eliminated.

3. Results

3.1. Measurements

Figs. 1–4 show the measurement data for the plant quality after a display period of 7 days, including the biological variance represented as the standard error of the mean. For simplicity, the measurement data after a display period of 14 days (*Anthurium* and *Cyclamen*) are not shown.

In the *Phalaenopsis* species, quality was optimally preserved at 15 °C. Compared to storage at 15 °C, both storage at higher and at lower temperatures decreased quality. It seemed that the storage temperature optimum of cultivar 'Atlantis' was a little higher than that of cultivar 'Tropic Snowball' (Fig. 1). In plants stored for prolonged periods of time at the highest temperature (25 °C) bud desiccation and abscission increased. At the lowest temperature (10 °C) leaf darkening and water soaking increased as symptoms of chilling injury. Both at high and low temperatures, the longer the storage time, the more pronounced the symptoms were.

Similar to what was found in *Phalaenopsis*, *Anthurium* suffered from chilling injury and quality was optimally preserved at 15–20 °C. The cultivar 'Chico Green' seemed more sensitive to chilling than cultivar Arion (Fig. 2). Quality loss in *Anthurium* was mainly determined by the decreased quality of the leaves. At high temperature (20 °C) the leaves showed brown tips and brown senescent areas and at low temperatures (10 and 5 °C) dark water soaked areas on the leaves appeared. Also defects of the spathe and the spadix (yellowing, browning and desiccation) determined the quality.

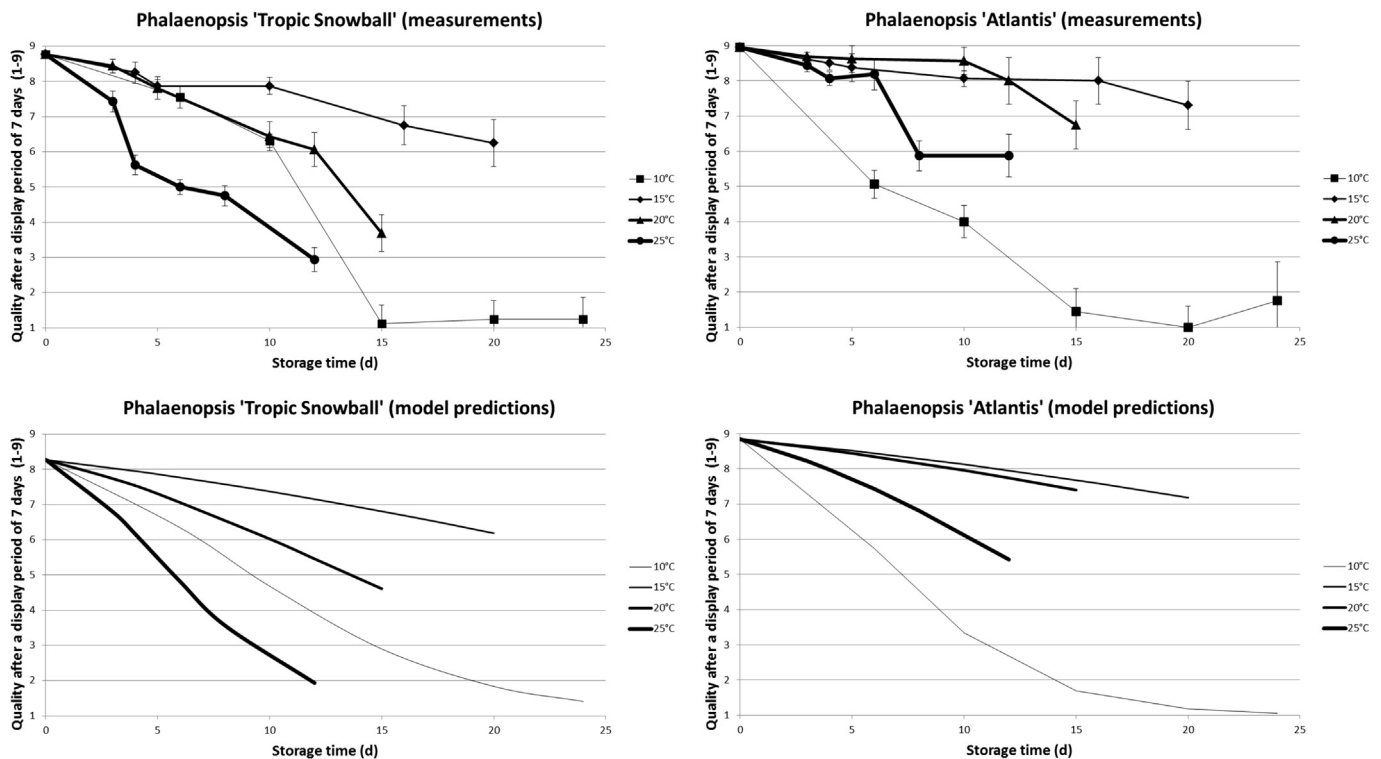


Fig. 1. Measurement data (error bars represent standard errors) and model predictions for *Phalaenopsis* 'Tropic Snowball' (left) and *Phalaenopsis* 'Atlantis' (right).

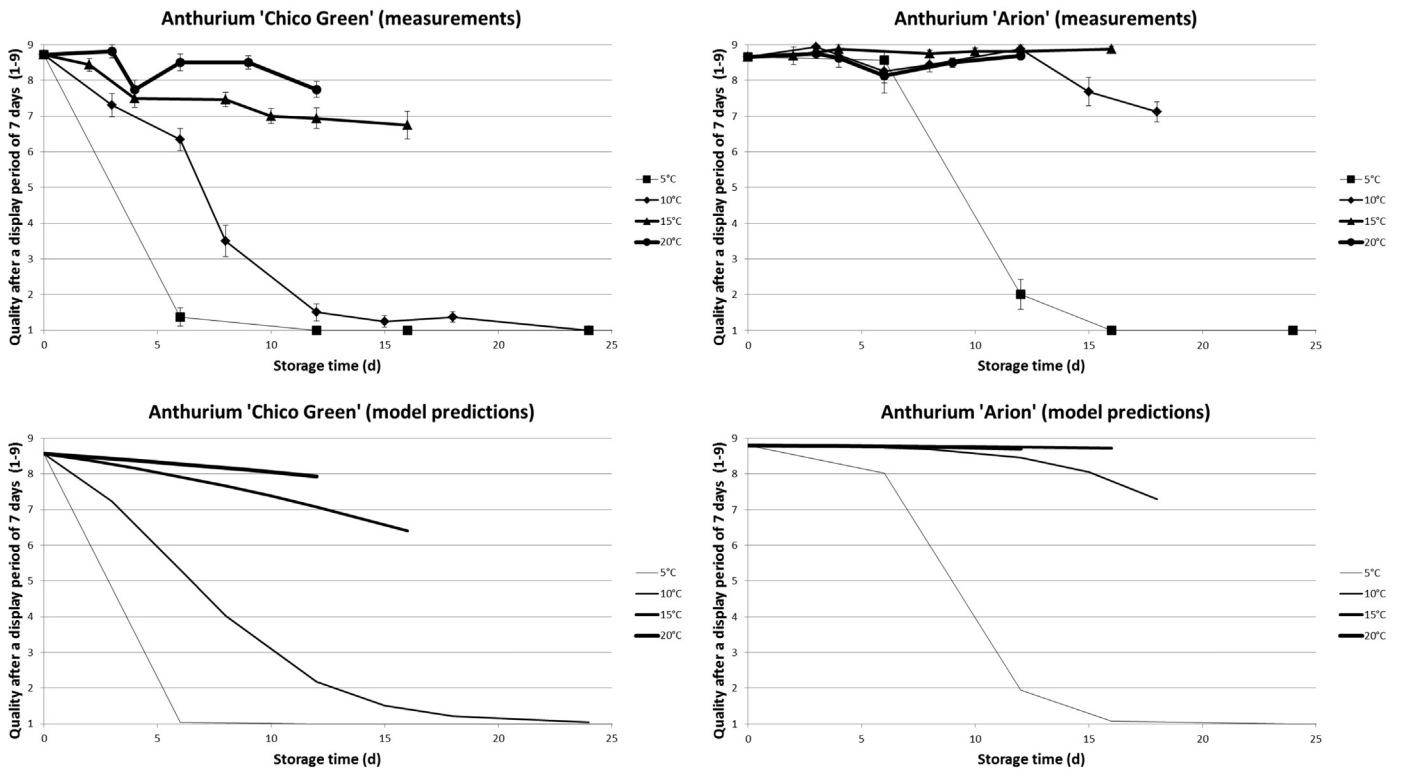


Fig. 2. Measurement data (error bars represent standard errors) and model predictions for *Anthurium* 'Chico Green' (left) and *Anthurium* 'Arion' (right).

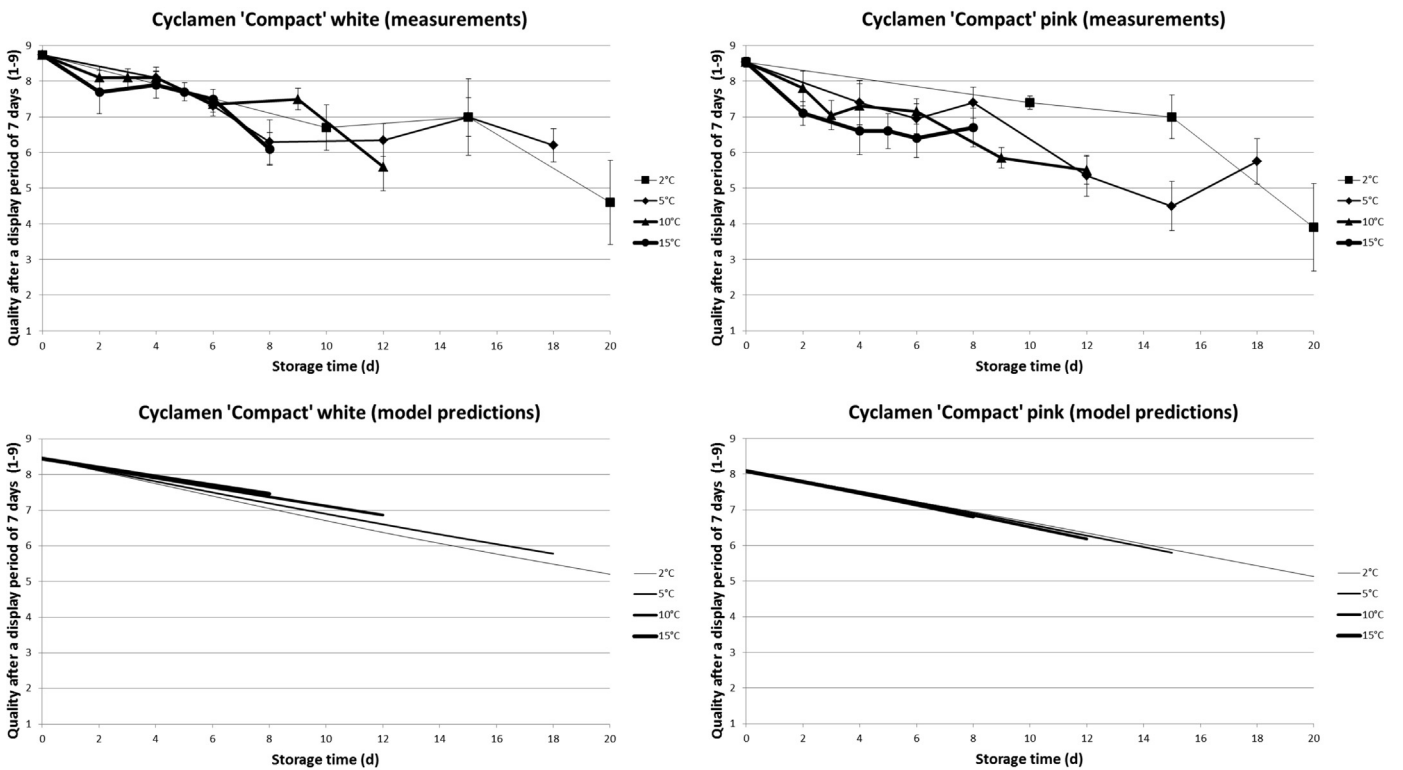


Fig. 3. Measurement data (error bars represent standard errors) and model predictions for *Cyclamen* 'Compact' white (left) and *Cyclamen* 'Compact' pink (right).

For the two *Cyclamen* cultivars it is hard to discern a clear optimal storage temperature due to the fact that the different storage temperatures show similar quality behaviour (Figs. 3 and 4). Moreover, variability is significantly larger than for the other species.

3.2. Models

Table 2 presents the fit results regarding the parameters of the different models. As an example of how to interpret the values presented in Table 2 the model that describes the quality decay of

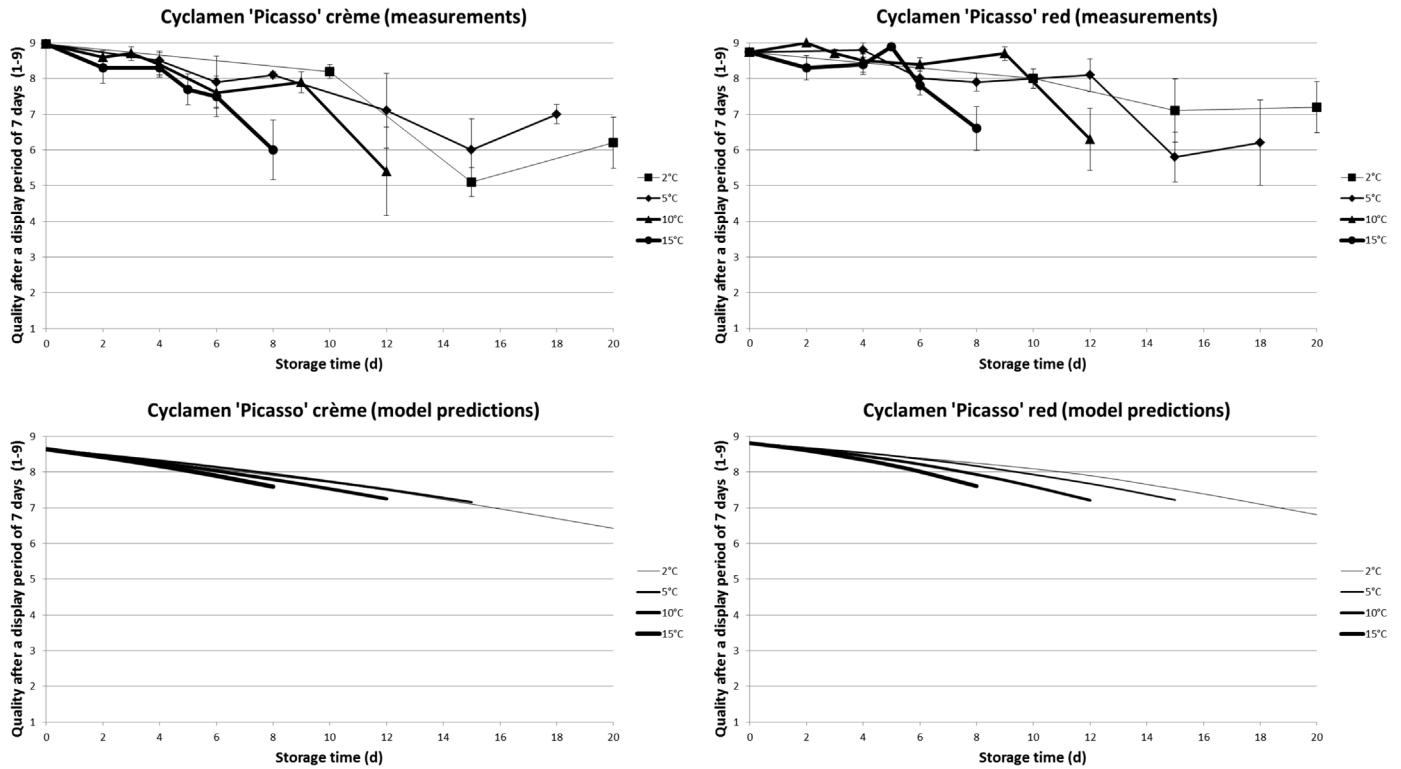


Fig. 4. Measurement data (error bars represent standard errors) and model predictions for *Cyclamen* 'Picasso' crème (left) and *Cyclamen* 'Picasso' red (right).

Phalaenopsis 'Tropic Snowball' directly after storage (no display period) has become:

$$q(t) = \frac{(9.71 - 1)(9.08 - 1)e^{-k_T t}}{(9.71 - 1) + (9.08 - 1)(e^{-k_T t} - 1)} + 1$$

with

$$k_T = 0.131e^{1.52 \times 10^4((1/T_{ref}) - (1/T))} + 4.76 \times 10^{-4}e^{-4.89 \times 10^4((1/T_{ref}) - (1/T))}$$

In the figures with the measurement results, the model predictions for the quality after a display period of 7 days are shown as well (Figs. 1–4). It is emphasized that these model predictions are based on models that have been fit on a data set that not only includes the measurement data after a display period of 7 days but also the measurement data just after dark storage (*Phalaenopsis*, *Anthurium* and *Cyclamen*) and after a display period of 14 days (*Anthurium* and *Cyclamen*).

3.3. Quality of fit

The coefficients of determination are in the range of 0.41–0.95 (Table 2). The coefficients of determination based on the unexplained variation due to lack of fit are in the range of 0.86–0.99. For each cultivar, the standard errors regarding the parameter q_0 (the quality of non-stored potted plants) are small (within 5%), indicating a low uncertainty. Regarding the other parameters the standard errors are sometimes much higher (Table 2).

4. Discussion

4.1. Measurements

For different cultivars of the same species a comparable response to storage temperatures was expected. In the two *Phalaenopsis* cultivars, similar behaviour was observed showing an optimal storage temperature between 15 and 20 °C and an

decreased quality when stored at both higher and lower temperatures (Fig. 1). The cultivar 'Atlantis' was more tolerant to higher storage temperatures and less tolerant to lower storage temperatures than the cultivar 'Tropic Snowball'.

Also in the two *Anthurium* cultivars, similar behaviour was observed, showing an optimal storage temperature between 15 and 20 °C. The cultivar 'Chico Green' was more sensitive to chilling injury.

As the genetic variability between the colour variants was supposedly very minor, it was assumed that especially the two-colour variants of both cultivars should show a similar response to storage temperature. However, regarding the four *Cyclamen* variants, even at the longest storage period, the effects of storage on quality were only minor. Therefore it is hard to conclude about this similarity in response. Moreover, *Cyclamen* showed a high biological variation. The variability in *Cyclamen* can be due to the fact that seed lines were used which normally will have some heterogeneity, while *Phalaenopsis* and *Anthurium* are tissue culture based clones so usually very homogeneous. The variability in *Cyclamen* can be due to cultivation conditions too.

4.2. Models and quality of fit

The behaviour of the *Phalaenopsis* and the *Anthurium* cultivars was well described by their models, incorporating two non-interfering Arrhenius temperature dependencies. The coefficients of determination based on the unexplained variation due to lack of fit were in the range of 0.97–0.99, except for *Phalaenopsis* 'Tropic Snowball' (0.89).

Anthurium and *Phalaenopsis* are chilling-sensitive plants. For these plants, the quality measurements immediately after storage were too optimistic, because the effects of chilling exposure are commonly manifest only when the chilled plants are returned to ambient temperatures. Therefore, the quality immediately after storage at 5 °C and 10 °C was not taken into account for *Anthurium*

Table 2 Fitted values and standard errors of parameters of the logistic curve with two non-interfering temperature dependencies according to Arrhenius. R^2_{fit} is calculated on the basis of the total unexplained variation. R^2_{fit} is based on the lack of fit only.

Cultivar	Fitted values					Standard errors					Quality of fit					
	q_0	$q_{\text{-inf}}$	B_1	$k_{\text{ref},1}$	B_2	$k_{\text{ref},2}$	SE_{q_0}	$SE_{q_{\text{-inf}}}$	SE_{B_1}	$SE_{k_{\text{ref},1}}$	SE_{B_2}	$SE_{k_{\text{ref},2}}$	R^2	R^2_{fit}	Pure error	Lack of fit
<i>Phalaenopsis</i>	9.08	9.71	1.52E04	0.131	-4.89E04	4.76E-04	0.155	0.356	1083	0.0161	1.70E04	9.83E-04	0.781	0.892	216	209
'Tropic Snowball'	9.27	10.17	1.66E04	0.0592	-3.62E-04	0.00354	0.124	0.536	2297	0.0149	4518	0.00208	0.820	0.971	255	49.7
<i>Phalaenopsis</i>	8.86	9.82	2.21E05	0.0178	-2.11E05	0.0240	0.0841	0.328	2.48E10	0.0316	1.08E04	0.0314	0.932	0.980	298	121
'Atlantis'	8.80	8.81	1.76E05	0.120	-1.47E04	0.0469	0.0347	0.0357	2.11E08	0.0188	423	0.00476	0.949	0.990	124	31.7
<i>Anthurium</i> 'Arion'	9.37	18.6	8550	0.0127	-3810	0.0173	0.218	12.7	6.17E04	0.0543	1.07E04	0.0552	0.414	0.863	578	177
<i>Cyclamen</i> 'Compact' 'white'	9.02	11.3	3340	-0.198	2430	0.265	0.234	1.65	7.12E05	2.97	4.79E06	270	0.410	0.860	719	224
<i>Cyclamen</i> 'Compact' 'pink'	9.30	10.0	2890	0.107	-6.36E-04	6.49E-09	0.172	0.542	777	0.0228	6.54E06	9.97E-08	0.489	0.865	341	123
<i>Cyclamen</i> 'Picasso' 'crème'	9.15	9.43	3570	0.194	1.63E05	-0.0730	0.147	0.269	1140	0.0529	1.03E08	0.0479	0.484	0.891	312	84.2

and *Phalaenopsis*. However, the slightly lower fit of *Phalaenopsis* 'Tropic Snowball' could probably be explained by still having an unobserved chilling-injury effect after a display period of 7 days (Fig. 1). Other methods to measure chilling injury such as chlorophyll fluorescence may be useful to detect the disorder immediately after storage (Ferrante et al., 2012).

Also regarding the four *Cyclamen* variants, the coefficients of determination based on the unexplained variation due to lack of fit only were rather high. However, if the study had included storage of these plants at the higher temperatures for longer times, it would have presumably showed that this was undesirable. Already at 8 days for plants stored at 15 °C and at 12 days for plants stored at 10 °C, quality was significantly poorer than for plants stored at lower temperatures. Presumably, with an extended dataset, increasing the storage duration at higher temperatures, different models would have been obtained for the *Cyclamen* variants. These latter models are expected to show clearly S-shaped logistic curves, just as the *Phalaenopsis* and *Anthurium* models.

Nevertheless, these latter models will have important limitations too. Unlike *Phalaenopsis* and *Anthurium*, *Cyclamen* showed a high biological variation, such that the coefficients of determination were rather poor in this case. This aspect puts additional limitations on using the type of models as applied in this paper for making quality predictions about the *Cyclamen* variants, because these models only predict the average quality. This will probably limit the value of any model for *Cyclamen* which does not take into account the biological variation.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.postharvbio.2015.02.003>.

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