

Causes of Quality Loss of Cut Flowers - a Critical Analysis of Postharvest Treatments

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Abstract

Temperature is one of the most important factors in the postharvest phase to control quality losses, yet temperature is still poorly managed, partly because its effects are not always understood well. Temperature affects both physiological (development and senescence of flowers, wound responses at the cut stem end) and physical (water loss, condensation/drying) processes involved in quality loss. Moreover, pathogens like *Botrytis* (germination rate of conidia) and growth of bacteria are affected by temperature. Handling, like placing flowers in water during transport or keeping them dry, re-cutting of stems or not, will interact with some of the processes affected by temperature. A previous simulation model, based on temperature effects on the rate of senescence and on the development of *Botrytis* infection, was extended by including the effects of temperature and handling on the water balance of the cut flower. Some outcomes of simulations of temperature combinations and handling in hypothetical chains are demonstrated. They showed that the effects of temperature in the chain can be largely overruled by properties of the crop or by the handling of the flowers. The model is meant to find and understand the critical points in postharvest cut flower chains. Most of the parameters are based on limited available data from literature or preliminary experiments. Moreover, the model is not validated. For these reasons, in its present status the model should not be used to predict vase life of cut flowers for practical purposes.

INTRODUCTION

The cut flower market is a globalized market. As a result, cut flowers are transported for several days or even weeks over various distances. The quality of the flowers at the final consumer will be affected by the transport conditions and handling in the supply chain. In these chains several links (partners) will be involved, often with different environmental conditions. Until now, there has been little critical analysis to identify the principal sites of quality loss and their relative importance. To ensure a certain quality of the flowers at the final consumer, and to prevent investments without a clear positive return, the critical control points for quality in the production and distribution chain should be investigated.

The main reasons for loss of ornamental value at the consumer are i) flower senescence, ii) deterioration of petals due to *Botrytis*, and iii) a loss of turgor of petals, leaves or stem due to a negative water balance. All these phenomena are affected by the conditions and handling in the postharvest chain. Temperature is one of the most important factors in controlling quality losses (Goszczyńska and Rudnicki, 1988; Nell and Reid, 2000; Kader, 2002), yet temperature in commercial flower chains is still poorly managed, partly because its effects are not always understood well. Temperature affects both physiological (development and senescence of flowers, wound responses of cut stems) and physical (water loss, condensation/drying) processes involved in quality loss. Also pathogens like *Botrytis* (germination rate of conidia, flower-petal resistance against

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B. growth) and growth of bacteria are affected by temperature. Handling, like sleeving, boxing, placing flowers in water during transport or keeping them dry, re-cutting of stems or not, will interact with some processes affected by temperature. The final result of temperature (fluctuations) in the postharvest chain on quality of the flowers will depend on the duration of the (links of the) chain and the flower genotype involved. Due to these complex interactions, simulation models may be good tools to identify the critical points for quality management in a particular supply chain. In a previous paper, we discussed some outcomes of a preliminary simulation model based on temperature effects on the rate of senescence and on the development of *Botrytis* infection (van Meeteren, 2007). In this paper, we have extended this model by including the effects of temperature and handling on the water balance of the cut flower. We have used this model to find and understand the critical points in postharvest cut flower chains as far as related to temperature management.

KEY PROCESSES AND ASSUMPTIONS

To identify the critical control points for quality management, the model should predict to what extent conditions in postharvest chains will affect the length of vase life at the final consumer. Besides postharvest factors, the actual vase life is also affected by pre-harvest growth conditions (Stamps et al., 1989; Gudín, 1992; Paull et al., 1992; Gorsel, 1993; van Meeteren et al., 2005; In et al., 2007) and the conditions at the consumer. To identify the critical points, however, the change in vase life due to alterations in chain conditions is of more importance than the actual length of vase life. Therefore, the effects of changes in chain conditions on average data about vase life for a specific crop can be used. Because most vase life studies in literature are carried out at 20°C and 60% RH (Reid and Kofranek, 1980), these conditions were used in the simulations as condition at the final consumer. The predicted vase life should be the result of the effects of air temperature and humidity in the various links of a supply chain on rate of senescence, germination of *Botrytis* conidia and the water balance of the cut flowers. Whether cut flowers are placed in water in some of the links or not, as well as re-cutting by the consumer should be taken into account.

It was assumed that flower senescence is a developmental process from stage zero (commercial harvesting stage) to unity (senescent stage \approx end of vase life) with a rate that is affected by flower temperature, but not by the developmental stage of the flower.

For most cut flowers, infection of flower petals by the fungus *Botrytis cinerea* is one of the main causes of quality loss in the postharvest chain. Spread of a large number of necrotic spots on the flower petals or total collapse of the flower will be the end of vase life, whatever the development stage of the flower is. Different steps are critical in the infection process: germination of conidia, penetration of the petal tissue, killing of petal tissue followed by lesion expansion and tissue maceration (van Kan, 2006). In the present model only germination of conidia was taken into account. Vase life was assumed to be finished as soon as 50% of the conidia had germinated. Conidia of *Botrytis* need a high relative humidity (>93%) or a thin layer of water to germinate (Salinas et al., 1989). Temperature changes, which will occur in the postharvest chain, can cause condensation on plant tissue or packaging materials as well as drying of the petals and packaging surfaces. As a result, there can occur periods with high air humidity or free water on the petals. In the present model, germination processes of *Botrytis* conidia were assumed to start as soon as condensation on the flowers started, and to take place at the temperature of the condensed water. Packaging of the flowers was not taken into account.

Many flowers do not reach full physiological senescence at the consumer because of loss of sufficient ornamental value as result of a negative water balance of the flowers, that is, their rate of water uptake has become lower than the transpiration rate. Negative water balance is due to an occlusion in the xylem vessels in the stems (van Meeteren, 1989, 1992; van Meeteren et al., 2006). The occlusion can be caused by (i) growth of bacteria on the cut stem surface or in the xylem vessels, (ii) wounding induced enzymatic reactions in the stem tissue as part of a plant defence mechanism, (iii) presence of air in

the xylem vessels that is aspired directly after cutting or during dry storage of the cut flower stems (van Doorn, 1997), or (iv) a disruption of the water column continuity in the xylem vessels caused by a low water potential in the flower stems (cavitation) (Tyree and Dixon, 1986; Williamson and Milburn, 1995). Transpiration rate will be affected by environmental conditions (vapour pressure difference) as well as by the water potential in the leaves (due to stomatal closing). It was assumed that vase life ends when flowers in the consumer phase reached a fresh weight of less than 94% of the initial fresh weight at harvest. A transient water deficit in flower tissues could hasten the senescence process of flowers (Mayak et al., 1985; Mayak and Faragher, 1986). This was not taken into account.

METHODS

Flower Senescence

Based on previous results of fitting data from literature about senescence-rate and temperature (van Meeteren, 2007), equation (1) was used to describe the effect of temperature on senescence-rate:

$$k_s = \frac{k_{\max}}{1 + 10^{(T_{\text{half}} - T_s) \cdot \text{slope}}} \quad (1)$$

in which k_s [day^{-1}]=rate of senescence at temperature T_s [K], k_{\max} [day^{-1}]=maximum rate of senescence, T_{half} [K]=temperature at which the senescence rate is half of k_{\max} and slope [K^{-1}] describes the steepness of the curve. Parameterization for specific flowers was done using data from literature (Cevallos and Reid, 2000, 2001; Çelikel and Reid, 2002, 2005) as described before (van Meeteren, 2007).

Botrytis

As stated above, germination processes of *Botrytis* conidia were supposed to start as soon as condensation started. Temperature largely affects the time until the first germinated conidia can be observed (lag-time) and the rate of germination after this lag period (van Meeteren, 2007). The temperature of condensed water was used as the decisive temperature for the germination processes and was assumed to be the dew point temperature at which condensation on the flowers took place. To simulate the effect of temperature, equation (2) (van Meeteren, 2007) was used. It describes the relation between the time it takes to 50% germination of *B. cinerea* conidia in PDB solution (12 g L⁻¹ Potato Dextrose Broth) and temperature during incubation.

$$t_{50} = (t_{T0} - t_{\min}) \cdot \exp^{(-K \cdot T)} + t_{\min} \quad (2)$$

where t_{50} =time to 50% germination [h], t_{T0} = t_{50} at 0°C [h], t_{\min} =minimum t_{50} [h], and K is a rate constant [$\text{h} \cdot ^\circ\text{C}^{-1}$]. When water is evaporated before germination occurred it was assumed that the conidia were not germinated; successive periods with the occurrence of condensation were treated separately.

Hydric Status of the Flower

The hydric status of the flower is the result of transpiration, water uptake and its initial status at harvest. It was assumed that it is at its maximum (100%) (i.e. fully saturated) at harvest. Transpiration rate is determined by the vapour pressure difference between the flower tissue and the surrounding air, and the resistance encountered by water vapour to diffuse out the plant tissue into the surrounding air. Among others, this resistance is affected by the hydric status (water potential) of the leaves (due to stomata closing). The rate of water uptake is the result of xylem water potential and the conductivity for water flux through the stem (stem hydraulic conductivity). Water can only be taken up in the links of the chain in which the flowers are placed in water. It was assumed that in the flower shop as well as during the consumer phase the flowers were always placed in water; in the other links the model had the option to choose whether flowers were placed in water or not.

1. Leaf Water Vapour Resistance. To obtain parameters about the relation between leaf water potential and transpiration rate, saturated cut rose stems were placed on a balance without water at constant environmental conditions. Fresh weight was registered every 20 s. In this way a relation between the rate of water loss and relative water content (RWC) could be obtained. At some time intervals water potential of the leaves was measured with a pressure bomb. Because water potential is directly related to RWC in a function that is relatively linear (Dixon et al., 1988), water potentials could be calculated from the measured fresh weight during the drying out experiment. The relation between water potential and transpiration rate could be fitted by equation (3).

$$J=J_{\max} \quad \text{when } \Psi > -\Psi_0$$

$$J=J_{\min}+(J_{\max}-J_{\min})\cdot\exp(-K\cdot(\Psi-\Psi_0)) \quad \text{when } \Psi \leq -\Psi_0 \quad (3)$$

J =transpiration rate [g h^{-1}], Ψ =xylem water potential [MPa], Ψ_0 = xylem water potential at which J reached its maximal value (stomata fully opened) [MPa], J_{\max} = transpiration rate at Ψ_0 [g h^{-1}], and J_{\min} =minimal transpiration rate (all stomata closed) [g h^{-1}].

2. Stem Hydraulic Conductivity. For the initial conductance average values of cut chrysanthemums (van Ieperen et al., 2002; van Meeteren et al., 2005, 2006) and roses (Fanourakis, personal communication) were used, measured using the method described by van Ieperen et al. (2000). Hydraulic conductivity will decrease due to growth of bacteria, wounding induced enzymatic reactions, aspired air (emboli) or cavitation. As discussed in another paper in this Acta (van Meeteren and Arévalo-Galarza, 2009), these processes are independent and their effects are superimposed on each other.

Bacteria. Bacteria are normally present on the outer surface of cut flower stems. Water is the medium for transport of bacteria from the outer stem surface into the xylem vessels; because of this, placing stems in water was taken as the start point of the growth of bacteria. Subsequent dry storage of rose stems resulted in an increase in the number of bacteria in the stems, similar to that occurring in stems that were held in water (van Doorn and Witte, 1991). Therefore, in the present model, growth of bacteria was not affected when flowers were taken out off water. The effect of temperature on the growth rate of the bacteria was modeled by a modified Ratkowsky model (Zwietering et al., 1991). The flower temperature was used as temperature in the simulation of the growth of bacteria. If flower stems were re-cut, the number of bacteria was reset to 10, which was also the starting level when stems were placed in water. The relation between number of bacteria and the inhibition of hydraulic conductance was calculated using (4):

$$I_{\text{bac}} = \frac{I_{\max}}{(1+10^{(\log(\text{bac}_{50})-\log(\text{bac}))})}/100 \quad (4)$$

in which I_{bac} =inhibition of conductance by bacteria [%], I_{\max} =maximum inhibition by bacteria [%], bac_{50} =number of bacteria that gives 50% inhibition of conductance [cfu], bac =number of bacteria [cfu]. For bac_{50} we used 10^7 cfu, based on van Doorn et al. (1989).

Wounding Response. As soon as stems are cut a wounding response will start (van Meeteren et al., 2006). This wounding response is highly temperature sensitive (van Meeteren and Arévalo-Galarza, 2009); however, detailed data about temperature effects on the rate of the wounding response were not available. It was assumed that the rate is affected by temperature according to a sigmoid relation. The total wounding response was limited to a maximum percentage of the initial hydraulic conductance.

Emboli. Emboli will be present in cut flower stems as result of air aspiration into the xylem vessels directly after cutting. After placing the stems in water, a part of the air will be replaced by water. This refilling of the vessels reaches a plateau (maximal hydraulic conductance) after 1-2 h (van Ieperen et al., 2002). Thereafter, changes in the number of vessels with emboli will be very small. Therefore, the presence of embolised vessels was implemented as a constant value (%) lowering the hydraulic conductance. This percentage can largely be affected by cultivar and growth conditions (van Meeteren et al., 2005).

Cavitation. It was assumed that cavitation started when the water potential (Ψ) becomes <-0.2 MPa (Dixon et al., 1988) and that there is an exponential relation between the rate of cavitation appearance and water potential. Based on the data for roses of Dixon et al. (1988) 50% loss of conductance due to cavitation was reached at $\Psi=-1.2$ MPa and 100% cavitation was reached at $\Psi=-4$ MPa. It was assumed that at maximum cavitation 80% of hydraulic conductance is blocked. Moreover, it was assumed that disappearance of cavitation occurred when Ψ rises, with a rate that is one third of the rate of induction of cavitation.

Re-Cutting. The option was implemented to re-cut the flower stems at the start of the consumer phase. When stems were re-cut, the blockage due to bacteria and the wounding response were reset to 0% and restarted. Blockage due to emboli and cavitation were assumed not to be affected by re-cutting.

Model

To have the possibility for some scenario studies about effects of various temperature–time combinations in hypothetical chains on vase life, a preliminary model was developed. Driving forces in the model were the air temperature and humidity. Flower temperature was simulated using the air temperature and taking into account a heating and cooling delay because of heat transport processes and heat capacity of the flower. Heat production by the flower as result of respiration was not taken into account. Flower temperature was assumed to control the rate of flower senescence. Using flower temperature, air temperature and air humidity the occurrence of condensation and evaporation of condensed water on the flower was simulated. The temperature of condensed water was assumed to be the dew point temperature at which condensation took place. To simulate a chain with several links, a link of the chain was treated as a module. At the start of a link flower temperature, flower senescent (development) stage, the presence or absence of condensed water, number of bacteria, the amount of blockage of hydraulic conductivity due to wounding response, percentage of cavitation, and water potential at the end of the previous link were used as starting values. It was assumed that air temperature and air humidity were constant within a link. At the end of the supply chain the maximal remaining vase life at the consumer was calculated using the simulated senescence stage and the potential vase life of the specific flower at harvest. The actual vase life was ended if flowers in the consumer phase reached a fresh weight of less than 94% of their initial weight at harvest or when the calculated maximal remaining vase life was reached. The model was implemented using Powersim Studio Academic 2003, Powersim Software AS, Norway.

RESULTS AND DISCUSSION

In a first scenario study we supposed a chain existing of only two links: a transport phase and a flower shop. The temperature during the transport was varied as well as the length of the transport; RH was 60% at all temperatures. During transport, flowers were held dry or were placed in water. The conditions in the flower shop were assumed to be constant (20°C, 60% RH); the period in the shop was 6 h. In the shop the flowers were always placed in water. After selling (the start of the consumer phase) flowers were intact or were re-cut. As can be seen in Table 1, the effect of temperature during transport on the final vase life interacted strongly with the handling of the flowers (water supply; re-cutting). In most combinations flowers lost their ornamental value due to wilting as consequence of xylem blockage. When flowers were held without water during the transport phase, their water potential decreased strongly. In some temperature x duration combinations this resulted in such high levels of cavitation that the flowers did not recover in the flower shop, resulting in a vase life of 0 day. When the water loss during transport did not exceed this critical value there was little effect of temperature and duration of the transport. Because the flowers were not placed in water during transport, growth of bacteria started in the flower shop and proceeded at the consumer. As the conditions in the shop as well as at the consumer were always the same, it resulted in

about the same vase life. The small effect of temperature when flowers were not re-cut was due to the effect of temperature on the wounding response of the stems. With re-cutting this difference was taken away. The small positive effect of re-cutting (when flowers were transported without water) was due to the removal of the wounding response during the transport and flower shop phases as well of the bacteria grown in the flower shop. In the case that flowers were placed in water during transport, cavitation did not exceed the critical level; therefore vase life was never 0 day. The main reason for end of vase life was now xylem blockage due to the wounding response and growth of bacteria. In this case the growth of bacteria started already during transport; therefore at higher transport temperatures without re-cutting vase life was less compared to transport without water. This effect of high transport temperatures on bacteria growth was taken away by re-cutting, resulting in the same vase life of 6 days as compared to transport without water. At some temperature x duration combinations the vase life was limited due to senescence of the flowers (indicated by ^s in Table 1). In these combinations flowers senesced before they wilted due to xylem blockage.

The effect of temperature during the transport phase was rather limited due to the large effects of cavitation, wounding response and growth of bacteria. Cavitation was the result of low flower water potentials due to excessive water loss without water uptake. Besides placing flowers in water, low water potentials can also be prevented by lowering the transpiration rate. In most commercial flower chains flowers will be sleeved and/or boxed; humidity within the packages will be high and air velocity around the flowers will be low. Because of this, transpiration rate will be low. Exceptions can be in coolers, during pre-cooling, sorting and (un)loading of trucks and airplanes. Water is the medium for transport of bacteria from the outer stem surface into the xylem vessel. The longer the introduction of bacteria into the xylem vessels is postponed in the chain, the better. Therefore it could be wondered whether flowers should be placed in water before the end of the transport chain at the flower shop. Without excessive water loss, data in literature showing a positive effect on vase life of placing flowers in water somewhere in the transport phase of the postharvest chain are scarce. Because temperature has a large effect on the growth of bacteria as well as on the rate of the wounding response, in the case flowers are placed in water, the temperature of this water should be as low as possible.

For the rose flowers in Table 1 a temperature × senescence-rate relationship with a maximal vase life of 10 days was assumed. When we simulate a flower with a shorter maximal vase life or which shows a stronger effect of temperature on the rate of senescence (like *Gypsophila* or iris) the full senesced developmental stage will be reached before the growth of bacteria will have resulted in end of vase life. In these cases temperature during transport will have been of more importance. In the calculated scenarios, maximal inhibition of hydraulic conductance caused by a wounding response was assumed to be 60%. When we assumed that this maximum was 70% (as in chrysanthemum), the fully senescent stage was not reached in any of the temperature × duration combinations, even when the flowers were placed in water during transport, without re-cutting. With re-cutting the results were not affected. In all the above scenarios it was assumed that there were no chemicals added to the vase water to inhibit growth of bacteria or the enzymes responsible for the wounding response. From these results it is clear that effects of conditions in this short chain can be totally overruled by properties of the crop or the handling of the flowers.

In the next scenario studies more realistic postharvest chains were simulated, in which several links with different temperatures and humidities were involved. Two different chains for roses were simulated: (i) production in the Netherlands, transport to and sale at a Dutch flower auction and transport to a flower shop in Germany, and (ii) an international chain with production in Colombia, transport by airplane to the Netherlands followed by truck transport to Italy. Time, temperature and humidity conditions used in the simulations are given in Table 2. The conditions in the ‘short chain’ (Table 2A) resulted in a vase life of 6.0 days, which was the same as in the chain of Table 1. However, due to changes in temperature combined with the relative high temperatures,

the danger of germination of *Botrytis* conidia is rather high. When RH in the last 4 h-transport to the flower shop was 82% (at 15°C; vapour pressure of 14 hPa) conidia germinated at the end of the transport. When the water vapour during the short sorting phase was 15 hPa (RH is 77.5%) conidia started to germinate the first hour of the final transport. According to the simulation, this could be overcome by lowering the temperature during the last 4 h of transport to 10°C when RH during this phase is below 80%. These results show that temperature (and humidity) management in this chain is important to prevent loss of quality due to *Botrytis* and not because of senescence of the flowers. A constant temperature (the same temperature in all links) is even more important than a low temperature (assuming that the RH<92%).

The simulation of the international chain (Table 2B) resulted in a vase life of 6.0 days. Condensation on the flowers occurred at 3 points during this 'international chain' - during sorting, at the start of the transport to the airport after the post-cooler, and at the end of the transport to Italy. In all cases, because of the low temperature, this did not result in germination of conidia. The most critical was the condensation during sorting, because the flowers dried only very slowly during the post-cooler period. So, even for this long chain, decisions about investments in cooling have to be carefully considered. Besides development and senescence of the flowers, the other processes affected by temperature should be taken into account, as well as the costs of the investments.

We have to keep in mind, that the simulation model was developed for flowers that were neither sleeved nor packed. As result of this, condensation mostly takes place when a cold flower is transferred to a warmer environment. The consequence of this is that the temperature of the condensed water is low, resulting in a long lag-phase and slow rate of germination of *Botrytis* conidia. When flowers are sleeved, it may be expected that transferring the sleeved flowers from a warm environment to a cooler one will cause condensation on the inside of the sleeves. When this water drops on the (still warm) flowers germination rate will be high.

Due to the simplifications in the model, the meaning of the outcomes is still limited; also there has been no validation of the model. The purpose of this article is to demonstrate the complexity of temperature management in the postharvest flower chain and the possible use of a simulation model as tool for critical analysis.

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Tables

Table 1. Simulated vase life (days) of rose flowers (potential vase life 10 days) after a supply chain with two links: transport and flower shop. Temperature during and length of transport phase was varied; RH was 60%. In the transport phase flowers were held dry or were placed in water. The conditions in the flower shop were constant (20°C, 60% RH, length 6 h, flowers placed in water). At start of the consumer phase flowers were not or were re-cut. ^s indicates that ornamental value was lost due to senescence; in all other situations ornamental value was lost due to wilting.

| | Transport duration (h) | Without water | | | | | | With water | | | | | |
|--------------------|------------------------|---------------|-----|-----|-----|-----|-----|------------|-----|------------------|------------------|------------------|------------------|
| | | Temp (°C) | | | | | | Temp (°C) | | | | | |
| | | 2 | 5 | 8 | 11 | 14 | 17 | 2 | 5 | 8 | 11 | 14 | 17 |
| Without re-cutting | 24 | 5.9 | 5.9 | 5.9 | 5.8 | 5.8 | 5.8 | 5.9 | 5.9 | 5.8 | 5.7 | 5.4 | 5.1 |
| | 48 | 5.9 | 5.9 | 5.9 | 5.8 | 5.8 | 5.8 | 5.9 | 5.9 | 5.7 | 5.5 | 5.0 | 4.5 |
| | 72 | 5.9 | 5.9 | 5.9 | 5.8 | 5.8 | 0 | 5.9 | 5.9 | 5.7 | 5.3 | 4.6 | 3.8 |
| | 96 | 5.9 | 5.9 | 5.9 | 5.8 | 0 | 0 | 5.9 | 5.9 | 5.6 | 5.1 | 4.2 | 3.2 |
| | 168 | 5.9 | 5.9 | 0 | 0 | 0 | 0 | 5.9 | 5.8 | 5.1 ^s | 3.9 ^s | 3.1 ^s | 1.2 |
| With re-cutting | 24 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| | 48 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| | 72 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 |
| | 96 | 6.0 | 6.0 | 6.0 | 6.0 | 0 | 0 | 6.0 | 6.0 | 6.0 | 6.0 | 5.9 ^s | 5.8 ^s |
| | 168 | 6.0 | 6.0 | 0 | 0 | 0 | 0 | 6.0 | 6.0 | 5.1 ^s | 3.9 ^s | 3.1 ^s | 2.8 ^s |

Table 2. Conditions used in simulations of two different postharvest chains of cut rose flowers. Flowers were not placed in water and re-cut after the flower shop.

A. Short local chain.

| Link | Length (h) | Temperature (°C) | RH (%) |
|--------------------------|------------|------------------|--------|
| Greenhouse | 1 | 20 | 77 |
| Cooler | 4 | 4 | 86 |
| Sorting | 1.5 | 17 | 62 |
| Transport to auction | 1 | 15 | 82 |
| Cooler at auction | 1 | 5 | 80 |
| Transport to flower shop | 4 | 15 | 77 |
| Flower shop | 6 | 20 | 60 |
| Total length | 18.5 | | |

B. International chain.

| Link | Length (h) | Temperature (°C) | RH (%) |
|--------------------------------------|------------|------------------|--------|
| Greenhouse | 1 | 25 | 77 |
| Pre-cooler | 3 | 10 | 65 |
| Sorting | 2 | 20 | 81 |
| Post-cooler | 15 | 5 | 92 |
| Transport to airport and by airplane | 20 | 10 | 73 |
| Cooler at auction | 10 | 5 | 92 |
| Transport to Italy and retailer | 30 | 5 | 92 |
| Flower shop | 6 | 20 | 60 |
| Total length | 87 | | |

