Transport and storage of cut roses: endless possibilities?

Guide of practice for sea freight of cut roses developed within GreenCHAINge project

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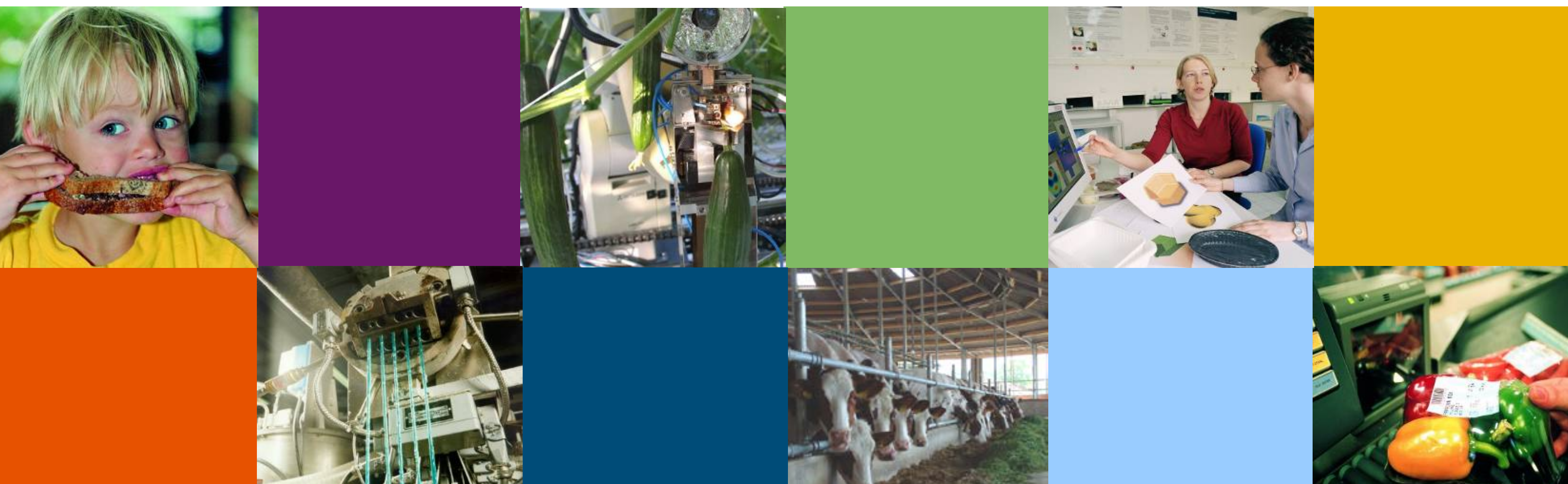

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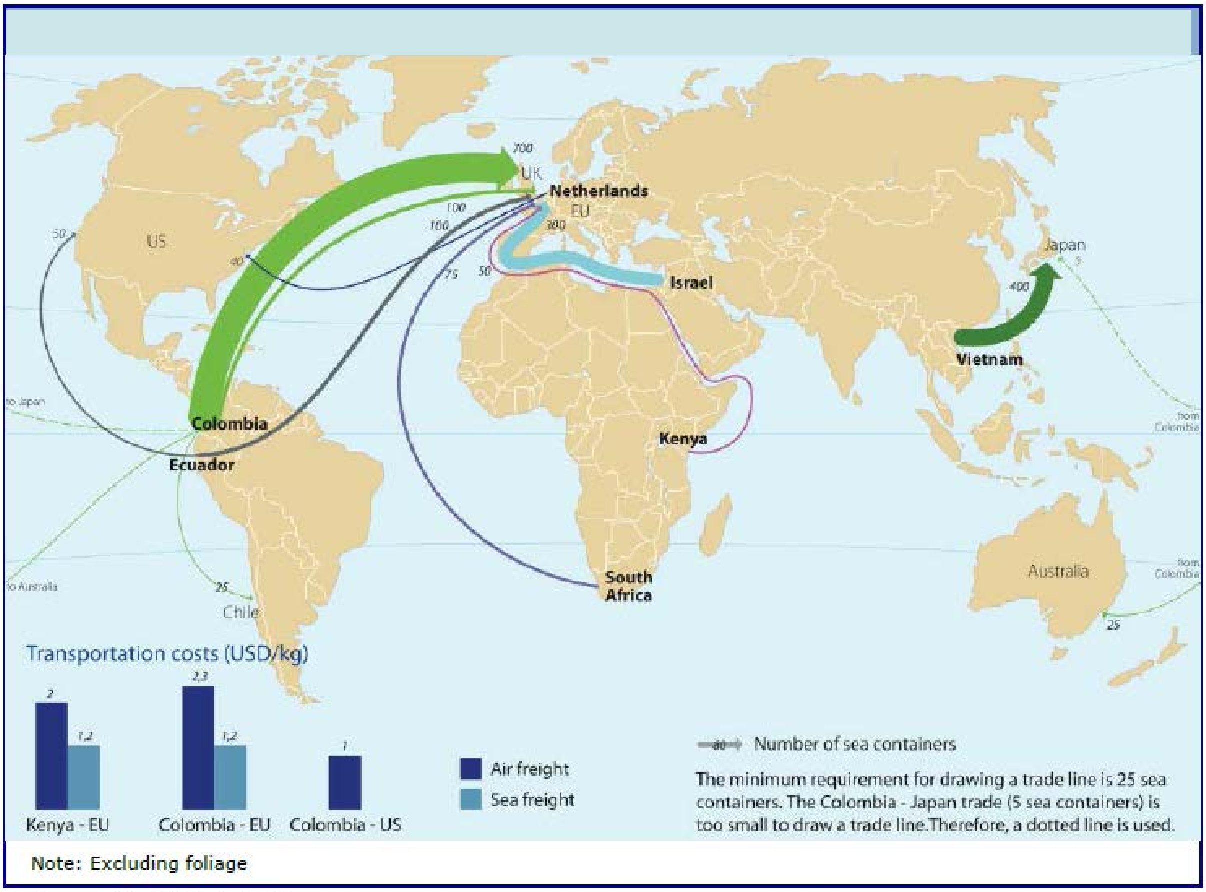
Content

1 Introduction

1.1 General introduction

Roses are cultivated in many different production locations around the world (Colombia, Ecuador, Kenya, Netherlands). They are mainly sold to consumers located in other regions of the world (Europe, North America, Japan). In the last years, global changes have taken place in the distribution chains for cut flowers in general and for roses specifically. For instance, long distance transport by sea has become a serious way of transport (Figure 1), where this was not the case 10 years ago.



Source: FloraHolland, 2014.

Figure 1. Global map illustrating global trade lines of cut flowers transported by reefer containers in 2013

Rose supply chains change continuously, because of different factors such as production costs (labour, energy prices, etc), new cultivars, new growing technology and post-harvest technology, consumer markets and consumer demands. In order to visualise the complexity of the distribution chain, we draw as an example a rose chain for an African rose transported by sea freight meant for e.g. a German supermarket (Figure 2). Roses are harvested, sorted, packed at the grower, transported to a consolidation centre, placed in a reefer container, transported to the harbour, shipped and transported to an auction/distribution centre and further transported to the shop targeted for the supermarket.

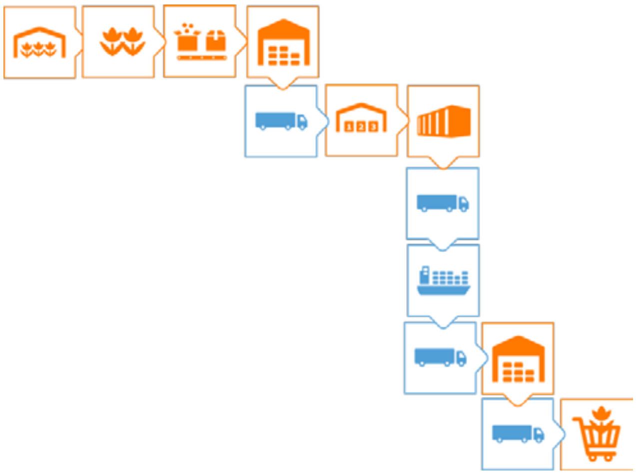


Figure 2. Example of a rose supply chain with sea freight from grower to shop

In practice there are many differences between chains:

- Firstly the number of transport and storage steps can vary per specific chain. For instance, a short local chain (production and sales in the same area) will have less transport steps.
- Secondly, the conditions during each step are different between chains. Examples of these conditions are, climate, duration of each step, temperatures and handling methods. The conditions will each have their own influence on quality of the rose.
- Third, each market has its own quality specifications and habits. Depending on the final wholesaler branch specificity, the quality expectation of the cut-rose will differ: for instance, bunches of roses sold in a supermarket formula can have a guarantee of 7 days vase life whereas roses for a florist formula will encounter higher quality expectations.

Research over the past 10 years[1] and practical experience repeatedly show that roses can be stored for long periods at low temperature during their post-harvest life. This potentially gives more flexibility in chains. Sea freight is considered a lucrative and a more sustainable way of transport comparing to air freight. It is not an easy change that can be made by a single actor in the chain. The whole chain needs to adapt, to make this means of transport feasible in the supply chain.

Post-harvest research on roses provides new ideas enabling new chains. Research can give better insight in the consequences of certain actions within the chain on the final quality of the rose. Based on experience and on knowledge from research, actors in a chain will make their own choices to change their way of working and the organization of the chain, in such a way that it fits their purpose: delivering the desired price/quality roses to consumers.

[1] *HenK, Compact & Droog, Starflower, CoCoS, Q-cotrans, GreenCHAINge*

1.2 Aim of the report

This document is aimed to support all chain actors involved in long-term (2-5 weeks) transport or (dry) storage of roses. The goal is to provide a broader background, supporting the practical guidelines for sea freight transport which has been developed for growers and trading companies in 2016 within the project GreenCHAINge. Next to this we intend to inspire actors with this information to improve quality in current chains and to bring up innovative ideas for new chains.

This report is based on results of fundamental and applied research from 2012-2016 within the GreenCHAINge project, combined with earlier research on long-term storage and container transport of cut flowers within Wageningen Food & Biobased Research.

We aim with this report to:

- Make the reader aware of the do's and don'ts when storing or shipping roses for a longer time (practical guidelines) and explain why
- Stimulate understanding of rose quality behaviour so that people in the chain can communicate and make better decisions in varying situations, now and in future
- Provide sources where more information can be found on specific topics
- Indicate areas which need further knowledge development

1.3 Set-up of the report

The report is organized as follows:

- Chapter 2 starts with a definition of quality of a cut rose and which factors are associated with post-harvest quality in general.
- In the following chapters 3-8 we will discuss more in depth the main causes of quality issues when transporting cut roses long-term (mainly transport by reefer containers). What should be done differently or should get more attention to assure final quality of the rose? Each chapter discusses a specific factor: before harvest (chapter 3), temperature control in the chain (chapter 4), limiting Botrytis influence on quality (chapter 5), impact of dehydration (chapter 6), effects of ethylene (chapter 7) and prevention of mechanical damage (chapter 8). Each chapter ends with a summary of practical recommendations.
- The chapters are followed by a discussion (chapter 9) on the value of these recommendations. How can the above mentioned factors be balanced to make the right choices in the chain to optimize quality. Recommendations for further research are provided.
- Chapter 10 summarizes the report and the practical recommendations, organized per step in the chain.
- References to publications are listed in chapter 11. A short description per project is provide hereafter, including references to publications from that project. Within each chapter references to projects and/or publications are listed in the footnote.

2 Quality and factors influencing quality of cut roses in general

2.1 What is quality?

Quality of a cut rose is a conception of different attributes for which each player in the distribution chain has its own definition. Definition of quality is complex and subjective. Actors in the beginning of the chain do not necessarily see the quality at the end of the chain. A grower thinks different about quality than a consumer.

The quality trait "vase life" is a commonly accepted measurement, stating the amount of days in which a flower (or a bunch of flowers) still has a good appearance when kept on the vase at standardized vase life conditions. These conditions are a temperature of 20 °C, a relative humidity of 60% and 12 hours light (~12 μmol m^{-2} s^{-1}), 12 hours dark. The vase life or appearance is limited by a number of attributes:

- Petal Senescence (e.g. due to natural physiological process)
- Petal Wilting (e.g. due to limited water up-take)
- Bent neck (e.g. due to limited water uptake)
- Colour changes of the flower (colour fading or blueing or blackening)
- Damages (e.g. due to rough handling of the rose during harvesting and transport chain)
- Flower opening
- Botrytis infection
- Leaf quality (colour, dehydration)
- Stem-end browning

Common criteria for evaluation of these attributes have been summarized by the Dutch Flower Auctions Association and FloraHolland[2].

Vase life tests are a valuable tool when performed in a correct and standardized way[3]. They give insight in actual quality of a batch at that moment. It can also be used to compare roses that have been treated differently. The main disadvantages are that it takes time and doesn't provide a clear indication of quality at each moment in the chain.

Vase life should not be confused with commercial quality. Commercially acceptable quality is different per chain and per actor. For example supermarkets can offer a quality guarantee to their consumers, such as no quality defect allowed at purchase (no Botrytis infection, good leaf quality) or 7 days vase life guarantee (at least 70% of the bunch should have a vase life of at least 7 days). A consumer judges quality at the buying (and giving moment) and on vase life. Some remove the whole bunch in one time when 3 flowers have reached their end of life, while others will remove one flower per day until for instance half of the bunch reaches the end of vase life.

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[2] *http://www.vbn.nl/en-US/Evaluation%20cards%20flowers/Rosa%20Engelse%20afschrijvingskaart.pdf*
[3] *Fanourakis et.al (2013) (6)*

An important aspect when talking about quality is whether growers and wholesalers know what their treatments and handling implies for the quality at the florist or the retailer and in the home of the consumer? And vice versa, do consumers and retailers know how their requirements translate into specification upstream the supply chain?

2.2 Factors influencing quality of cut roses in general

A review article of Fanourakis et al. (2013) provides a quite complete overview on factors influencing vase life. They describe pre-harvest factors (environmental factors and genetics) and post-harvest factors (harvest factors, cutting and conditioning methods, test room conditions and vase life terminating symptoms) influencing vase life. These factors are important for optimization of vase life, but also for standardization of performing vase life tests and to be able to compare results. We will explain shortly the main factors in the following paragraphs.

2.2.1 Climate and growing conditions

The climate (temperature, relative humidity, sun radiation) before harvest is important for quality. In the wet season, the relative humidity outside and in the greenhouse is high. This increases the chance on infection by Botrytis. The light conditions also have an effect on Botrytis. In an experiment with Dutch roses it was shown that roses that are grown in a period with a higher light sum (> 1500 $J/cm^2/day$) during the last 7 days before harvest, show less Botrytis infection[4]. But other factors of light conditions like intensity, photoperiod and spectrum have also been described to have influence[5].

Roses grown at higher relative humidity show more stomata that do not function optimal. These stomata are less able to close in circumstances that they should close in the postharvest phase. Therefore these roses will lose water and dehydrate more quickly[6].

2.2.2 Cultivar

The genotype of a cultivar has a pronounced effect on post-harvest performance and specifically vase life. In one of our projects we found that 31% of the differences in vase life of the roses that were tested could be explained by cultivar[7]. Transport and climate conditions played a smaller role in the vase life performance. The reasons of variation in vase life between cultivars are not fully understood. Breeding companies launch new cultivars that are selected mostly on their appearance, growing characteristics and disease resistance. Breeding for cultivars which are better adapted to changing post-harvest conditions is limited at this moment.

2.2.3 Harvest factors

To assure a complete opening of the flower bud during the vase life period, it is essential to harvest the roses in the right bud stage (Figure 3). The optimal bud stage is cultivar dependent.

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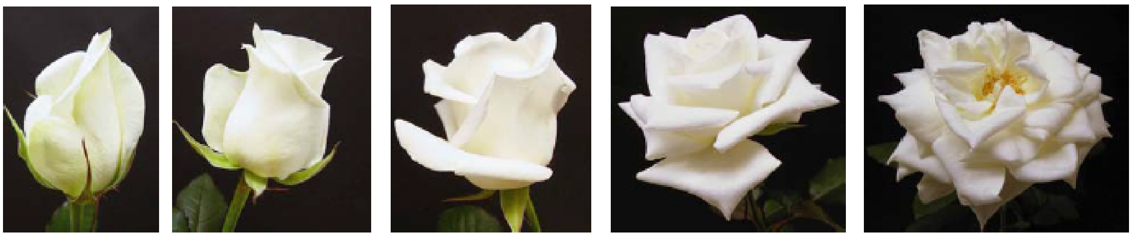
[4] *HenK (3)*
[5] *Fanourakis et al. (2013) and references herein (6)*
[6] *Fanourakis et al. (2013) and references herein (6)*
[7] *QCotrans*

Tight buds could be less sensitive to Botrytis[8], but tight buds have a chance to fail to completely open during vase life. On the contrary more open buds open better during vase life, but have tendency to develop too fast during the distribution chain, particularly during the retail phase.



1 firm pointed bud | 2 loose pointed bud, cylindrical | 3 half-open flower | 4 open flower | 5 maximally opened flower, heart is visible

Figure 3. Maturity stages described following the VBN standard (source www.vbn.nl)

The age of the crop when harvesting can also have a clear effect on vase life in general. A newly planted crop often shows shorter vase life for the first harvested roses. Vase live improves after several flushes[9]. The time of the day at which harvest occurs is also reported to have influence on flower opening and vase life. It is preferred to harvest shortly after beginning of the light period[10].

2.2.4 *Temperature and time after harvest*

The life of an organism is very much related to the respiration activity. The respiration activity is dependent on the temperature: with increasing temperature the respiration increases exponentially. This means that especially higher temperatures have a pronounced effect on the speed of senescence. Longer periods at higher temperatures are detrimental for quality.

After harvest, roses are still alive. They respire and produce heat. The respiration and metabolic activity can be slowed down by keeping the temperature low. Product temperatures of around 0.5 ˚C minimize biological activity, without completely stopping it. Lowering the metabolic activity will save energy for the rose and thereby keep its potential vase life.

In research of the past years a clear relation has been found between the temperature sum (see text box) or

> ***Temperature sum or degree days:***
>
> The total sum of average realised temperature multiplied by the number of days stored or transported.
>
> Examples:
> ***3 days transport at 10 °C equals a temperature sum of 30 degree days***
>
> ***30 days at 1 °C equals also a temperature sum of 30 degree days***
>
> In case of stepwise changes of temperature in the chain, having the value of T_i (°C) at time interval i of duration t_i (days), the time–temperature sum built up during storage is given by $\sum i T_i t_i$ (°C day) (T_i>0 °C)

[8] *Starflower (4)*
[9] *Särkkä et al. (1997)(11)*
[10] *Fanourakis et al. (2013) and references herein (6)*

degree-days and vase life (Figure 4). When roses are from the same origin, roses with lower temperature sum will have a longer vase life than roses with a high temperature sum history. A storage of 3 days at 10 °C will have a similar remaining vase life as roses stored 10 days at 3 °C. It should however be emphasized that the model is only valid between certain boundaries. Both at very low temperatures (below 2 °C) and very high temperatures (over 20–25°C) the relation may not be linear[11]. Also the model may deviate at both very long storage times (>30 days) and very short storage times (<2 days).

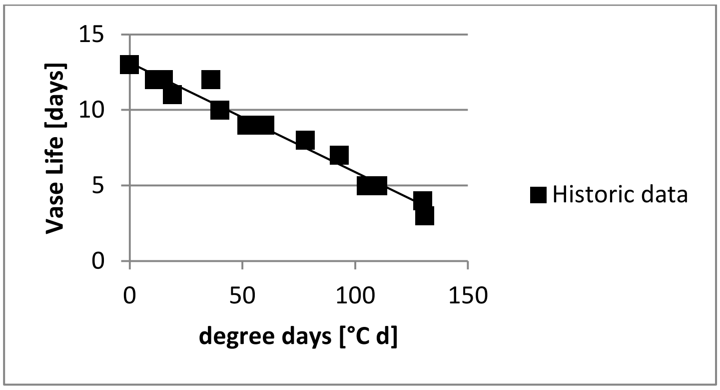


Figure 4. Historic average vase life data of various pilots and cultivars related to realized degree*days, showing a linear relation

2.2.5 Botrytis

Botrytis cinerea (called hereafter Botrytis) is a fungal infection of rose petals and receptacles. Its infection symptoms are a major vase life terminating criterion[12]. Figure 5 shows the infection cycle of Botrytis.

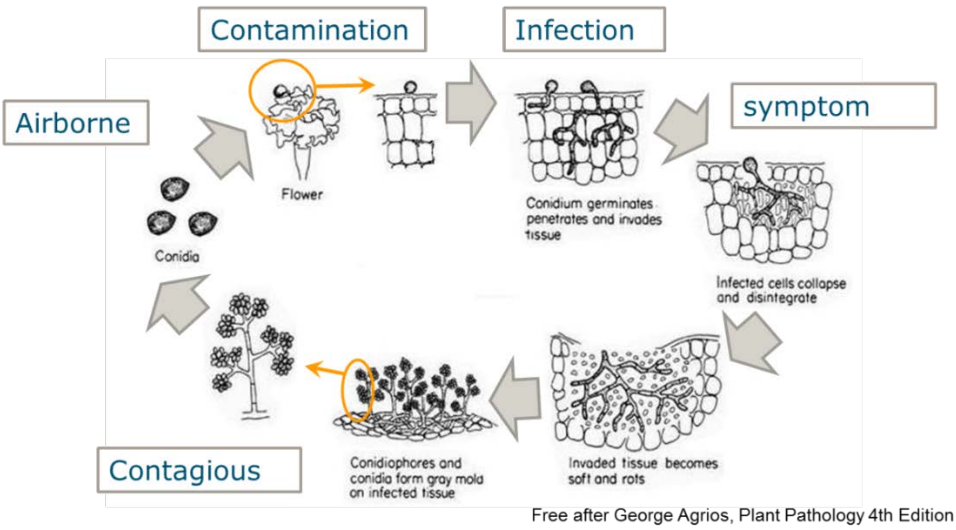


Figure 5. Schematic overview of infection cycle of Botrytis

[11] *Tromp et al (2012)(13)*
[12] *van Meeteren (2007)(14)*

Botrytis spores are dispersed during the growth of the flower or during the post-harvest handling. Fungal spores (including Botrytis) are always present in the air in areas where roses are grown. The Botrytis spores need free-water (condensation water) or a high relative humidity to germinate and infect the rose tissue. The germination of the spore and the infection of the plant tissue is temperature dependent, with its optimum *in vitro* between 17 and 18 ºC and its limits for sporulation above 30 ºC. When Botrytis is colonizing a petal (infecting) it cannot be reached anymore by contact fungicides nor can it be removed from the plant tissue.

Susceptibility of the rose for Botrytis infection is dependent on various factors. High temperature and low relative humidity can lower the susceptibility[13] whereas calcium deficiency increases susceptibility[14].

Flowers with Botrytis symptoms at harvest have to be removed. Absence of visible symptoms after harvest is no guarantee for a Botrytis free bunch of roses in the flower shop. The spores and infecting hyphae are not visible with the naked eye (Figure 6).

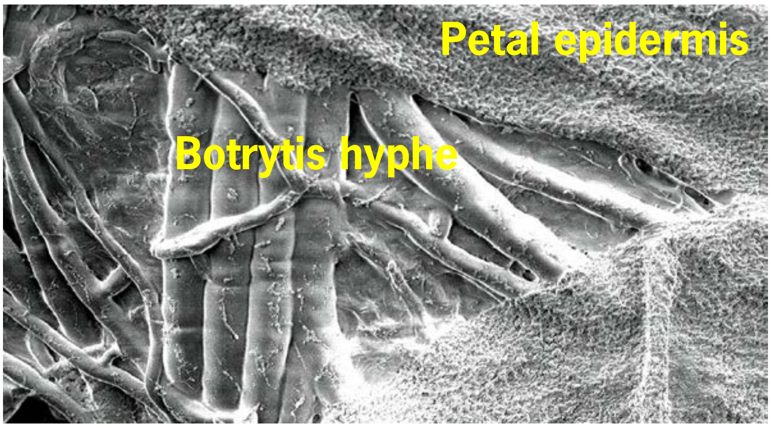


Figure 6. Microscopic picture of a Botrytis hyphae infecting a rose petal via the epidermis

The first Botrytis symptoms appear mostly during the retail period or during the consumer's phase. Using sleeves in the retail phase creates a high relative humidity around the flower bud. Emphasized by high temperature (20 °C) it stimulates the growth of Botrytis. Keeping the distribution chain after air or sea transport as short and cool as possible may limit its effect on Botrytis, and thereby on the length of vase life. An example of the effect of a long distribution chain on the vase life is shown in Table 1. Rose cv. Aqua was infected seriously with Botrytis: the decrease in vase life after the distribution simulation was mainly due to Botrytis[15].

During the retailer's phase it is recommended to unpack the flowers and ventilate them as much as possible. Also an overload of bunches in the bucket will result in high relative humidity between the bunches.

[13] *Fanourakis et al. (2013) and references herein (6)*
[14] *Fanourakis et al. (2013) and references herein (6)*
[15] *GreenCHAINge (2014)*

Table 1. Effect of a distribution chain on the vase life of roses that were transported by sea or by air

vase life (days)	Aqua		Tropical Amazon	
	air transport	sea transport	air transport	sea transport
direct on vase	15.0	14.6	13.0	14.5
distribution simulation	1.5	6.4	11.0	9.3

distribution simulation:
2 days at 4°C (dry) + 2 days at 8°C (in Chrysal T-bag) + 4 days at 20°C (in Chrysal T-bag)

2.2.6 *Water balance and turgidity*

The word 'turgid' means 'swollen'. In plants turgid means that the plant is full with water. Turgid flowers have stiff stems, leaves without any sign of drought. The flowers itself feel stiff, without any wilting symptoms, not limp. When cut flowers are turgid, this is considered as a positive quality trait. When cut roses loose water (dehydrate) they become less turgid and the above mentioned quality traits drop. However, turgid flowers are also very susceptible to mechanical damages due to pressure or bumping[16]. So during transport it is not always desired to have full turgescent flowers.

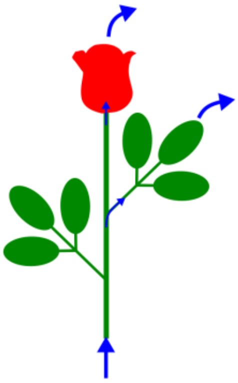


Figure 7. Schematic representation of the water balance within cut roses

Water balance in cut flowers is basically determined by two factors: water uptake through the stem and water loss through the organs (leaves, flower and stem; Figure 7). Ideally flowers should have a positive water balance, meaning that the loss of water is less or equal to the water uptake. In such condition, the cells are turgescent. When water loss is higher than water uptake, a negative water balance develops. After some time, petals and leaves will look wilted. During dry storage/transport a negative water balance develops inevitably. If the water loss is more than a few percent, the flowers may develop a wilted appearance. Generally a rehydration treatment will quickly restore a positive water balance. As long as water loss does not exceed a certain limit, there is no irreversible damage to the flower. This limit is not a strict limit and seems to be dependent on cultivars and other unknown growing conditions. In various experiments it was seen that a limited percentage of dehydration does not show a relation with vase life[17]. Leaves have more problems to recover completely[18]. A slight water loss may somewhat restrict Botrytis development.

[16] *Starflower (4)*
[17] *CoCoS (9), GreenCHAINge (2016)*
[18] *CocCos (9)*

3 (Pre-) harvest conditions

As described in chapter 2, pre-harvest factors such as cultivar choice, growing conditions, time of the year and grower have great impact on post-harvest performance of roses. This chapter discusses the impact of these conditions on the storage performance.

3.1 Cultivar selection

Cultivars suitable for transport by air are not necessarily suitable for transport by sea and vice versa. Results from GreenCHAINge pilots (2013) can be used to visualize this. 21 Kenyan rose cultivars from 1-3 origins, transported via air freight, were compared with roses transported ~27 days in a reefer container. Figure 8 shows great differences in vase life per cultivar. Figure 9 shows the relative differences in vase life between air freight and sea freight for each cultivar. About two third of the cultivars (no. 1-14) have comparable vase lives (within 10-20% difference) irrespective of the transport mode. However, one third of the cultivars shows 20-50% shorter vase life when transported by sea (no. 15-21) compared to those transported by air. These findings indicated that cultivars react differently to the transport conditions and some cultivars are not or less suitable for transport. At this stage of the research, conditions of pilot sea shipments were not yet 100% optimized for sea freight.

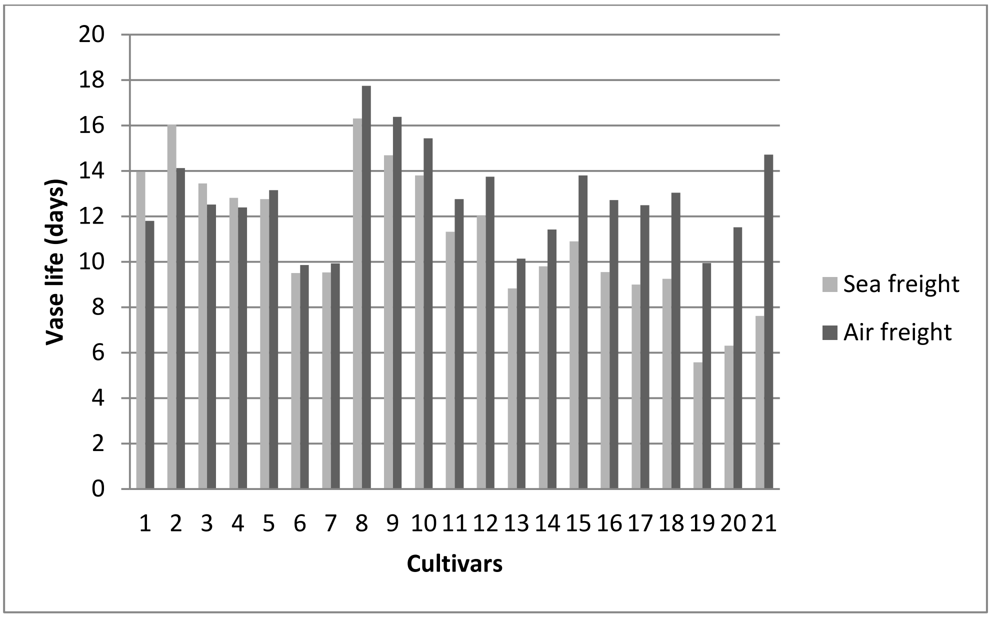


Figure 8. Average rose vase lives per cultivar after sea freight compared to air freight from Kenya. Bars indicate averages of 1-3 origins, 2 repetitions per origin, no retail simulation

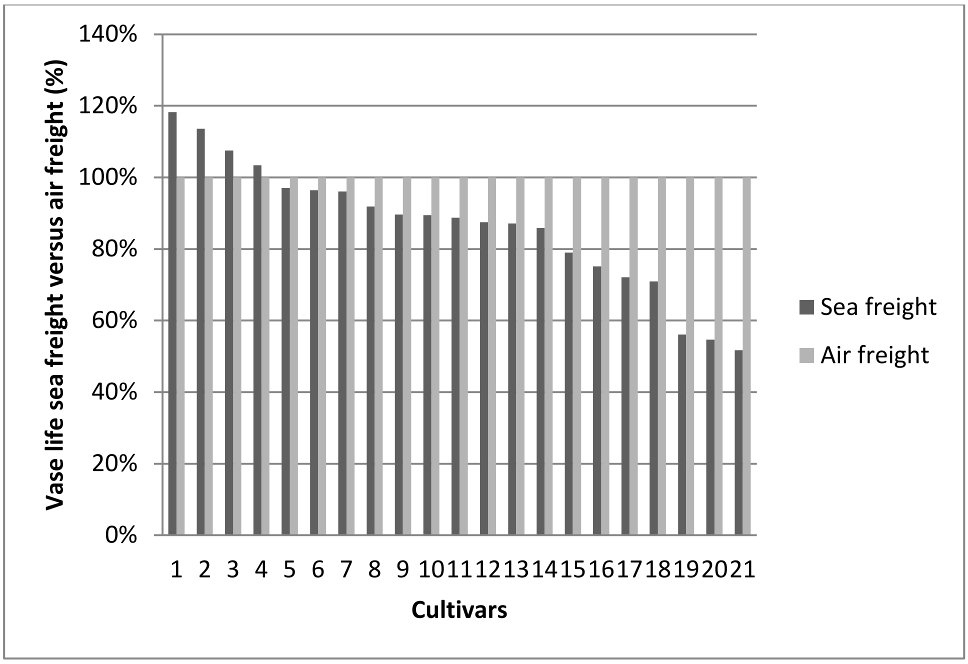


Figure 9. Vase lives per cultivar after sea freight pilots compared to air freight from Kenya (vase life air freight = 100%)

In the follow up of the GreenCHAINge project a list with cultivars was prepared, indicating the potential for sea freight transport from Kenya to the Netherlands (including retail stage) based upon standard test and quality criteria (VBN). Vase life results from roses from various growers and/or several pilot shipments have been used. The list classifies approximately 80 Kenyan rose cultivars. Each cultivar is classified according to three distinct classes: suitable for sea freight, suitable with restrictions (e.g. not in wet season), and not suitable for sea freight. The classification is based on jointly agreed criteria of acceptable vase life performance (>7 days), Botrytis sensitivity and ethylene sensitivity of each cultivar tested. (VGB, FloraHolland, Wageningen Food&Biobased Research together with sector representatives). The recommendations and classification criteria that were followed, are available upon request via above mentioned partners. The sea freight variety list is unique and a first for the fresh-cut export market. It is useful for selection of varieties with the biggest chance on a good result for long-term shipments. It is advised to actualise the recommendations per cultivar with new vase life data from shipments (following the sea freight protocol).

3.2 Effects of climate and growing conditions at the farm

Creating climate and growing conditions that result in a healthy, strong crop and good initial quality of roses, increases the chance for successful long-term transport. Some diseases like Botrytis may establish themselves in a more severe way after long-term cold storage, if not handled optimally (chapter 5). Also other fungal infections already present in the greenhouse (such as downy mildew) c more pronounced after sea transport compared to air freight (Figure 10). This example indicates the importance to take actions

Figure 10. Red Calypso leaf, likely infected by downy mildew

during cultivation to prevent conditions that stimulate disease incidence. Investigation of other specific relations between climate, disease management, fertilization and performance after storage has not been the focus in our research projects

3.3 Maturity stage at harvest

In general during transport, the bud will keep opening at a slow rate. We have no indications of structural differences between air freight and reefer sea freight in this respect (when temperature sum is comparable). The conditions in retail phase (high temperature, in a plastic sleeve) stimulate bud opening more than transport itself [19](Figure 11).

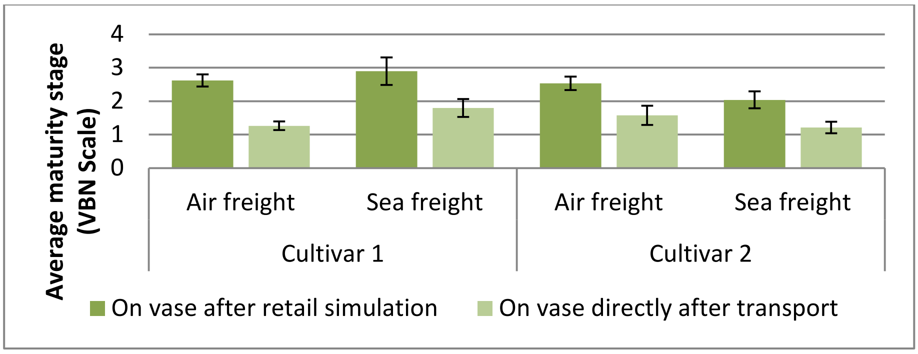


Figure 11. Average maturity stage on day 1 at the vase of 2 cultivars after air freight and reefer transport; put directly on the vase or after a retail simulation. Error bars indicate standard deviation

3.4 Recommendations (pre-) harvest conditions

- Select a cultivar that generally has a good vase life performance, low sensitivity for Botrytis, not subjected to water uptake shortage, and not sensitive to pathogens and disease. The list with a provisional classification of cultivars suitable for sea freight can help.
- Perform a pre-transport test with new cultivars. Store roses under controlled conditions for 3 weeks and evaluate vase life before shipping.
- Harvest rose at correct maturity stage, taking the cultivar and the market specifications into consideration.
- Make sure that the crop (in the greenhouse) is disease-free: no fungi or virus infection. During wet season, apply an anti-botrytis treatment in the weeks before harvesting.
- Use strong roses, do not use roses issued from the first productions of a newly planted crop as the roses will not be strong enough for long cold transport.

[19] *GreenCHAINge (2013)*

4 Temperature control

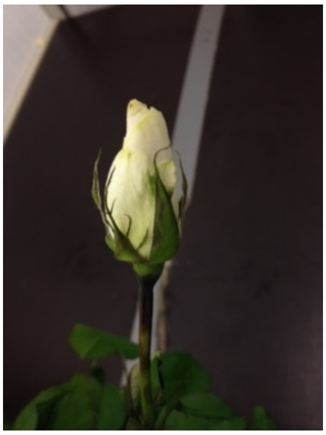


Figure 12. Rose with chilling injury symptoms (black stem) after reefer transport with too cold air temperature (<0 °C)

One of the most important factors in transport and storage of roses is the temperature and time Temperature should be as low as allowed for the roses (about 0.5-1 °C) during all steps in the chain. This is the lowest temperature allowed, otherwise roses may show chilling injury or freezing symptoms (Figure 12)[20]. This chapter describes importance of temperature control and how it can be realized in long-term (reefer) transport.

4.1 Temperature sum and long-term transport

The temperature sum model described in chapter 2.2.4 provides a tool for prediction of remaining vase life, when knowing starting quality, time and storage/transport temperature. The linear relation between temperature sum and vase life is not always there when going for extremes like > 40 days transport or temperature <2 °C or when vase life is restricted by other symptoms than natural senescence, such as Botrytis[21].

According to the temperature sum model, similar vase lives should be reached after transport where temperature fluctuates, compared with constant temperatures, as long as the transports have the same temperature sum. Research confirms that fluctuations in temperature have impact on natural senescence, but only when the temperature sum is significantly increased[22] (Figure 13). For longer storage periods and lower temperatures this effect has not been specifically researched. Temperature fluctuations may increase the risk on Botrytis (Chapter 5).

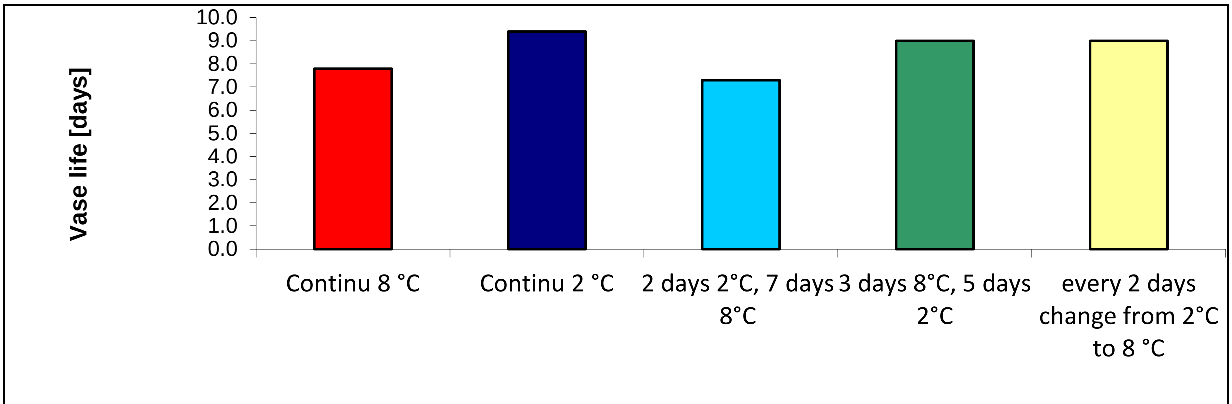


Figure 13. Vase life results of roses after 9 days storage

[20] *GreenCHAINge (2016)*
[21] *Tromp et al. (2012)(13)*
[22] *HenK (1)*

4.2 Actions to ensure cold roses in the chain

All steps from harvest till displaying the flowers on the shop floor play a role in the temperature sum methodology. Maintaining vase life requires lowering the temperature or duration to the lowest possible. The transport temperature set point for reefer transport of cut-rose is recommended at 0.5 °C.

A refrigerated truck cannot cool down products, it can only keep the product cool. A reefer container can cool down the product to a limited extent. Therefore it is important that all steps before shipping help to realize a rose product temperature as low as possible (<2 °C).

4.2.1 Harvesting, grading, bunching, packaging (by the grower)

To assure the best control of the temperature, roses should be cooled down as quickly as possible after harvest and should not be "warmed" up at any step while being processed. In general, the handling processes such as grading, bunching and packing are done at the packing house. There are several options to start the cooling process:

- Pre-cooling of flowers before packing (Figure 14, upper and middle drawing).
- Pre-cooling after packing of the flowers (Figure 14, lower drawing).

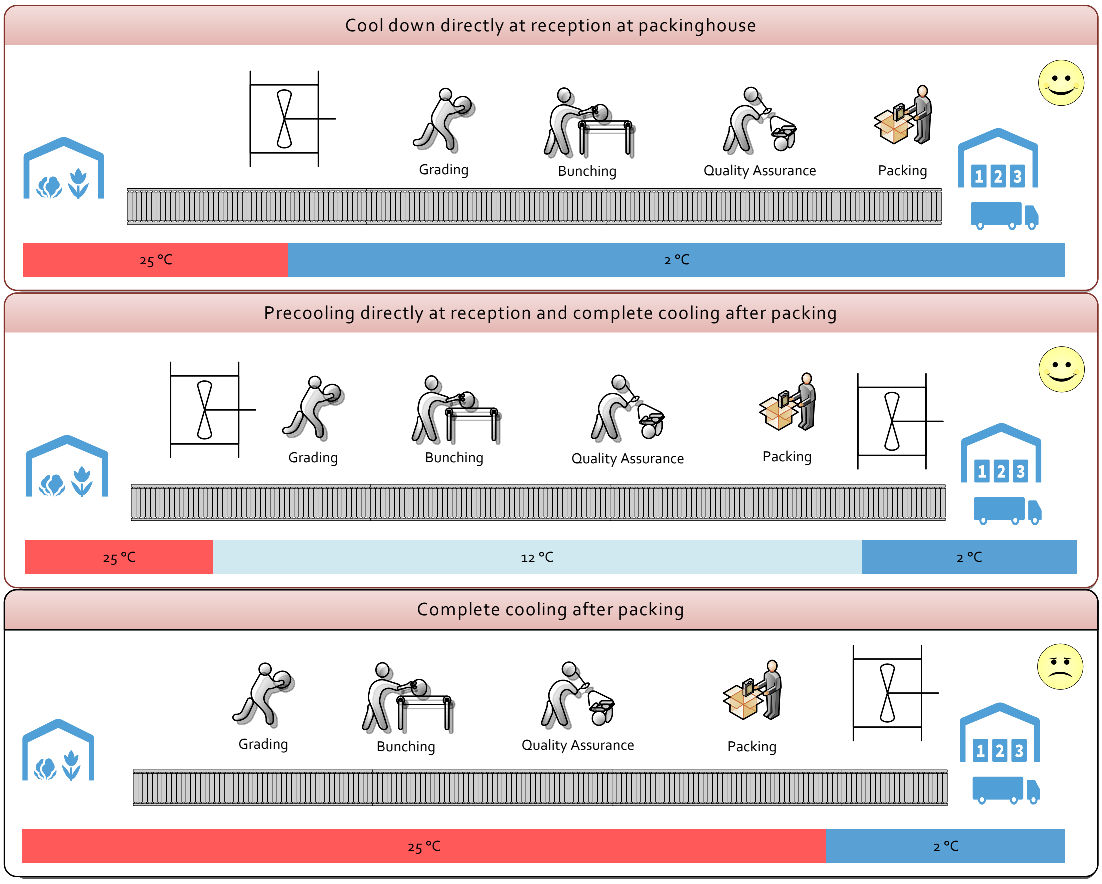


Figure 14. Three options on cooling process and handling

In the case of pre-cooling of flowers **before** packing, it is essential to proceed with packaging at the same or lower temperature as the flower temperature, in order to avoid any condensation on the flower bud. It is an option to cool down the flower in several steps in order to control and minimize the temperature sum and assure proper working conditions for the workers in the meantime (Figure 14, middle drawing).

In the case of pre-cooling **after** packing of the flowers, it is important to make sure the handling processes are done quickly after harvest and make sure that boxes can be cooled fast and effective using forced air cooling or vacuum cooling.

4.2.2 Packaging type and stacking

The choice of packaging type has a great effect on effectivity of cooling. Most of the time, the dimensions of boxes are mainly determined to reach an optimal load in a truck, plane or container. However, the bigger the box, the more difficult it is to cool it down quickly and uniform throughout the whole box (Figure 15)[23]. The smaller the box, the faster the product can warm up if it comes in a warmer area (Figure 16)[24]. So it is important to take the cooling process also into account when choosing the dimensions of the carton box.

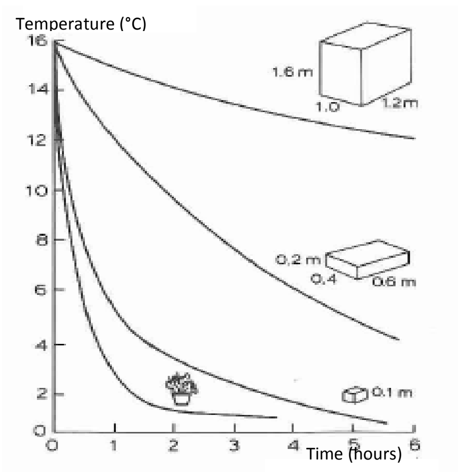


Figure 15. Cooling speed of roses in various packaging dimensions

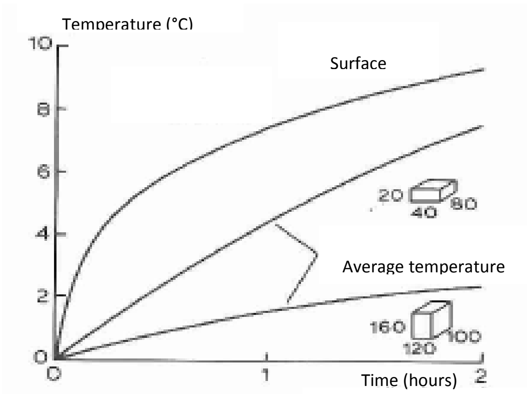


Figure 16. Increase of temperatures over time when prior cooled product is transferred from 0 °C to 10 °C. Depending on the dimensions of the box (20*40*80cm and package 160*120*100) product temperature increases to 2 or 8 °C within 2 hours, while surface temperature of both boxes reaches 9 °C

[23] *Hoogerwerf et al.(1986)(8)*
[24] *Hoogerwerf et al.(1986)(8)*

Holes in the cartons at front and back-end are needed for horizontal airflow, when using forced-air cooling. Other holes present in the carton should be closed/limited during this type cooling to make sure the air passes through the box to cool the product. Holes in the top/bottom or at the sides are helpful to cool down when you don't use forced air or vacuum cooling for pre-cooling. In this case, using a criss-cross way of stacking the cartons also creates more airflow through all cartons, improving effectivity of cooling (Figure 17)

Figure 17. Example of stacking "criss-cross" to increase speed of cooling flowers

Uniform airflow during the complete duration of a reefer shipment will be assured by the holes which are positioned vertically. Thanks to this flow, the temperature of the product is kept low and warm spots in the load will be limited. It is essential that the holes in the cartons are placed in such a way that they are not obstructed by roses, sleeves or liners, by the pallet or by T-bars in the container. The size, position and the amount of holes should be carefully chosen to assure a good airflow (Figure 18). At the same time water loss of the product should not exceed certain limits because of too much airflow (chapter 6).

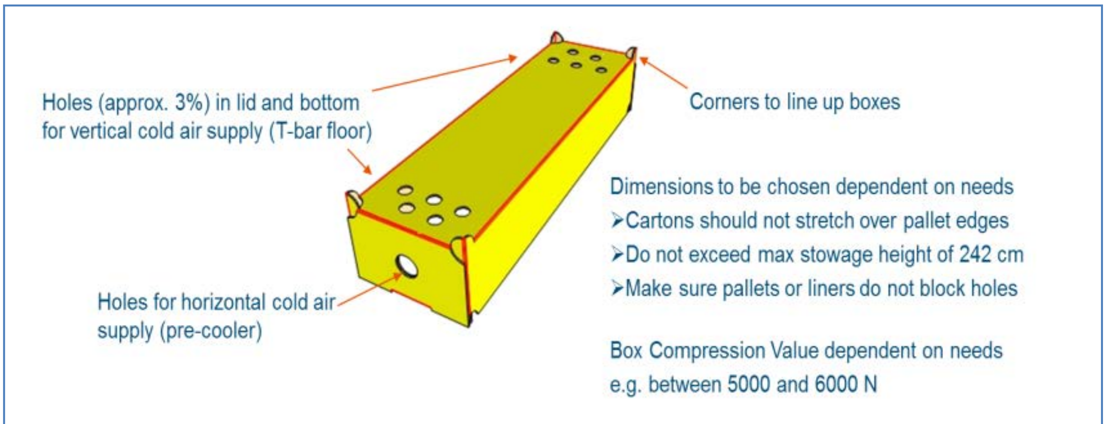


Figure 18. Example of Cardboard box optimised for reefer transport of cut-flowers

Within GreenCHAINge a box has been developed for specifically for sea freight from Kenya to the Netherlands. This box has been optimised for dimensions to fit in a 40-ft reefer container and can be placed on pallets (more information at VGB). For this box a pack rate matrix has been developed to prevent overstuffing. The speed of cooling decreases, if a box is loaded with too many roses. The recommended amount of roses per box is based on size of bud and length of flower.

The use of sleeves per bunch in the box influences cooling speed too. Especially forced air cooling of cut flowers will take more time (2-3 times)[25], compared to just using a protective liner covering all bunches. A liner can also block airflow, but less than individual sleeves.

4.2.3 Cold storage facilities

Management of cold stores and logistics at the farm have great effects on effectivity of the cooling process. The cooling equipment present in the cooling room, the initial products temperature and the flow of product going via the cooling room will create temperature profile specific to each farm, grower and cold store.

To make cooling effective, it is important to

- know the target temperature of your product at different stages
- measure the air temperature at different spots in your cold store
- measure the temperature of your product depending of its emplacement inside the cold store

It is also helpful to understand that temperature **set point** of cold storage cell **is not the same as**:

- the average realized temperature in the cell
- the realized temperature at any place in the cell
- the realized temperature of the product (in a box)

Several types of cooling systems can help to cool down your product more effectively, e.g. forced air cooling or vacuum cooling. The main differences between these 2 technologies is that vacuum cooling can cool down much faster than forced air cooling. In previous experiments[26] it was shown that the speed of cooling (20 min, 2 hours or 10 hours) did not have a significant effect on quality of cut roses, as long as it reaches the target temperature. Both systems dehydrate the product to some extent (1-2%). This does not need to be a problem if it stays within limits (Chapter 6).

4.2.4 Transport from farm to consolidation centre

In an ideal situation for sea freight, the product temperature in the boxes at the farm should already be below 2 ˚C and the boxes should be loaded inside the reefer container at farm location. However in many cases the boxes will be transported via refrigerated trucks to a consolidation centre. When leaving the farm, the recommended temperature of the roses in the box is lower than 2˚C. The truck needs to be refrigerated. Even then, the temperature of the product in the boxes might still rise to temperatures above 6 ˚C, influenced by outside air temperature and the cooling capacity of the refrigerated truck (too low). This must be prevented.

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[25] *GreenCHAINge (2016)*
[26] *HenK (1)*

4.2.5 Consolidation centre

At a consolidation centre, sufficient space and time should be allocated to cool down properly the product before loading the reefer container (<2 ˚C). A vacuum cooler can be used to bring the product in a very short time to desired temperature. However, this will also dehydrate the product further. The higher the product temperature is, the more it will dehydrate. This also implicates the importance of lowering the temperature at the grower directly after harvest. In the cold storage facilities of the consolidation centre it is important to check regularly the product temperatures at several places in the storage cell and only ship products that have a product temperature below 2 ˚C.

4.2.6 Loading and settings of a reefer container

When using pallets, appropriate stacking is essential in order to ensure proper temperature control in the whole load. Hotspots and cold spots can be prevented by taking into account airflow and temperature distribution in a reefer container. In reefer containers the cold air enters from beneath the load through the T-bar floor. This airflow is directed through or alongside the flower cartons to the upper part of the container where it is directed back to the cooling equipment (Figure 19).

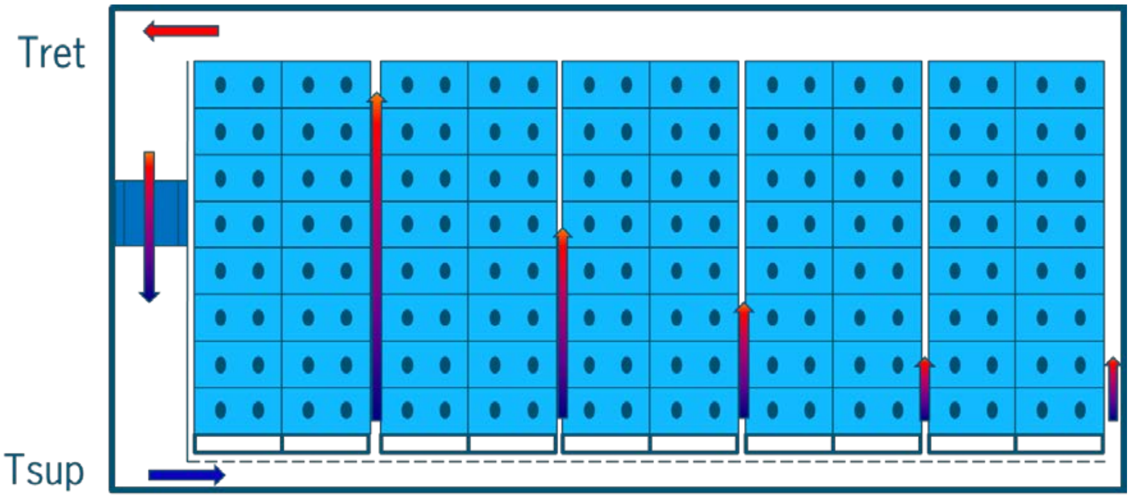

Figure 19. Schematic side view of typical airflow distribution in a reefer. Left side is unit-end, right side is door-end. Tsup= Temperature supply air, Tret = temperature return air

The optimal stowage pattern of the pallet/boxes in the container depends on temperature of product, heat production of product, and the temperature difference between outside and set point (Table 2). In general it is important to make sure enough air reaches the door end via the T-bar floor. For long-term transport of flowers in a reefer it is different than typical products like bananas or frozen products. The flowers need to be protected from outside temperature and their own produced heat needs to be removed. This means that cold air is needed everywhere: along the walls to prevent outside heat to influence temperature of those boxes placed against the walls and through/along the boxes to remove the produced heat of the product. All this needs to be in balance, as too much air through the box can lead to too much dehydration.

Table 2 Overview of differences in recommended stuffing profile for various situations

Product example	**Flowers (0.5 °C)**	**Frozen products (-18 °C)**	**Bananas (13.5 °C)**
During transport $T_{outside}$ vs $T_{setpoint}$	Semi high difference	High difference	Low difference
During loading $T_{product} = T_{set\ point}$	Approximately (<2 °C)	Yes	No
Heat production by product	Medium	Low	High
Action of reefer	Keep product cool Removal outside influence Removal of produced heat	Keep product cool Removal outside influence	Removal of field heat Removal produced heat
Optimal air route	Partly along walls, partly through and between boxes.	Along walls around load, via door end	Through boxes (via holes)
Measures to achieve optimal airflow route	Make sure enough air reaches the door-end. Limit the gaps between load and walls, and mutually between boxes. Block airflow at the door-end as indicated in Figure 20.	Stow the cargo as one tight block. Avoid direct contact with the walls (use reefer sticks), but make sure enough air reaches the door-end.	Avoid gaps between load and walls. Avoid or block chimneys. Block airflow at the door-end .

For roses it is important to pay attention to get enough cold air at the door end. This can be realized by minimizing "chimneys" between stacks of boxes, but also by covering the floor at the door end in the correct way (Figure 20). When this is not covered, too much air will escape at door end and there is too little air left, that passes in between the pallet/through the boxes to remove the flower heat. However, the T-bar opening should be left open to create some airflow at the door-end removing heat that possibly enters through the door. Next to this the pallets/boxes itself should be placed with little space between them. Always obey the red load lines at the ceiling and the door-end. Do not load above the red line, as this will reduce the return airflow. If loaded above the red load line any claim related to loss of quality will be rejected. It is recommended to cover the floor completely with load even when container is not 100% full in height. This is best for airflow and can also prevent boxes tipping over.

Figure 20. Examples of covering up the T-bar floor (when working with pallets) at the door end to avoid air return through open area (A & C). In the correct picture (B) the pallet and floor is covered, but the T-bars are left open. When working without pallets C is also correct.

If the container is loaded on a dock where temperature is controlled (strongly preferred), then it is advised to precool the empty container prior to loading. This means running the container empty at temperature set-point for at least 3 hours with doors closed. However, when temperature is not controlled at the dock, then pre-cooling of the container should not be done as a lot of condensation will occur in the container when loading is started. During the loading itself the cooling unit should be turned off. The loading should be done quickly in less than one hour. After loading directly close the doors. After closing the doors, the cooling unit must be switched on (temperature set point +0.5 °C). In most cases power supply of the container should be assured by a Genset till moment of arrival at the harbour (dependent on distance, travel time and outside temperature). Make sure that the container is connected to a power supply at the harbour location till loading onto the vessel (usually done by harbour operator).

Other set points of the container next to temperature are:
Ventilation/Fresh air exchange: 20 m^3/hr
Drain holes open and clean
Humidity control: OFF
Defrost cycle: automatic

Keep in mind that described recommendations on stowage and settings of a container have a general nature. Specific situations may require special attention that is not covered by this current research. For follow up research please contact Wageningen Food & Biobased Research (see contact details).

4.3 Examples of temperature profiles of roses in air and sea freight

To give an idea of temperature profiles realized in practice in various chains we provide a few examples in Figure 21 and Figure 22[27]:

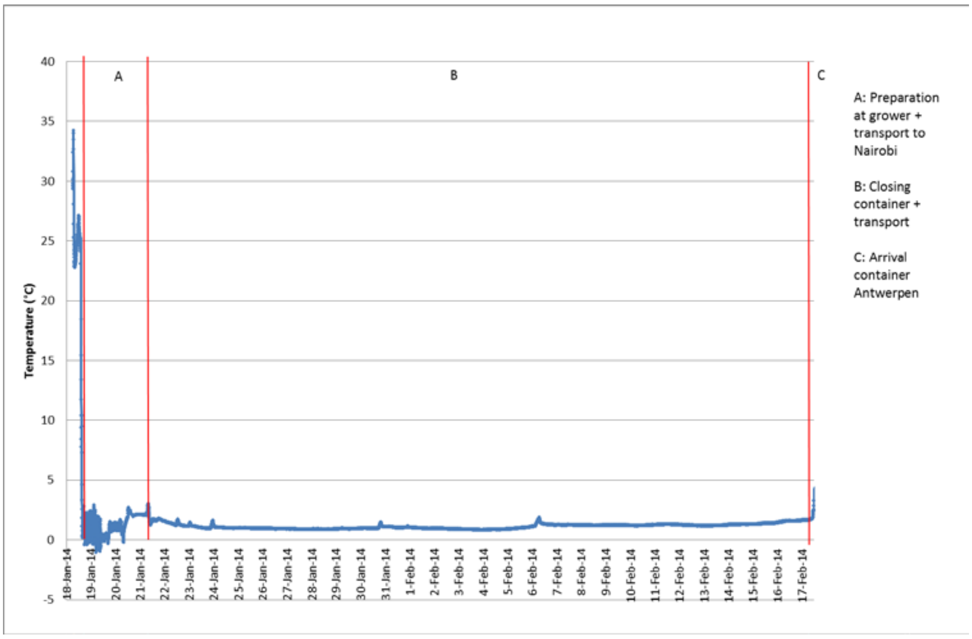

Figure 21. Temperature profile of reefer transport during pilot from Kenya to Antwerpen

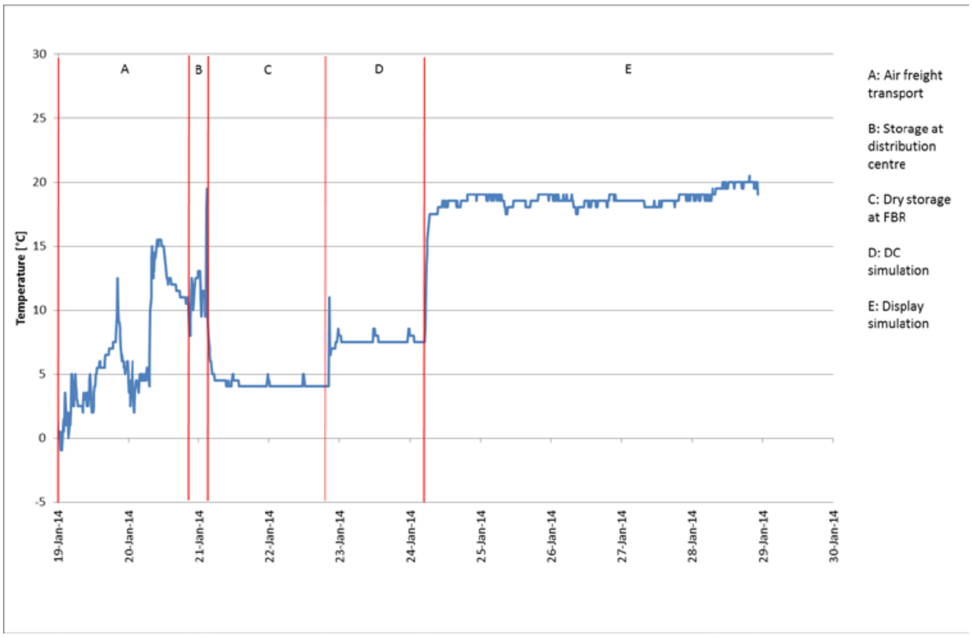

Figure 22. Temperature profile of air transport and following steps in one of the pilots from Kenya to Antwerpen

[27] *GreenCHAINge (2014)*

4.4 Recommendations temperature control in a sea freight chain

- Select a cultivar that can handle long cold periods
- Cool product as soon as possible after harvest
- Keep the temperature as low as possible (0.5 ˚C) in the whole chain. Below this temperature, roses could show chilling injury and freezing symptoms
- Avoid higher temperatures and temperature fluctuations as these stimulate senescence and/or Botrytis development
- Removal of field heat of the product needs to be done before loading the boxes in the reefer container
- Use specific boxes optimized for reefer transport and load the container (with or without pallet) in such a way that air circulation is homogenous through the complete load
- Measure and log temperatures of product and cold storage facilities to monitor any temperature issues occurring in the production chain

5 Botrytis control

The low temperatures during long-term transport or storage will limit Botrytis growth and sporulation compared to higher temperatures in regular air or truck transport. When given enough time, Botrytis will even develop at temperatures of 0.5 °C. How much time depends on cultivar and storage conditions. High relative humidity during long storage can have a stimulating effect. The susceptibility of the rose to Botrytis infection might also be changed because of different transport conditions. This chapter will explain background on results from experiments and observations in pilots, and provide recommendations what can be done to control Botrytis.

5.1 Actions to limit Botrytis infections after long-term transports

5.1.1 (Pre-)harvest

Selection of cultivars that are not susceptible to Botrytis is the first step to avoid Botrytis infection. A cultivar presenting Botrytis symptoms directly after air freight transport is too sensitive also for long-term transports. The sea freight cultivar list, developed within GreenCHAINge, can also be used as it has also given a classification on Botrytis incidence.
Special care should be given during the 'Botrytis season': During the wet season roses are more susceptible to Botrytis infection than during the dry season. This will also be the case for long-term transport. We strongly recommend during the wet season the application of a regular (commercial) preventive anti-Botrytis treatment before harvest. The effect of the wet season can play a role during the transport from the greenhouses to the pack-house. Prevent contact of free water/rain drops with the flowers in order to avoid the germination of the Botrytis spore.

Performing a hotbox test at the grower, informs the user about the Botrytis risk linked to growing conditions (high spore density already present on the flower buds) and about the sensitivity of the flower buds to Botrytis spore germination. Per batch of roses, a few bunches are placed in vases inside a Plexiglas box at ambient temperature (Figure 23)[28].

Figure 23. Example of hotboxtest. Condensation on the box hinders the view somewhat.

[28] *Starflower (4)*

Inside the box, the relative humidity is artificially brought to 95-100% by placing wetted paper on the bottom. The high relative humidity accelerates the germination of Botrytis spores present on the flower buds. This hotbox test is an indication for the Botrytis infection of the tested batch: after e.g. 3-4 days it shows the maximum infection that can appear on the investigated batch of roses. When no Plexiglas is present on the farm, the Plexiglas box can be replaced by a transparent plastic bag placed over the vase.

5.1.2 Packing Station

Additionally to the pre-harvest anti-Botrytis treatment, we recommend application of a postharvest anti-Botrytis treatment. ***For safety and health reasons, it is essential to check first whether these treatments are allowed by the national regulation, and to take special precaution to assure healthy working conditions for the workers.***

Solutions against Botrytis are provided by commercial companies such as Chrysal or Floralife.

The use of these products has shown beneficial effects against Botrytis growth. The products should be applied with intensive collaboration with the professional technician of the providing companies. The use of chlorine solution (sodium hypochlorite = NaOCl) as an anti-Botrytis treatment has also shown effects against Botrytis growth, in several cases better than conventional fungicides (Medallion, Python, Switch and Vangard)[29]. A dip of the buds for 1 second in a solution of 100-200 ppm free chlorine is sufficient, within a pH range of 5.5-8.5 (Figure 24). Higher concentrations can give damage to petals (dependent on cultivar). So it is essential to check the free chlorine concentration (and pH) before the start of the treatment with chlorine measurement equipment (e.g. via chlorine measurement strips indicating the right range of concentration, available via company FlowerWatch).

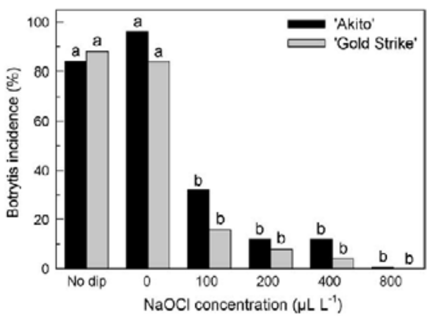

Fig. 1. The incidence of *Botrytis cinerea* infection on *Rosa × hybrida* 'Akito' and 'Gold Strike' flowers after a 7-d vase life at 20 °C and 90% RH. Flowers were dipped in 0, 100, 200, 400 or 800 μL L⁻¹ NaOCl (provided by Clorox® Ultra bleach solution) for 10 s at 20 °C on day 0 of vase life. Additional control flowers were not dipped in solution. Within each cultivar, data ($n = 25$) followed by different letters are significantly different ($P \leq 0.05$).

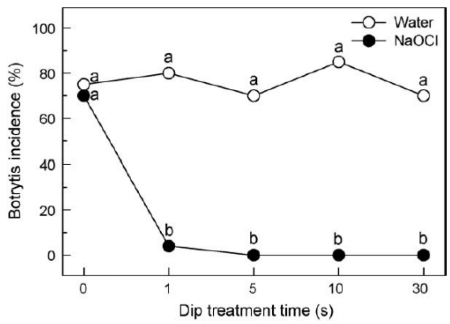

Fig. 2. The incidence of *Botrytis cinerea* infection on *Rosa × hybrida* 'Gold Strike' flowers after a 7-d vase life at 20 °C and 90% RH. Flowers were dipped in 0 (water) or 200 μL L⁻¹ NaOCl (provided by Clorox® Ultra bleach solution) for 1, 5, 10 or 30 s at 20 °C on day 0 of vase life. Data ($n = 20$) followed by different letters are significantly different ($P \leq 0.05$).

Figure 24. Left: Effectivity of dips with various NaOCL concentrations on Botrytis incidence in roses on the vase. Right: Effectivity of duration of dip treatment (NaOCl) on Botrytis incidence in roses on the vase[30]

[29] *Macnish et. al. (2010)(10)*
[30] *Macnish et. al. (2010) (10)*

The concentration can change over time, under influence of the water (pH) and the type of sodium hypochlorite that is used. Moreover the sun (UV-radiation), temperature and organic matter influence the concentration. In pilots in Kenya we have measured a reduction of concentration of ~100ppm during a couple of hours in non-used solution in the greenhouse compared to non-used solutions stored in an office[31]. The concentration decrease may differ per situation, therefore we recommend to measure the concentration regularly during the treatment. Refresh the solution when necessary. Make sure that the excess water after dipping the flower is correctly removed and no free-water stays on the flower bud.

5.1.3 Packing, transport

Anti-Botrytis treatments are not 100% effective. Therefore choosing optimal packaging and transport conditions which limit chances for further development or cross-contamination are important. Especially the high humidity conditions in long term transport can still be a risk. Each following item should be optimized:

- Cleaning of the transport modalities
    - If any rotting plant material is found in the transport modality it should be cleaned. Cleaning a transport unit to eradicate any Botrytis spores is not necessary. When the unit is used to transport other commodities the conditions in the container are mostly unfavourable for Botrytis. In addition most flowers are already infected before being loaded in a transport unit[32].
- Packaging of the bunches
    - Use SFK (Single Folded Kraft) around the flower buds. The cardboard will absorb a part of the free water. Take care that the temperatures of the flower buds and the SFK are the same. Warm SFK's around cold roses may favour condensation and so accelerate the germination of the Botrytis spores already at the beginning of the transport. (More about SFK in chapter 8.1)
    - Sometimes roses are bunched with buds not at the same level (e.g. in case of larger buds) (Figure 25). In one of our sea freight pilots we have measured a higher incidence of Botrytis in the roses positioned below the upper buds [33].

Figure 25. Picture of roses bunched in 2 layers, with buds not at same level.

[31] *GreenCHAINge (2016)*
[32] *CoCoS (9)*
[33] *Starflower (4)*

- Sleeves, plastic films
    - When flowers are already packed in sleeves at the packing house, we recommend using sleeves with perforations around the flower buds. We observed less Botrytis infection when flowers were packed in perforated sleeves compared to flowers packed in non-perforated sleeves. More open sleeves tend to decrease the Botrytis infections, but this positive effect is only visible when flowers are lightly infected with Botrytis spores[34].
    - When using a liner, cover the leaves but leave the flowers open.
    - Packing the flowers in modified atmosphere (MA) film may decrease the Botrytis infection. A modified atmosphere package is a package made from a plastic film with micro-perforations. In such MA package, due to the respiration, the oxygen (O_2) concentration will decrease and the carbon dioxide (CO_2) concentration will increase. It creates a balance in gas conditions which targets a decrease of respiration of the roses. The package also protects against dehydration. A third benefit may be reduction of Botrytis growth due to increased CO_2 levels. The balance between O_2 and CO_2 depends on the temperature and the amount and dimension of the micro perforations. The benefits for roses have not been proved in laboratory experiments yet, except for protection against water loss. There are also risks when the MA-package is not optimized and/or applied in abuse transport conditions (abuse temperature in the chain, too high packing rate), high CO_2 may cause damage to the leaves. The risk on Botrytis infection will be higher when not reaching the desired MA-conditions because of the higher humidity in the bag. At this moment we do not recommend the use of MA packaging for long-term transport or storage of roses[35].
- Box and packing
    - Package design should be used as a practical tool for controlling Botrytis infection. Size and location of holes have a significant effect on the Botrytis infection, but also on dehydration. Boxes with large ventilation holes and effective air ventilation around the buds improves the dispersion of condensed water on the packed flowers and thus lowers the chance of germination of Botrytis spores[36]. However, large holes may cause irreversible water loss (Chapter 6).
- Temperature low and steady
    - We recommend a low (0.5 °C) and steady temperature at all locations during transport and storage. Botrytis grows faster at a higher temperature, which, when contaminated, leads to more visible Botrytis symptoms. Also condensation on a cold product when roses are put in a space with higher temperature will result in higher chance on Botrytis.

[34] *HenK(2)*
[35] *Starflower (4)*
[36] *Sman, van der et. al (1996)(12)*

- Between door closing and opening of a transport modality very little can be done to counteract and Botrytis related issues. All efforts need to be done before and after shipment.

5.1.4 *After transport*

After unloading the transport unit or after storage we generally recommend not to rehydrate the roses immediately, but to keep the roses dry during the remaining distribution chain (provided that the temperature is kept low). At the retailer the flowers should be placed in water in any case, after recutting the stems. We have seen that roses which are kept dry after harvest until the retailer, show less Botrytis than flowers put on water in two or more links in the distribution chain[37](Table 3). However, after longer dry transport immediate rehydration might be more crucial than the relatively small reduction in Botrytis infection.

Table 3. Effect of wet/dry links in the distribution chain on Botrytis development after 7 days of vase life.

Pretreatment	Transport by air	Exporter 24 h 10→5°C	Truck 24 h 5→1°C	Retail 48 h 18°C	Botrytis index (0 - 4) after 7 days in vase Tropical Amazon	Aqua!
dry	dry	dry	dry	water	0.82	0.08
water	dry	dry	dry	water	1.38	0.28
water	dry	water	water	water	2.00	0.44

5.2 Recommendations to limit impact of Botrytis on quality after long-term storage/transport

- Select cultivars with a low sensitivity to Botrytis
- Apply a preventive anti-Botrytis treatment before harvest
- Avoid contact between rain drops and roses
- Apply the 'hot box test' as an indicator of Botrytis infection of batches
- Use an anti-botrytis post-harvest treatment: A chlorine solution or a commercial solution
- Use SFK's around the flowers.
- Pack the flowers in sleeves with (large) perforations around the flower buds
- Pack the flowers in bunches with the buds at the same level
- Store and transport the flowers at low temperature (0.5 °C)
- Rehydrate the roses after transport as late as possible, still able to rehydrate
- Unpack the flowers as soon as possible, ventilate the flower buds
- Display the flowers in water at low temperature, as short as possible
- Do not place too many bunches in one bucket during display

[37] *Compact & Droog (7)*

6 Control of water loss

The relative humidity (or actually the vapour pressure deficit) around the flower and leaves is one of the driving factors with respect to dehydration. Managing the relative humidity (RH) around roses is often a compromise between managing water loss and Botrytis development. High relative humidity around the roses prevents excessive dehydration but promotes Botrytis. All kinds of tools (sleeves, liners, bags, boxes) are available to keep the RH high around the roses and prevent dehydration during dry transport. How different should the control of water balance be for roses in a long storage/ transport chain versus a normal chain?

6.1 Effect of prolonged transport or storage on the water balance of roses during vase life

Flower wilting, reduced flower opening and bent-neck are all symptoms related to a negative water balance in which the water loss (transpiration) is larger than the water uptake. Both aspects of the water balance were studied in laboratory experiments with prolonged stored roses[38]. On the one hand the water conductance through the stems was determined and on the other hand the transpiration, mainly through the stomata in the leaves. We did find a loss of functionality of the stomata in some cultivars after long-term storage. We did not find a changed water conductance through the stems as a result of long-term storage/transport. As such, issues regarding the water balance after storage or transport are likely related to reduced functionality of the stomata. If the stomata do not function well, especially in combination with other suboptimal conditions, this enhances the chance for flower wilting and bent neck. This effect of transport and storage on stomatal functionality was different per cultivar. An interesting direction is the development of a test, for different cultivars and batches, to predict the water balance after long-term transport and storage to anticipate their suitability for such methods.

6.2 Actions to limit dehydration during long-term transport chain

A pilot with roses 'Tropical Amazon' and 'Aqua!', transported by air from Kenya to the Netherlands and subsequently by truck to Germany, shows that hydration in one of the steps in the chain gives better results than hydration in more steps (Table 3, pg 32). Placing the roses into water at the retailer is absolutely necessary (preventing limp flower on display) and results in the best quality during vase life at the consumers. Although the retailer received the roses in suboptimal quality (mostly dehydrated), the flowers recovered during the hydration phase. The standard chain, where roses are put into water at all links in the chain with exception during air transport, showed more Botrytis development and poor flower opening (Compact & Droog project). In this pilot flowers were placed in water without additives with the aim to investigate the effect of dehydration. In practical circumstances roses will mostly be placed in water with additives, which may have a positive effect on the quality. Similar results were observed in other air transport pilots with roses from Ecuador destined for the German and French market.

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[38] *GreenCHAINge, 2016 (5)*

Although above example indicates that hydration after harvest was not necessary for short transport chains, it seems more important to limit weight loss during long-term transport and distribution. The cooling step of the product will realize a 1-2 % dehydration and the airflow in a cold storage cell or reefer transport are dehydrating forces that can push the limit in some cases. Too much water loss enhances symptoms like bent-neck during vase life of the roses.

Weight loss during transport and subsequently in the distribution chain depends on the post-harvest treatment received by the flowers. Water loss during dry transport in a reefer container can be increased depending on their handling between harvest and stuffing the sea container.

The following treatment/packaging affects the weight loss rate during long-term transport and storage. Decrease of weight loss can be realized by:

- ***Maintaining low temperature in distribution and storage*** lowers the transpiration and evaporation rate of cut roses.
- ***Wrapping the flowers in plastic*** helps to decrease the weight loss by 1 - 2 % during long-term transport and storage[39]
  Sleeves: Roses packed in sleeves show 2 - 3% less weight loss during a 21 days long-term transport and storage[40]
  A Plastic liner used during long-term transport of 23 days at 0.5°C reduces the weight loss by 1 - 2% (when the roses are packed in hot needled perforated sleeves with corrugated paper)[41]
  Dipping the rose in solution of sodium hypochlorite helps to reduce the weight loss during long-term transport and storage, in addition to protect the roses against Botrytis[42] (More information about the dip in hypochlorite in Chapter 5)
- ***Boxes without holes***: Roses packed in boxes with perforations have 2 - 3% extra weight loss depending on the amount and diameter of the holes[43]

The quantitative effect of these measures will depend on cultivars and batches.

6.3 Improving water uptake during hydration in clean and cool environment

During the distribution chain, flowers have to be hydrated at least one time. In the case of application of a compound via water uptake against bacterial growth or ethylene early in the distribution chain (chapter 7), hydration between harvest and packing is a consequence of this treatment.

Rehydration after transport or storage should be done in a clean and cool environment to assure best water uptake. Make sure you use clean buckets and water. Several commercial products are

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[39] *CoCoS (9)*
[40] *Starflower (4)*
[41] *Starflower (4)*
[42] *CoCoS(9)*
[43] *Starflower (4)*

available for cut rose hydration. Often these products contain a biocide and surfactant to improve the hydration process. Recutting the stems with a sharp and clean cutter is important for water uptake. At the cut surface and in the stems bacteria and their waste products clog the xylem vessels. The water has to go through these vessels. When the stems are clogged by bacteria, the rose is not able to absorb water. Most bacteria are present in the lowest part of the stems. Recutting 3 - 4 cm of the stems will not remove all bacteria, but in most cases it is enough to assure a sufficient uptake of water. Hydration in cold water and in a cold room (5°C) increases the water uptake and avoids air embolism in the xylem vessels in the stem. Placing the flowers in water of 20°C in a cold room does not have similar effect as the combination low water temperature and low air temperature[44]. This effect could be different when using commercial products.

6.4 Balance between water balance and the chance on Botrytis

Managing the water status of cut roses during the distribution chain is looking for the best balance between turgidity and the chance of Botrytis development. When rose cultivars are not sensitive or completely resistant to Botrytis, they should be treated in a way minimizing water loss through the whole chain.

When roses that are sensitive to Botrytis and/or when roses are not effectively treated against Botrytis, opting for turgescent roses is in conflict with the chance on Botrytis development during the distribution, even when temperatures are low (0.5 ºC). Flowers transpire and evaporate water increasing the relative humidity. Minimizing dehydration by preventing evaporative loss of water by packaging in sleeves without perforations leads to an even higher relative humidity around the flower buds, which increases the chance on Botrytis development.

6.5 Recommendations to control dehydration and manage water balance of cut rose after long-term storage/transport

- Improve water uptake
  - Disinfect buckets before use
  - Remove with a sharp cutter 3 - 4 cm of the stems before hydration
  - Use clean water and/or use a conditioner as recommended by the supplier
  - Hydrate in cold water or commercial solution in a cold room
- Prevent weight loss
  - Pack the roses in plastic sleeves or film or use a plastic liner
  - Cool only once to distribution temperature and keep the product at temperature
  - Use boxes with limited amount and sizes holes
  - *Optional: dip the rose buds in a solution of sodium hypochlorite (see Chapter 5)*

[44] *Van Meeteren (1992)(15)*

7 Ethylene damage after long-term storage or transport

7.1 Ethylene effects

Roses are generally known as not or little sensitive to ethylene whereas some other flowers like carnations, lilies and freesia's are. Recent results of experiments show clear effect of the temperature during long term storage on the ethylene sensitivity.[45] Four rose cultivars that are known in the market as sensitive to ethylene were exposed in dry conditions for 27 days at 1°C and 4°C at several exogenous ethylene concentrations between 0.1 and 10 ppm Table 4.

Table 4. Four rose cultivars are exposed to different ethylene concentrations (< 0.1 ppm - 10 ppm) during 27 days at 1 or 4°C. The concentrations that are shown are the lowest concentrations that negatively affect the quality during vase life.

Temperature	Fuchsiana	Inka	Marie-Claire	Red Calypso
1°C	> 10 ppm	> 10 ppm	1 ppm	1 ppm
4°C	0.1 ppm	0.1 ppm	0.1 ppm	0.1 ppm

Ethylene damage symptoms are in general leaf abscission and disturbed flower opening. In Marie-Claire flowers open star like, in Red Calypso flowers do not open complete and they show early wilting (Figure 26).

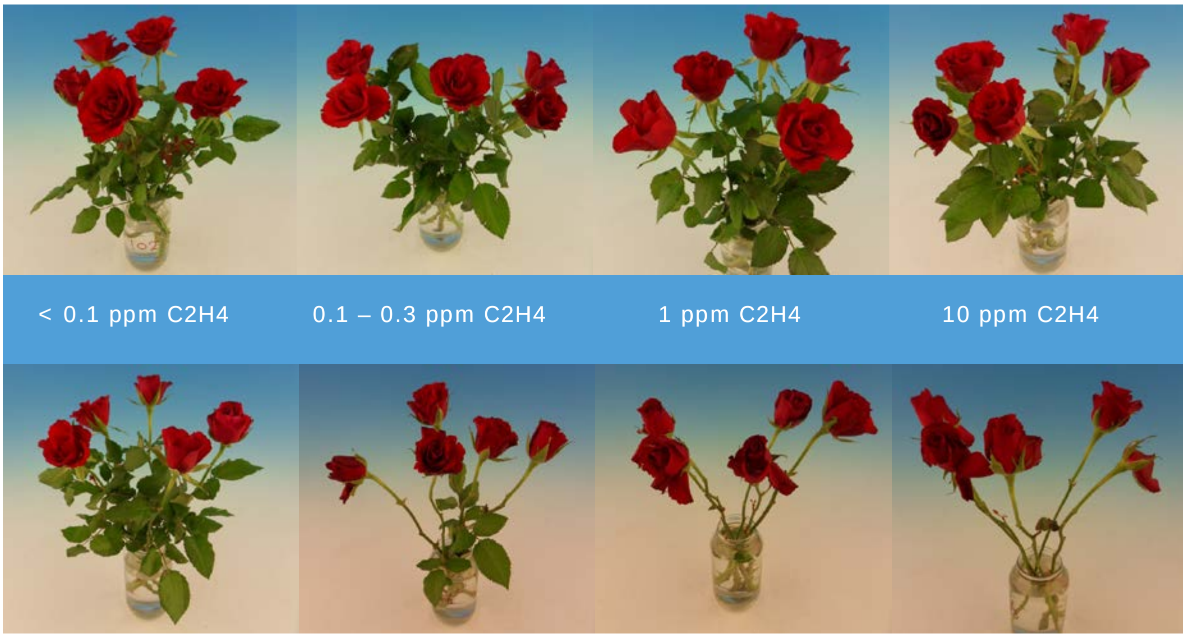


Figure 26 Rose 'Red Calypso'. Roses were stored 27 days at 1°C (upper row) or 4°C (lower row), at ethylene concentrations from < 0.1 ppm - 10 ppm ethylene (C_2H_4).

[45] *Nanonext*

We found that

- at low temperature (1°C) no effect of ethylene could be determined for ethylene concentrations below 1 ppm
- at 1°C the ethylene sensitivity is cultivar dependent
- at 4°C very low ethylene concentrations (<0.1 ppm) affect the quality

Low temperatures (0.5 °C) during transport and storage will minimize the risk on damage symptoms. A solution to prevent problems with ethylene is a treatment with a post-harvest solution containing Silver thiosulfate (STS). STS blocks the ethylene receptor of the rose and reduces significantly its ethylene sensitivity during the complete long-term transport and storage. Even under conditions where there was no effect of exogenous ethylene, we have observed improved vase life when STS was used[46]. The reason for this is not understood, further research into the subject is needed.

7.2 Recommendations against ethylene damage

- Keep the temperature as low as possible through the whole chain
- Keep the rooms/transport units free of any source of ethylene (e.g. ripening fruit)
- Application of STS after harvest helps to prevent ethylene damage in sensitive cultivars.
- Even though not all cultivars are sensitive to ethylene, the use of an anti-ethylene solution based on STS can benefit them as well.

[46] *CoCos (9)*

8 Limiting mechanical damage

Flower buds, especially the rose petals, are sensitive to any mechanical damages that occur during harvest, packing and transport processes. In this chapter we describe several aspects that are especially important with respect to long-term dry transport.

8.1 Protection by Single Folded Kraft (SFK)

The use of SFK is generally used to prevent handling damages and protection during transport. Applying the SFK should be done with care: first align the buds correctly and then pack in SFK material. Examples of different ways of folding the SFK are shown in Figure 27. It also gives physical support to heads during rehydration after transport or storage.


Figure 27. Examples of various types of SFK used at a farm in Kenya

8.2 Correct packaging

The choice of packaging and pack rate have an influence on the chance of mechanical damage. The box should be able to withstand rough handling, weight of stacked packages on top, vibrations of transport and high humidity during long-term transport and storage. The specific pack rate matrix for a Kenyan sea freight box, developed within GreenCHAINge project, helps growers to pack the carton box with optimal load. The matrix is based on the dimensions of the box, the length of the flowers and the bud size. Under-packing may lead to movement of the bunches in the box. Over packing will damage the buds due to long-term pressure on the buds whilst being in the reefer container. Be careful when strapping the boxes, this can also damage the rose buds.

8.3 Preventing damage to petals caused by dehydration

Dry transport of roses may also create a risk on 'mechanical' damage when flowers are too much dehydrated. We have observed cultivars showing, after rehydration, osmotic damages at the extremity of the flower petal (Figure 28 left). It seems that osmotic or intracellular pressure during the water uptake after transport was too high for the weak cells. Therefore it is essential to select correct cultivars, limit dehydration percentage during transport and use correct rehydration solution to avoid osmotic shocks. One could argue whether for this reason transport of flowers on water would be better. However, when flowers are transported on water, they also become more susceptible to bruises as they are more turgid, compared to a dry chain (Figure 28 right). Another disadvantage is the drop in pack rate of the load when flowers are shipped on water.

Figure 28. Damage on petals: Left probably caused by too much dehydration not able to handle pressures during rehydration. Right: Bruises which occurred during transport on water

8.4 Movement of roses and vibrations during transport

In any circumstances roses packed in boxes should be restrained for movement. The packed boxes and pallets in the truck or container should be restrained and preventive measures should be taken to prevent tipping over. The vibrations during transport in Western circumstances do not cause damage. This was confirmed by transport simulation tests with roses on water in the HenK project[47]. However, these simulations were not performed in more tough infrastructure conditions and with dry transported flowers, such as ones that could be find nowadays in Kenya.

8.5 Preventing damage during application of post-harvest treatments

When applying an post-harvest treatment, special care should be taken to avoid any mechanical damages due to rough handling or over-concentrating the chemical solution (e.g. anti-Botrytis solutions (Figure 29).

Figure 29. Example of damage on rose petals (left) and rose leaves (right) because of application of too high concentrations sodium hypochlorite dip

[47] *HenK (1)*

For application of any dipping treatments make sure that there is enough dipping solution to dip the flower buds completely without contact between the flower buds and the bottom of the bucket. Next to this make sure the bucket is wide enough to prevent the buds touching the sides of the bucket (Figure 30).

Another issue may be damage due to sun burn. Sun burn of petals may occur when flowers are placed directly in the sun after dipping or when condensation is present on the flower bud.

Figure 30. Example of buckets used for post-harvest sanitizing treatments in Kenya

8.6 Recommendations to prevent mechanical damages

- Protect the flower bud with a SFK (Single Folded Kraft)
- Stuff the flower bunches in the carton box in a way that no contact is possible between the flower bud and the box
- Pack the boxes using a pack rate matrix, such as the one developed for sea freight in the GreenCHAINge project (Appendix)
- Avoid to strip the boxes where the flower buds are placed. Preferably strip boxes on the outside
- Reinforce the lower boxes on the pallets with plastic corners that should be placed between the box and its top lids at the first two lower layers of the pallet
- Strap correctly the pallet to avoid any tipping during (sea) transport
- Prevent mechanical damages during the application of post-harvest treatments (e.g. anti-Botrytis)
- Select suitable cultivar, limit dehydration and use correct rehydration solution to avoid osmotic shocks and damages at the extremity of the petals.

9 Discussion

9.1 General

The past 10 years our post-harvest research on long-term transport/storage of cut roses focused on two questions:

1. Is it possible to store and transport cut roses several weeks with acceptable quality (vase life)?
2. How can this be achieved?

The research line followed was directed by the involved partners. The research can be characterized as solution-driven research, such as trial and error, followed by more in depth study to find explanations for encountered problems.

The combination of pilots and research experiments proved the possibility of transporting roses over large distances in a reefer container. 15 years ago it seemed impossible to transport cut-roses longer than 14 days. With the current knowledge we are able to extend this period to 4 weeks for several cultivars.

Background information on long-term storage and transport of cut-roses is provided in this report together with recommendations on how to act throughout the chain. Several additional tools have been developed by partners in the GreenCHAINge project to provide assistance growers and traders that want to ship roses in reefer containers (e.g. practical guidelines for sea freight, sea freight cultivar classification, the pack rate matrix). In future, recommendations should be optimized further based on new knowledge and experience.

The results so far show that achieving good quality in long-term transport cut roses is possible. However, it is not achieved, nor self-evident in all situations. More regular commercial shipments will contribute to standardized conditions of pilots. Monitoring conditions and quality throughout the chain during the year will give valuable information where problems may arise. Fundamental research under more controlled circumstances will help to better understand relations between influencing factors. It will give more insight in physiological interactions and limits of transportability of the roses, providing new solutions to improve the success rate.

9.2 Balancing between quality influencing factors

Based on current experiences we believe that the main factors determining product performance after sea freight are: storage temperature and time, starting quality, the management of Botrytis and post-harvest water loss.

1. Temperature control by all actors in the chain must have top priority. Proper pre-cooling and temperature control are key. Monitoring conditions in the chain gives insight in realized temperature sums and what actually happens with the product in the chain. This creates opportunities to pin point the bottlenecks and improve temperature management.
2. High starting quality of roses after harvest is important. Improved quantification of starting quality and transportability via biomarkers would be helpful.

3. Management of Botrytis and post-harvest water loss. The management of Botrytis and irreversible post-harvest water loss requires balanced choices in treatments and packaging, adapted to both risks. Quantifying risks and impact of actions is difficult because of natural variation of plant material, rate of contamination and interaction between various influencing factors on quality traits. The best choice also depends on buyer or end-user.

9.3 Novel technology giving insight in post-harvest quality

A decision-support tool based on expert data and real-time data of a specific chain helps to find the balance between above described factors. A software prototype for a 'real-time' quality-control system (IQ-Flora) is being developed to predict and monitor post-harvest quality of cut roses. This is based on real-time input from temperature sensors, tracking & tracing information, quality assessment and a prediction module. The prediction module is developed within GreenCHAINge by experts from Wageningen University and Research and Royal Flora Holland. Their knowledge, research results and models are used as baseline input. The prediction based on artificial intelligence, can be coupled to actual operational data from sensors and quality information via a smartphone app. The calculation rules from the prediction model are increasingly refined (self-learning), which improves the reliability of the prediction. At this moment (December 2016) the prototype of the software is being finished and is planned to be tested in a pilot in a real rose chain (project Kwaliteitsgestuurde Rozenketen)[48]. It is an innovative tool which could result in more transparency, cooperation and learning in practical situations, giving more support to make better decisions to optimize the rose chain.

9.4 Recommendations for further research & development

With respect to long-term storage and transport several recommendations for further research and development can be done:

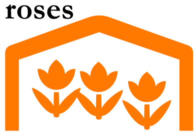
- breeding and selection for genotypes suitable for long-term cold transport and storage. Breeding programs should be focussed on different processes that contribute to quality problems during long-term storage
  - sensitivity to Botrytis
  - cold resistance
  - sensitivity to ethylene
  - drought resistance
- development of technologies that eliminate Botrytis
  - new pre- or postharvest treatments to lower spore vitality and contamination
  - novel packaging technology to improve microclimate management
- development of technologies to improve flower water balance
- novel anti-transpirant treatments
- improved reefer technology and container stacking protocols

[48] *Kwaliteitsgestuurde rozenketen*

10 Summary & Conclusion

In this summary we have selected the main attention points and recommendations written in the report, which are relevant to realize good quality with long-term transport or storage (max 30 days) of roses. We placed them in a sequential order following the different steps in the chain from producer to consumer. In our research we have paid less attention to pre-harvest, retail and consumer conditions.

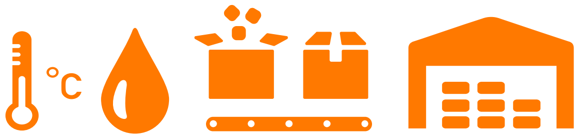
10.1 Summary of recommendations for long-term storage/transport of cut roses



10.1.1 Cultivation and harvest

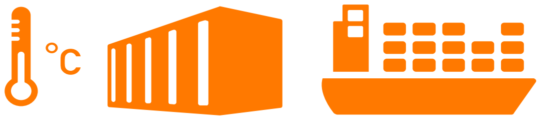
- **Select cultivars** that have shown good results in sea freight, or choose cultivars that generally have a long vase life, show low incidence of bent-neck, have low sensitivity to Botrytis, drought and ethylene.
- **Growing conditions** affect quality. Generally flowers will perform worse when grown under relatively low light and high humidity. If cultivation conditions are unfavourable extra care should be taken to prevent Botrytis and to prevent excessive dehydration.

10.1.2 Post-harvest at the grower



- **Cool down roses quickly and realize target temperature**, whilst preventing condensation on the product. Each company has its own cooling process, but in all cases producers should target on bringing the temperature down to about 1-2 °C within 1 day after harvest.
- **Work in clean environment to prevent any cross contaminations**
- **Proper post-harvest treatments** are important against e.g. ethylene damage and to prevent bacterial stem blockage. Application should be done by using stable (commercial) products and good water quality (preferably reversed-osmosis water). Anti-Botrytis post-harvest treatments help to kill spores on flowers. Performing regular hotbox tests will help giving insight in risk and sensitivity to Botrytis.
- **Dry transport of flowers** is preferred when choosing long-term transport as it decreases chance on Botrytis and bruising. As a consequence some precautions should be taken against too much dehydration (packaging, sleeves).
- **Packaging** is essential as it may affect all the quality attributes during and after long-term transport. Correct packaging protects against too much dehydration, limits Botrytis development, prevents mechanical damage, helps to cool down and keeps the roses cool, being practical for handling. Packaging includes the carton dimensions, material, the packaging density and organisation of the flowers in the carton, the type of sleeves or liners. There is not one solution that fits all.

10.1.3 *Loading and transport container*



- When cartons are placed in a reefer container, **the temperature of flowers in the box must be <2˚C.** In the case flower boxes have been first transported per truck to consolidation centrum, check the temperature of the flowers upon arrival and before loading them in the container. Even refrigerated trucks can have difficulties with keeping the load at set point. Placing roses at a too high temperature in the container is a guarantee for a poor vase life and higher risk on Botrytis. Do not ship these roses.
- Check **set points of container** regarding temperature (**0.5 ˚C)**, and others.
- **Stack cartons correctly** to make sure that the air circulates uniformly around, between and through all the load, preventing short-cuts of air circulation, which create hot-spots.
- Assure **power supply** during transport towards the port.

10.1.4 *End of container transport: auction/wholesaler*

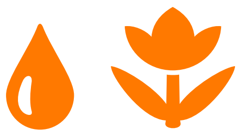
- When cartons are opened after a long-term transport the roses might look more dehydrated than after a short transport. This is not necessarily a problem for vase life. **Recutting the stems** and placing the roses in **clean, preferably cold water or a commercial hydration solution,** will quickly rehydrate the flowers. If the roses are still turgid after transport, the distance to the retailer is short, and the temperature is low, one can keep the roses dry.

10.1.5 *Transport to retailer/florist*

- Transport the roses cool

10.1.6 *Retailer /florist*

- When the roses are not rehydrated after reefer transport the roses should be recut stems, and put into cold water or commercial hydration solution in a cold environment (2-4 ºC).
- Remove plastic if possible.
- Display at lowest temperature possible.



10.1.7 *Consumer*

- Consumers do not need to take special care for long stored roses. They should act the same as always. Use clean vases, use commercial flower food dissolved in tap water and cut stem ends correctly before placing into solution.

10.2 Conclusion

Storage or transport of cut roses in reefer containers up to 4 weeks is possible if all actors in the chain conform to the guidelines and recommendations. In pilots and laboratory experiments, we have shown that roses from long-term transport (Reefer) can still have a satisfactory vase life (at least 7 days), comparable with short-term transport (airplane). The variability of the product and the changing conditions in practice, however, make it hard to guarantee success. Experience and cooperation within the complete chain will help to make the proper decisions adapted to specific situations which will help delivering stable quality.

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11.2 Project descriptions

11.2.1 GreenCHAINge 2013-2016 (www.greenchainge.com)

Financed by the Dutch ministry of Economic Affairs; TKI & Top sector Horticulture and the Horticultural Product Board. In commission of VGB and LTO Glaskracht. (Reference nr. 5)

This project aims for sustainable logistics in international horticulture to reduce CO_2 output by developing a quality-control system approach, based on high initial quality, choice of product by the grower, variety selection by the breeder, conditioned transport in supply and trade chains, monitoring plant health, and passing-on quality information between the links in the chain. This will guarantee a predicted vase life and satisfaction to the end-consumer. Plant breeders, growers, and wholesalers (import and export) work together in the GreenCHAINge project to increase sustainability of international floriculture transport flows. The switch from air freight to sea freight and from road to rail is an important factor. For roses the research and pilots were focused on import from Kenya to the Netherlands by sea freight.

11.2.2 Kwaliteitsgestuurde rozenketen 2015-2016 (www.tuinbouwdigitaal.net)

Financed by the Dutch ministry of Economic Affairs; TKI & Topsector Horticulture within program Tuinbouw Digitaal.

This project aims to develop a prototype of an innovative quality-control system (IQ-Flora) in which product quality of cut roses is monitored and predicted real-time in the chain from producer until retailer. This improved control should lead to better quality for the end user, less waste and lower logistic costs because of better use of capacity and shorter lead times. The project is performed within the program Tuinbouw Digitaal, in cooperation with GreenCHAINge.

11.2.3 Nanonext 2013-2015

Financed by the Dutch ministry of Economic Affairs, performed in cooperation with Leiden University and companies Nanosens and EMS

The project aimed to develop and ethylene sensor for use during transport of fresh products. Part of this project was focused on research on sensitivity of flowers to ethylene during realistic transport conditions.

11.2.4 Qcotrans (Research for co-modal ornamental flower transport) 2010-2013

Financed by the Horticultural Board in commission of the VGB

Trade lanes of cut flowers and plants become more global, which increases the transport distance and times. Together with a growing population, urbanization and congestion on the western roads this calls for durable solution for means of transport for these products. The development of alternative transport methods (deep sea transport and by train) with respect to product quality is of importance. The research did 20 recommendations to stimulate alternative transport modalities.

11.2.5 "Compact en Droog" duurzaam (weg)transport van snijbloemen 2010-2012

Financed by the Horticultural board commissioned by Metz, Celieplant, Sierafor, Bloom, Heyl jr. Wesseling and Partnerplant. (Reference nr.7)

This project aimed at increasing the pack rate of transport modalities by shipping cut flowers without water. The research answered questions such as: How should cut flowers be handled without water, what postharvest treatments are needed, what is the impact on carbon emissions.

11.2.6 Pasteur 2009-2012

Financed by the European Union.

In this project an RFID-sensor was developed to monitor quality of various perishables throughout their lifetime. One of the products targeted was rose. Several experiments were conducted to establish a predictive model for the shelf life (vase life) of roses based on sensor data. A Botrytis decision-tree was developed.

11.2.7 Containerisatie en conditionering in sierteeltketens (CoCoS) 2008–2010

Financed by 'Pieken in de Delta' and commissioned by the VGB, performed in cooperation with Royal FloraHolland. (Reference nr. 9)

This project developed and disseminated knowledge about conditioned transport of flowers and plants. The knowledge developed consisted of optimal transport conditions and the logistics from grower to end-user.

11.2.8 Starflower 2005-2007

Commissioned by Maersk Line. (Reference nr. 4)

The project aimed to develop distribution protocols for cut flower using (Maersk Line) reefer containers. Flowers that where tested are: Hypericum, Carnation, Gypsophyla, Rose, Alstroemeria, and Chrysanthemum.The results contributed to lower transport costs, better temperature control, and lower carbon footprint.

11.2.9 HenK 2002-2004

Commissioned by the Horticultural Board (Reference nr. 1,2,3)

This project developed quality-decay models for various crops, including roses, in reaction to different cooling regimes and temperature/duration combinations in the chain. Variables like cultivar, origin and growing conditions (season) were included in the research. Moreover effects of condensation and mechanic vibrations on quality were investigated.

12 Acknowledgments

The authors thank specifically Horticultural Marketing Board ('Productschap Tuinbouw') and the Ministry of Economic Affairs (Topsector Tuinbouw & Uitgangsmaterialen) for financing the GreenCHAINge project. Without this funding it would not have been possible to write this overview of the past year's applied research on long-term transport and storage of roses.

The support of partners VGB and Royal Flora Holland, Intergreen, Fleurametz, Hilverda de Boer, FlowerWatch, Chrysal and Floralife in the GreenCHAINge rose steering committee, as well as growers who have provided their roses and facilities, is highly appreciated. We want to thank them for sharing their experiences and expertise, providing input for research, supporting pilots and for having discussions on results of experiments. Without this cooperation it would not have been possible to realize successful long-term storage and transport of cut roses.

