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Review

Post-production physiology and handling of ornamental potted plants

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ABSTRACT

Flowering or foliage potted plants are ornamental items usually grown in greenhouses under optimal growing conditions. Cultivation in protected environments allows for rapid growth and high quality characteristics. When plants reach the desired commercial size they can be transferred to hardening greenhouses or directly sent to the distribution chain. The growing and post-production conditions such as storage and transportation can have very deleterious effects on the ornamental quality of plants. The major post-production disorders are bud and flower abscission in flowering potted plants or leaf abscission or yellowing in foliage potted plants. On the other hand, the ornamental quality of potted plants is extremely important and depends on the number and colour of flowers or leaves, flower, leaf and plant longevity. The presence of flowers on flowering potted plants depends on flower longevity and turnover. The colour and size of leaves of foliage potted plants is linked to pre- and post-production environmental conditions. The post-production quality losses of flowering potted plants can be mainly ascribed to natural flower senescence. This phenomenon is highly regulated by plant hormones such as ethylene and abscisic acid, but the post-production environment can dramatically influence plant hormone equilibrium. Quality losses of foliage potted plants are mainly due to leaf senescence usually associated with inadequate acclimatization from the production area to the post-production chain.

1. Introduction

The ornamental industry over the last 25 years has had to deal with a very competitive worldwide trade and face an increase in international competitiveness. The market of ornamentals is already global and is currently undergoing transformation. New production areas have been expanding, leading to a gradual delocalization towards countries with favourable climatic conditions, plenty of natural resources and with lower production costs. Gradually, the major producers in the USA and in Europe have transferred part of the production of these commodities into areas characterized by lower labour cost and more favourable climatic conditions in order to reduce the energy requirements for cultivation (mainly heating costs). It means that growing areas and markets are often very separated and potted plants have to be shipped over long distances. Therefore, these products must be suitably handled to maintain high quality and longevity, features of primary importance in the ornamental industry. Understanding of the physiological responses of ornamental plants during the post-production stage becomes very important to preserve their quality. In the past, economic successes of the ornamental potted plants were based on maximizing the plant growth rate using extensive cultivation systems, in relation to relatively low costs of most inputs (Majsztrik et al., 2011). Currently, commercial benefits are estimated on the basis of critical steps during post-production such as storage and transport. Moreover, highly and detailed logistic plans allow for reaching of different parts of the world in a few hours. During storage and transport, potted plants are often damaged and quality can be compromised. In fact, these post-production stages are usually characterized by sub-optimal environmental conditions (temperature, humidity, water and light) for plants and consequently the photosynthetic machinery is impaired (Starman et al., 2007). Thus, the maintenance of ornamental quality of these commodities is the main goal for their commercial success. Unlike what happens for cut flowers, for which the problems connected with postharvest quality are sufficiently delineated, in potted plants, knowledge associated with the intense vegetative activity of plants is lacking. Indeed, flowers and leaves have a relationship that is more complex than that established in a cut stem. This review focuses on the description and discussion of how post-production

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environmental conditions and treatments can affect the quality of potted plants.

2. Post-production of potted plants

2.1. Quality of potted plants

The quality of flowering and foliage potted plants is essentially defined by visual appearance, which depends on shape, size, colour, turn-over of flowers and leaves. Plotted plants include a wide number of species with many peculiar ornamental characteristics that make them very attractive. For flowering potted plants the main quality parameters are represented by colour, and flower number (Noordergraaf, 1994), while for foliage plants by leaf shape, sizes and greenness (Wang et al., 2005).

The variation of quality parameters during post-production depends on the species. For example in miniature roses, loss of quality during post-production is still an important problem and is mainly associated with leaf, flower and bud drop (Buanong et al., 2005). However, other authors have linked the quality losses of miniature roses with leaf yellowing, and flower, bud and leaf abscission (Serek, 1993; Williams et al., 2000). Hence, it is important to define when flowers can be considered "healthy". In general, flowers can be considered in good health when they are half-open or fully open without any senescence symptoms (Müller et al., 1998). Flower drop does not only affect the visual appearance of the potted plant but can also increase the incidence of *Botrytis* and other saprophytic pathogens (Burana et al., 2013). In other species such as potted lilies the quality losses are associated with leaf yellowing or browning, leaf abscission, bud abortion, and reduced flower and inflorescence longevity (Ranwala and Miller, 2005). Gago and Monteiro (2012) found that the quality of *Bougainvillea spectabilis* 'Killie Campbell' is essentially defined by bract longevity. In some species the quality can be also defined on the basis of flower senescence percentage on the plant. In particular, the quality of potted carnations can be considered compromised when at least 50% of the flowers per pot are senesced (Karimi et al., 2012).

Horticulturists are faced with the problem of defining the quality of plants in terms of aesthetic criteria, stress resistance, longevity and after-sales development. One of the main criteria for the visual quality of an ornamental potted plant is its shape, which should be compact and well branched (Morel et al., 2012). However, each species can have peculiar features which contribute to define the quality. For instance, the growth and visual quality of weeping fig (*Ficus benjamina* L.) 'Danielle' was evaluated in relation to different shading conditions (reductions of 50, 58, 66, 80 and 86% of the incident irradiation outside of the greenhouse). The highest shading level positively influenced parameters such as plant shape (lower height/width ratio) and leaf characteristics (greater unit area, flat stereometry and dark green colour), all important parameters in determining the visual quality of ornamental foliage plants (Scuderi et al., 2013).

The use of image analysis could be an efficient way for helping to determine indicators that characterize plant quality. An analysis of the morphology of plant features could be particularly useful through the use of a quality index. However, these indices vary in relation to plant characteristics and cannot be generalized. Ban˜òn et al. (2011) applied a visual index to evaluate aesthetic quality of *Lantana camara* and *Polygala myrtifolia* at the end of an experiment with wastewater treatments. In this case, the index ranged from 1 (non-commercial) to 5 (very good quality) based on the amount of leaf discoloration, leaf necrosis, defoliation and flowering. As a reference value, healthy control plants were used and the parameters were expressed as a percentage. Leaf yellowing and petal, bud and flower abscission were scored using hedonic scales: 0–5 (dark green to completely yellow) and 0–3 (no abscission to complete abscission). Plant quality grade in poinsettia was evaluated after 30 days in an interior environment using a classification ranging from 1 = poor to 5 = excellent (Wang and Blessington, 1990). An analogous system has been adopted by different authors (Sawwan and Ghunem, 1999; Chen et al., 2001) for indoor evaluation of different species of foliage plants (*F. benjamina*, *Dieffenbachia*, *Anthurium*, *Aglaonema*, *Schefflera arboricola*).

In some bedding plants the evaluation grade considered the plant wilt status with a classification from 1 to 5, where 5 = completely turgid, 4 = soft to the touch, 3 = starting to wilt, 2 = wilted with complete loss of turgor, 1 = wilted to the point that leaves were dry and brittle (Waterland et al., 2010a). In the same experiment, leaf chlorosis was also evaluated with a score ranging from 11 (leaves completely green with no sign of chlorosis) to 1 (leaves with a chlorosis ranging from 91 to 100%) (Waterland et al., 2010a). However, the use of SPAD readings can be coupled with visual estimations in order to objectively estimate the overall quality of green-leaved foliage plants (Wang et al., 2005). Indeed, visual quality grading of the green-leaved plants was closely related to the SPAD reading, which was highly correlated with the chlorophyll content. Five foliage species were graded visually based on a scale of 1–5, where 1 = leaves are chlorotic, poor quality and 5 = leaves are dark green, excellent quality (Wang et al., 2005). The SPAD-502 has been also used in *Aglaonema* potted plants for evaluating the quality after 1-MCP treatment (Fan et al., 2009).

In Table 1 the main parameters considered to evaluate the performance of flowering and foliage plants during the post-production stage are shown. Of course, in a single paper, several parameters may have been considered. In 36.8% of the papers listed, the authors considered the visual quality of plants while 33.3% of them based their studies on leaf drop. This latter parameter is mainly linked to the limited light conditions during the production and post-production stages. The other parameters considered were plant longevity (17.5%), quality index (15.8%), leaf wilting (19.3%), leaf chlorosis (17.5%), flower number (19.3%), wilted flowers (24.6%), flower or inflorescence longevity (21.1%).

2.2. Physiological disorders

Ornamental potted plants are usually grown in greenhouses under optimal environmental conditions for each species in order to have fast growth and to reach the commercial stage as soon as possible. When the plants are transferred to storage rooms or track containers, they undergo severe stress and quality can be compromised. The most common post-production disorders are represented by leaf yellowing (in both flowering and foliage potted plants), colour loss of bracts, flowers or leaves, flower wilting or abscission and fungi development (Fig. 1).

The drop of flowers and leaves is the major post-production disorder of potted plants. Although it is a natural aspect of plant life, it leads to a loss of quality and, consequently, a reduction in profit for both the producer and the seller (Embry and Northnagel, 1994; Ascough et al., 2008). Interest in the plantscape has recently increased the development of international markets for tropical foliage plants. Indoor plants have many benefits: physically, they contribute to a cleaner, healthier air, thus improving well-being and comfort (Lohr, 2010). However, the positive effect on human health is linked with the quality and health status of the plant itself. Therefore, the prime goal for shippers and wholesalers is to deliver plants with minimal quality deterioration (Fan et al., 2009).

Leaf yellowing can rapidly occur in sensitive plants that are held for several days in dark or dim light conditions. Dark incubation has been extensively used to induce leaf senescence artificially in order to understand the molecular mechanisms involved (Zhang and Zhou, 2013). Leaf yellowing is mainly due to chlorophyll

Table 1
Parameters analyzed to evaluate the quality of ornamental potted plants in relation to different factors.

Parameters	Paper numbers (%)	Species	Studied factors
Visual quality	21 (36.8%)	*Brassaia actinophylla*, *Schefflera arboricola* (Braswell et al., 1982); *Ficus benjamina*, *F. lyrata* (Buck and Blessington, 1982); *Campanula carpatica* (Serek, 1990); *Rosa hybrida* (Rajapakse et al., 1994; Rajapakse and Kelly, 1994); *Osteospermum ecklonis* (Olsen and Andersen, 1995); *Dicentra eximia*, *D. formosa*, *D. spectabilis* (Roberts et al., 1995); *Azalea indica*, *Begonia* × *hybrida*, *Dendranthema grandiflora*, *Cyclamen persicum*, *Dieffenbachia* 'Marianne', *Dracaena fragrans*, *Euphorbia pulcherrima*, *Ficus benjamina*, *Saintpaulia ionantha*, *Yucca aloifolia* (Tijskens et al., 1996); *Campanula carpatica* (Dinesen et al., 1997); *Schefflera arboricola* (Sawwan and Ghunem, 1999); *Kalanchoe blossfeldiana* (Serek and Reid, 2000); *Adiantum raddianum* (Yeh and Wang, 2000); *Rosa* (Mortensen et al., 2001); *Campanula carpatica*, *Schlumbergera truncata* (Serek and Sisler, 2001); *Hibiscus rosa-sinensis* (Reid et al., 2002); *Anturium* × 'Red Hot', *Ficus benjamina*, *F. binnendykii*, *F. elastica*, *Philodendron bipinnatifidum*, *P. scandens*, *Spathiphyllum* × 'Viscount', *Dracaena deremensis*, *Eucharis grandiflora* (Wang et al., 2005); *Kalanchoe blossfeldiana* (Christensen and Müller, 2009); *Hydrangea macrophylla* (van Iersel et al., 2009); *Impatiens walleriana*, *Pelargonium* × *hortorum*, *Petunia* × *hybrida*, *Tagetes patula*, *Salvia splendens*, *Viola* × *wittrockiana* (Waterland et al., 2010a); *Aglaonema*, *Anthurium scherzerianum*, *Aphelandra squarros*, *Chlorophytum comosum*, *Codiaeum variegatum pictum*, *Dieffenbachia maculata*, *D. marginata*, *Euphorbia milii*, *E. splendens*, *Ficus benjamina*, *Polyscias fruticosa*, *Radermachera sinica*, *Schefflera elegantissima*, *S. arboricola*, *Spathiphyllum* sp. (Macnish et al., 2011); *Impatiens walleriana* (Burana et al., 2013).	Breeding (3), light (6), light quality (1), temperature (2), air humidity (1), growth retardants (1), plant nutrition (2), water deficit (1), CO_2 enrichment (1), ethylene (2), ethylene inhibitors (4), abscisic acid (2), supplemental irradiance (1), modified atmosphere packaging (1).
Plant longevity	10 (17.5%)	*Denranthema* × *grandiflorum*, *Euphorbia pulcherrima* (Nell et al., 1990); *Rosa hybrida* (Müller et al., 1998; Serek, 1993; Tjosvold et al., 1994); *Campanula carpatica* (Dinesen et al., 1997); *Begonia* × *cheimantha*, *Euphorbia pulcherrima*, *Kalanchoe blossfeldiana*, *Chrysanthemum morifolium* (Mortensen, 2000); *Rosa* (Mortensen et al., 2001); *Impatiens walleriana*, *Pelargonium* × *hortorum*, *Petunia* × *hybrida*, *Tagetes patula*, *Salvia splendens*, *Viola* × *wittrockiana* (Waterland et al., 2010a); *Coprosma* spp. (Hong and Suh, 2012); *Dianthus caryophyllus* (Karimi et al., 2012).	Breeding (1), light (2), temperature (1), air humidity (2), plant nutrition (3), water deficit (1), ethylene inhibitors (3), abscisic acid (1).
Quality index	9 (15.8%)	*Brassaia actinophylla*, *Schefflera arboricola* (Braswell et al., 1982); *Euphorbia pulcherrima* (Wang and Blessington, 1990); *Chrysanthemum morifolium*, *Euphorbia pulcherrima*, *Kalanchoe blossfeldiana* (Mortensen, 2000); *Ficus benjamina*, *Dieffenbachia* spp., *Anthurium* spp., *Aglaonema* spp. (Chen et al., 2001); *Aglaonema* spp. (Fan et al., 2009); *Impatiens walleriana*, *Pelargonium* × *hortorum*, *Petunia* × *hybrida*, *Tagetes patula*, *Salvia splendens*, *Viola* × *wittrockiana* (Waterland et al., 2010a); *Petunia* × *hybrida*, *Viola* × *wittrockiana* (Waterland et al., 2010b); *Lantana camara*, *Polygala myrtifolia* (Ban˜ òn et al., 2011); *Ficus benjamina* (Scuderi et al., 2012).	Breeding (2), light (2), air humidity (1), growing media (1), wastewater (1), water deficit (1), ethylene (1), ethylene inhibitors (1), plant hormones (1), abscisic acid (2).
Leaf number	1 (1.8%)	*Adiantum raddianum* (Yeh and Wang, 2000).	Light (1).
Leaf drop	19 (33.3%)	*Brassaia actinophylla*, *Schefflera arboricola* (Braswell et al., 1982); *Ficus benjamina*, *F. lyrata* (Buck and Blessington, 1982); *Euphorbia pulcherrima* (Wang and Blessington, 1990); *Leea coccinia*, *L. rubra* (Sarracino et al., 1992); *Azalea indica*, *Begonia* × *hybrida*, *Dendranthema grandiflora*, *Cyclamen persicum*, *Dieffenbachia* 'Marianne', *Dracaena fragrans*, *Euphorbia pulcherrima*, *Ficus benjamina*, *Saintpaulia ionantha*, *Yucca aloifolia* (Tijskens et al., 1996); *Rosa hybrida* (Buanong et al., 2005; Müller et al., 1998; Müller et al., 1999; Nielsen and Starkey, 1999); *Schefflera arboricola* (Sawwan and Ghunem, 1999); *Ficus benjamina* (Bulle and de Jongh, 2001); *Ficus benjamina*, *Dieffenbachia* spp., *Anthurium* spp., *Aglaonema* spp. (Chen et al., 2001); *Ficus benjamina*, *Dieffenbachia maculata* 'Camille', *Anthurium* × 'Red Hot' (Chen et al., 2005); *Lilium* spp. (Ranwala and Miller, 2005); *Ficus benjamina* (Scuderi et al., 2005) *Pachira aquatica* (Li et al., 2009); *Salvia splendens* (Kim and van Iersel, 2011); *Bouganvillea spectabilis* (Gago and Monteiro, 2012); *Coprosma* spp. (Hong and Suh, 2012).	Breeding (2), light (11), temperature (4), air humidity (1), plant spacing (1), growth retardants (1), growing media (2), plant nutrition (2), water deficit (1), ethylene inhibitors (3), abscisic acid (2).
Leaf wilting	11 (19.3%)	*Ficus benjamina*, *F. lyrata* (Buck and Blessington, 1982); *Dieffenbachia* 'Marianne', *Dracaena fragrans*, *Ficus benjamina*, *Saintpaulia ionantha*, *Yucca aloifolia* (Tijskens et al., 1996); *Chrysanthemum morifolium*, *Euphorbia pulcherrima*, *Kalanchoe blossfeldiana* (Mortensen, 2000); *Adiantum raddianum* (Yeh and Wang, 2000); *Ficus benjamina* (Bulle and de Jongh, 2001); *Ficus benjamina*, *Dieffenbachia* spp., *Anthurium* spp., *Aglaonema* spp. (Chen et al., 2001); *Hydrangea macrophylla* (van Iersel et al., 2009); *Rosa* spp. (Dresbøll, 2010); *Impatiens walleriana*, *Pelargonium* × *hortorum*, *Petunia* × *hybrida*, *Tagetes patula*, *Salvia splendens*, *Viola* × *wittrockiana* (Waterland et al., 2010a); *Petunia* × *hybrida*, *Viola* × *wittrockiana* (Waterland et al., 2010b); *Salvia splendens* (Kim and van Iersel, 2011).	Breeding (1), light (5), temperature (2) air humidity (1), growing media (1), water deficit (2), plant hormones (1), abscisic acid (4).
Leaf chlorosis	10 (17.5%)	*Rosa hybrida* (Müller et al., 1998; Rajapakse and Kelly, 1994; Rajapakse et al., 1994; Tjosvold et al., 1994); *Ficus benjamina*, *Dieffenbachia* spp., *Anthurium spp.*, *Aglaonema* spp. (Chen et al., 2001); *Lilium* spp. (Ranwala and Miller, 2005); *Aglaonema* spp. (Fan et al., 2009); *Impatiens walleriana*, *Pelargonium* × *hortorum*, *Petunia* × *hybrida*, *Tagetes patula*, *Salvia splendens*, *Viola* × *wittrockiana* (Waterland et al., 2010a); *Petunia* × *hybrida*, *Viola* × *wittrockiana* (Waterland et al., 2010b); *Pelargonium* × *hortorum* (Àlvarez et al., 2013).	Breeding (2), temperature (1), light quality (1), CO_2 enrichment (1), water deficit (2), plant hormones (1), ethylene (1), ethylene inhibitors (3), abscisic acid (2).

Table 1 (*Continued*)

Parameters	Paper numbers (%)	Species	Studied factors
Flower number	11 (19.3%)	*Campanula carpatica* (Serek, 1990); *Dicentra eximia, D. formosa, D. spectabilis* (Roberts et al., 1995); *Azalea indica, Begonia* × *hybrida, Dendranthema grandiflora, Cyclamen persicum, Euphorbia pulcherrima, Ficus benjamina* (Tijskens et al., 1996); *Rosa hybrida* (Müller et al., 1999); *Kalanchoe blossfeldiana* (Serek and Reid, 2000); *Exacum affine* (Serek and Trolle, 2000); *Rosa hybrida* (Williams et al., 2000); *Anthurium* spp. (Chen et al., 2001); *Campanula carpatica, Schlumbergera truncata* (Serek and Sisler, 2001); *Hibiscus rosa-sinensis* (Hansen and Petersen, 2004); *Bouganvillea spectabilis* (Gago and Monteiro, 2012).	Breeding (2), light (2), temperature (1), supplemental irradiance (2), plant nutrition (2), water deficit (2), ethylene (2), ethylene inhibitors (4), abscisic acid (1).
Flower diameter	5 (8.8%)	*Osteospermum ecklonis* (Olsen and Andersen, 1995); *Kalanchoe blossfeldiana* (Serek and Reid, 2000); *Rosa hybrida* (Williams et al., 2000); *Anthurium* × 'Red Hot' (Chen et al., 2005); *Bouganvillea spectabilis* (Gago and Monteiro, 2012).	Breeding (1), light (1), growth retardants (1), water stress, ethylene (1), ethylene inhibitors (1).
Healthy flowers	6 (10.5%)	*Rosa hybrida* (Müller et al., 1998; Müller et al., 1999; Tjosvold et al., 1994; Williams et al., 2000); *Hibiscus rosa-sinensis* (Hansen and Petersen, 2004); *Pelargonium* × *hortorum* (Àlvarez et al., 2013).	Breeding (1), plant nutrition (1), water deficit (3), abscisic acid (1), ethylene inhibitors (2).
Wilted flowers	14 (24.6%)	*Campanula carpatica* (Serek, 1990); *Azalea indica, Begonia* × *hybrida, Dendranthema grandiflora, Cyclamen persicum, Euphorbia pulcherrima* (Tijskens et al., 1996); *Campanula carpatica* (Dinesen et al., 1997); *Rosa hybrida* (Nielsen and Starkey, 1999; Williams et al., 2000); *Rosa* sp. (Mortensen et al., 2001); *Hibiscus rosa-sinensis* (Hansen and Petersen, 2004); *Anthurium* × 'Red Hot' (Chen et al., 2005); *Kalanchoe blossfeldiana* (Christensen and Müller, 2009); *Hydrangea macrophylla* (van Iersel et al., 2009); *Impatiens walleriana, Pelargonium* × *hortorum, Petunia* × *hybrida, Tagetes patula, Salvia splendens, Viola* × *wittrockiana* (Waterland et al., 2010a); *Petunia* × *hybrida, Viola* × *wittrockiana* (Waterland et al., 2010b); *Phalaenopsis* (Chang et al., 2013); *Phalaenopsis* (Hansen et al., 2013).	Breeding (1), light (2), temperature (1); air humidity (2), plant spacing (1), growing media (1), plant nutrition (5), water deficit (3); plant hormones (1), ethylene (1), ethylene inhibitors (2), abscisic acid (3).
Flower drop	7 (12.3)	*Rosa hybrida* (Tjosvold et al., 1994); *Azalea indica, Begonia* × *hybrida, Dendranthema grandiflora, Cyclamen persicum, Euphorbia pulcherrima* (Tijskens et al., 1996); *Rosa hybrida* (Buanong et al., 2005; Müller et al., 1998); *Plectranthus* spp. (Ascough et al., 2008); *Pelargonium* × *hortorum* (Àlvarez et al., 2013); *Impatiens walleriana* (Burana et al., 2013).	Breeding (1), light (2), temperature (1), water deficit (2), ethylene inhibitors (4), modified atmosphere packaging (1).
Flower or inflorescence longevity	12 (21.1%)	*Campanula carpatica* (Serek, 1990); *Rosa hybrida* (Monteiro et al., 2002; Serek, 1993); *Osteospermum ecklonis* (Olsen and Andersen, 1995); *Kalanchoe blossfeldiana* (Serek and Reid, 2000); *Campanula carpatica, Schlumbergera truncata* (Serek and Sisler, 2001); *Lachenalia* spp. (du Toit et al., 2004); *Lilium* spp. (Ranwala and Miller, 2005); *Pelargonium* × *hortorum* (Àlvarez et al., 2013); *Impatiens walleriana* (Burana et al., 2013); *Phalaenopsis* sp. (Chang et al., 2013; Hansen et al., 2013).	Breeding (1), temperature (2); water deficit (1), plant nutrition (1), growth retardants (1), ethylene (2), ethylene inhibitors (5), modified atmosphere packaging (1), exogenous sucrose (1).
Colour change flowers	3 (5.3%)	*Rosa hybrida* (Müller et al., 1998); *Anthurium* × 'Red Hot' (Chen et al., 2005); *Phalaenopsis* (Hansen et al., 2013).	Breeding (1), light (1), ethylene (1); ethylene inhibitors (2).
Bracts abscission	4 (7.0%)	*Euphorbia pulcherrima* (Wang and Blessington, 1990); *Begonia* × *cheimantha, Euphorbia pulcherrima, Kalanchoe blossfeldiana, Chrysanthemum morifolium* (Mortensen, 2000); *Bougainvillea spectabilis* (Chang and Chen, 2001; Gago and Monteiro, 2012).	Air humidity (1), growing media (1), ethylene inhibitors (2).
Bud wilted or damaged	2 (3.5%)	*Rosa hybrida* (Tjosvold et al., 1994; Williams et al., 2000).	Water deficit (1), ethylene inhibitors (1).
Bud abortion	3 (5.3%)	*Hibiscus rosa-sinensis* (Hansen and Petersen, 2004); *Lilium* spp. (Ranwala and Miller, 2005); *Pelargonium* × *hortorum* (Àlvarez et al., 2013).	Temperature (1), plant nutrition (1), water deficit (2).
Bud drop	5 (8.8%)	*Azalea indica, Begonia* × *hybrida, Dendranthema grandiflora, Cyclamen persicum* (Tijskens et al., 1996); *Rosa hybrida* (Buanong et al., 2005; Müller et al., 1998; Müller et al., 1999); *Phalaenopsis* sp. (Hansen et al., 2013).	Breeding (1), light (1), temperature (1), ethylene (1), ethylene inhibitors (3), abscisic acid (1).
Pest and disease	2 (3.5%)	*Rosa hybrida* (Müller et al., 1998); *Rosa* spp. (Dresbøll, 2010).	Breeding (1), growing media (1), ethylene inhibitors (1).
Chlorophyll content	7 (12.3%)	*Ficus benjamina, F. lyrata* (Buck and Blessington, 1982); *Leea coccinia, L. rubra* (Sarracino et al., 1992); *Schefflera arboricola* (Sawwan and Ghunem, 1999); *Ficus benjamina, Dracaena maculata, Anthurium* × 'Red Hot' (Chen et al., 2005); *Ficus benjamina* (Kubatsch et al., 2005); *Anturium* × 'Red Hot', *Ficus benjamina, F. binnendykii, F. elastica, Philodendron bipinnatifidum, P. scandens, Spathiphyllum* × 'Viscount', *Dracaena deremensis, Eucharis grandiflora* (Wang et al., 2005); *Petunia* × *hybrida, Viola* × *wittrockiana* (Waterland et al., 2010b).	Light (4), temperature (2), plant hormones (1), abscisic acid (1), ethylene inhibitors (1).

degradation combined with absence of new biosynthesis. The last key step of chlorophyll biosynthesis, the conversion of δ-aminolevulinic acid to protochlorophillide, is light-dependent and is catalyzed by the NADH protochlorophyllide reductase (POR) enzyme. Reduced light availability is a trigger for leaf senescence initiation since the leaves respire and reduce sugars and hence the energy resources (Ferrante and Reid, 2006). The absence of light affects the metabolite composition of leaf cells and it has been found in *Arabidopsis* leaves that at the end of the night period, reducing sugars are reduced to 10–50% compared to that at the beginning of night (Usadel et al., 2008; Trivellini et al., 2012). The lack of energy sources influences the flowering time and turnover with negative effects on visual appearance and quality of flowering potted plants. The lack of light or limited light intensity in foliage potted plants induces marked leaf abscission and compromises the commercial value. The negative effect of low light conditions is particularly visible in ornamental plants that have bracts such as *Bougainvillea* spp. (Gago and Monteiro, 2012) and *Euphorbia pulcherrima* (Wang and Blessington, 1990).

The abscission of flowers, leaves and bracts is aggravated by the presence of ethylene in the environment, especially in ethylene sensitive species. The effect of ethylene can be dramatic at extremely low concentrations such as 0.1 $\mu L L^{-1}$ (Woltering, 1987; Macnish et al., 2011). Epinasty is another post-production disorder that involves downward curling of a leaf blade due to the asymmetrical growth of a lea, this morphology disorder affects the ornamental value of the potted plants. Epinasty is mainly induced by ethylene and the intensity of the damage depends on the sensitivity of the species to ethylene (Woltering, 1987). During storage and transport, flower and leaf wilting can occur. These disorders can be again induced by ethylene or by water stress, and thus the plants lose aesthetic value within a short period of time (Starman et al., 2007). Leaf desiccation and necrosis are the main deleterious outcomes from inadequate watering.

2.3. Non-destructive techniques to assess the plant quality

The ornamental value of both flowering and foliage potted plants depends on the plant health conditions. The colour of leaves can be objectively assessed by chlorophyll metres. These portable instruments are able to evaluate the greenness of leaves before and after storage or during transportation. This simple and rapid measurement can be useful to estimate the loss of chlorophyll and leaf senescence. It is a non-destructive method that can be routinely used for quality evaluation during the post-production distribution chain. Visual grading is highly subjective and the use of a chlorophyll metre can be an easy and rapid method for grading potted foliage plants (Wang et al., 2005). The chlorophyll metres indirectly measure the chlorophyll concentrations but the correlation becomes weak in leaves that accumulate other pigments such as anthocyanins. In some species, leaf senescence can occur without yellowing, but may result in brown spots due to membrane degradation. In this case the chlorophyll readings can increase but values do not represent leaf senescence status or quality. During prolonged storage or transportation, chlorophyll may increase due to water loss and the chlorophyll metres again cannot be used for quality assessment or grading. The same problem arises for ornamental plants insensitive to yellowing where leaf senescence is not associated with chlorophyll content. However, even if the chlorophyll content does not decline, the functionality of leaves and photosynthetic machinery can be impaired. The reduction of leaf functionality and vitality can be measured using chlorophyll *a* fluorescence instruments. Chlorophyll *a* fluorescence has been used as non-destructive method to evaluate the stress conditions in plants (Maxwell and Johnson, 2000), as it is well known that stressed plants, in order to resist adverse conditions, reduce plant metabolism and in particular, photosynthetic activity. Plants under stress reduce leaf functionality and it is possible to estimate the degree of stress through chlorophyll *a* fluorescence. If the source of the stress is well defined and identifiable, such as in the post-production chain of ornamentals, chlorophyll *a* fluorescence can be used for estimating the quality before, during and after storage or transportation (Ferrante et al., 2012).

It is also able to detect stress conditions in plants even after short periods of exposure to a specific stress. In a distribution chain, this measurement can give quantitative information on how much a plant is stressed, but provides no evidence on the nature of the stress. Moreover, the basic information derived from chlorophyll *a* fluorescence *Fo* (minimal fluorescence), *Fm* (maximal fluorescence) and *Fv*/*Fm* (maximum quantum efficiency of photosystem II) is not always able to allow detection of stress conditions, especially with mild stresses. As an example, the use of the *Fv*/*Fm* ratio was not able to highlight the stress conditions in *Phalaenopsis* potted plants after 21 days of dark shipping (Hou et al., 2010).

If the chlorophyll *a* fluorescence is recorded using a Handy PEA instrument, which measures all data points of the fluorescence induction curve, the JIP test can be performed and its derived indexes can be calculated providing good information on the plant stress status (Ferrante et al., 2012). The JIP test represents an elaboration of the fluorescence induction curve data and provides information regarding the fate and efficiency of energy transport in the first step of the photosynthetic leaf apparatus. Among the JIP-derived indexes, the most promising quality marker is the Performance Index (PI), that is an overall estimation of leaf functionality and health status (Strasser and Strasser, 1995). However, other indexes such as dissipation energy or active reaction centres per cross section can be useful for quality evaluation of potted plants (Ferrante et al., 2012). In potted *Bougainvillea* plants, chlorophyll *a* fluorescence and derived indexes were successfully used for evaluating the efficiency of treatments to counteract the stresses during a simulated transportation. The JIP indexes have been tested in postharvest of cut foliage and the best indexes related to vase life and quality were the dissipation energy per cross section (DIo/CS) and PI (Pacifici et al., 2013).

Chlorophyll *a* fluorescence can be also measured in plants under modulated light intensity and data can be also used to identify a possible tool for quality evaluation. The response of plants adapted to light environments or under modulated light conditions provides information on the effective leaf light efficiency use. Among the different parameters the efficiency of electron transport rate (ETR) in the photosynthetic membranes (thylakoids) in the leaves has been used for potted plant quality evaluation. ETR was measured in *F. benjamina* 'Exotica', *Dieffenbachia picta* 'Camilla' and *Codiaeum variegatum* 'Excellent' potted plants (Kooten et al., 1991). The results obtained were promising and the ETR parameter measured under modulated light conditions can be suggested as a fast and non-invasive technique to determine the physiological status of the potted plants.

The non-destructive measurements applied for evaluating quality or stress conditions in ornamental sector may have a wide range of applications. Research should be focused on the use of non-destructive measurements in estimating the post-production performance of the most important potted plants. In particular, it would be interesting to evaluate if there is a correspondence between stress detected or undergone during cultivation and measured at harvest and potential post-production life. The non-destructive measurements can be used to estimate the quality of the ornamental plants at the entry of the distribution chain and for cooperatives this information can be also used for selecting the best growers or providers. Moreover, the economic value might be correlated to the health status of the plants, hence with the chlorophyll *a* fluorescence values.

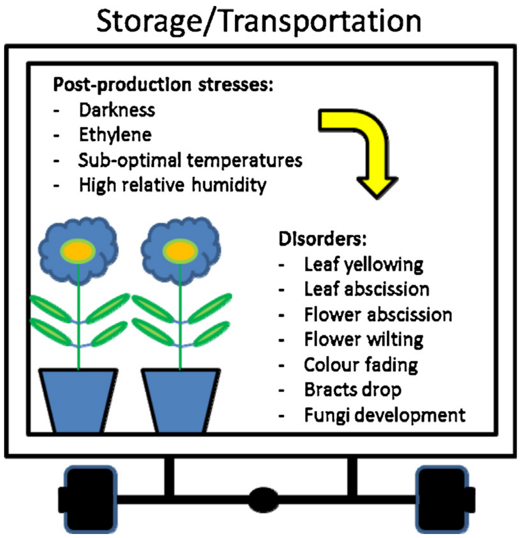

Fig. 1. The post-production stresses that can influence the quality of potted plants during storage or transportation.

3. Chemical treatments for reducing post-production disorders

Abiotic and biotic stresses during the post-production stage can induce several physiological disorders, which can have detrimental effects on plant quality (Fig. 1). The post-production performance of ornamental potted plants can be preserved using optimal environmental conditions and additionally by applying appropriate chemical preservative treatments. In ethylene sensitive flowers, treatments with 1-methylcyclopropene (1-MCP) or silver thiosulfate (STS) can avoid the physiological effects of ethylene by blocking its action. The ethylene action inhibitors prevent leaf, bracts and flowers abscission in many ethylene sensitive potted plants (Table 2).

In *Begonia* × *hiemalis* the application of 1-MCP before packaging in a simulated transport avoided leaf senescence, yellowing and wilting over a period of 14 days (Kim and Kim, 2012). Positive effects of 1-MCP and STS were also observed in *Begonia* × *elatior hybrida*, *Rosa* × *hybrida* and *Kalanchoe blossfeldiana* plants (Serek et al., 1994). Analogues of 1-MCP, 1-octylcyclopropene (1-OCP) and the 1-decylcyclopropene (1-DCP), substituted in the 1-position with a longer carbon chain, showed positive effects in protecting miniature potted roses from ethylene at higher concentrations but with shorter treatment times (Buanong et al., 2005).

The use of aminooxyacetic acid (AOA) is commonly used in floral industries to inhibit ethylene biosynthesis in cut flowers. AOA is an inhibitor of the last step of ethylene biosynthesis by blocking the 1-aminocyclopropanecarboxylate (ACC) oxidase enzyme, which convert ACC into ethylene. Unfortunately, the AOA is not a specific inhibitor and blocks also other important enzymes such as phenylalanine ammonia lyase (PAL). This is a negative effect, especially in coloured flowering potted plants because blocking the phenylpropanoid pathway may result in flower colour fading. In general, potted plants are transported or stored at low temperature and the activity of ethylene biosynthetic enzymes is automatically slowed down. Moreover, blocking the last step of ethylene biosynthesis with AOA induces an accumulation of ACC in the tissues and when the plants are transferred to higher temperatures, a burst of ethylene production occurs, promoting leaf and flower drop (Ferrante et al., 2012).

Cytokinins are important plant hormones in preventing senescence and their use can improve the quality of ornamental potted plants, as reported for different species. *Salvia splendens* potted plants treated with 500 μM 6-benzyladenine (BA) had extended flower life and reduced flower abscission (Ferrante et al., 2006). Analogous results were found in potted miniature roses where the best concentration was 800 μM BA (Serek and Andersen, 1993). Other substances with cytokinin-like activity have been also successfully used, such as the thidiazuron [TDZ, phenyl-N′-(1,2,3-thiadiazol-5-yl) urea]. This is a synthetic compound with a strong cytokinin-like activity and can reduce the quality losses of potted plants sensitive to leaf yellowing. TDZ is commonly used at high concentrations (100 mM) as a defoliant in cotton production and in low concentrations (1 mM) for the regeneration of *in vitro* tissue culture (Arndt et al., 1976; Shan et al., 2000). Furthermore, it was reported that chrysanthemum, alstroemeria and tulip cut flowers treated with TDZ have delayed leaf senescence (Ferrante et al., 2002, 2003). Jiang et al. (2008) have shown that the application of TDZ sprays on various ornamental plants has a positive effect on post-production performance. In addition to reducing leaf yellowing, a positive effect was observed on the quality of flowering in terms of longevity. TDZ has been also successfully used to inhibit leaf yellowing in geranium, freesia, *Ornithogalum*, and *Euphorbia fulgens* potted plants (Jiang et al., 2009).

As already discussed with regard to the post-production stage, the plants may experience water stress. In order to avoid quality losses and help potted plants to maintain their marketability longer, it is important to perform an effective post-production treatment against water loss. Treatments with ABA or anti-transpirants may help to reduce water loss by transpiration and prevent quality loss. Plants treated can have longer shelf-life and fast recovery after storage or transport.

ABA is a plant hormone produced in response to environmental stresses, particularly in response to drought conditions. In plants exposed to drought stress, ABA is accumulated in leaves and regulates guard cell movement inducing stomata closure (Tallman, 2004; Jiang and Hartung, 2008), thus reducing transpiration (Mahdieh and Mostajeran, 2009). Therefore, exogenous ABA applications can be used to reduce water loss. In *S. splendens*, ABA drenches increased the shelf-life by decreasing stomatal conductance and transpiration, which reduced plant water uptake from the substrate (Kim and van Iersel, 2011). Moreover, root dips of synthetic abscisic acid (s-ABA) have been shown to reduce the transpiration rate and subsequently prolong postharvest longevity in a selected group of herbaceous ornamental crops such as *Impatiens* (Gibson and Crowley, 2006). According to this study, to reduce labour costs associated with hand-watering and prolong post-production performance in low light conditions, such as indoor retail conditions, the root substrate should be drenched with ABA.

4. Storage and transport of ornamental potted plants

4.1. Packaging of potted plants

Focus during the post-production stage must be on maintaining plant functionality and reducing physiological disorders that affect quality. If physiological processes are not impaired but only slowed down, plants can easily recover after storage or transportation without quality reduction. The post-production stage should be studied and optimized for each ornamental potted plant, since they are represented by a wide range of species.

The packaging of potted plants is very important because this avoids mechanical damage during handling, optimizes use of container space during storage or transport, and facilitates loading and unloading procedures. There is little information on packaging systems and plant responses. However, many patents have been produced for the packaging of ornamentals including potted plants. The most common packaging method used in the

Table 2
Post-production treatments for preserving the quality of flowering or foliage potted plants.

Species	Post-production disorder	Treatments	References
Aphelandra squarrosa	Leaf abscission	1-MCP (900 nL L^{-1} per 5 h at 21 °C)	Macnish et al. (2011)
Aglaonema sp.	Leaf yellowing	1-MCP (300 nL L^{-1} per 6 h)	Fan et al. (2009)
		1-MCP (900 nL L^{-1} per 4 h at 21 °C under 10 μmol m^{-2} s^{-1} light)	Macnish et al. (2011)
Begonia × *elatior hybrid*	Buds and flowers abscission	1-MCP (5 nL L^{-1} per 6 h) or 0.5 mM STS	Serek et al. (1994)
Begonia × *hiemalis*	Buds and flowers abscission	1-MCP (25–125 nL L^{-1} per 6–14 h)	Kim and Kim (2012)
Bougainvillea	Bracts and leaf abscission, leaf yellowing	300 mg L^{-1} NAA (spray until uniform wet)	Gago and Monteiro (2012)
Dianthus caryophyllus	Flower wilting	1-MCP (70 nL L^{-1})	Karimi et al. (2012)
Euphorbia milii	Bracts abscission	1-MCP (900 nL L^{-1} per 5 h at 21 °C)	Macnish et al. (2011)
Euphorbia fulgens	Leaf yellowing, flower drop	5 μM TDZ spray	Jiang et al. (2008)
Hibiscus rosa-sinensis	Flower wilting	1-MCP (500 nL L^{-1} per 6 h)	Trivellini et al. (2011)
Impatiens wallerana	Flower and leaf senescence	ABA drenches (250 mg L^{-1})	Gibson and Crowley (2006)
Ornithogalum sp.	Leaf yellowing	5 μM TDZ spray	Jiang et al. (2008)
Rosa hybrid	Flowers and leaf abscission	1-MCP (20 nL L^{-1} per 6 h) or 0.5 mM STS	Serek et al. (1994) and Serek and Andersen (1993)
		100 μL L^{-1} + 1 mM STS	Tjosvold et al. (1994)
		1-OCP (1000 nL L^{-1}) and 1-DCP (1500 nL L^{-1})	Buanong et al. (2005)
Kalanchoe blossfeldiana	Flower abscission	1-MCP (20 nL L^{-1} per 6 h) or 0.5 mM STS	Serek et al. (1994)
Pelargonium peltatum	Petal abscission	1 μl L^{-1} 1-MCP	Cameron and Reid (2001)
Pelargonium hortorum	Leaf yellowing, petal abscission	10 μM TDZ spray	Jiang et al. (2008)
Polyscias fruticosa	Leaf abscission	1-MCP (900 nL L^{-1} per 4 h at 21 °C under 10 μmol m^{-2} s^{-1} light)	Macnish et al. (2011)
Salvia splendens	Flower wilting and abscission and leaf abscission	0.5 mM BA (spray until run-off)	Ferrante et al. (2006)
		ABA drenches (250 mg L^{-1} and 500 mg L^{-1})	Kim and van Iersel (2011)
Schefflera arboricola	Leaf abscission	1-MCP (900 nL L^{-1} per 4 h at 21 °C under 10 μmol m^{-2} s^{-1} light)	Macnish et al. (2011)

ornamental industries is to wrap the plants and the trolleys with a plastic film. An alternative is to cover the single plant with a plastic sleeve or bag-like container in order to avoid contact with other plants and so protect them. The film permeability can be also used for controlling gas exchange and modulating respiration and ethylene accumulation. In this field, the effects of packaging methods and materials on quality retention in potted plants should be taken into consideration in future research. Moreover, applied research should be used to identify plants which can have the same storage conditions without compromising quality.

4.2. Effects of environmental conditions on quality of potted plants

The most important environmental parameters during storage and transport are temperature, relative humidity and light. Temperature is directly correlated with respiration and ethylene biosynthesis, and therefore, the ornamental species should be maintained at the lowest tolerable temperature (Nowak and Rudnicki, 1990; Reid, 1991; Ferrante and Reid, 2006). Considering that many tropical species may undergo chilling injury if exposed below the threshold of tolerance that commonly is 10 °C, it is important to perform hardening treatments using a pre-cooling system in order to ensure that plants will be transported and shipped at temperatures that do not damage them. In containers, cold air is often not able to lower plant temperature, especially if the plants are packed with plastic films. The circulated air in containers may not be able to reach the inside of foliage and the temperature inside can slowly increase (Nowak and Rudnicki, 1990).

The distribution chain, from the grower to the consumer, is characterized by different steps with several intermediaries, and so continuity of environmental conditioning cannot be easily maintained. The effect of environmental oscillations is not taken into consideration in much research performed on potted plants and further investigations should be made in this field. Potted plants differ from cut flowers since they have to maintain active metabolism and slow down physiological processes until reaching the consumer, while with cut flowers, metabolism, being a degenerative process, must be slowed down or inhibited during the whole postharvest period.

Temperature is thus the most important parameter to control in storage rooms and transportation containers. The effect of temperatures has been tested in different flowering potted plants, with regard to two groups: sensitive or insensitive to chilling injury. For sensitive plants, the majority of foliage plants, the recommended temperature is from 16 to 19 °C (Conover and Poole, 1983), however differences among species must be taken into consideration. For potted plants that are not sensitive to chilling injury the temperature can be lower than 13 °C. Among the flowering potted plants, the most important are roses and carnations. In carnation potted plants, flower and plant longevity were not affected if storage was limited to three days and temperatures ranged from 1 to 13 °C (Leonard et al., 1995). If storage duration and temperatures exceeded these values, the flower number and plant longevity declined. Analogous results were obtained for potted roses stored at 8, 16 or 28 °C for 2, 4 or 6 days. Longer storage increased the incidence of leaf chlorosis in all cultivars used in the experiments (Clark et al., 1991).

Another important flowering potted plant, *E. pulcherrima*, should be transported at a temperature of 10–16 °C to avoid bract discoloration, leaf and cyathia drop (Sterling and Molenaar, 1986; Nell et al., 1995; Ferrante and Martinetti, 2011). Colour loss is particularly evident in young bracts. The loss of bracts and leaves is also typical of potted *Bougainvillea* spp. during storage or transportation (Ferrante et al., 2012). This ornamental species, as well as *E. pulcherrima*, is chilling sensitive, therefore the storage temperature should not go below 10 °C for most cultivars.

Regarding foliage potted plants, the optimal storage temperature and duration depends on species. Information in the literature largely refers to experiments performed in the 1980s and the continuous renewal of cultivars may invalidate the findings from old cultivars. Therefore, all the information should be re-confirmed. Pre-harvest conditions and acclimatization procedures for storage and transportation play a crucial role in successful consumer satisfaction.

The commercial value of foliage potted plants essentially depends on the healthy status of the leaves and the chlorophyll content (greenness). It is well known that dark storage and transportation negatively affect visual appearance. However, negative effects can be limited using the lowest storage temperature, considering the tolerance threshold of the species and the shortest transportation period. The most important foliage potted plants are *F. benjamina* and *S. arboricola* and the optimal storage temperature ranges from 5 to 15 °C (Sterling and Molenaar, 1986).

Relative humidity (RH) is important in potted plants since this affects transpiration and fungal diseases such as *Botrytis cinerea* that develop even at low temperature. About 24 h prior to storage or transport, the potted plants should be well watered and left to drain excess water. Usually the RH should be maintained around 80–90% in packed potted plants in order to avoid over-drying during shipment (Nowak and Rudnicki, 1990). In the literature, there are no studies focused on the effects of RH on quality of potted plants and this topic requires more attention in order to have better information on plant response during and after storage and transport.

Modifying light during storage and transportation in potted plants has limited application, especially in order to reduce the costs. However, as discussed above, dark conditions induce leaf senescence and chlorophyll loss. Pioneering studies performed using different light intensities during transportation or storage have demonstrated that leaf quality is preserved and shows better post-transportation performance (Costa et al., 2013; Braidot et al., 2014). The storage light does not provide energy for photosynthesis but it has a function in maintaining chlorophyll turnover. Light is necessary for chlorophyll biosynthesis and reduces loss of colour. The role of light and its application in the post-production stage of potted plants should be studied more comprehensively. In particular, the minimum light requirements in terms of intensity and duration in order to preserve leaf colour and functionality should be identified. Results can have practical applications and can help to better understand the recovery of leaf functionality in different ornamental species.

5. Plants recovery after storage and transport

Potted plant recovery after storage and transport has not been widely studied yet. This topic represents an interesting field of study and future works should be performed to understand the correlation between the degree of stress and the recovery capacity of plants. Few papers have been published on plant recovery. In *Bougainvillea* spp. treated with ethylene inhibitors and stored for 7 days in the dark, during the recovery period the control plants showed a faster leaf functionality recovery as demonstrated by chlorophyll *a* fluorescence data (Ferrante et al., 2012). In this species the inhibition of ethylene biosynthesis or action seems to slow down the re-activation of the plant physiological processes. The role of ethylene in potted plants that have to recover all metabolic function should be re-considered and investigated.

Leaves of species sensitive to leaf yellowing, after storage, can reconvert the chromoplasts into chloroplasts, showing the re-greening of the tissues. The re-greening has been widely studied in young plant organs such as seedlings and during the re-greening stage the chromoplasts accumulate chlorophylls and new thyllakoid membranes are formed (Thomson et al., 1967). The re-greening can be induced by treatments with cytokinins under light exposure. Senescent tobacco leaves exposed to light and treated with benzyladenine showed faster re-greening (Zavaleta-Mancera et al., 1999). The reactivation of photosynthesis is crucial, especially for flowering potted plants, since the flower production is tightly connected with the carbohydrate status of plants.

The applications of appropriate chemical treatments after storage and transport can greatly improve the recovery ability of plants and exert better performance for the consumer.

6. Conclusion

The post-production stage of the potted plants can be considered as a transient stage from the plant growth and development phase to the ornamental indoor life. Potted plants should be prepared for the transient stage by lowering plant metabolism and reducing the physiological processes associated with ornamental losses. The plants have to maintain vitality and functionality of their organs in order to recover and display a good post-production life. Research activities should be more focused on plant physiology reactivation and on suitable treatments in order to guarantee good performance with the end-user.

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References

Àlvarez, S., Ban˜òn, S., Sànchez-Blanco, M.J., 2013. Regulated deficit irrigation in different phenological stages of potted geranium plants: water consumption, water relations and ornamental quality. Acta Physiol. Plant. 35, 1257–1267.

Arndt, F., Rusxh, R., Stilfried, H.V., 1976. SN 1976. 49537, a new cotton defoliant. Plant Physiol. 57, 99.

Ascough, G.D., Rice, L.J., Van Staden, J., 2008. Consideration for evaluating flower abscission in potted plants with multiple inflorescences – *Plectranthus* as a case study. S. Afr. J. Bot. 74, 753–756.

Ban˜òn, S., Miralles, J., Ochoa, J., Franco, J.A., Sànchez-Blanco, M.J., 2011. Effects of diluted and undiluted treated wastewater on the growth, physiological aspects and visual quality of potted Lantana and Polygala plants. Sci. Hortic. 129, 869–876.

Braidot, E., Petrussa, E., Peresson, E., Patui, S., Bertolini, A., Tubaro, F., Wählby, U., Coan, M., Vianello, A., Zancani, M., 2014. Low-intensity light cycles improve the quality of lamb's lettuce (*Valerianella olitoria* [L.] Pollich) during storage at low temperature. Postharvest Biol. Technol. 90, 15–23.

Braswell, J.H., Blessignton, T.M., Price, J.A., 1982. Influence of production and postharvest light levels on the interior performance of two species of Scheffleras. HortScience 17, 48–50.

Buanong, M., Mibus, H., Sisler, E.C., Serek, M., 2005. Efficacy of new inhibitors of ethylene perception in improvement of display quality of miniature potted roses (*Rosa hybrida* L.). Plant Growth Regul. 47, 29–38.

Buck, T.L., Blessington, T.M., 1982. Postharvest effects of temperatures during simulated transit on quality factors of two *Ficus* species. HortScience 17, 817–819.

Bulle, A., de Jongh, M., 2001. Effects of growing conditions on the shelf life of *Ficus benjamina*. Acta Hortic. 543, 113–117.

Burana, C., Yamane, K., Yamaki, Y., 2013. Effects of 1-methylcyclopropene (1-MCP) and modified atmosphere packaging (MAP) treatments during transportation on the quality of potted impatiens (*Impatiens walleriana*). Acta Hortic. 970, 223–228.

Cameron, A.C., Reid, M.S., 2001. 1-MCP blocks ethylene-induced petal abscission of *Pelargonium peltatum* but the effect is transient. Postharvest Biol. Technol. 22, 169–177.

Chang, Y.C.A., Lin, W.L., Hou, J.Y., Yen, W.Y., Lee, N., 2013. Concentration of 1-methylcyclopropene and the duration of its application affect anti-ethylene protection in *Phalaenopsis*. Sci. Hortic. 153, 117–123.

Chang, Y.S., Chen, H.C., 2001. Variability between silver thiosulfate and 1-naphtaleneacetic acid applications in prolonging bract longevity of potted bougainvillea. Sci. Hortic. 87, 217–224.

Chen, J., Henny, R.J., McConnell, D.B., Nell, T.A., 2001. Cultivar differences in interior performances of acclimatized foliage plants. Acta Hortic. 543, 135–140.

Chen, J., Wang, Q., Henny, R.J., McConnell, D.B., 2005. Response of tropical foliage plants to interior low light conditions. Acta Hortic. 669, 51–56.

Christensen, B., Müller, R., 2009. *Kalanchoe blossfeldiana* transformed with *rol* genes exhibits improved postharvest performance and increased ethylene tolerance. Postharvest Biol. Technol. 51, 399–406.

Clark, D.G., Kelly, J.W., Pemberton, H.B., 1991. Postharvest quality characteristics of cultivars of potted rose in response to holding conditions and cytokinins. HortScience 26, 1195–1197.

Conover, C.A., Poole, R.T., 1983. Handling and Shipping Acclimatized Plants in Reefers. Produce Marketing Almanac, pp. 149–151.

Costa, L., Montano, Y.M., Carrión, C., Rolny, N., Guiamet, J.J., 2013. Application of low intensity light pulses to delay postharvest senescence of *Ocimum basilicum* leaves. Postharvest Biol. Technol. 86, 181–191.

Dinesen, L.G., Andersen, A.S., Serek, M., 1997. Influence of late fertilization in the field on forcing and quality of potted *Campanula carpatica*. Sci. Hortic. 71, 235–242.

Dresbøll, D.B., 2010. Effect of growing media composition, compaction and periods of anoxia on the quality and keeping quality of potted roses (*Rosa* sp.). Sci. Hortic. 126, 53–63.

du Toit, E.S., Robbertse, P.J., Niederwieser, J.G., 2004. Temperature regime during bulb production affects foliage and flower quality of *Lachenalia* cv. Ronina pot plants. Sci. Hortic. 102, 441–448.

Embry, J.L., Northnagel, E.A., 1994. Leaf senescence of postproduction poinsettia in low-light stress. J. Am. Soc. Hortic. Sci. 119, 1006–1013.

Fan, S.-T., Yeh, D.-M., Wang, T.-T., 2009. Cultivar sensitivity to ethylene during storage and 1-methylcyclopropene protection of *Aglaonema*. HortScience 44, 202–205.

Ferrante, A., Hunter, D., Hackett, W., Reid, M., 2002. Thidiazuron: a potent inhibitor of leaf senescence in Alstroemeria. Postharest Biol. Technol. 25, 333–338.

Ferrante, A., Martinetti, L., 2011. Effetto del thidiazuron e della benziladenina sulla qualità post-produzione della stella di Natale. Bullettino dell'Agricoltura, Atti della Società Agraria di Lombardia 3–4, 97–106.

Ferrante, A., Mensuali-Sodi, A., Serra, G., Tognoni, F., 2006. Evaluation of post-production performance of *Salvia splendens* potted plants for interiors use. Acta Hortic. 723, 415–419.

Ferrante, A., Reid, M., 2006. Postharvest physiology of cut flowers. Italus Hortus 13, 29–41.

Ferrante, A., Tognoni, F., Mensuali-Sodi, A., Serra, G., 2003. Treatment with thidiazuron for preventing leaf yellowing in cut tulips and chrysanthemum. Acta Hortic. 624, 357–363.

Ferrante, A., Trivellini, A., Borghesi, E., Vernieri, P., 2012. Chlorophyll a fluorescence as a tool in evaluating the effects of ABA content and ethylene inhibitors on quality of flowering potted Bougainvillea. Sci. World J., 1–11, ID 684747.

Gago, C.M.L., Monteiro, J.A., 2012. NAA and STS effects on bract survival time, carbohydrate content, respiration rate and carbohydrate balance of potted *Bougainvillea spectabilis* Willd. Postharvest Biol. Technol. 60, 235–243.

Gibson, J.L., Crowley, S., 2006. Abscisic acid drenches improve postproduction shelf life of impatiens. HortScience 40, 511–512.

Hansen, C.W., Petersen, K.K., 2004. Reduced nutrient and water availability to *Hibiscus rosa-sinensis* 'Cairo Red' as a method to regulate growth and improve post-production quality. Eur. J. Hortic. Sci. 69, 159–166.

Hansen, M.M., Müller, R., Lütken, H., 2013. Effect of the ethylene inhibitor 1-MCP in postharvest chains of Mini-*Phalaenopsis*. Acta Hortic. 970, 205–211.

Hong, J., Suh, J.K., 2012. Pre- and post-production characteristics of *Coprosma* as influenced by temperature, irradiance, and nutrient treatments. Sci. Hortic. 145, 46–51.

Hou, J.Y., Setter, T.L., Chang, Y.C.A., 2010. Effects of simulated dark shipping on photosynthetic status and post-shipping performance in *Phalaenopsis* Sogo Yukidian 'V3'. J. Am. Soc. Hortic. Sci. 135, 183–190.

Jiang, C.-.Z., Wu, L., Macnish, A.J., King, A., Yi, M., Reid, M.S., 2009. Thidiazuron, a non-metabolized cytokinin, shows promise in extending the life of potted plants. Acta Hortic. 847, 59–66.

Jiang, C.Z., Wu, L., Macnish, A.J., King, A., Yi, M., Reid, M.S., 2008. Thidiazuron, a non-metabolized cytokinin, shows promise in extending the life of potted plants. Acta Hortic. 847, 59–66.

Jiang, F., Hartung, W., 2008. Long-distance signaling of abscisic acid (ABA): the factors regulating the intensity of the ABA signal. J. Exp. Bot. 59, 37–43.

Karimi, M., Asil, M.H., Zakizadeh, H., 2012. Increasing plant longevity and associated metabolic events in potted carnation (*Dianthus caryophyllus* L. Clove Pink). Braz. J. Plant Physiol. 24, 247–252.

Kim, J., van Iersel, M.W., 2011. Abscisic acid drenches can reduce water use and extend shelf life of *Salvia splendens*. Sci. Hortic. 127, 240–243.

Kim, Y.J., Kim, K.S., 2012. 1-MCP improves display life in *Begonia* × *hiemalis* 'Blitz' and 'Carnival'. Korean J. Hortic. Sci. Technol. 30, 152–157.

Kooten, O., Mensink, M., Otma, E., Doorn, W., 1991. Determination of the physiological state of potted plants and cut flowers by modulated chlorophyll fluorescence. Acta Hortic. 298, 83–92.

Kubatsch, A., Grüneberg, H., Ulrichs, C., 2005. Acclimatization of *Ficus benjamina* to temperature and irradiance conditions in indoor landscapes. J. Appl. Bot. Food Qual. 79, 117–121.

Leonard, R.T., Nell, T.A., Barrett, J.E., 1995. Effects of production and postproduction factors on longevity and quality of potted carnations. Acta Hortic. 405, 356–361.

Li, Q., Deng, M., Chen, J., Henny, R.J., 2009. Effects of light intensity and paclobutrazol on growth and interior performance of *Pachira aquatica* Aubl. HortScience 44, 1291–1295.

Lohr, V.I., 2010. What are the benefits of plants indoors and why do we respond positively to them? Acta Hortic. 881, 675–682.

Macnish, A.J., Leonard, R.T., Nell, T.A., 2011. Sensitivity of potted foliage plant genotypes to ethylene and 1-methylcyclopropene. HortScience 46, 1127–1131.

Mahdieh, M., Mostajeran, A., 2009. Abscisic acid regulates root hydraulic conductance via aquaporin expression modulation in *Nicotiana tabacum*. J. Plant Physiol. 166, 1993–2003.

Majsztrik, J.C., Ristvey, A.G., Lea-Cox, J.D., 2011. Water and nutrient management in the production of container-grown ornamentals. Hortic. Rev. 38, 253–297.

Maxwell, K., Johnson, G.N., 2000. Chlorophyll fluorescence – a practical guide. J. Exp. Bot. 51, 659–668.

Monteiro, J.A., Nell, T.A., Barret, J.E., 2002. Effects of exogenous sucrose on carbohydrate levels, flower respiration and longevity of potted miniature rose (*Rosa hybrida*) flowers during postproduction. Postharvest Biol. Technol. 26, 221–229.

Morel, P., Crespel, L., Galopin, G., Moulia, B., 2012. Effect of mechanical stimulation on the growth and branching of garden rose. Sci. Hortic. 135, 59–64.

Mortensen, L.M., 2000. Effects of air humidity on growth, flowering, keeping quality and water relations of four short-day greenhouse species. Sci. Hortic. 86, 299–310.

Mortensen, L.M., Ottosen, C.O., Gislerød, H.R., 2001. Effects of air humidity and K:Ca ratio on growth morphology, flowering and keeping quality of pot roses. Sci. Hortic. 90, 131–141.

Müller, R., Andersen, A.S., Serek, M., 1998. Differences in display life of miniature potted roses (*Rosa hybrida* L.). Sci. Hortic. 76, 59–71.

Müller, R., Stummann, B.M., Andersen, A.S., Serek, M., 1999. Involvement of ABA in postharvest life of miniature potted roses. Plant Growth Regul. 29, 143–150.

Nell, T.A., Leonard, R.T., Barrett, J.E., 1990. Production and postproduction irradiance affects acclimatization and longevity of potted chrysanthemum and poinsettia. J. Am. Soc. Hortic. Sci. 115, 262–265.

Nell, T.A., Leonard, R.T., Barrett, J.E., 1995. Production factors affect the postproduction performance of poinsettia – a review. Acta Hortic. 405, 132–137.

Nielsen, B., Starkey, K.R., 1999. Influence of production factors on postharvest life of potted roses. Postarvest Biol. Technol. 16, 157–167.

Noordergraaf, C.V., 1994. Production and marketing of high quality plants. Acta Hortic. 353, 134–148.

Nowak, J., Rudnicki, R.M., 1990. Postharvest handling and storage of cut flowers. In: Florist Greens and Potted Plants. Timber Press, Portland, OR, pp. 210.

Olsen, W.W., Andersen, A.S., 1995. The influence of five growth retardants on growth and postproduction qualities of *Osteospermum ecklonis* cv. 'Calipso'. Sci. Hortic. 62, 263–270.

Pacifici, S., Burchi, G., Del Carlo, A., Ferrante, A., 2013. Effect of storage temperature and duration on vase life of cut *Ruscus racemosus* L. foliage. Acta Hortic. 970, 69–74.

Rajapakse, N.C., Clark, D.G., Kelly, J.W., Miller, W.B., 1994. Carbohydrate status and postharvest leaf chlorosis of miniature roses as influenced by carbon dioxide enrichment. Postharvest Biol. Technol. 4, 271–279.

Rajapakse, N.C., Kelly, J.W., 1994. Influence of spectral filters on growth and postharvest quality of potted miniature roses. Sci. Hortic. 56, 245–255.

Ranwala, A.P., Miller, W.B., 2005. Effects of cold storage on postharvest leaf and flower quality of potted Oriental-Asiatic- and LA-hybrid lily cultivars. Sci. Hortic. 105, 383–392.

Reid, M.S., 1991. Effects of low temperatures on ornamental plants. Acta Hortic. 298, 215–224.

Reid, M.S., Wollenweber, B., Serek, M., 2002. Carbon balance and ethylene in the postharvest life of flowering hibiscus. Postharvest Biol. Technol. 25, 227–233.

Roberts, C.M., Serek, M., Andersen, A.S., 1995. Supplemental irradiance and STS improve the display life of *Dicentra* species forced as flowering potted plants. Sci. Hortic. 62, 121–128.

Sarracino, J.M., Merritt, R., Chin, C.K., 1992. Light acclimatization potential of *Leea coccinia* and *Leea rubra* grown under low light flux. HortScience 27, 404–406.

Sawwan, J.S., Ghunem, R.S., 1999. Light acclimatization of *Schefflera arboricola*. Adv. Hortic. Sci. 13, 151–155.

Scuderi, D., Giuffrida, F., Leonardi, C., 2013. Growth and visual quality of weeping fig in relation to shading conditions. J. Food Agric. Environ. 11, 1828–1832.

Scuderi, D., Giuffrida, F., Toscano, S., Romano, D., 2012. Growth, physiological response and quality characteristics of weeping fig in response to shading levels and climatic conditions. HortScience 47, 1586–1592.

Scuderi, D., Romano, D., Leonardi, C., 2005. Keeping plant quality of weeping fig during indoor life in relation to previous growing conditions. Acta Hortic. 682, 1795–1800.

Serek, M., 1990. Effects of pre-harvest fertilization on the flower longevity of potted *Campanula carpatica* 'Karl Foerster'. Sci. Hortic. 44, 119–126.

Serek, M., 1993. Ethephon and silver thiosulfate affect postharvest characteristics of *Rosa hybrida* 'Victory Parade'. HortScience 28, 199–200.

Serek, M., Andersen, A., 1993. AOA and BA influence on floral development and longevity of potted victory parade miniature rose. HortScience 28, 1039–1040.

Serek, M., Reid, M.S., 2000. Ethylene and postharvest performance of potted Kalanchoë. Postharvest Biol. Technol. 18, 43–48.

Serek, M., Sisler, E.C., 2001. Efficacy of inhibitors of ethylene binding in improvement of the postharvest characteristics of potted flowering plants. Postharvest Biol. Technol. 23, 161–166.

Serek, M., Sisler, E.C., Reid, M.S., 1994. Novel gaseous ethylene binding inhibitor prevents ethylene effects in potted flowering plants. J. Am. Soc. Hortic. Sci. 119, 1230–1233.

Serek, M., Trolle, L., 2000. Factors affecting quality and post-production life of *Exacum affine*. Sci. Hortic. 86, 49–55.

Shan, X., Li, D., Qu, R., 2000. Thidiazuron promotes in vitro regeneration of wheat and barley. In Vitro Cell. Dev. Biol. Plant 36, 207–210.

Starman, T.W., Beach, S.E., Eixmann, K.L., 2007. Postharvest decline symptoms after simulated shipping and during shelf life of 21 cultivars of vegetative annuals. HortTechnology 17, 544–551.

Sterling, B., Molenaar, P., 1986. The influence of time and temperature during simulated shipment on the quality of pot plants. Acta Hortic. 181, 429–434.

Strasser, B.J., Strasser, R.J., 1995. Measuring fast fluorescence transients to address environmental questions: the JIP-test. In: Mathis, P. (Ed.), Photosynthesis: From Light to Biosphere. Kluwer Academic Publishers, Dordrecht, pp. 977–980.

Tallman, G., 2004. Are diurnal patterns of stomatal movement the result of alternating metabolism of endogenous guard cell ABA and accumulation of ABA delivered to the apoplast around guard cells by transpiration? J. Exp. Bot. 55, 1963–1976.

Thomson, W.W., Lewis, L.N., Coggins, C.W., 1967. The reversion of chromoplasts to chloroplasts in Valencia oranges. Cytologia (Tokyo) 32, 117–124.

Tijskens, L.M.M., Sloof, M., Wilkinson, E.C., van Doorn, W.G., 1996. A model of the effects of temperature and time on the acceptability of potted plants stored in darkness. Postharvest Biol. Technol. 8, 293–305.

Tjosvold, S.A., Wu, M.J., Reid, M.S., 1994. Reduction of postproduction quality loss in potted miniature roses. HortScience 29, 293–294.

Trivellini, A., Ferrante, A., Vernieri, P., Serra, G., 2011. Effects of abscisic acid on ethylene biosynthesis and perception in *Hibiscus rosa-sinensis* L. flower development. J. Exp. Bot. 62, 5437–5452.

Trivellini, A., Jibran, R., Watson, L.M., O'Donoghue, E.M., Ferrante, A., Sullivan, K.L., Dijkwel, P.P., Hunter, D.A., 2012. Carbon deprivation-driven transcriptome reprogramming in detached developmentally arresting *Arabidopsis inflorescences*. Plant Physiol. 60, 1357–1372.

Usadel, B., Blasing, O.E., Gibon, Y., Retzlaff, K., Hohne, M., Gunther, M., Stitt, M., 2008. Global transcript levels respond to small changes of the carbon status during progressive exhaustion of carbohydrates in *Arabidopsis rosettes*. Plant Physiol. 146, 1834–1861.

van Iersel, M.W., Seader, K., Dove, S., 2009. Exogenous abscisic acid application effects on stomatal closure, water use, and shelf life of Hydrangea (*Hydrangea macrophylla*). J. Environ. Hortic. 27, 234–238.

Wang, Q., Chen, J., Stamps, R.H., Li, Y., 2005. Correlation of visual quality grading and SPAD reading of green-leaved foliage plants. J. Plant Nutr. 28, 1215–1225.

Wang, Y.T., Blessington, T.M., 1990. Growth and interior performance of poinsettia in media containing composted cotton burrs. HortScience 25, 407–408.

Waterland, N.L., Campbell, C.A., Finer, J.J., Jones, M.L., 2010a. Abscisic acid application enhances drought stress tolerance in bedding plants. HortScience 45, 409–413.

Waterland, N.L., Finer, J.J., Jones, M.L., 2010b. Benzyladenine and gibberellic acid application prevents abscisic acid-induced leaf chlorosis in Pansy and Viola. HortScience 45, 925–933.

Williams, M.H., Rosenqvist, E., Buchhave, M., 2000. The effect of reducing production water availability on the post-production quality of potted miniature roses (*Rosa* × *hybrida*). Postharvest Biol. Technol. 18, 143–150.

Woltering, E.J., 1987. Effects of ethylene on ornamental pot plants: a classification. Sci. Hortic. 31, 283–294.

Yeh, D.M., Wang, H.M., 2000. Effects of irradiance on growth, net photosynthesis and indoor performance of the shade-adapted plant, maidenhair fern. J. Hortic. Sci. Biotechnol. 75, 293–298.

Zavaleta-Mancera, H.A., Thomas, B.J., Thomas, H., Scott, I.M., 1999. Regreening of senescent Nicotiana leaves II. Redifferentiation of plastids. J. Exp. Bot. 50, 1683–1689.

Zhang, H., Zhou, C., 2013. Signal transduction in leaf senescence. Plant Mol. Biol. 82, 539–545.