



POSTHARVEST BEHAVIOR AND KEEPING QUALITY OF POTTED POINSETTIA: A REVIEW

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ABSTRACT

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Poinsettia is one of the most important potted plants in the ornamentals industry. The most attractive parts of the poinsettia are its bracts and cyathia. Stem breakage, bract fading, bract edge burn (BEB), bract bruising and bract discoloration reduce its ornamental value. The ornamental value of poinsettia is affected by both pre- and postharvest factors. During cultivation as well as after harvest, sub-optimal or improper supply and / or management of temperature, light, relative humidity, nutrition and hygiene affect the quality of potted poinsettia. A low K : Ca ratio can reduce the incidence of bract necrosis and stem breakage. These disorders are negatively affected by high K and NH₄-N fertilizer due to an antagonistic relationship with Ca. Spraying either CaCl₂ or Ca(NO₃)₂ (400mg/l of Ca per week) or a silicon spray (7.12 mM Na₂SiO₃) and increasing the transpiration rate by reducing the relative humidity can reduce the incidence and severity of bract necrosis. Appropriate variety selection can lessen the risks of leaf drop and BEB. Propagating with thick stemmed cuttings (> 7.5 mm diameter) and carefully watering of plants can also help to prevent stem breakage. The optimum temperature range to achieve expected bract color, size and bud formation during the growth period is 16 to 22°C. Inappropriate light intensity and quality can delay flowering and promote cyathia abscission by decreasing plant carbohydrate status. Ethylene is central to the leaf and cyathia abscission. 1-MCP treatment can be used during short time (2-3 day) transportation to prevent ethylene responses by blocking ethylene receptors. Avoiding rough handling and shortening transportation play an important role in maintaining the quality of harvested poinsettia. The most important pathological problem is *Botrytis* infection. Low temperatures of 20 to 21°C during cultivation and 10 to 13°C during transport combined with low relative humidity of 60 to 70% RH can reduce infection by *Botrytis cinera*.

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INTRODUCTION

The ornamentals or floriculture industry is a very important part of the overall horticulture industry. Cut flowers and foliage, potted flowering and foliate plants, bedding plants and nursery plants for gardens and landscapes are divisions in the floriculture industry (Chandler, 2003; Chandler and Brugliera, 2011). Poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) is one of the most important flowering potted plant lines. They are targeted to the Christmas market in regions, including in North America, Europe, Asia and Australia. This sector represents as an industry valued at over \$ 154 million per annum (Ecke et al., 2004; USDA, 2009). Poinsettia is also called 'Christmas Star'; December 12th is designated as 'national poinsettia day' in the USA. Potted poinsettias have red, pink or white coloured bracts. Poinsettia production in the USA and the EU is ~ 50 and ~ 100 million plants per year, respectively (Lütken et al., 2012). Potted poinsettia plants are exported where road transport is adequate and are moved in large numbers between countries, especially in Europe.

Poinsettia is sold for its colorful inflorescence (cyathia) and bracts (transition leaves). Important indicators of a good postharvest quality in poinsettia plants are fully formed, turgid, blemish free evenly coloured bracts and leaves along with intact, fresh-looking cyathia. The estimated postharvest loss of flowers is around 10 to 30% over all stages in the value chain (Personal communication, Sissel Torre, Norway). In the 1960's, poinsettia was sold just a week before Christmas time due to the risks of epinasty and abscission of cyathia. The epinasty problem has been largely overcome by new or modern cultivars (Personal communication, Jim Faust, USA). The most serious current postproduction disorders of poinsettia are stem breakage, bract fading, leaf yellowing, bract edge burn (BEB) or necrosis and bract bruising (Ranch, 2012; Whipker, 1999). These disorders are influenced by to varietal selection, environmental conditions and nutrition during growth and postharvest management. Ethylene plays an important role in the abscission of leaves and cyathia of poinsettia. Breeders today are focusing more on the postharvest quality of poinsettia. New cultivars with a longer postharvest life are available. Poinsettia is now-a-days in the marketplace by early November (Bævre, 1994; Odula, 2011).

As an ornamental product in an economic context, it is important to maintain poinsettia quality throughout postharvest handling and distribution from the producer to the consumer (Fig. 1). Postharvest management begins with determining the harvest maturity stage that the plants are ready for market. It continues through establishing the proper storage, transport, retail and consumer conditions. The overarching goal is to maximize crop performance and quality. Considerable research effort has been devoted to improving the keeping quality of poinsettia plants.

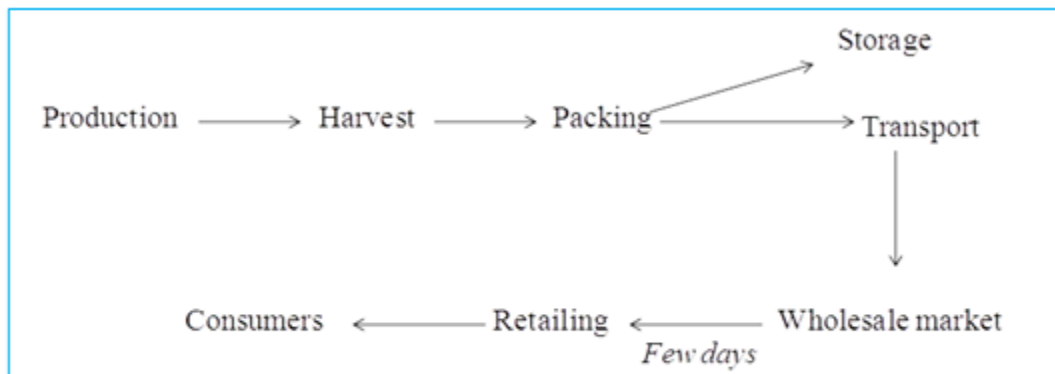


Figure 1: Flow diagram showing the serial steps of postharvest handling of ornamental plants such as poinsettia, orchid and others.

As noted above, considerable research has been carried out on poinsettia. For example, Islam et al. (Islam et al., 2012; 2013; 2014) recently worked on controlling poinsettia shoot elongation investigating light quality, hormonal physiology, genetic engineering and postharvest quality. However, there is no recent review on the postharvest quality of poinsettia. In this regard, recent research on keeping quality and postharvest behavior of poinsettia is overviewed herein. This review considers genetics, climatic factors, production techniques, nutritional disorders, transport and storage.

POSTHARVEST PROBLEMS OF POINSETTIA

Stem breakage

Plant pinching promotes the growth of lateral shoots resulting compact plants. However, fewer shoots may develop in a horizontal orientation leading to pressure at the branch junction resulting in stem breakage (Kuehny et al., 2000). Low light levels during the vegetative growth phase after pinching can contribute to poor structural development in the crotch area and / or lateral weak branch growth (Fig. 2A). Small diameter cuttings, improper plant spacing and inappropriate fertilization can also influence lateral stem breakage. Stem breakage is problematic during production and / or after sleeving. Such breakage markedly reduces market value and, thus, economic returns.

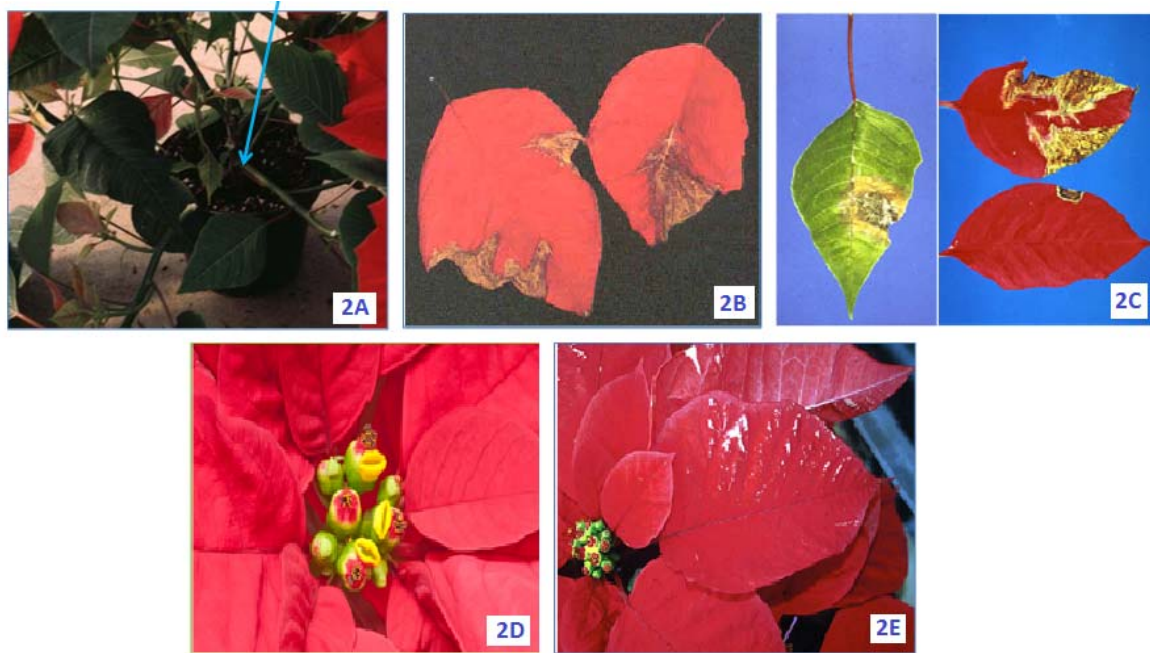


Figure 2A: Weak lateral stems (arrows) that tend to stem breakage (Hammer, 1999).

Figure 2B: Bract necrosis/bract edge burn (BEB) (Tayma and Roll, 1990)

Figure 2C: *Botrytis* infected leaf (left) and bracts (right) (Jones, 1999)

Figure 2D: Bracts (transition leaves) and cyathia of poinsettia (Photo: Md. Ashraful Islam)

Figure 2E: Bract abrasion (arrow) due to excessive contact (Whipker, 1999)

Bract necrosis and Botrytis infection

Bract necrosis is also called bract edge burn (BEB) (Fig. 2B). BEB starts as small brown necrotic lesions along the bract margin. The lesions may expand through the develop *Botrytis* infection to damage the entire bract that essentially renders the plants unmarketable. Low level of calcium might be the reasons of the disorder or bract margin. On the other hand, calcium translocating system is difficult in some varieties which are essential elements for the cell expansion. It will not be possible to solve using more application of calcium which are cultivar dependant (Ranch, 2011). Botrytis blight or gray mold (Fig. 2C) is caused by the fungal pathogen *Botrytis cinerea*. In poinsettia, Botrytis blight can occur at all stages during production and postharvest. Regardless of the tissue affected, the rot begins as water soaking developing into tan to brown lesions.

Excess fertilizer application, particularly ammonium sources of nitrogen at the late stage production, can lead to bract burn and then *B. cinerea* infection. It is considered that contributory factors to bract necrosis include excess soluble salt levels in the growing medium that causes root injury, reduced water absorption stress from excessive or insufficient irrigation, damage from pesticides, pollutants, and high relative humidity.

Leaf drop and yellowing

A lack of irrigation water can cause leaf drop that affects older leaves. Leaf fall under stress conditions occurs at an abscission layer at the junction of petiole and the stem. It is believed that leaf drop is mediated by a loss of auxin export across the abscission zone from the leaf blade under stress condition. Irregular

irrigation, low light intensity, warm temperature and low relative humidity are thought to influence leaf drop at any level in the supply chain up to and including where the poinsettia plant is placed by the consumer. In particular, the lower leaves yellow and drop if the plants are kept under very low light intensity for several days.

Cyathia abscission

Premature abscission of one or more of the cyathia or true flowers on poinsettia also reduces the ornamental value (Fig. 2D). Abscission *per se* results from degradation pectin in the mid-lamella and of pectin, cellulose and arabinose in cell walls of the abscission zone (AZ). The levels of xylan and xyloglucan in the AZ zone is shown to increase prior to abscission, rendering the cell walls more loosely organized and susceptible to degradation (Lee et al., 2008).

Bract discoloration / abrasion

Poinsettia bracts are fragile and easily discolor. They can be severely damaged by temperatures below 10°C (Love, 1999). Expansion of discoloration depends on the duration of exposure to such cold temperature. Red bracts develop a blue to silver white color (Fig. 2E). During shipping, bract abrasion occurs due to rubbing against the sleeve or against each other. Sleeves and boxes which are taller than the plants can help to prevent bract abrasion as well as confer a degree of protection against chilling injury.

IMPROVING THE POSTHARVEST QUALITY OF POINSETTIA

Genotype

Genotype or cultivar selection is one of the most critical decisions for growers. Poinsettia breeding has attracted considerable attention resulting in increased demand for better quality cultivars. Thus, cultivar selection is important to the commercial grower. New poinsettia cultivars are introduced by poinsettia breeding companies each year. A national poinsettia trial programme has been evaluating poinsettia cultivars with the collaboration of poinsettia breeding companies for over 19 years since started in 1993. Barrett and Dole (2012) surveyed 21 new poinsettia cultivars of varying color and type in three locations in a comparison with established cultivars. Cultivar 'Ice Punch' was selected as the best cultivar with strong (46%) consumers support. Dunn et al. (2011) studied 40 cultivars at different temperatures and determined differences in bract numbers, size and lateral shoots among the cultivars. BEB emerged as a major problem in the late 1970s with the introduction of 'Gutiber V-14 Glory'. Now-a-days it is considered that BEB is cultivar dependent (Ranch, 2011).

Self-branching cultivars, such as 'Annette Hegg Dark Red' and 'Gutibar' have thin stems that are prone to bend and break during handling or shipping (Larson et al., 1978). Some cultivars like 'Success' and 'Red Splendor' are relatively more resistant to stem breakage (Whipker, 1999). More recently introduced cultivars show better postproduction quality as compared to older ones. Some newer varieties were evaluated by Ranch (2012) for their relative postproduction problems. All varieties are ranked into the categories of 'excellent', 'good' or 'below average' after 4 weeks considering postproduction performances like bract edge burn (BEB), bract fading, leaf yellowing, leaf drop, bract bruising etc.

Environmental factors

Light

Light intensity during the growth period can affect the post-production keeping quality of potted ornamental plants (Fjeld, 1990). In poinsettia, low light intensity was shown to reduce stem strength, delay flowering and increase cyathia abscission (Faust et al., 1998; Fjeld, 1992; Moe et al., 1992a; 2006). A stem breakage problem was observed by Kuehny et al. (2000) in cv. 'Freedom Red'. Due to pinching, a large number of lower laterals grew out and upwards towards light. This growth habit caused weaker lateral stems and wider lateral branch angles, especially in lower stems. In general, after pinching the competition for light during the vegetative growth causes weak lateral branching (Smith and Cox, 2009).

An increase in irradiation from 12 to 73 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ during production increased cyathia retention in the 1st and 2nd weeks of postharvest testing under indoor climate conditions (Moe et al., 1992b). Extending the photoperiod from 10 h to 24 h the last 3 weeks of production resulted in higher postharvest cyathia abscission rate and discoloration. Moe et al. (2006) tested postharvest performance of cvs. 'Lilo' and 'Millenium' and established differences. Bract discoloration occurred on 'Lilo' under production in a 24 h photoperiod as compared to the 10 h control treatment. One hundred (100) % bract discoloration occurred in 'Lilo' during the last 3 weeks of cultivation under the 24 h photoperiod. However, 'Millenium' showed no discoloration in red bract under control as well as with the supplemental light of 24 h photoperiod. Carbohydrate depletion might be the reason for cyathia abscission. It is not clear about the retention capacity of cyathia in different cultivars

(Moe et al., 2006). Bract discoloration may be a result of accumulation of anthocyanin or other phenolic compounds under high light intensity or long photoperiods. Petal blackening of roses occurred due to this phenomena at low night temperature exposure (Zieslin and Halevy, 1969). Overall, premature abscission is interlinked with long photoperiod and low light intensity (Scott et al., 1983; 1984a; Staby and Kofranek, 1979).

Carbohydrate status and sugar supply to floral organs likely play a role in cyathia abscission (van Doorn, 2001). In *Christmas begonia*, Fjeld (1992) measured sucrose content and abscission rate during the marketing stage for plants grown at different irradiance level. The sucrose content was a higher contributor to the dry matter of inflorescences and leaves (10%) and the abscission rate was lower for flowers and buds (19%) on plants grown under $60 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ as compared to $15 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ (2.1% sucrose and 36% abscission).

Towards saving energy and manipulating plant growth in an environmentally sounder manner that also improves plant health, the use of specific light qualities provided by light emitting diodes (LED) is attracting attention. It is well known for a variety of long day plants that blue (B) and red (R) light promote flowering while far-red (FR) delays flowering (Simpson and Dean, 2002). No difference in the keeping qualities of poinsettia cvs. 'Christmas Spirit' and 'Christmas Eve' was found after exposure to LED lamps providing 80% R and 20% B light irradiance at $100 \mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ (Islam et al., 2012). Light quality manipulation resulting in an increased R : FR ratio at the EOD (end of day) for 30 min used to avoid unwanted extension growth. It is well known that both phytochrome and cryptochrome are involved in the content of hormone gibberellin (Hisamatsu et al., 2005; Zhao et al., 2007). However, this treatment did not have any effect on the flowering of the two cultivars of poinsettia (Islam et al., 2014). Nevertheless, postharvest behavior is cultivar dependent. It has been recorded that the senescence of poinsettia was faster under fluorescent lamps as compared to under incandescent tungsten lamps (Scott et al., 1984a).

Temperature

Stem breakage, flower bud formation, flower development, bract color, bract size, bract discoloration, bract necrosis and *Botrytis* infection are all influenced by temperature during the plant growth period. Pritchard et al. (1996) observed that the bract and foliage infected area increased during the postproduction, if the temperature is increased both at day and night time from 16 to 22°C during the poinsettia production. Higher temperature was considered to increase turgor pressure that resulted in the extracellular leakage of nutrients, salts and sugars in the bract and to the leaf surface which influence the germination of *Botrytis cinera* conidia (Blakeman, 1975; Salinas et al., 1989; Van Meeteren, 1980). As per above, common symptoms caused by *Botrytis* infection are leaf spots and blighting which may affect leaves, stems and petioles (Hausbeck and Moorman, 1996). Schnelle and Barrett (2011) recorded chroma values for bract fading or discoloration at 27°C as compared to at 21 and 24°C. Bract discoloration at the higher temperature of 27°C gave a chroma value of 39 as being significantly lower than 55 at 21°C and 54 at 24°C. Also, it has been observed that ~ 34% lateral shoots were broken at a relatively lower temperature and 4% at a higher temperature while the night temperature was maintained at 20°C with the day temperature was 30 or 37°C (Faust et al., 1998). Too low average daily temperatures cause slowed plant development, delayed color development, reduced bract size and elicited lower leaf loss from poinsettia plants (Whipker, 1999). Runcle and Faust (2008) reported that poinsettias growth stopped at < 13°C.

Moe et al. (1992a) tested the keeping quality of poinsettia plants grown under different day and night temperatures (DIF). A negative temperature difference between day and night (DT < NT) was found to delay flowering (Moe et al., 1992a; 1995). In these plants, bract necrosis and cyathia abscission were higher during the 1st and 2nd week postharvest as compared to plants that experienced positive (DT > NT) and zero (DT = NT) DIF. After 4 weeks, there was no difference in bract necrosis between the plants grown under the different temperature treatments. Although there is limited information on the effect of temperature on carbohydrate status in poinsettia, premature cyathia abscission is probably linked to carbohydrate depletion (Miller and Heins, 1986). Photosynthetic rates are correlated with temperature and a lower photosynthetic rate was found under negative DIF as compared to positive and zero DIFs (Berghage et al., 1990). Moe et al. (1992a) mainly applied negative DIF to get compact plants, but the postharvest quality was not good. However, such a treatment given early in poinsettia production with an ADT (average daily temperature) 23 to 26°C from visible bud formation to flowering can result in compact plants without serious reduction in postharvest quality (Berghage, 1989). Temperature after flowering appears to be important for the keeping quality of poinsettia. In general, the optimum temperature for bract development is 22 to 23°C during the day and 19 to 20 °C at night. Before shipping for 2 weeks, the temperature should be maintained at 21°C and 20 °C day and night, respectively, during production (Whipker, 1999). The lowest postharvest quality rating was scored at <17°C in regard of leaf yellowing, cyathia drop and bract edge burn (Syngenta (2009).

Water and air humidity

Water supply and air humidity conditions affect the morphological and physiological condition of ornamental plants, including their postharvest life. It is claimed that excess water stress or water deficiency stress both interfere with the longevity of plant organs. Despite this general understanding, the effects of water

supply on the longevity of ornamental plants have not been comprehensively examined. Water supply and air humidity both have correlative influences on plant transpiration. For instance, the water consumption per unit leaf area is lower at higher humidity and Mortensen (2000) mentioned that water consumption per unit area of leaf is decreased 39% in poinsettia during the water vapour pressure deficits (VPD) decreased from 660 to 155 Pa.

The effect of air humidity on keeping quality is unclear for poinsettia and other greenhouse grown flowering plants (Grange and Hand, 1987). However, deficit irrigation and low air humidity can both stimulate tissue dehydration to cause lower stomatal conductance values (g_s) reflecting efficient stomatal regulation (Sánchez-Blanco et al., 2004). Drought stress to water potentials of -1.3 to -1.1 MPa can elicit leaf drop in poinsettia during the reproductive growth stage (Gilbert et al., 1982; Whipker, 1999). Drought stress may induce endogenous ethylene resulting premature loss of organs.

In contrast, high humidity can reduce the rate of transpiration (Ehret and Ho, 1986). Mortensen (2000) observed transpiration rates for poinsettia during the growth at air humidities of 70%, 81% and 93%. The transpiration rate was higher at $31.9 \pm 2.9 \text{ g} \cdot \text{day}^{-1}$ under 70% RH as compared to $23.7 \pm 2.2 \text{ g} \cdot \text{day}^{-1}$ under 93% RH. It has been shown that Ca plays an important role for postharvest life of ornamental plants like cut roses and *Antirrhinum*. Ca uptake and transport are affected by transpiration rate (Higaki et al., 1980; Marschner, 1995; Michalczuk et al., 1989; Nielsen and Starkey, 1999; Starkey and Pedersen, 1997). As previously described, Ca is integrally related to bract necrosis and stem breakage of poinsettia. Tissues having low xylem flow due to low transpiration rate have low translocation of Ca into the bracts leading to bract necrosis. Thus, the Ca content becomes lower in bracts and leaves of poinsettia grown at high RH as compared to those grown at moderate RH. Similar results were found for flowers and leaves of cut roses grown under high RH, resulting in their comparatively shorter postharvest life (Baas et al., 1998; Strømme et al., 1994; Torre et al., 2001). There also appears to be a difference in transpiration rates between the bracts and leaves of poinsettia. Consequently, the Ca content is commonly lower in the bract (Robichaux, 2008; Strømme et al., 1994). Insufficient Ca in bracts may be due to low stomatal density in this relatively low transpiring organ (Nell and Barrett, 1986a).

Both high air humidity and water stress favor *B. cinerea* in greenhouses (Hausbeck and Moorman, 1996; Whipker, 1999). During the growing phase, roots are primarily affected. Infection may later cause stem rot and plant death. Stressed or wounded leaf tissues and true flowers of poinsettia are particularly affected by *B. cinerea*. Low Ca levels favour this pathological disorder (Ranch, 2011). Lowering the air humidity, maintaining good air circulation, reducing moisture in the plant canopy, cleaning away plant debris, and application of approved fungicides like benzimidazole and dicarboximide can prevent *B. cinerea*. During production, small physical breaks sometimes occur at branch and main stem junctions under the force of hand watering. Watering gently can reduce this type of stem breakage.

Management practices

Cuttings and space

Poinsettias are vegetatively propagated by cuttings. Stem breakage, which is the most important production problem in poinsettia, is affected by cutting diameter. Two times more stem breakage was observed for 4.5 mm or less cutting diameters as compared to 7.5 mm or greater diameters (Ranch, 2011). Poinsettia plant development is weak from thin diameter cuttings. Consequently, resulting inflorescences cannot be kept erect without the staking. Plants growing in pots from cuttings should be placed close together at the beginning of production cycle in order to encourage upright growing. Otherwise, angled to horizontal lateral shoots will be produced in the open space. In addition to thicker stem cuttings, support rings can help prevent stem breakage.

Nutrition

Fertilization influences the postproduction performance of poinsettia. The greatest difference in Ca contents in the interior part of leaf blades was between healthy leaves and those suffering from leaf edge burn (LEB). At the end of the postharvest period, Ca content was analyzed in the bracts of poinsettia (Strømme et al., 1994). The Ca content was lower at the margin as compared to middle or interior bract sections, indicating localized Ca deficiency. McAvoy et al. (1998) observed condensed tannins in bract tissues with necrotic lesions as compared to healthy tissue.

Application of a high $\text{NH}_4\text{-N}$ fertilizer level indirectly resulted in necrotic spots by reducing Ca absorption (Nell and Barrett, 1985). On the other hand, high $\text{NH}_4\text{-N}$ treatment in solution 'A' was associated with the lowest incidence with no influence on Ca uptake (Strømme et al., 1994). It has been reported that BEB increased by two fold when the nitrogen (N) supply concentration was increased from 200 ppm to 400 ppm (Ranch, 2011). The reason may be that NH_4 is converted to NO_3 quickly such that very little NH_4 is left to compete with Ca uptake. Ammonia-nitrogen promotes vegetative growth that may lead to also vegetative

growth as well as weaker stem resulting stem breakage (Whipker, 1999). After application of different ratios of $\text{NH}_4\text{-N} : \text{NO}_3\text{-N}$ (0.1, 1.2 and 2.1) during production, a difference was detected in Ca contents between the outer margins and the interior section of leaf blades (Biermann et al., 1990).

Although the mechanism is not entirely clear, spraying with CaCl_2 and Si can suppress bract necrosis development, (McAvoy and Bible, 1996a; 1996b; McAvoy et al., 1998; Woltz and Harbaugh, 1985). Si spray reduces the incidence of bract necrosis / LEB without effects on macro or micro nutrient contents in the leaf / bract margin tissues (McAvoy and Bible, 1996b). Si is taken up by plant roots in the form of silicic acid and transported to the shoot. Si treatment can reduce the plant transpiration rate (Ma and Takahashi, 2002). Termination of Si fertilization 1 to 4 weeks prior to harvest appears to reduce leaf drop (Prince and Cunningham, 1988; Ranch, 2011). Ca and Si treated poinsettia plants typically show better stem strength (Kuehny et al., 2000; Robichaux, 2008). Ca plays a key role in cell wall structure. It is involved in cross-linking pectin molecules (Ferguson and Drøbak, 1988; Hepler, 2005). As above, poinsettia stem breakage, leaf edge burn (LEB) and bract necrosis are reportedly linked to calcium (Ca) supply and can be improved by spraying with Ca and silicon (Si) (McAvoy and Bible, 1995; Robichaux, 2008; Woltz and Harbaugh, 1985).

There is an apparent antagonistic relationship between potassium (K) and Ca (Tsutsui and Aoki, 1981). Ca is translocated from the root to the different parts of the shoot through the transpiration stream in the xylem and Ca mobility through the phloem is limited (Strømme et al., 1994). Substrate pH is important for poinsettia production. Leaf edge burn occurs and mature leaves in the middle of the plants become yellow due to molybdenum (Mo) deficiency (Whipker et al., 2002). At pH 6.5, new leaves become yellow due to iron (Fe) deficiency.

Storage and transportation

In addition to production factors, the keeping quality of poinsettia is dependent on postproduction factors. Deterioration occurs quickly such that the ornamental value is reduced due to poor treatment, handling, transportation and storage. It is important to understand the plants physiological requirements in respect to postharvest environmental factors (e.g. light, temperature, air humidity) from harvest to the consumer (Fig. 1). In general, growers, distributors and wholesalers use preservative chemicals, hygiene and cold chain management to maintain product quality (Eason, 2006). In poinsettia, problems such as bract discoloration, leaf yellowing, and shrinkage in terms of plant losses occur during the postharvest period. These issues mean lower returns and ultimately to cost cutting on the input side. Thus, it is vitally important to give due care and attention to proper handling, transportation, and storage to retain harvest quality.

In Norway by way of example, poinsettia plants are placed either in open framed Danish containers or into sleeves and boxed before leaving the growers premises for transportation. As poinsettia is a chilling sensitive species, the paper sleeves may protect the plants from low temperature injury. Leaf drop and bract discoloration can occur due to non-optimal temperatures and long durations of storage. These disorders are associated with ethylene and auxin physiology (Sacalis, 1978; Saltviet et al., 1979; Staby et al., 1980; 1978). Active auxin transport inhibits the formation of abscission layers by reducing abscission zone sensitivity to ethylene. On the other hand, ethylene inhibits the transport of both indole-3-acetic acid (IAA) and α -naphthalene acetic acid (NAA) in midrib sections, resulting in reduced auxin transport through the abscission zone (Riov and Goren, 1979). Ethylene is considered the primary regulator of abscission process and auxin acts as a suppressor of the ethylene effect (Taiz and Zeiger, 2010).

Faust and Enfield (2010) suggested that 10 to 15°C is the optimum temperature range for shipping of un-rooted poinsettia. Higher temperatures can increase ethylene concentrations. For example, ethylene increased over 48 h from 0.0 to 0.5 ppm with increasing temperature from 10 to 26°C in plastic bags packaged un-rooted poinsettia cuttings while ethylene was measured at 12, 24, 48 and 72 h (Faust and Lewis, 2005). Following 72 h storage, 4 days in propagation, the leaf abscission was increased at the temperature from 10 to 26°C.

Light is also known to influence auxin content and thus leaf drop. Decreased cyathia retention occurred during storage for 3 to 6 d under darkness (Scott et al., 1982, 1984b; Shanks et al., 1970). In retail shops, poinsettia plants are typically packed tightly on shelves tightly in low light. Their deterioration under such conditions reduces their ornamental value.

Ethylene can stimulate abscission of whole flowers and flower buds from ornamental plants (Woltering, 1987). Among other chemical compounds, 1-methylcyclopropene (1-MCP) can effectively block ethylene responses at the receptors (Serek et al., 2006). 1-MCP has been shown to protect many potted plants as well as other horticultural produce against ethylene action (Faust and Lewis, 2005; Serek et al., 1994; Serek et al., 2006). It can be used in shipping boxes or containers. Preventing gas leakage during treatment makes for effective delivery. Faust and Lewis (2005) used 1-MCP sachets during shipment to prevent the ethylene action and reduce leaf yellowing and abscission in un-rooted poinsettia cuttings. Similar findings were found in Pothos (*Epipremnum pinnatum*) (Muller et al., 1997). Faust and Lewis (2005) showed a potential benefit of placing 1-MCP sachets in with un-rooted poinsettia cuttings shipped at the relatively warm temperature of 18

to 26°C. At low temperature (5 to 10°C), 1-MCP is not necessarily needed due to low ethylene production at low temperature (Jiang et al., 2002).

Botrytis disease is favored at room temperature due to injured or succulent tissue (Ecke et al., 1990). Infection can occur during transportation, particularly if the plants become too wet with moisture on their foliage. Temperature fluctuations during transportation and / or storage commonly result in high humidity and condensation of water onto bracts or leaves. Thus, maintaining a stable temperature is important. The optimum temperature appears to be about 12 to 13°C. A low temperature of < 4°C results in chilling injury and higher temperatures of 16 or 24°C are associated with leaf abscission (Nell and Barrett, 1986b; Scott et al., 1983).

In general terms, it can be difficult to manage poinsettia plants during shipping or on retail display in respect to providing proper light and water management (Barrett, 2011). Darkness is a particularly poor condition for the plant. Sleeving plants can avoid damage during handling by customers.

RECOMMENDATIONS

The keeping quality of poinsettia plants is influenced by cultivar selection, optimum pre-harvest cultural and pre- and postharvest environmental conditions (viz., temperature, light, air humidity) as well as general management practices, including during transportation and storage. To maintain high-quality poinsettia plants, the following guidelines may be followed.

- Selection of 'new' poinsettia cultivars which are less susceptible to BEB and leaf drop as compared to 'old' cultivars.
- Avoidance of high temperature after flowering and maintenance of an optimum growing temperature of 20 to 21°C.
- Provision of at least 100 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ B (20%) and R (80%) LED light for growing poinsettia for no negative effect on postharvest behaviour. Under indoor conditions, a minimum irradiation of 10 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ should be provided by fluorescent tubes.
- Maintenance of 60 to 70% air humidity for poinsettia production and around 40 to 60% RH for postharvest and / or indoor conditions.
- Achievement of an optimum temperature range at between 10 to 13°C during transportation and avoidance of excess water during storage with a view to minimise BEB and *Botrytis* infection. Long distance transport for > 3 d should be avoided and 1-MCP sachets can be used.
- At retail level, realising a minimum light level (10 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$) and a temperature of about 18 to 20°C in the shop. Plants should ideally be kept on shelves or racks with spacing that ensures optimum light to them all. A few plants might be separated display with the aim of avoiding rough handling of the others by consumers.
- Optimum fertilization should be practised with thought to K, Ca and N due to potential antagonistic effects. EC and pH levels should be considered. Towards the end of the production phase, applications of K and $\text{NH}_4\text{-N}$ should be reduced. Conversely, Ca should be applied during the last weeks before harvest.
- Spraying of leaves and bracts with calcium chloride or calcium nitrate (400 mg/l of Ca per week) or with silica (7.12 mM Na_2SiO_3) to reduce the incidence and severity of necrosis. Also, maintenance of low air humidity with a view to increasing plant organ Ca contents and minimising *Botrytis* blight.

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