Effect of Exogenous Adenosine Triphosphate Supply on the Senescence-related Physiology of Cut Carnation Flowers

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Carnation (Dianthus caryophyllus L.) flowers deteriorate rapidly after harvest. Symptoms of deterioration include petal in-rolling and discoloration, which results in reduced vase life (Badiyan et al., 2004; Bowyer et al., 2003; Thompson et al., 1982). The short vase life of cut carnation flowers may limit successful marketing.

Energy metabolism related to physiological disorders and senescence of plant tissues has been investigated in various harvested horticultural crops, such as litchi fruit, pear, and carnation (Duan et al., 2004; Saquet et al., 2003; Solomos and Gross, 1997; Veltman et al., 2003). In carnation and rose, membrane deterioration and senescence are associated with a decrease in respiratory activity and may be delayed when flowers are supplied with respiratory substrates (Fobel et al., 1987; Monteiro et al., 2001; Thompson et al., 1982; Trippi and Paulin, 1984). Trippi and Paulin (1984) showed that an increase in membrane permeability was associated with a decrease of energy production in senescing cut carnation flowers. Vase solutions containing adenosine triphosphate (ATP) can extend the vase life of cut carnation flowers (Song et al., 2006b). Thus, it is suggested that the low-energy status of plant tissues may lead to cut flower senescence and reduced vase life.

This investigation determined the effects of exogenous ATP supply on the senescence-related physiology of cut carnation flowers. With a view to understanding better the role of tissue energy status in the senescence of carnation flowers, the effects of exogenous ATP supply on time to maximum flower expansion, vase life, rates of ethylene production and respiration, and endogenous ATP and adenosine monophosphate (AMP) concentrations during vase life of cut carnation flowers were investigated.

Carnation cv. ‘Master’ flowers were obtained from a commercial market in Guangzhou, China. Flowers were transported to the laboratory within 6 h. Flowers were uniform at commercial maturity (outer petals horizontal), as described by Wu et al. (1992). Their stems were recut under water to a length of ~30 cm. Stems were assigned at random to flasks containing either distilled water (control) or 0.1 mmol L⁻¹ ATP solution until the end of the vase life of the control flowers (up to 10 d). The concentration of 0.1 mmol L⁻¹ ATP is the most beneficial in extending the vase life of the cut flowers, as identified by Song et al. (2006b). The volume of ATP solution or distilled water was maintained at constant levels by replenishing the flasks daily. There were four flowers per flask and three replicates. Data were tested by analysis of variance using SPSS version 7.5. Least significant differences (LSDs) were calculated to compare significant effects at the 5% level.

Application of 0.1 mmol L⁻¹ ATP to the vase solution extended the vase life of cut carnation flowers from 12.7 to 16.3 d, an increase of 3.6 d, and delayed the time to maximum flower expansion by 1.7 d, compared with non-ATP-treated flowers held in distilled water (Table 1). Fresh weight of cut carnation flowers increased within the first 2 d of vase life, but declined at day 6 (Fig. 1A). The ATP-treated cut carnation flowers had a relatively high fresh weight compared with the control flowers throughout the vase life evaluation period (Fig. 1A). Similar results were observed in response to provision of respiratory substrates to potted and cut rose flowers (Monteiro et al., 2002; Podd and Van Staden, 2002; Van Doorn and Reid, 1991).

Cut carnation flowers can show a marked climacteric-like respiration pattern during senescence (Mayak and Dilley, 1976; Podd and Van Staden, 2002). However, Trippi and Paulin (1984) found generally decreasing

| Time to maximum flower expansion (d) | Vase life (d) |
|-------------------------------------|--------------|
| Control                             | 7.1 ± 0.2 a   | 12.7 ± 0.9 a |
| 0.1 mmol L⁻¹ ATP                    | 8.8 ± 0.4 b   | 16.3 ± 1.0 c |

Data are the mean ± se of 12 flowers. Means within a column followed by a different letter are significantly different at the 5% level.

ATP, adenosine triphosphate.
respiratory activity during senescence of cut carnation flowers. Van Doorn and Reid (1991) reported that respiratory patterns of cut carnation flowers during vase life were cultivar dependent. In this study, exogenous supply of 0.1 mmol L\(^{-1}\) ATP generally enhanced respiratory activity (Fig. 1B). The observed trends in respiration rate during vase life evaluation were only weakly climacteric.

Ethylene production by the cut carnation flowers slowly increased after 4 d and reached a maximum after 8 d of vase life (Fig. 1C). The peak in ethylene production rate was coincident with the appearance of visible senescence symptoms, including petal in-rolling and withering. Provision of 0.1 mmol L\(^{-1}\) ATP in the vase solution consistently reduced ethylene production rates throughout the vase life evaluation period. Van Doorn and Reid (1991) observed that vase life extension in cut flowers was related to inhibition in ethylene production. Borochov and Adam (1984) found that ATP supply inhibited ethylene production of detached carnation petals.

Adenosine triphosphate is the primary energy pool in living tissues. Endogenous ATP content in cut carnation flowers increased from day 0 to day 4, and then decreased (Fig. 2A). In contrast, AMP content increased after day 4 (Fig. 2B). Exogenous ATP supply maintained relatively a higher ATP content and reduced the increase in AMP content at the later stages of vase life. Exogenous sucrose to vase life solution increased carbohydrate levels, enhanced respiration, and extended the longevity of potted miniature rose, possibly as a result of maintenance of tissue energy (Monteiro et al., 2002). A correlation between energy metabolism and incidence of core browning of pear fruit or senescence of cut carnation flower has been established (Saquet et al., 2001; Trippi et al., 1988; Veltman et al., 2003). Reduction of the ATP level synthesized in the cell could lead to a loss of cellular integrity, and incomplete terminal oxidation (Pradet and Raymond, 1983). In longan fruit, high ATP content and adenylate energy charge level of pericarp tissues could contribute to maintenance of membrane integrity (Su et al., 2005). Furthermore, exogenous application of ATP increased tissue energy status and exhibited potential for browning control and quality maintenance of harvested litchi fruit (Song et al., 2006a). It is suggested that an exogenous ATP supply could contribute to the maintenance of tissue energy and thereby delay senescence of cut carnation flowers.

In conclusion, an exogenous ATP supply extended the vase life and retarded the senescence of cut carnation flowers mediated through increasing fresh weight, enhancing respiration, reducing ethylene production rates, and maintaining higher endogenous ATP concentration in tissues, and showed the potential for practical horticultural value.

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