Mobility and Ionic Form of Silver as Related to Longevity of Cut Carnations

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Abstract. The mobility of different ionic forms of silver ($^{110m}$Ag) has been studied using semiconductor radiation detectors. Silver, applied as silvernitrate (2 mM), moves upward in the stems of cut carnations (Dianthus caryophyllus L.) at about 3 cm day$^{-1}$. This transport has the characteristics of a chromatographic exchange transport, but is not promoted by the addition of other cations (K$^+$ or Ca$^{2+}$). The silverthiosulphate anionic complex is transported at the same speed as [$^{32}$P]phosphate (about 2 m h$^{-1}$); orders of magnitude faster than Ag$^+$. The antiethylene action of silver is preserved in this complex, as shown by a significant improvement of the longevity of carnation flowers in the presence or absence of ethephon, even after a short treatment with the silverthiosulphate complex. Analysis of the silver content of different flower parts after a silverthiosulphate treatment shows a distinct accumulation in the receptacle, possibly associated with the antiethylene action.

Key words: Dianthus — Flower longevity — Ion mobility — Silver (ionic forms).

Introduction

The vase-life of cut carnations can be increased by pretreatment with silver salts (Halevy and Kofranek, 1977; Kofranek and Paul, 1972). As well as the established bactericidal effect of a silver treatment (Mayak et al., 1977), it has been shown in recent years that this ion acts as a potent antiethylene agent in various plants (Beyer, 1976a; 1976b) and thereby improves longevity.

A basal treatment of cut carnations with silver salts has far less effect on the longevity than a direct treatment of flowers (Halevy and Kofranek, 1977). This may be explained by the fact that silver ions are not translocated in measurable amounts to the carnation flower (Kofranek and Paul, 1972). Further, Pettersson (1976) demonstrated the extremely low mobility of silver in cucumber plants.

This relative immobility can be due to the participation of the silver (Ag$^+$) in the cation-exchange processes at the negatively charged sites of the walls of the xylem vessels, shown to be the basic translocation mechanism for calcium and some other divalent cations (Biddulph et al., 1961; Bell and Biddulph, 1963; Ferguson and Bollard, 1976; Petit and Van de Geijn, 1978). On the other hand, the presence of SH-groups in the various tissues could give rise to an irreversible sequestering of the silver by these groups. The very low solubility product of silversulphide ($K_{S0} = 10^{-35}$) (Sillén and Martell, 1964) lends support to this possibility.

The low mobility of calcium and similar cations can be increased by the chelation of the metal in an anionic complex (Millikan and Hanger, 1965; Ferguson and Bollard, 1976; Jacoby, 1967), as the negatively charged ionic complexes are not, or to a much smaller extent, subject to the adsorption and exchange processes.

In the present paper transport of the silver ion and its negatively charged thiosulphate complex are compared, as well as their physiological effect on the longevity of cut carnations.

Materials and Methods

Carnation flowers (Dianthus caryophyllus L., cv. White Sim) were harvested in a commercial nursery, trimmed to a uniform length of 45 cm, and kept out of water overnight at 4°C.

In the longevity experiments the plants were separated into four groups and subsequently supplied for 24 h respectively with a solution of AgNO$_3$ (2 mM); a mixture of AgNO$_3$ and Na$_2$S$_2$O$_3$·5H$_2$O (final concentration respectively 2 and 16 mM); Na$_2$S$_2$O$_3$·5H$_2$O (16 mM); or deionized water (control). After the treatment
half of each group was transferred either to deionized water or to 50 ppm ethephon, (2-chloroethyl)-phosphonic acid. The longevity was determined as the mean number of days after harvest until initial wilting or rolling-in of the petals (Halevy and Kofranek, 1977). The experiments were carried out in a greenhouse compartment under natural daylight conditions, giving day and night supplementary light (13 W m⁻², Philips HPLN, 400W). The temperature varied between 16°C and 24°C, and the relative humidity between 60 and 70%.

For the study of transport kinetics and distribution processes silver was labeled with ¹¹⁰mAg, obtained from the Radiochemical Centre, Amersham, U.K. (1.0 mCi/0.81 mg Ag). Carrierfree [³²P]orthophosphate was purchased from the same centre.

The transport experiments were carried out in a climate controlled growth chamber (temp. 20°C; cont. light 35 W m⁻²; rel. hum. 60 to 70%). Three semiconductor radiation detectors (surface barrier detectors, ORTEC, 25 mm² x 300 gtm) were placed along the stem of a cut carnation, 7.5 cm apart, the lower one about 12 cm from the base. The small volume and relatively low detection efficiency of this type of detector for high energy γ-rays, allow the direct measurement of the intensity of the β-radiation from the stem at a specific point, and thereby the estimation of the kinetics of silver transport into the stem, even in the presence of a rather substantial background radiation. To reduce the background contribution from the labeled solution, a 1.5 cm thick lead shield was inserted between the radioactive solution and the lower detector.

The equipment for the measurement and recording of the count rate has been described before (Melloni et al., 1969). The transpiration of the flower was monitored by continuously recording the weight of the experimental solution. The quantity of ¹¹⁰mAg added to the solutions, was adapted to the actual experiment (1-2μCi ml⁻¹ for AgNO₃; 8μCi ml⁻¹ for Ag(S₂O₃)²⁻). [³²P] phosphate transport (8μCi ml⁻¹) was measured under identical conditions.

The radioactivity in different parts of the carnation flower itself, after 24 h of uptake from a Ag(S₂O₃)²⁻ solution, was analysed by pulverising the different flower parts in liquid nitrogen, freeze-drying, and ashing of samples for at least 24 h at 550°C. The ash was dissolved in 2 ml 0.1 N HNO₃ and finally 15 ml scintillation liquid (on a dioxane-naphthalene-butyl PBD basis) was added. Radioactivity was counted in a liquid scintillation spectrometer with a counting efficiency of about 66%.

Results

The extremely low mobility of silver, supplied as silvernitrate, is illustrated by the count rate curves in Figure 1. In the course of an experiment the transpiration remained constant (about 1 ml h⁻¹) for 2 to 3 days and then decreased gradually, to less than 0.1 ml h⁻¹ after 8 days. The front of the silver moved at a speed of about 3 cm day⁻¹, corresponding to a silver accumulation of 8 mg silver per g fresh material. The propagation of the front could also be followed visually, as the stem turned black upon the arrival of the silver. As the shift of the color coincided with the steep increase in count rate, the former was used subsequently to test the dependence of the movement on AgNO₃ concentration and the influence of the addition of other cations. Increasing the concentration of AgNO₃ in the experimental solution caused a slightly less than proportional increase in the speed of propagation of the color shift (2 mM: 3 cm day⁻¹; 8 mM: 8 cm day⁻¹; 20 mM: 16 cm day⁻¹). Termination of the supply of Ag⁺, by a shift to deionized water, did not immediately stop the movement, but slowed it down gradually. Addition of other cations to a 8 mM AgNO₃ solution (10 mM KNO₃ or 5 mM Ca(NO₃)₂) did not have an effect on the translocation speed. However, the shift from a ¹¹⁰mAg-labeled silvernitrate solution (2 mM) to a non-labeled one at the time indicated

[Fig. 1. Response with time of the count rate measured at two positions along the stem of a cut carnation flower. The ¹¹⁰mAg labeled silvernitrate solution (2 mM) was replaced by a nonlabeled solution at the time indicated.]

caused a complete change of the transport phenomena. As shown in Figure 2, the silver is translocated within minutes to the top of the stem. The time lag between initial detection at the different detector positions allowed estimates to be made of the translocation speed. This velocity was about 2 m h⁻¹, orders of magnitude faster than without thiosulphate. The translocation of [³²P]phosphate in the same stem is shown also in Figure 2. The virtually equal time lag between the arrival at the various detector positions illustrates the similarity between the transport of Ag(S₂O₃)²⁻ and ³²P. The different phases of the process can clearly be seen in the count rate curves: initial filling of the vessels, followed by a steady state of lateral accumulation, and eventually, upon a switch to water, the clearing of the vessels. The lateral accumulation can be due either to a 'leakage' of the complex from the xylem vessels, or to a competition between the complex and binding sites at the vessel walls having a high affinity for silver. The high stability constant of the silverthiosulphate complex (β₃ = 12.63) (Sillén and Martell, 1971) and the presence of excess thiosulphate lend support to the first possibility.