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Sugars Prevent the Detrimental Effects of Gamma Irradiation on Cut Chrysanthemums

Toru Hayashi and Setsuko Todoriki
National Food Research Institute, Ministry of Agriculture, Forestry and Fisheries, Kannondai, Tsukuba, Ibaraki 305, Japan

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Abstract. **Aqueous solution (2%) of sucrose, glucose, fructose, or maltose delayed bloom wilting and foliage yellowing of cut chrysanthemums [*Dendranthema ×grandiflorum* (Ramat.) Kitamura] caused by gamma irradiation at 750 Gy. Solutions of silver thiosulfate, sodium dodecylbenzenesulfonate, polyoxyethylene lauryl ether, potassium sorbate, mannitol, sorbitol, glycerol, 6-benzylamino purine, and gibberellin did not reduce irradiation damage. Holding chrysanthemum cut flowers in a sucrose solution before and during irradiation did not influence the vase life, but holding the cut flowers in a sucrose solution following irradiation prolonged the vase life. The results suggest that sugars reduce radiation-induced physiological deterioration of chrysanthemums.**

Some cut flowers contaminated with insect pests are fumigated with methyl bromide for quarantine purposes. However, using methyl bromide will be restricted in the future because of its ozone-depleting effect [International Consultative Group on Food Irradiation (ICGFI), 1994]. Therefore, establishing alternative quarantine techniques would be highly desirable; one such technique is exposure to ionizing radiation (ICGFI, 1994).

Radiation not only destroys pests but also damages some kinds of cut flowers (Chiu, 1986; Dohino and Hayashi, 1995; Haasbroek and Rousseau, 1971; Haasbroek et al., 1973; Joyce, 1988; Kikuchi et al., 1994; Seaton and Joyce, 1992; Tanabe and Dohino, 1993, 1994). One flower extremely sensitive to radiation is chrysanthemum (Chiu, 1986; Dohino and Hayashi, 1995; Kikuchi et al., 1994; Tanabe and Dohino, 1993), which is frequently infested with insect pests; most of the chrysanthemums imported to Japan are contaminated with pests and are subjected to quarantine treatments (Dohino and Hayashi, 1995). Irradiation accelerates chrysanthemum bloom wilting and foliage yellowing and suppresses bud opening (Chiu, 1986; Dohino and Hayashi, 1995; Kikuchi et al., 1994; Tanabe and Dohino, 1993); thus, a method to prevent radiation-induced deterioration of chrysanthemums needs to be developed. Floral preservative solutions are effective in preventing deterioration of irradiated cut flowers of protea (*Protea compacta* R.Br.) (Haasbroek et al., 1973) and chrysanthemum (Chiu, 1986; Dohino and Hayashi, 1995; Kikuchi et al., 1994). Floral preservatives contain germicides, sugars, surfactants, growth regulators, and silver (Halevy and Mayak, 1979, 1981; Uda et al., 1989). We examined the effects of aqueous solutions of such components on irradiated chrysanthemums to determine the chemicals responsible for prevention of radiation-induced deterioration.

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Materials and Methods

Plant material. Flowers of chrysanthemum (small single type, white, cv. Seishu) grown in Ibaraki, Japan, and harvested at the bud stage (diameter ≈2 cm and fresh weight ≈2.5 g) were obtained from a local florist in Tsukuba, Japan. The chrysanthemum stems had not been treated with any chemicals since harvest. The stems were recut to 20 cm, which retained one flower and five leaves, and then were placed in various vase solutions.

Flower irradiation and storage. Chrysanthemum stems were placed in various vase solutions (see Table 1) for 15 h at 25C, 50% to 60% relative humidity (RH), and 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux (PPF). Then they were irradiated at 750 Gy with a Gammacell 220 (4.7×10^3 $Gy \cdot h^{-1}$, 2.1×10^2 TBq of ^{60}Co; Nordion Intl., Ont., Canada) at 25C and 50% to 60% RH, while standing in the vase solutions and in darkness. The irradiated chrysanthemum stems then were held in the same vase solutions at 25C, 50% to 60% RH, and 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPF. Vase solutions were changed daily to prevent spoilage. The stem ends (5 mm) were trimmed every 5 days to reduce plugging of the stem base.

Assessment of chrysanthemum quality. Five flowers and 25 leaves were cut daily from five chrysanthemum stems in each vase solution after irradiation. We then determined flower fresh weight. Thereafter, all the florets removed from the flowers and all the leaves from the stems were examined. Flowers with >10% browned florets were defined as wilted and leaves with >10% yellow area were defined as yellowed.

Timing of sucrose treatment on irradiated chrysanthemums. Chrysanthemum stems were placed in water or 2% sucrose for 15 h and irradiated at 750 Gy in the vase solutions noted. The irradiated chrysanthemum stems were held in water or 2% sucrose and assessed daily. The conditions for preirradiation, irradiation, and postirradiation and the procedure for quality assessment were as previously noted.

Data analysis. The experiments were performed three times: May to June, June to July, and July to Aug. 1994. The same results were obtained in the three experiments. Mean values, standard errors, and the test criteria for Duncan's multiple range test were calculated, and the significant differences between mean

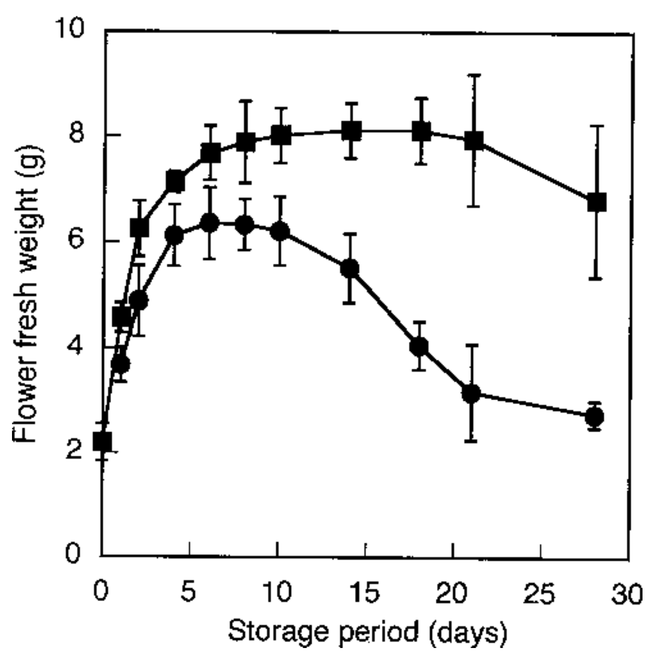

Fig. 1. Changes in flower fresh weight of (■) nonirradiated and (●) irradiated chrysanthemums held in water at 25C. Vertical bars represent SE.

values were determined according to Gacula and Singh (1984). The results of the third experiment (July to Aug. 1994) are reported in this paper.

Results

Effects of gamma irradiation. Flowers and leaves of chrysanthemums were damaged by gamma irradiation. Flower fresh weights of irradiated chrysanthemums increased for ≈6 days and those of nonirradiated ones increased for ≈10 days when they were held in water at 25C (Fig. 1). Wilting started after ≈8 days in irradiated flowers and after ≈22 days in nonirradiated ones. The decline in fresh weights coincided with the onset of flower wilting and desiccation. Foliage yellowing started after ≈6 days in irradiated chrysanthemums and after ≈19 days in nonirradiated ones (Fig. 2). All of the leaves on irradiated stems wilted within 18 days after irradiation, while only a few leaves on nonirradiated ones had wilted by 21 days.

Effects of chemical solutions on irradiated chrysanthemums. Aqueous solutions of 0.02% 8-hydroxyquinoline sulfate (HQS), 0.01% polyoxyethylene lauryl ether (PLE), 0.03% sodium dodecylbenzenesulfonate (DBS), 0.24% silver thiosulfate (STS), 0.1% potassium sorbate, 2% mannitol, 2% sorbitol, 2% glycerol, 0.01% 6-benzylamino purine (BA), or 0.001% gibberellin did not significantly delay the onset of flower wilting and foliage yellowing in irradiated chrysanthemums (Table 1). However, 2% sucrose, 2% fructose, 2% glucose, and 2% maltose promoted bud opening and development and delayed the onset of bloom wilting and foliage yellowing. Consequently, irradiated chrysanthemum samples held in these sugar solutions had significantly higher flower fresh weights, and those in the other vase solutions without sugars showed significantly lower flower fresh weights compared with the nonirradiated control. Most of the leaves on the irradiated chrysanthemum stems held in the sugar solutions did not wilt even after 21 days, while all of the leaves on the irradiated stems held in the other vase solutions without sugars yellowed by 21 days. These results indicated that germicides (HQS and sorbate), surfactants (PLE and DBS), silver (STS), polyols (mannitol, sorbitol, and glycerol), and growth regulators (BA and gibberellin) had little effect on the flowers and leaves of irradiated chrysanthemums. The presence of germicides, such as HQS and potassium sorbate, in sucrose solution had little effect on the flowers and leaves of irradiated chrysanthemums held in sucrose solution (Table 1).

Effects of timing of treatment with sucrose. Setting the stems in a sucrose solution before and during irradiation did not improve the quality of irradiated chrysanthemums when the sucrose solution was replaced by water after irradiation (Table 2). However, holding irradiated chrysanthemums in a sucrose solution after irradiation delayed flower wilting and foliage yellowing, even if chrysanthemums were held in water before and during irradiation. The flower fresh weights of chrysanthemums held in a sucrose solution after irradiation were significantly higher than the nonirradiated chrysanthemums held in water (control), while those held in water after irradiation were lower than the control. Most of the leaves on the irradiated stems held in a sucrose solution did not wilt after 21 days, while all of the leaves on the irradiated stems

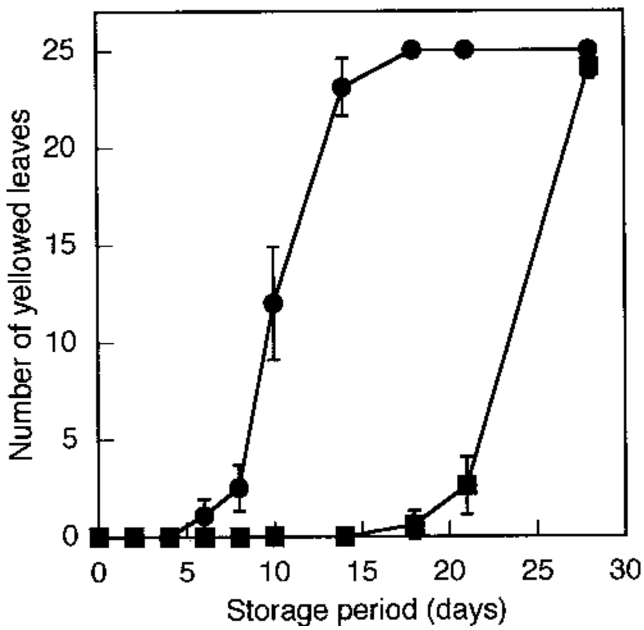

Fig. 2. Number of yellowed leaves in 25 leaves of (■) nonirradiated and (●) irradiated chrysanthemums held in water at 25C. Vertical bars represent SE.

Table 1. Quality of irradiated chrysanthemums held in various vase solutions for 28 days at 25C. Data are mean values and SE of five replicate measurements.

Vase solution	Onset of flower wilting (days)[z]	Onset of leaf yellowing (days)[y]	Flower fresh wt (g)[x]	No. yellowed leaves[w]
Water	8.3 ± 2.2 a[v]	5.9 ± 0.9 a	3.17 ± 0.51 a	25.0 ± 0.0 a
0.02% 8-Hydroxyquinoline sulfate (HQS)	8.5 ± 2.5 a	5.5 ± 1.8 a	3.56 ± 0.48 a	25.0 ± 0.0 a
0.1% Potassium sorbate	7.9 ± 1.8 a	6.1 ± 1.5 a	3.33 ± 0.79 a	25.0 ± 0.0 a
0.03% Sodium dodecylbenzenesulfonate	8.0 ± 2.2 a	6.2 ± 1.1 a	3.75 ± 0.81 a	25.0 ± 0.0 a
0.01% Polyoxyethylene lauryl ether	8.3 ± 2.5 a	6.3 ± 1.6 a	3.55 ± 0.76 a	25.0 ± 0.0 a
0.024% Silver thiosulfate	7.8 ± 2.6 a	5.9 ± 1.8 a	3.78 ± 0.79 a	25.0 ± 0.0 a
0.01% 6-Benzylamino purine	8.2 ± 2.7 a	5.5 ± 1.8 a	3.88 ± 0.68 a	25.0 ± 0.0 a
0.001% Gibberellin	8.6 ± 2.4 a	5.9 ± 1.8 a	3.68 ± 0.88 a	25.0 ± 0.0 a
2% Glycerol	7.9 ± 2.5 a	5.7 ± 1.8 a	3.21 ± 0.92 a	25.0 ± 0.0 a
2% Mannitol	7.8 ± 2.8 a	5.8 ± 1.6 a	3.59 ± 0.78 a	25.0 ± 0.0 a
2% Sorbitol	8.3 ± 2.9 a	5.8 ± 1.7 a	3.03 ± 0.87 a	25.0 ± 0.0 a
2% Sucrose	22.0 ± 1.8 b	19.9 ± 2.6 b	13.56 ± 0.84 b	2.0 ± 1.2 b
2% Glucose	21.5 ± 1.4 b	19.2 ± 2.1 b	13.25 ± 0.78 b	2.2 ± 0.9 b
2% Fructose	22.6 ± 1.5 b	19.1 ± 1.9 b	12.98 ± 0.91 b	2.0 ± 0.8 b
2% Maltose	22.6 ± 1.4 b	18.9 ± 2.3 b	13.32 ± 0.89 b	2.2 ± 1.0 b
2% Sucrose + 0.02% HQS	22.0 ± 1.7 b	18.2 ± 2.2 b	12.58 ± 1.09 b	2.5 ± 0.9 b
2% Sucrose + 0.1% potassium sorbate	22.5 ± 1.6 b	19.6 ± 1.9 b	13.35 ± 0.85 b	2.6 ± 1.1 b
Control[u]	22.3 ± 1.7 b	19.4 ± 2.0 b	7.93 ± 0.83c	2.4 ± 1.3 b

[z]Days after irradiation when the first wilted flower was observed.
[y]Days after irradiation when the first yellowed leaf was observed.
[x]Flower fresh weight 21 days after irradiation.
[w]Number of yellowed leaves out of 25 on five stems 21 days after irradiation.
[v]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[u]Nonirradiated chrysanthemums held in water.

Table 2. Quality of irradiated chrysanthemums treated with sucrose before and during and/or after irradiation and held for 28 days at 25C. Data are mean values and SE of five replicate measurements.

Treatment	Onset of flower wilting (days)[z]	Onset of leaf yellowing (days)[y]	Flower fresh wt (g)[x]	No. yellowed leaves[w]
Water–water[v]	8.2 ± 2.3 a[u]	5.7 ± 1.7 a	3.09 ± 0.57 a	25.0 ± 0.0 a
2% Sucrose–water	7.9 ± 2.1 a	6.2 ± 1.3 a	3.25 ± 0.59 a	25.0 ± 0.0 a
2% Sucrose–2% sucrose	22.5 ± 1.8 b	18.2 ± 2.3 b	13.56 ± 1.05 b	2.2 ± 1.2 b
Water–2% sucrose	21.6 ± 1.5 b	19.1 ± 2.1 b	12.85 ± 0.97 b	2.9 ± 1.3 b
Control[t]	22.9 ± 1.8 b	19.8 ± 1.9 b	8.25 ± 0.87 c	2.8 ± 1.5 b

[z]Days after irradiation when the first wilted flower was observed.
[y]Days after irradiation when the first yellowed leaf was observed.
[x]Flower fresh weight 21 days after irradiation.
[w]Number of yellowed leaves out of 25 on five stems 21 days after irradiation.
[v]Stems were held in the first solution before and during irradiation and, in the second solution, after irradiation.
[u]Mean separation in columns by Duncan's multiple range test at $P \leq 0.05$.
[t]Nonirradiated chrysanthemums held in water.

held in water wilted by 21 days, irrespective of the presence of sucrose before and during irradiation.

Discussion

Surfactants improve water uptake and balance (Uda et al., 1989), and germicides prevent the plugging of stems caused by microbial growth (Halevy and Mayak, 1979, 1981; Uda et al., 1989). The lack of effect of DBS, PLE, HQS, and potassium sorbate on irradiated chrysanthemums suggests that neither poor water uptake nor microbial growth is responsible for the deterioration of chrysanthemums caused by irradiation.

Silver and BA extend vase life of cut flowers by retarding ethylene-induced senescence (Halevy and Kofranek, 1977; Halevy and Mayak, 1981; Reid et al., 1980, 1989). Tanabe and Dohino (1994) reported that irradiation reduced ethylene production by cut flowers. Seaton and Joyce (1992) reported that STS did not extend vase life of irradiated cut flowers of various species. These reports and our data presented in this study showing that STS and BA had little effect on irradiated chrysanthemums indicate that treatments that inhibit ethylene-induced senescence would not reduce the detrimental effect of radiation on chrysanthemums.

The results showing that sucrose supplied after irradiation prevented radiation-induced damage suggest that sucrose inhibited the physiological deterioration that took place during storage following irradiation. Gamma irradiation increases respiratory rate and alters membrane structure and function of agricultural products (Todoriki and Hayashi, 1994; Urbain, 1986). Sugars would be consumed by accelerated respiration, and the membrane structure and function would undergo changes earlier in irradiated chrysanthemums than in nonirradiated ones, resulting in shorter vase life of irradiated chrysanthemums when they were held in water. Sugars supplied by vase solutions would prevent the shortage of sugars in irradiated chrysanthemums and contribute to the extension of vase life, although further experiments are necessary to clarify the mechanism of the preventive effects of sugars.

Irradiation at 300 Gy, or even lower, can effectively control any insect pest in agricultural products for quarantine purposes (ICGFI, 1994). Aqueous solutions of sugars, such as sucrose and glucose, could prevent the detrimental effects of irradiation at 750 Gy, which indicates that solutions containing sugars can be used for preventing the radiation-induced deterioration of chrysanthemums.

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