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Mineral Movement in Relation to Pollination in Two Perennial Plants

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두 다년생 식물에 있어서 受粉에 따른 무기물의 이동 양상

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ABSTRACT

A new technique involving gamma-spectrometry was used to determine the effects of pollination on mineral uptake in petals, ovaries and leaves of tulips and daffodils. A gamma-emitting radionuclide solution containing selenium-75, cesium-137, manganese-54, and zinc-65 was applied to the roots of tulips and daffodils growing in water. Mineral uptake was monitored in plant parts over a 24 day period. Pollinated tulip flowers showed a rapid withdrawal of minerals from the petals and an increase in ovary mineral content, while such a source-sink relationship was not established in daffodils. In both species, the concentration of most minerals in petals and ovaries declined prior to abortion of the plant part. The roots and bulbs of the plants contained the vast majority of the labeled minerals. This study demonstrated a possibility that certain plant parts could be isolated and monitored for mineral uptake over time without destruction.

INTRODUCTION

Flowers, although often smaller and shorter lived than other organs, have a complex morphology and physiology for reproduction. Most floral structures undergo great morphological (Gori, 1983; Arditti, 1976) and physiological changes (Halevy *et al.*, 1984; Mayak and Halevy, 1980; Arditti *et al.*, 1971; Trippi and Tran Thanh Van, 1971; Burg and Dijkman, 1967) after pollination. However, the effects of pollination on the resource allocation to floral structures have not been well studied despite the importance of resources available for flower and fruit production (e.g., Bookman, 1983; Kang and Primack, 1991; Stephenson, 1981). For example, although organic molecules and some minerals are transported from the perianth to the ovary (Arditti and Harrison, 1979; Harrison and Arditti, 1976; Hsiang, 1951), and from the vegetative organs to the developing seeds or fruits (Hocking, 1984; Hocking and Pate, 1977; Van Goor and Wiersma, 1974), the importance of pollination itself regarding redistribution of resources is not clear. The currency of resource allocation is another problem when analyzing post-pollination phenomena (e.g., Stanton and Galloway, 1990). In many species flowers and fruits contribute significantly to photosynthesis (Bazzaz *et al.*, 1979), confounding the patterns of resource transport after pollination. This implies that mineral distribution and movement, which may not be affected by photosynthesis in a flower or a fruit, may be a better indicator of the physiological changes that occur due to pollination (Thompson and Stewart, 1981).

Furthermore, the studies described above have used destructive methods to determine the effects of pollination on the resource distribution in flowers. These me-

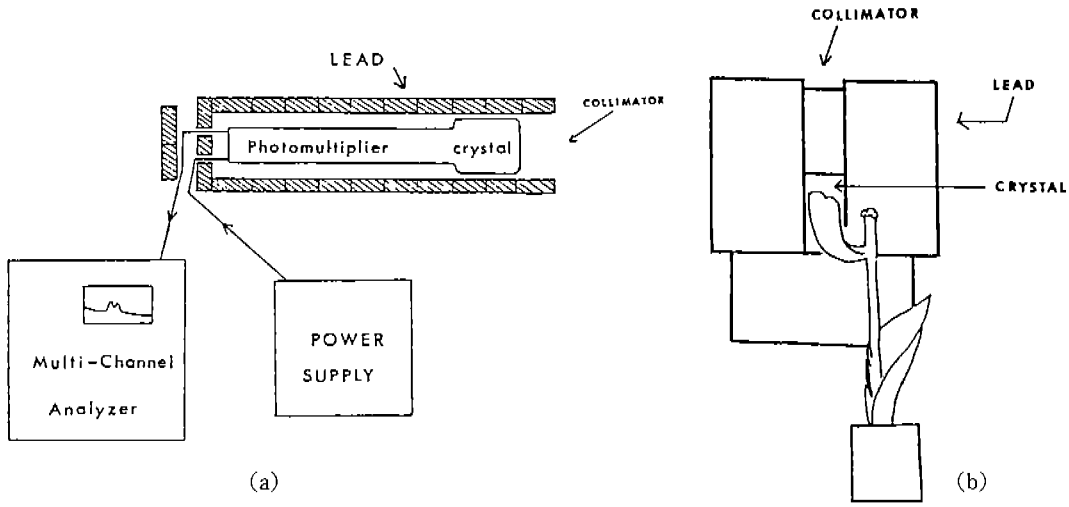

Fig. 1. a. The crystal scintillation counter capable of detecting gamma radiation. This system consists of an NaI (TI) crystal detector with an associated photomultiplier, a 1024 channel pulse height analyzer and a regulated power supply.
b. Front view of the crystal detector. A small plant part can be isolated and counted by controlling the width of collimator.

thods may cause the alteration of a plant's physiological and biochemical activities (Goldschmidt and Huberman, 1974; Harborne, 1981), and may result in the inability to detect the dynamic nature of mineral movement. Also, one or a limited number of measurement times may not provide enough information to obtain an accurate picture of the dynamics of mineral movement in a plant. For example, how fast do the minerals arrive in each part of the plant? How does the rate of mineral uptake change throughout the lifespan of the flower? What is the next destination of minerals once they have arrived in each part of the flower? The answers to these questions may not be obtained by the typical destructive methods.

We investigated mineral movement and distribution within flower parts using a new technique, gamma spectrometry. We analyzed the movements of 4 gamma-ray emitting radionuclides (selenium-75, cesium-137, manganese-54 and zinc-65) into individual leaves and flower parts of both hand-pollinated and unpollinated flowers of tulips and daffodils by a non-destructive method. Two main hypotheses were tested. First, minerals could be withdrawn very rapidly from petals on pollinated flowers in comparison with unpollinated control flowers, because the source-sink relationship between ovaries and the other flower parts would be established soon after pollination. Second, mineral uptake in the ovaries of pollinated flowers would increase greatly compared with that of unpollinated ones, because the pollinated ovaries will require a great amount of minerals to maintain their high metabolic activity. An additional object of this project was to determine if small floral parts could be isolated and studied using a gamma spectrometry method. To the best of our knowledge, the technique of gamma spectrometry has never been used to study the physiological ecology of flowers.

MATERIALS AND METHODS

A crystal scintillation counter capable of detecting gamma-radiation was used. This system consists of one NaI (II) crystal detector with a photomultiplier, a 1024 channel pulse height analyzer, a regulated power supply and associated electronic equipment (Fig. 1a). The technology of crystal scintillation counting is described by Faires and Boswell (1981) and Chapman and Ayrey (1981). The crystal was housed in a 5 cm thick box of lead, a thickness sufficient to completely shield the crystal. The crystal would only respond to gamma radiation coming from the plant part in front of the collimator. The collimator was formed by two lead bricks, so that its width could be adjusted to accomodate a small plant part, such as an ovary or a petal (Fig. 1b).

Uniform sized (17-20 cm tall) 10 tulips and 5 daffodils were selected for the experiment. Each plant was planted

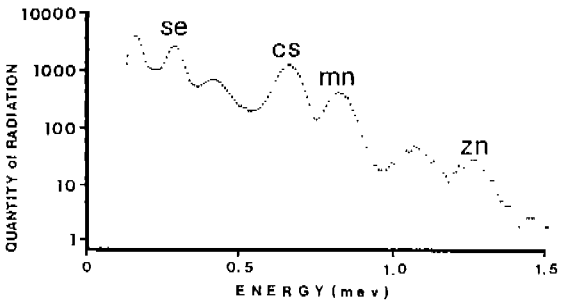

Fig. 2. The display from the pulse height analyzer.

in a 600 m*l* beaker containing perlite 10 days before the experiment began. Each beaker was wrapped in aluminum foil to prevent algal infection. Plants were maintained at room temperature and watered every other day with distilled water. Although tulips and daffodils are self-incompatible (Frankel and Galun, 1977), all the stamens of each plant were removed just before anthesis since plant breeding systems are not necessarily fixed (Kress, 1983). The tulip plants had only one flower each (genet). The daffodil plant each had 3-4 flowers on separate stalks but only two flowers were measured per plant. On the morning of Day 0, two of three petals and all sepals were removed from each tulip flower in order to facilitate the measurement of the ovary and a single petal separately. We assumed that this removal did not greatly change the basic pattern of mineral movement in a plant. Daffodils were used intact because they have inferior ovaries which can be measured without obstruction.

On Day 0 a solution of 4 radionuclides in 50 m*l* of deionized water was added to each plant. The solution contained 1.0 microcurie each of selenium-75, cesium-137, manganese-54, and zinc-65. These radionuclides have unique gamma-emitting peaks that can be distinguished from each other (Fig. 2). Each of these radionuclides has importance in plant nutrition. Selenium and cesium are considered to be analogues for the macronutrients, sulfur and potassium, respectively, while manganese and zinc are essential micronutrients required for plant growth (Robertson, 1957). Selenium was in the form of selenic acid while the other nuclides were chloride salts. On Days 1 and 3, respectively, 5 flowers randomly chosen from the 10 tulip flowers were hand-pollinated. Two stalks of daffodil flowers were randomly chosen from each pot (beaker); one of the two flowers was pollinated twice. The remaining flowers of tulips and daffodils were left as unpollinated controls. For the tulips, one petal, the ovary and a part of a leaf in each plant were measured separately with a width setting of 2 cm for the collimator. For the daffodils, the perianth, the ovary and several leaves below each flower were measured separately with a 3.5 cm collimator width. The measured parts of the leaves were marked to keep the same positions every measuring time. Each plant organ was monitored for a period of 120 seconds, beginning 4 hours after the initial labeling on Day 0, once a day for the next two weeks, and two to three day intervals for the next 10 days. Monitoring was performed at the same time of the day when possible. Plant parts were always at the same distance from the crystal face to ensure repeatability of measurements.

Tulip petals began to abscise during the early part of the experimental period (Day 4-6). Each abscised petal was kept in an envelope in order to measure its dry weight and labeled mineral content. When the petals of a daffodil began to dry (at around Day 12), they were removed and kept in separate envelopes. Later ovaries of the daffodils were also removed (Day 17).

At the end of the experiment, the plants were separated into ovary, pedicle, stem, two parts of leaves (measured tip part and remaining part of leaves), bulb, root and other shoots, if any, for precise determination of the distribution of radionuclides in each plant part. All parts were air-dried until biomasses became constant. All values presented here were corrected to account for the physical decay rate of each radionuclide. The amount of minerals taken up were compared by a non-parametric Kruskal-Wallis 1-way ANOVA, followed by a Mann-Whitney U test for comparison of pairs of values. Comparisons of pollinated and unpollinated flowers were performed by a Mann-Whitney U test (for tulips) and by a Wilcoxon matched pairs signed-ranks test (for daffodils). Significance was assigned to alpha=0.05 level, but it was corrected by Bonferonni Equality for pairwise comparisons.

RESULTS

Tulips. In both treatment groups of plants (pollinated and unpollinated), most of the labeled minerals were detected in the petals, ovaries and leaves on Day 1 (Table 1). The rest of those appeared by Day 5. The concentrations of 4 minerals which had been present in the petals of pollinated plants decreased to zero on Day 6 after reaching a peak on Day 5. In the petals of unpollinated plants, selenium, cesium and manganese remained until abscission, while zinc was not detected after Day 3. Immediately following Day 5, mineral concentrations

Table 1. Uptake of four labeled minerals in three organs of pollinated (PO) and unpollinated (UP) tulips over 24 days

	Se (%)						Cs (%)						Mn (%)						Zn (%)					
	Petal		Ovary		Leaves		Petal		Ovary		Leaves		Petal		Ovary		Leaves		Petal		Ovary		Leaves	
Day	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.001	0.003	0.002	0.006	0.012	0.010	0.000	0.008	0.000	0.007	0.016	0.011	0.000	0.018	0.005	0.008	0.009	0.000	0.000	0.020	0.015	0.020	0.042	0.023
2	0.006	0.010	0.013	0.019	0.023	0.011	0.000	0.022	0.011	0.018	0.000	0.022	0.000	0.000	0.000	0.009	0.000	0.025	0.000	0.037	0.000	0.055	0.000	0.073
3	0.004	0.010	0.022	0.014	0.026	0.030	0.000	0.022	0.048	0.024	0.038	0.035	0.000	0.016	0.028	0.036	0.035	0.060	0.000	0.000	0.092	0.043	0.000	0.073
5	0.002	0.007	0.029	0.032	0.016	0.022	0.011	0.010	0.030	0.037	0.011	0.016	0.010	0.013	0.063	0.012	0.008	0.009	0.037	0.000	0.049	0.000	0.000	0.000
6	0.000	0.008	0.059	0.058	0.022	0.028	0.000	0.075	0.072	0.061	0.045	0.078	0.000	0.013	0.090	0.060	0.019	0.045	0.000	0.000	0.055	0.000	0.031	0.000
7	–	–	0.060	0.045	0.026	0.022	–	–	0.086	0.032	0.038	0.045	–	–	0.074	0.089	0.030	0.033	–	–	0.189	0.116	0.075	0.061
10	–	–	0.096	0.057	0.025	0.026	–	–	0.138	0.085	0.038	0.035	–	–	0.124	0.080	0.025	0.000	–	–	0.226	0.128	0.031	0.037
11	–	–	0.134	0.071	0.029	0.028	–	–	0.210	0.096	0.067	0.032	–	–	0.206	0.109	0.036	0.027	–	–	0.287	0.134	0.037	0.024
12	–	–	0.104	0.085	0.025	0.026	–	–	0.187	0.110	0.051	0.074	–	–	0.158	0.146	0.053	0.050	–	–	0.144	0.232	0.075	0.116
14	–	–	0.229	0.093	0.025	0.031	–	–	0.368	0.106	0.074	0.059	–	–	0.242	0.123	0.064	0.060	–	–	0.495	0.116	0.104	0.061
20	–	–	0.195	0.090	0.032	0.024	–	–	0.271	0.203	0.058	0.046	–	–	0.228	0.085	0.052	0.055	–	–	0.318	0.177	0.116	0.079
24	–	–	0.145	0.094	0.033	0.027	–	–	0.212	0.140	0.090	0.052	–	–	0.233	0.115	0.059	0.039	–	–	0.263	0.165	0.134	0.092

Five replicates were used per organ. All values were corrected for the decay rates of the radionuclides. The content of radionuclides was read for somewhat different periods among organs due to senescence.

Table 2. Uptake of four labeled minerals in three organs of pollinated (PO) and unpollinated (UP) daffodil flowers over 23 days

	Se (%)						Cs (%)						Mn (%)						Zn (%)					
	Petal		Ovary		Leaves		Petal		Ovary		Leaves		Petal		Ovary		Leaves		Petal		Ovary		Leaves	
Day	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP	PO	UP
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.008	0.024	0.011	0.030	0.037	0.028	0.000	0.005	0.009	0.005	0.012	0.022	0.000	0.005	0.000	0.005	0.000	0.007	0.000	0.000	0.000	0.000	0.018	0.000
2	0.023	0.034	0.022	0.033	0.046	0.055	0.000	0.026	0.061	0.020	0.021	0.027	0.030	0.023	0.037	0.034	0.021	0.012	0.030	0.073	0.030	0.073	0.018	0.033
4	0.021	0.062	0.028	0.063	0.061	0.086	0.010	0.012	0.005	0.005	0.013	0.016	0.033	0.044	0.023	0.044	0.006	0.007	0.000	0.030	0.000	0.015	0.000	0.037
5	0.019	0.057	0.027	0.059	0.068	0.120	0.012	0.028	0.018	0.023	0.012	0.011	0.017	0.033	0.031	0.036	0.017	0.014	0.000	0.055	0.018	0.043	0.015	0.049
6	0.023	0.064	0.031	0.064	0.079	0.126	0.016	0.016	0.018	0.015	0.020	0.031	0.032	0.055	0.034	0.060	0.009	0.015	0.021	0.064	0.015	0.058	0.015	0.055
7	0.016	0.057	0.047	0.058	0.074	0.074	0.015	0.029	0.025	0.036	0.007	0.009	0.026	0.068	0.039	0.072	0.014	0.027	0.049	0.052	0.073	0.067	0.043	0.015
9	0.014	0.066	0.043	0.067	0.084	0.085	0.029	0.026	0.029	0.021	0.009	0.018	0.022	0.084	0.068	0.089	0.000	0.015	0.030	0.055	0.079	0.055	0.024	0.024
10	0.040	0.069	0.060	0.075	0.094	0.129	0.030	0.041	0.034	0.039	0.015	0.014	0.087	0.095	0.097	0.104	0.017	0.019	0.027	0.052	0.055	0.064	0.033	0.058
11	0.026	0.065	0.042	0.068	0.072	0.098	0.030	0.046	0.027	0.050	0.015	0.019	0.104	0.268	0.107	0.270	0.019	0.019	0.079	0.062	0.085	0.070	0.024	0.091
12	0.012	0.009	0.033	0.038	0.066	0.104	0.030	0.019	0.037	0.022	0.025	0.013	0.016	0.022	0.068	0.057	0.016	0.017	0.012	0.024	0.097	0.036	0.036	0.049
13	–	–	0.046	0.047	0.039	0.068	–	–	0.030	0.019	0.011	0.011	–	–	0.090	0.062	0.022	0.023	–	–	0.046	0.024	0.044	0.052
15	–	–	0.043	0.034	0.049	0.100	–	–	0.027	0.030	0.023	0.008	–	–	0.089	0.063	0.018	0.017	–	–	0.058	0.061	0.030	0.030
17	–	–	0.029	0.030	0.051	0.085	–	–	0.036	0.027	0.022	0.022	–	–	0.038	0.041	0.008	0.017	–	–	0.046	0.015	0.021	0.033
19	–	–	–	–	0.051	0.083	–	–	–	–	0.019	0.010	–	–	–	–	0.017	0.016	–	–	–	–	0.036	0.034
23	–	–	–	–	0.059	0.073	–	–	–	–	0.018	0.016	–	–	–	–	0.022	0.020	–	–	–	–	0.037	0.082

All values were obtained by the same way as in tulips.

in the ovaries of pollinated plants increased markedly. This pattern was more conspicuous in pollinated ovaries than in unpollinated ones. Leaves of both treatment groups of plants showed relatively stable uptake patterns for most minerals throughout the experimental period.

The overall temporal patterns of mineral absorption seemed to be similar in ovaries of different treatment groups. However, pollinated ovaries absorbed much higher amounts of minerals than unpollinated ovaries (Mann-Whitney U test: Se, $Z=-2.36$, $P<0.05$; Cs, $Z=-3.15$, $P<0.01$; Mn, $Z=-2.71$, $P<0.01$; Zn, $Z=-3.60$, $P<0.001$). For example, based on the mean values of mineral concentration of Day 14 when the concentrations of most minerals in the ovaries had reached their peaks, pollinated ovaries contained 2.46, 3.47, 1.97, and 4.27 times as much selenium, cesium, manganese and zinc, respectively, as unpollinated ovaries. However, no significant difference between treatment groups was observed in any mineral absorbed in either petals or leaves. The amounts of minerals withdrawn from the senescing petals were small compared to the markedly increased amounts of minerals in ovaries. Thus, in tulips, the only strikingly responsive organ to pollination was the ovaries.

Comparing the amounts of minerals absorbed in an organ, significant differences were observed only in the leaves. Leaves of both treatment groups of plants contained significantly more cesium (pollinated: PO, $Z=-2.75$, $P=0.0059$; unpollinated: UNPO, $Z=-3.27$, $P=0.0011$; P to reject $Ho=0.0083$) and zinc than selenium (PO, $Z=-2.70$, $P=0.0070$; UNPO, $Z=-2.71$, $P=0.0067$).

At the conclusion of the experiment on Day 24, roots and bulbs contained the largest amounts of each mineral (over 94% of the total sum concentration of each mineral detected in all parts). Only flower pedicels of pollinated plant parts contained significantly higher amounts of manganese and zinc than did those of unpollinated ones (Mann-Whitney U test: Mn, $Z=-2.20$; Zn, $Z=-2.45$, both $P<0.05$).

Daffodils. Although there were variations in the timing of first detection of minerals depending upon the organs and treatments, minerals were detected in all three organs of both treatment groups by Day 4 (Table 2). Few radionuclides appeared to reach equilibrium level, as their concentrations fluctuated throughout the experimental period. The mineral uptake in petals increased with some fluctuations until Day 11, after which it decreased greatly prior to senescence of the petals (Table 2). The concentration of minerals in the petals did not drop to zero in either treatment. The mineral uptake in ovaries also increased with fluctuations until Day 11 and then tended to decrease in both types of flowers. Leaves maintained relatively stable uptake patterns in comparison with the petals and ovaries, generally reaching equilibrium concentrations around Day 11.

Throughout the experimental period, unpollinated flower parts appeared to contain higher concentrations of minerals than those of pollinated flowers (Wilcoxon matched pairs test: Se, $Z=-4.71$, $P<0.001$; Cs, $Z=-2.76$, $P<0.01$; Mn, $Z=-3.47$, $P<0.001$; Zn, $Z=-2.74$, $P<0.01$). As an example, based on the average values of mineral concentration on Day 11 when most mineral concentrations reached peaks, petals of unpollinated flowers absorbed 2.50, 1.53, and 2.58 as much selenium, cesium and manganese respectively as those of pollinated flowers. Ovaries of unpollinated flowers absorbed significantly higher amounts of selenium and manganese than did pollinated ovaries (Se, $Z=-4.00$, $P<0.001$; Mn, $Z=-2.22$, $P<0.05$). Also, leaves below unpollinated flowers had more selenium and zinc than did leaves under pollinated flowers (Se, $Z=-4.77$, $P<0.001$; Zn, $Z=-2.11$, $P<0.05$).

Differences were apparent in the amounts of the 4 minerals taken up by each organ. As shown in tulips, plant parts seemed to possess varying ability to take up specific minerals. While ovaries of both treatments contained more manganese than cesium (PO, $Z=-3.05$, $P<0.0023$; UNPO, $Z=-4.31$, $P<0.0001$; P to reject $Ho=0.0083$), unpollinated ovaries also had more selenium than cesium ($Z=-3.56$, $P=0.0004$). In leaves, selenium was higher in concentration than cesium (PO, $Z=-7.93$, $P<0.0001$; UNPO, $Z=-9.18$, $P<0.0001$), and zinc (PO, $Z=-5.93$, $P<0.0001$; UNPO, $Z=-4.99$, $P<0.0001$).

The overall tendency of mineral distribution in dry parts of daffodils was similar to that of tulips with an exception that no comparisons of pollinated and unpollinated parts were significant in terms of the amounts of labeled minerals contained.

DISCUSSION

Mineral movements in tulip and daffodil flowers are highly dynamic in nature when measured using gamma spectrometry. Minerals show patterns of increase, equilibrium, and decline in flower parts which can be tracked on a daily basis. Mineral withdrawal from the petals following pollination seemed to occur in different patterns in the two species. Minerals were withdrawn rapidly from the petals of pollinated tulips, attaining zero concentration

on Day 6 in contrast to those of unpollinated tulips. In daffodils, the patterns of mineral withdrawal from the senescing petals varied among the types of minerals and treatment; some minerals (selenium, cesium, manganese) were more rapidly withdrawn from unpollinated flowers, but the other mineral (zinc) from pollinated flowers. Thus, in daffodils, it is likely that the mineral withdrawal was largely due to senescence of petals, not due to the pollination treatment.

The timing of an increase of most minerals in pollinated ovaries of tulips coincided with withering of petals which occurred around Day 5. Furthermore, in tulips, minerals appeared to be absorbed in greatest quantity by ovaries, followed by leaves, during the experiment. These results obtained from tulips correspond to the patterns of organic resource transport in orchid flowers following pollination (Arditti and Harrison, 1979; Harrison and Arditti, 1976; Hsiang, 1951); ovaries became metabolically active upon pollination, being subjected to extensive mineral uptake. However, the mineral contents increased in different degrees between the two treatment groups of ovaries, indicating that pollen deposition on the stigma is not the only cause of mineral transport in this organ. For example, in orchids, emasculation of unpollinated plants may possibly produce acetylene, which also is responsible for inducing post-pollination phenomena (Arditti, 1976; Halevy *et al.*, 1984). On the other hand, mineral concentration declined in both types of ovaries and petals of daffodil flowers after Day 11. Unpollinated flower parts of daffodils in general contained higher amounts of minerals. These results from daffodil flowers, therefore, did not support our predictions about the pattern of mineral movement in a flower after pollination.

Consequently, the pollination treatment generated different effects in these two species. This is directly reflected in the amount of ovary growth following pollination. Pollinated ovaries of tulips were swollen by around Day 17, while the two groups of daffodil ovaries showed no difference in their size. Such differences between species may suggest different physiological mechanisms relating to the genet structure of the two species. It is also possible that horticulture may have modified the breeding systems of these species in different ways, although both species are known to be self-incompatible (Frankel and Galun, 1977).

The organs showed different temporal patterns of uptake which were related to their lifespans. In tulips, those patterns were quite consistent among 4 minerals absorbed in each organ. For example, relatively short lived petals and ovaries of both treatments showed peculiar uptake patterns with rapid decreases accompanied by senescence of petals and ovary abortion. The leaves which were persistent showed less variability in uptake patterns in comparison with other organs. Unlike tulips, mineral uptake in daffodils did not occur in any interpretable pattern among the three organs. This may suggest that redistribution does not occur under a simple source-sink control between spatially close organs. It has been shown that stored resources in the perennating organs are important for fruit development (Kozlowski and Keller, 1966; Udovic and Aker, 1981). Roots and bulbs of the two perennial species contained over 90% of labeled minerals, whereas petals possessed quite limited amounts of those minerals. Consequently, the transportation of labeled minerals through direct absorption from the roots may contribute substantially to the increase of minerals in both tulip and daffodil ovaries.

Gamma spectrometry has several distinct advantages over existing techniques for studying mineral uptake which involve destructive sampling (Primack and Levy, 1988; Wolterbeek *et al.*, 1984). First, samples are not destroyed during analysis, so that the same plant part, such as a petal, can be measured repeatedly for labeled mineral concentration over an extended time interval while it remains attached to the plants. Second, the amounts of labeled minerals in the target organ can be exactly determined even at very low concentrations due to the extreme sensitivity of the equipment. Third, the movement of a number of different minerals in the target organ can be detected simultaneously and continuously, since each radionuclide has a distinguishable peak of gamma emissions. And fourth, a small part, such as an individual ovary or petal in a flower can be monitored separately with careful design of the lead collimator.

Nonetheless, some potential disadvantages also became apparent. First, nutrient-free deionized water containing only 1 micro-curie each of selenium, cesium, manganese and zinc was used as a growing solution. Such a nutrient-poor situation may affect patterns of mineral uptake and distribution (Ramani and Kannan, 1975). This nutrient-poor solution may also be responsible for the eventual abortion of all ovaries observed in this experiment. Competition among flowers and fruits for limiting minerals was attributed to the abortion of those organs in an *Asclepias* species (Bookman, 1983). Second, the possibility that the removal of two petals and three sepals in tulips might change the pattern of mineral movement in a plant

cannot be denied. However, control tulips with a single petal had apparently no difference in their appearances or lifespans from other tulips that were not used in the experiment. Third, manipulative placement of plant parts against the collimator, even if plants were very carefully treated, may cause some damage to plant parts, which may change the physiological mechanism governing mineral uptake.

In summary, minerals were withdrawn more rapidly from senescing petals on pollinated tulips in comparison with petals on unpollinated tulips. At the same time, mineral concentration was increasing more rapidly in ovaries of the pollinated flowers than in those of the unpollinated flowers. However, daffodils exhibited quite different patterns from tulips. The difference which appeared under equal environmental conditions between daffodils and tulips may indicate species-specific breeding systems and/or physiological mechanisms relating to the genet structure. In any case, these methods of gamma spectrometry can be used to study mineral nutrient uptake in small plant parts. These methods can be readily extended to other plant species and questions of plant physiological ecology.

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적 요

튜울립과 수선화에 있어서의 꽃잎, 지방과 잎의 무기물 흡수에 대한 수분(pollination) 효과를 새로운 기구인 gamma spectrometry를 이용하여 조사하였다. 두 종을 gamma 선을 방출하는 radionuclides인 selenium-75, cesium-137, manganese-54와 zinc-65를 함유하는 용액에서 재배하여 각 기관의 표지된 무기물 흡수 양상을 24일 동안 측정하였다. 수분 후 튜울립에서는 표지된 무기물의 급속한 감소(꽃잎)와 증가(자방)가 관찰되었으나, 수선화에서는 이러한 source-sink 관계가 성립되지 않았다. 그러나 두 종에서 꽃잎과 지방의 표지된 무기물 농도는 각기 낙화와 낙과직전 급속히 감소하였따. 한편 표지된 무기물의 대부분은 뿌리와 구근에 함유되어 있었다. 본 연구는 특정 식물 부분의 무기물 흡수 양상이 식물체의 손상없이 장기간 측정될 수 있다는 가능성을 제시하고 있다.

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