JOURNAL OF THE TENNESSEE ACADEMY OF SCIENCE 76(2):53–56 APRIL 2001

ADAPTATIONS IN LEAFLET MORPHOLOGY AND EPIDERMAL DYNAMICS IN *PARTHENOCISSUS QUINQUEFOLIA* L. IN RESPONSE TO ENVIRONMENTAL POLLUTION

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ABSTRACT—Four populations of *Parthenocissus quinquefolia* L. (Virginia Creeper) growing in the mid-southern part of the United States were studied to determine the relationship between environmental pollution and leaflet morphology and leaflet epidermal dynamics. There was a decrease in the length and width of the central leaflet, petiolule length, and number of teeth on the margin of the central leaflet in plants of the polluted habitats when compared with parallel measurements in plants of less polluted environments. In addition, stomatal frequency values, size of the largest stoma, and the epidermal wall undulations exhibited a decrease in polluted habitats. Furthermore, trichome length and trichome frequency increased in polluted habitats. Subsidiary cell complex consisting of 4–5 cells remained unaffected by environmental pollution in all the four plant populations, suggesting its taxonomic significance for the taxon under investigation.

Various studies have pointed out the detrimental effects of environmental pollution on plants under natural and controlled conditions. Hill and Thomas (1933) described the effects of sulfur dioxide on the decreased yield of alfalfa. Chamberlain (1934) showed the fatal effects of environmental pollution on trees, especially *Pinus banksiana.* Furthermore, several investigators (Solberg and Adams, 1956; Feder, 1970; Pyatt, 1970; Mathis and Tomlinson, 1972) have indicated the effects of environmental contamination on the gross morphological features of plants. However, relatively little work has been done to show the relationship between environmental contamination and leaf epidermal dynamics. Preliminary investigations on the subject (Heath, 1950; Costonis, 1971; Sharma and Butler, 1973; Sharma and Tyree, 1973; Sharma and Mann, 1984; Sharma, 1993) suggest the usefulness of leaf epidermal features as bioindicators of environmental pollution. To understand further the relationship between leaf cuticular dynamics and environmental pollution, the vine *Parthenocissus quinquefolia* (Virginia Creeper) was selected because of its common occurrence in the southeastern United States.

The autumn foliage of Virginia Creeper turns to brilliant dull rose. It is an excellent ornamental for covering the walls of buildings, fences, and other objects. The young tendrils are used as food by wild turkey and the foliage is eaten by white-tailed deer. At times, it is prostrate in its growth habit, but mostly it climbs to the top of shrubs and trees (Steyermark, 1996).

MATERIALS AND METHODS

Four populations of *P. quinquefolia* representing different levels of environmental contamination were selected from similar microhabitats in the mid-southern parts of the United States (Table 1). Populations A and B were collected from the relatively unpolluted habitats of Reelfoot Lake area and Martin, Tennessee respectively. These plant populations represent rural, sparsely populated habitats with no major industry. However, local vehicular traffic is the main contributor of environmental pollution in the area. Population C from Jackson, Tennessee represents a habitat of moderate environmental contamination generated by industry and vehicular traffic. Population D was collected near the Nashville International Airport in Nashville, Tennessee. Nashville is one of the major cities in Tennessee and is characterized by heavy vehicular traffic, a large industrial complex, and a major international airport. All of these factors contribute to environmental pollution in the area. Each plant population consisted of 20 leaves collected at random from mature plants growing in the area. All leaf samples were collected in early autumn to ensure their maturity at the time of sampling. Morphological data were collected from the central leaflet. Length and width of the central leaflet, petiolule length, and the number of teeth on the margin of the central leaflet were recorded on each of the 20 leaves ($n = 20$) from each population. Statistical analysis (mean ± *SD*) of the data is shown in Table 2.

Epidermal imprints of the abaxial surface of the central leaflet were made by applying Duco cement to the washed and dried leaves (Williams, 1973). Slides were made by taking a small portion of the epidermal imprint from the central area of each central leaflet of each plant population. Stomatal frequency, size of the largest and smallest stoma, epidermal wall undulations, trichome frequency, trichome length, and subsidiary cell complex were studied for the leaflet abaxial surface for each population. Randomly selected 20 fields ($n = 20$) from slides from each population were studied at 400× magnification. Mean values and standard deviation of the epidermal data are shown in Table 3. A summary of the mean values and standard deviation of the leaflet morphological and epidermal data is shown in Table 4.

RESULTS

Leaflet features of the four plant populations (A to D) are shown in Table 2. Statistical analysis of the data indicates that mean length of central leaflet ranged from 4.6 cm in Nashville

TABLE 1. Experimental populations of *Parthenocissus quinquefolia* L. in Tennessee.

Population	Locality	Relative degree of pollution[1]	Source of pollution
A	Reelfoot Lake	+	None
B	Martin	+	Vehicular traffic
C	Jackson	+++	Industry, vehicular traffic
D	Nashville	+++++	Industry, vehicular traffic, international airport

[1] +++++ = highest level; + = lowest level

TABLE 2. Mean ± *SD* values ($n = 20$) for leaflet features from populations of *Parthenocissus quinquefolia.*

Feature	Population A	B	C	D
Leaflet length (cm)	11.1 ± 0.7	12.1 ± 2.3	9.5 ± 0.3	4.6 ± 0.6
Leaflet width (cm)	4.9 ± 0.6	5.7 ± 1.5	4.5 ± 0.4	1.8 ± 0.2
Petiolule length (cm)	10.8 ± 1.9	11.3 ± 2.2	8.3 ± 0.3	5.3 ± 1.5
Number of teeth on leaflet margin	19.8 ± 3.5	18.2 ± 2.7	13.7 ± 1.1	6.6 ± 1.8

(population D) to 12.1 cm in Martin (population B). Furthermore, the Reelfoot Lake area population (A) had a mean value of 11.1 cm for the central leaflet. Mean values for the central leaflet width ranged from 1.8 cm in the most polluted population (D; Nashville) to 5.7 cm representing the rural environs of Martin (population B). Petiolule length varied from 5.3 cm in population D of Nashville to 10.8 cm and 11.3 cm in populations A and B respectively, characterized by relatively low levels of environmental contamination. Number of teeth on the central leaflet margin had the lowest mean value of 6.6 in the polluted habitat of Nashville (population D) and the highest value of 19.8 in the rural environs of Reelfoot Lake (population A).

Statistical analysis of the epidermal data is shown in Table 3. It is clear from the data on the abaxial leaflet surface that the highest stomatal frequency value of 45.1 was found in population A from Reelfoot Lake area and the lowest mean value of 19.90 was in Nashville (population D). Furthermore, the mean size variation for the largest stoma was from 33.7 μm in population D (Nashville) to 38.7 μm in population A from the Reelfoot Lake areas. For the smallest stoma, the mean value ranged from 20.0 μm in population B from Martin to 22.7 μm in population A of the Reelfoot Lake area. Trichome frequency means ranged from 19.7 in the relatively clean habitat of Reelfoot Lake area (population A) to 39.4 in the polluted environs of the Nashville area (population D). For the trichome length, the highest mean value was 76.5 μm in population D from Nashville, while the lowest mean value of 35.4 μm was found in population A from the Reelfoot Lake area. Number of epidermal wall undulations on the abaxial leaflet surface had the highest mean value of 7.1 in population A (Reelfoot Lake area) and the lowest mean value of

TABLE 3. Mean ± *SD* values ($n = 20$) for epidermal features and subsidiary cell complex ranges from populations of *Parthenocissus quinquefolia.*

Feature	Population A	B	C	D
Stomatal frequency[1]	45.1 ± 4.3	29.9 ± 3.7	23.2 ± 2.1	19.9 ± 1.7
Length of largest stoma (μm)	38.7 ± 3.2	36.0 ± 2.0	36.1 ± 2.5	33.7 ± 1.8
Length of smallest stoma (μm)	22.7 ± 2.1	20.0 ± 2.0	21.7 ± 2.5	21.5 ± 2.5
Trichome frequency	19.7 ± 1.7	26.6 ± 4.2	29.0 ± 2.1	39.4 ± 2.4
Trichome length (μm)	35.4 ± 1.8	45.3 ± 3.4	55.1 ± 3.1	76.5 ± 3.8
Epidermal wall undulations	7.1 ± 0.8	5.8 ± 0.8	6.0 ± 0.6	4.4 ± 0.5
Subsidiary cell complex (range)	4–5	4–5	4–5	4–5

[1] Mean stomatal frequency = leaflet surface stomata (field area = 0.152 mm^2; 400 × magnification).

TABLE 4. Mean ± *SD* values (*n* = 20) for leaflet and epidermal features on the abaxial surface of the central leaflet of *Parthenocissus quinquefolia.*

Feature	Population A	Population B	Population C	Population D
Leaflet length (cm)	11.1 ± 0.7	12.1 ± 2.3	9.5 ± 0.3	4.6 ± 0.6
Leaflet width (cm)	4.9 ± 0.6	5.7 ± 1.5	4.5 ± 0.4	1.8 ± 0.2
Petiolule length (cm)	10.8 ± 1.9	11.3 ± 2.2	8.3 ± 0.3	5.3 ± 1.5
Number of teeth on leaflet margin	19.8 ± 3.5	18.2 ± 2.7	13.7 ± 1.1	6.6 ± 1.8
Stomatal frequency	45.1 ± 4.3	29.9 ± 3.7	23.3 ± 2.1	19.9 ± 1.7
Largest stoma (μm)	38.7 ± 3.2	36.0 ± 2.0	36.1 ± 2.5	33.7 ± 1.8
Smallest stoma (μm)	22.7 ± 2.1	20.0 ± 2.0	21.7 ± 2.5	21.5 ± 2.5
Trichome frequency	19.7 ± 1.7	26.6 ± 4.2	29.0 ± 2.1	39.4 ± 2.4
Trichome length (μm)	35.4 ± 1.8	45.3 ± 3.4	55.1 ± 3.1	76.5 ± 3.8
Epidermal wall undulations	7.1 ± 0.8	5.8 ± 0.8	6.0 ± 0.6	4.4 ± 0.5
Subsidiary cell complex (range)	4–5	4–5	4–5	4–5

4.4 in population D from Nashville. Subsidiary cell complex consisting of 4–5 epidermal cells adjacent to the guard cells can be called "paracytic type" (Metcalfe and Chalk, 1950). It remained the same in all the four plant populations.

DISCUSSION

Statistical analysis of the data indicates that there is a general decrease in central leaflet length and width with a corresponding increase depending on the degree of contamination in the environment. In addition, petiolule length and the number of teeth on the central leaflet margin had lower values in contaminated habitat. It is apparent that environmental pollution is detrimental to plant growth and physiological processes.

Stomatal frequency value was the highest in the rural habitat of Reelfoot Lake area, while the lowest value was found in the Nashville plant population growing near the Nashville International Airport. A similar trend was apparent for the largest stoma. However, the size of the smallest stoma did not seem to show a distinct trend in the populations of this plant species growing in different habitats. Trichome frequency was the highest in the polluted area of Nashville, while the lowest value for the trichome frequency was in the rural habitat of Reelfoot Lake area. Similarly, mean trichome length values were highest in the Nashville area plant population and lowest in the Reelfoot Lake area population. Epidermal wall undulations were affected by environmental pollution. The lowest mean value of 4.4 was found in the polluted habitat of Nashville, while the relatively clean, rural area of Reelfoot Lake had the highest mean value of 7.1. This modification is suggestive of the fact that a reduced surface area exposure to environmental pollution may be a defensive strategy for plants growing in polluted habitats.

A decrease in the stomatal frequency and the size of the largest stoma in the polluted habitat may restrict the entry of gaseous pollutants into the leaflets. An increase in trichome frequency and trichome length in a polluted environment may be of survival value to the plant. These changes may aid the plant in filtering out particulate matter and insulting the leaflet surface from detrimental pollutants which otherwise may enter the leaflet and disrupt metabolic activities in plant tissues.

The subsidiary cell complex remained constant in all the plant populations—thus suggesting its taxonomic usefulness for the taxon.

The leaflet and epidermal modifications apparent in *P. quinquefolia* populations in response to environmental pollution suggest these changes may be of ecotypic significance, enabling the plant species to adapt in such an environment. It has been suggested (Bennett et al., 1974) that plants do adapt to low levels of environmental pollution. It is, therefore, logical to assume that the leaflet features studied in this investigation may be used as bioindicators of environmental contamination. A comprehensive analysis of additional plant taxa is needed to make these assumptions applicable to the entire plant kingdom.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to K. Johnson for her assistance in the preparation of the manuscript. We also thank M. Sharma for the statistical analysis of the data.

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