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Dasheen Mosaic Virus as a Pathogen of Cultivated Aroids and Control of the Virus by Tissue Culture

Dasheen mosaic virus (DMV), which infects several cultivated genera of the Araceae, was first described in 1970 (14). Within 5 years, the tissue culture technology needed to control DMV was developed (4), and by 1980, this technology was successfully applied commercially to control this virus and other pathogens in several tropical foliage aroids. In some aroids for which commercial tissue culture technology has not yet proved economically feasible, however, the incidence of DMV remains high.

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The family Araceae has more than 100 genera and 1,500 species, many of which are of horticultural significance. *Alocasia, Amorphophallus, Colocasia, Cyrtosperma*, and *Xanthosoma* are important food staples of the new- and old-world tropics, and the aroids *Aglaonema, Caladium, Dieffenbachia, Epipremnum* (=*Pothos*), *Philodendron, Scindapsus*, and *Syngonium* (=*Nephthytis*) account for about one-third of the plants grown commercially for ornamental foliage. *Anthurium, Richardia*, and *Zantedeschia* are popular cut-flower crops, and several species of *Anubias* and *Cryptocoryne* are grown as aquarium plants.

DMV infects species in at least 16 genera of Araceae: *Aglaonema, Alocasia, Amorphophallus, Anthurium, Arisaema, Caladium, Colocasia, Cryptocoryne, Cyrtosperma, Dieffenbachia, Monstera, Philodendron, Richardia, Spathiphyllum, Xanthosoma*, and *Zantedeschia*. Although several other viruses are known to infect aroids, none is as prevalent or widespread as DMV.

Fig. 1. (Left) Distorted leaf from *Zantedeschia elliottiana* (Knight ex Watson) Engl. plant infected with dasheen mosaic virus compared with (right) leaf from healthy plant.

Fig. 2. Leaf distortion and mosaic of *Dieffenbachia maculata* (Lodd.) G. Don 'Perfection' infected with dasheen mosaic virus.

Fig. 3. Leaf symptoms induced by dasheen mosaic virus infection of *Caladium* × *hortulanum* Birdsey 'Candidum.'

DMV has a mean particle length of about 750 nm, induces cylindrical ("pinwheel") inclusions within the infected cell, is transmitted by aphids in a stylet-borne manner, and is serologically related to other potyviruses (13,15). The DMV genome has been analyzed by in vitro translation, and the genomic expression strategy and proposed gene map were determined to be similar to those of other potyviruses (J. Nagel and E. Hiebert, *unpublished*).

Symptoms and Epidemiology

Symptoms of DMV can be very severe in *Richardia*, in *Zantedeschia* (Fig. 1), and in many cultivars of *Dieffenbachia* (Fig. 2) but are much less evident in *Aglaonema* and *Spathiphyllum*. Conspicuous mosaic or "feathering" symptoms are expressed in many aroids of the tribe Colocasieae, e.g., *Caladium* (Fig. 3), *Colocasia* (Fig. 4), and *Xanthosoma*. Symptom expression is seasonal in *Dieffenbachia*, occurring most often during spring and autumn. Ornamental aroids with severe DMV symptoms, e.g., *Dieffenbachia* and *Zantedeschia*, are often unmarketable. In addition, the virus causes yield losses of up to 60% in *Caladium, Dieffenbachia, Philodendron*, and *Zantedeschia* (2,6,9, 13,15,16). DMV is rarely found in commercial plantings of some susceptible cultivars of *Dieffenbachia*, e.g., *Dieffenbachia* × *memoria-Corsii* Fenzi, apparently because they are hypersensitive to DMV and diseased plants are thus self-eliminating (2).

The aphids *Aphis craccivora* Koch, *A. gossypii* Glover, and *Myzus persicae* (Sulzer) are natural vectors of DMV and occur wherever aroids are grown. The aphid *Pentalonia nigronervosa* Coquerel, which readily colonizes certain aroids, apparently does not transmit DMV (13,15). DMV can be transmitted very rapidly under field conditions. A population of virus-free *Caladium* planted adjacent to diseased plants in a commercial field in Highlands County, Florida, became uniformly infected within 2 months after sowing (6). Fortunately, aroid populations can be maintained free from DMV when isolated from contaminated stock. Two populations of virus-free *Caladium* were maintained for at least 3 years in Alachua and Lee counties, Florida. The Lee County population was a 6-acre (2.4-ha) commercial planting located about 40 miles (65 km) from the nearest contaminated stock in Highlands County (Fig. 5).

Very high incidences of DMV have been reported from cultivated plantings of *Caladium, Colocasia, Dieffenbachia*, or *Xanthosoma* in Australia, Egypt, Europe, the Caribbean, the Far East, North and South America, Oceania, and South and West Africa (3,9,13,15,17). This virus has also been reported from

Tissue culture is a superior alternative to seed propagation or heat therapy for control of dasheen mosaic virus and other pathogens in cultivated aroids and results in a commercial product of unprecedented quality and uniformity

Fig. 4. "Feathering" symptoms induced by dasheen mosaic virus infection of *Colocasia esculenta*.

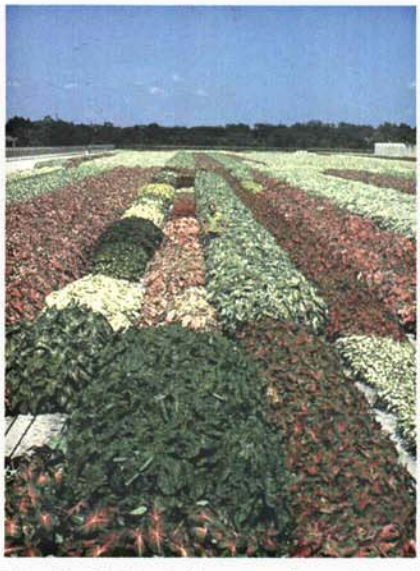

Fig. 5. Field of tissue culture-derived *Caladium* in Lee County, Florida, about 40 miles from the nearest contaminated stock and maintained free from dasheen mosaic virus infection.

Fig. 6. Germ plasm collection of *Xanthosoma* at the Saman Mocho Experiment Station, Carabobo State, Venezuela.

Alocasia in Brazil, *Cyrtosperma* in the Gilbert Islands, *Richardia* in Italy, *Aglaonema* and *Philodendron* in the United States (15), and *Zantedeschia* in the Republic of South Africa (9). High incidences of DMV have also been encountered in germ plasm collections of *Colocasia* and *Xanthosoma* (Fig. 6) in Hawaii, Puerto Rico, and Venezuela (13,15).

The horticultural importance of aroids has contributed greatly to the worldwide distribution of DMV. Taro (*Colocasia esculenta* (L.) Schott) is believed to be among the first plants to be cultivated by man, possibly predating rice. Taro has been transported throughout the Pacific Basin for hundreds of years and was cultivated as early as 100 B.C. in China (17) and 500 B.C. in Egypt (1).

Today, aroids are shipped throughout the world primarily as foliage and cut-flower ornamentals. Florida, for example, annually exports over 10 million foliage plants to over 50 countries.

Perhaps the most significant factor favoring the distribution of DMV is that most cultivated aroids are exclusively propagated by vegetative means and thus can harbor virus indefinitely. Although DMV is apparently not seedborne, obtaining genetically uniform, virus-free seed of most commercially grown aroids poses special problems. Protogyny occurs in many aroids, including *Caladium, Colocasia, Dieffenbachia, Philodendron*, and *Xanthosoma*; this condition prohibits self-pollination within the same inflorescence. Moreover, stigmata are usually receptive for only a few hours. Also, many commercial aroids flower infrequently unless treated by applications of gibberellic acid.

Seed of most aroids remain viable for relatively short periods of time and will not survive prolonged periods of storage. The seedling progeny of many aroids, including *Caladium, Colocasia, Dieffenbachia*, and *Xanthosoma*, are highly variable, which further detracts from the commercial acceptability of seed propagation as a routine measure to control DMV (5,8,10,12) (Fig. 7). *Philodendron selloum* C. Koch is exceptional in that seedling progeny are relatively uniform, and DMV infections in this susceptible, seed-propagated species are seldom encountered (11).

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Control Through Tissue Culture

Tissue culture (Fig. 8) is a superior alternative to seed propagation or heat therapy for the commercial control of DMV and other pathogens (13,15). *Caladium* and *Colocasia* were the first aroids propagated through tissue culture in Florida and Hawaii in 1972 (13). Since then, many additional aroids have been propagated by tissue culture: *Aglaonema, Alocasia, Amorphophallus, Anthurium, Anubias, Cryptocoryne, Dieffenbachia, Epipremnum, Homalomena, Monstera, Philodendron, Schismatoglottis, Spathiphyllum, Syngonium, Xanthosoma*, and *Zantedeschia*.

The commercial application of tissue culture technology for propagating aroids coincided with the accelerated demand for high-quality foliage plants during the 1970s and 1980s, a period referred to as the "foliage plant boom" when the industry in Florida increased in wholesale value from $16 million to $309 million annually. Currently, commercial tissue culture propagation of aroids is done primarily for purposes of rapid propagation and is largely confined to ornamentals that are usually greenhouse-grown, such as *Anthurium, Dieffenbachia, Philodendron, Spathiphyllum*, and *Syngonium*. Through tissue culture, over 70,000 *Dieffenbachia* cuttings can be produced in 1 year from a single shoot tip, compared with only 10–30 cuttings by conventional means. About 10% of the *Dieffenbachia* plants now sold commercially have been processed through tissue culture. In Florida, one laboratory alone sells about 1 million *Dieffenbachia* microcuttings annually, with a cash value of over $200,000 (Fig. 9).

The commercial application of tissue culture technology also resulted in a product of unprecedented quality and uniformity. *Dieffenbachia* cultivars, once ubiquitously infected with DMV, are now largely free from this and other pathogens, such as *Erwinia chrysanthemi* (McFad.) pv. *dieffenbachiae* (McFad.) Dye, wherever tissue culture-derived stock is employed and sound greenhouse management practices are followed. Before tissue culture-derived stock became available, a typical foliage grower in Florida had to commit as much as 75% of the total greenhouse space to the maintenance of stock plants. Despite the routine use of pesticides, disease losses of at least 20% could be expected, and the treated plants had to be rinsed of spray residues before they could be sold. Many of these problems were solved when growers began to use tissue-cultured stock. Microcuttings from tissue culture can be shipped in sealed plastic envelopes, planted directly into sterilized soil mix by the grower, and fertilized and watered automatically by a remote system (Fig. 10). After 3–6 months, the

Fig. 7. Phenotypic differences in foliar variegation patterns among siblings resulting from selfing *Dieffenbachia maculata* 'Perfection' (5).

Fig. 8. Fully differentiated *Caladium* × *hortulanum* 'Candidum' explant in tissue culture.

Fig. 9. Commercial greenhouse-grown planting of tissue culture-derived *Dieffenbachia maculata* 'Camille.'

Fig. 10. Commercially grown patented *Philodendron* hybrids 12–16 weeks after planting from microcuttings produced in a tissue culture laboratory.

Fig. 11. (A) Tissue culture transfer room of a large commercial laboratory in Florida. (B) Growth room where cultures are maintained aseptically in vitro under fluorescent lights at constant temperature.

Fig. 12. Field of *Colocasia esculenta* in Malaita, Solomon Islands.

Fig. 13. Typical commercial field of *Caladium* in Highlands County, Florida, planted with stock not derived from tissue culture.

plants can be sold as a finished product. Under these conditions, pesticides are rarely needed and labor and fuel costs are reduced substantially.

In addition to eliminating the need for large areas dedicated to stock, tissue culture has actually given growers and consumers a different product. Previously, the plant may have been grown from cuttings placed in 8-, 10-, or 12-in. pots after rooting. Now, tissue-cultured plantlets of large-leaved philodendrons and other plants with the potential to become large can be finished in pots as small as 3 in. and appear in proportion with the container. As the plantlets grow, they can be transplanted to, and eventually sold in, larger containers.

Tissue culture also facilitated a significant revival in breeding programs for tropical foliage aroids, such as *Philodendron* and *Dieffenbachia*. Indeed, some aroids, such as hybrid self-heading *Philodendron*, could not be grown economically before the commercial application of tissue culture. Now, hybrids are being released and made available to the consumer much faster than was formerly possible—and with a considerably reduced risk of "running out" prematurely because of DMV and other plant pathogens.

Technologically advanced commercial tissue culture laboratories are now located in many parts of the United States and abroad. The largest ones in the United States are in California, Florida (Fig. 11), Illinois, Tennessee, Texas, and Utah. Other large laboratories are located in Belgium, Brazil, France, Great Britain, Israel, Japan, and the Netherlands. Each of the larger facilities can produce 5–25 million tissue culture explants annually at an estimated wholesale value of 15–25¢ per microcutting. Many such laboratories with investment capital ranging from $20,000 to $250,000 were formed in the early 1970s, but a number of them failed shortly after inception. Those that survived the 1970s expanded their operations exponentially, and today investments in excess of $1 million for new facilities are not considered unusual.

Limitations of Tissue Culture

An initial expense of $2,000–$10,000 is required to prepare each new plant species or cultivar for development in tissue culture. Costs include labor, preliminary research to determine optimal in vitro growing conditions, and market analyses. Accordingly, the plant in question must have a relatively high cash value and sufficient market demand to justify the initial expense of developing it. Foliage and cut-flower aroids, such as *Anthurium, Dieffenbachia, Epipremnum*, self-heading *Philodendron, Spathiphyllum*, and *Syngonium*, are ideally suited for commercial production by

tissue culture. This is not necessarily the case for certain other important cultivated aroids, such as *Caladium, Colocasia*, and *Xanthosoma*, even though they can be propagated readily in tissue culture and freed from DMV and other phytopathogens (4,7).

The chief limiting factor for *Colocasia, Xanthosoma*, and other edible aroids is their much lower cash value per plant than their ornamental counterparts. Worldwide demand for these plants is not likely to increase appreciably in the near future, and these plants are usually grown in countries where growers can ill afford to buy tissue-cultured stock. Also, the edible aroids are an exceptionally diverse group of plants, consisting of innumerable cultivars grown by many different ethnic groups throughout the world on limited acreage and primarily under conditions of subsistence agriculture (Fig. 12). Even where few cultivars are involved, such as in Egypt and China, the total acreage and cash value of the marketed product is relatively low.

The limited acreage and seasonal production cycle of *Caladium* are deterrents to the use of tissue culture for propagation. Florida produces over 90% of the world's *Caladium*, virtually all of which are field-grown in Highlands County (Fig. 13). The entire crop consists of an annual production of 40–50 million corms with a modest retail cash value of $8 million. Unlike sales of other foliage aroids, sales of *Caladium* have not increased appreciably since the 1960s, and a significant market has not developed for some of the new *Caladium* hybrids.

Future Prospects

Control of DMV in *Caladium* and the edible aroids would be facilitated considerably if the costs for the tissue culture-derived product could be reduced to levels equivalent to those of conventional planting stock. At the present time, in vitro commercial propagation of aroids is by organogenesis and proliferation of axillary shoots, a relatively labor-intensive and expensive method. Propagation by somatic embryogenesis and cell/protoplast culture (suitable for automation) may provide solutions to this problem. The successful control of DMV in foliage aroids through tissue culture gives cause for optimism that additional research will provide the information necessary to make virus-free stock of *Caladium* and the edible aroids commercially available.

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