Anatomical Aspects of K, Mn, and Fe Deficiencies in Queen Palm

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Abstract. Anatomical differences in leaves of queen palm [*Syagrus romanzoffiana* (Chamisso) Glassman] showing visible K, Mn, and Fe deficiency symptoms are described. Potassium-deficient leaves showed less organization in the mesophyll than healthy leaves. Adaxial fibers increased in diameter. Chloroplast frequency was reduced overall, but most severely in areas of the leaf showing gross symptoms of the deficiency. Manganese-deficient leaves had reduced chloroplast frequency, especially in tissue near necrotic areas, and thicker and more fibers per unit length. Iron-deficient leaves had few chloroplasts throughout the mesophyll, and also thicker and more fibers per unit length.

Deficiencies of K, Mn, Fe, and Mg are very common on palms in many parts of the world. The queen palm is widely grown in warmer regions of the United States for its attractive form, moderate size, and cold tolerance. It is extremely prone to K and Mn deficiencies on alkaline and highly leached sandy soils (Chase and Broschat, 1991; Dickey, 1977) and often exhibits Fe deficiency symptoms when grown in poorly aerated soils or when transplanted too deeply (Broschat and Donselman, 1985; Chase and Broschat, 1991).

Potassium deficiency symptoms occur first on oldest leaves as small (1 to 2 mm), translucent, yellow-orange spots on the leaflets. As the deficiency progresses, newer leaves exhibit spotting, whereas marginal necrosis appears on leaflets of older leaves. In more severe cases, older leaves are entirely necrotic or frizzled in appearance and most younger leaves are chlorotic with extensive marginal necrosis. Eventually the trunk tapers to a point and the bud dies (Broschat, 1990; Chase and Broschat, 1991).

Manganese deficiency symptoms occur only on new leaves that emerge reduced in size, chlorotic, and have extensive necrotic streak-

ing. Succeeding leaves will be extremely small and completely necrotic (the condition is termed "frizzle-top" by nursery and landscape horticulturists). In later stages, only necrotic petiole stubs will emerge, and death of the bud will quickly follow (Chase and Broschat, 1991). Late-stage K deficiency and early stage Mn deficiency are virtually indistinguishable from a distance and misdiagnosis is common.

Early symptoms of Fe deficiency include

a general chlorosis of the newest leaves with small (2 to 4 mm) green spots scattered throughout otherwise yellowish leaves. Under more severe Fe deficiency conditions, the leaves are entirely yellow, with extensive leaflet necrosis and reduced leaf size (Chase and Broschat, 1991). Superficially, Fe deficiency symptoms are similar to those of midstage K deficiency or early stage Mn deficiency.

There is relatively little literature documenting anatomical changes in tissues of ornamental plants associated with specific nutritional deficiencies, and no reports relating to palms were found. Struckmeyer and her students studied the anatomical effects of N, P, K, Ca, Mg, B, S, and Zn deficiencies on poinsettia (Struckmeyer, 1960); Mg, Ca, and B deficiency on geranium (Struckmeyer, 1968) and daminozide on B-deficient marigold (McConnell and Struckmeyer, 1972). Bussler (1981) described some effects of Fe deficiency on leaf or root anatomy of sunflower, coleus, and cauliflower.

Since visual symptoms for K, Mn, and Fe deficiencies in queen palm overlap considerably, it would be useful to determine how these deficiencies differ in their effect on leaflet anatomy and to see if these differences can be used in diagnosing these deficiencies. Although visual deficiency symptomology has been described for many

Table 1. Chloroplast frequency and adaxial fiber size and frequency of healthy and nutrient deficient queen palm leaves.

Treatment	Symptoms ¹	Chloroplast frequency	Adaxial fibers	
			Frequency ²	Diam ³ (μm)
No deficiency		6.8 ± 1.2	1.2 ± 0.6	15.0 ± 4.0
Early K deficiency	+	2.1 ± 0.7	1.5 ± 0.4	16.0 ± 5.0
	—	4.9 ± 0.8		
Moderate K deficiency	+	2.2 ± 0.7	1.4 ± 0.5	38.0 ± 6.0
	—	3.8 ± 0.8		
Severe K deficiency	+	2.0 ± 0.8	1.2 ± 0.3	36.0 ± 5.0
	—	3.6 ± 0.7		
Mn deficiency	+	1.8 ± 0.7	3.3 ± 0.4	34.0 ± 7.0
	—	3.3 ± 0.5		
Early Fe deficiency	+	1.1 ± 0.6	3.8 ± 0.5	41.0 ± 8.0
Severe Fe deficiency	+	1.0 ± 0.2	3.6 ± 0.6	43.0 ± 6.0

¹+, areas with symptoms; —, areas without symptoms.

²Chloroplasts per mesophyll cell; mean ± SD of 30 cells per section from three sections each of two different leaves.

³Fibers per 250 μm section length; mean ± SD of 10 sections each of two different leaves.

⁴Mean ± SD of widest diameter of 20 fibers per section from three sections each of two different leaves.

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Fig. 1. Transverse section through healthy and K-deficient queen palm leaves. (a) Healthy. (b) Early stages of K deficiency (isolated orange flecking); note slight reduction in chloroplast frequency compared with (a) and conspicuous adaxial fibers. (c) Middle stages of K deficiency (extensive orange flecking); note marked decrease in chloroplast frequency and further increase in adaxial fiber diameter. (d) Late stages of K deficiency (marginal necrosis). e = epidermis, h = hypodermis, c = chlorenchyma, f = fiber, vb = vascular bundle. Adaxial surface at top of figures. All scales = 50 μm .

Fig. 2. Transverse section through Mn- and Fe-deficient queen palm leaves. (a-b) Mn deficiency. (a) Transition from non-necrotic to necrotic tissue. Note increased diameter and frequency of adaxial fibers. (b) Non-necrotic area. (c-d) Fe deficiency. (c) Early stages of Fe deficiency (green spotting). Note large diameter and high frequency of adaxial fibers. (d) Later stages of Fe deficiency (necrotic spot stage). f = fiber. Adaxial surface at top of figures. All scales = 50 μm .

species of palms (Broeshart et al., 1957; Broschat, 1984; Bull, 1961a, 1961b; Manciot et al., 1979, 1980), this is, to our knowledge, the first study of anatomical aspects of nutritional deficiencies in the family.

Leaf samples for anatomical studies were obtained from 3-year-old queen palms grown under shadecloth (maximum of 800 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$). Palms were grown in 10-liter plastic containers filled with media known to induce deficiencies of certain elements (Broschat and Donselman, 1985). Severe Mn deficiency was induced by growing palms in a composted sewage sludge medium from Ft. Lauderdale, Fla. Severe Fe deficiency was induced by growing in a composted urban yard waste (tree trimmings) medium low in Fe. Mild K deficiency symptoms were induced in a 4 pine bark : 2 sedge peat : 1 sand (by volume) medium in which the plants received insufficient K fertilizer. All symp-

toms were typical of those documented by Chase and Broschat (1991) for that species and were confirmed by leaf nutrient analysis.

One symptomatic leaf each was sampled from two plants within each treatment. Two leaflets from each leaf were removed from the mid-point of the rachis, cut into 20- to 25-mm² sections, fried in FAA, transferred to 50% ethanol (EtOH), dehydrated in graded EtOH and tert-butyl alcohol series, infiltrated with Hemo-D, and embedded in paraffin (Sass, 1958). Transverse sections 12 μm thick were prepared and stained with safranin and fast green (Sass, 1958). All measurements (Table 1) were made using camera lucida and a calibrated ocular micrometer.

Tomlinson (1961) characterized the leaf anatomy of *S. rozanoffiana* as dorsiventral, with a mostly single-layer hypodermis, a distinct adaxial palisade layer (not well-developed in our shade-grown material), and abundant, undignified fibers (Fig. 1a). In the

early stages of K deficiency (isolated orange flecking symptomatology), the mesophyll became less organized, with the palisade cells less distinguishable than in healthy tissue (Fig. 1b). Similar observations were reported by Struckmeyer (1960) in K-deficient poinsettia. Cell elongation is known to depend on K concentration (Haschke and Lüttge, 1975), which may explain changes in cell shape. Chloroplast frequency within the leaf chlorenchyma decreased overall, but not uniformly (Table 1). Regions of the mesophyll with fewer chloroplasts were always subjacent to areas of the epidermis exhibiting the orange, translucent spots. Intervenal areas of the mesophyll did not show as much reduced chloroplast frequency (Fig. 1b). No thickening of the lamina was observed, unlike that reported for cauliflower (Singh and Sharma, 1988). Leaves exhibiting extensive orange flecking showed a further slight decrease in chloroplast frequency in cells not immediately underlying symptomatic areas (Table 1), but again, more extensive chloroplast reduction was in mesophyll cells underlying the flecks (Fig. 1c). This is not surprising, since K deficiency is known to impair the synthesis of the important chloroplast protein ribulose biphosphate carboxylase (Marschner, 1986). An increase in size of the adaxial fibers in these areas was observed (Table 1). In the late stages of K deficiency (marginal necrosis), complete collapse of the mesophyll and loss of the palisade layer was associated with the necrotic regions of the lamina (Fig. 1d). Less affected regions of the lamina still exhibited high chloroplast frequency relative to tissue near necrotic areas (Table 1). This pattern suggests that the effects of K deficiency are not experienced evenly throughout any one particular leaflet, and that levels of K within the leaf tissue may vary from region to region.

In Mn-deficient leaves, there were fewer chloroplasts, but differentially, as in K-deficient tissue (Table 1). A very striking anatomical feature of Mn deficiency was the marked increase in frequency and diameter of the adaxial fibers underlying the hypodermal layer, a characteristic evenly distributed throughout the affected leaf (Fig. 2 a, b; Table 1).

Iron-deficient leaves (Fig. 2 c, d) showed extreme and uniform reduction in chloroplast frequency, even in the early stages (Fig. 2c, Table 1). This result contrasts with data on sugar beet that showed no decrease in chloroplast frequency with increasing Fe deficiency (Teny, 1980). As in Mn-deficient leaves, adaxial fibers increased in diameter and number. In more severely Fe-deficient leaves (Fig. 2d), overall mesophyll disintegration was evident in necrotic regions.

The anatomical expression of deficiency symptoms of K, Mn, and Fe in queen palm are sufficiently different to allow a more accurate diagnosis than reliance on macromorphological symptoms alone. Reduction in chloroplast frequency occurs in all three deficiencies, but only at uniform levels across Fe-deficient leaves. In K- and Mn-deficient

leaves, chloroplast frequency is lowest in the mesophyll cells located near or underlying parts of the leaf exhibiting gross deficiency symptomology. Increases in the diameter (all three deficiencies) and frequency (Mn and Fe) of adaxial fibers are two of the more striking shared anatomical characteristics (Table 1), although the reasons for these effects remain unknown. Although the physiological development of fibers is not well-understood, physical stress is known to foster fiber development (Cutter, 1969; Haberlandt, 1914). The stresses of nutritional deficiency, may have direct effects on endogenous hormone levels, which in turn influence fiber development. Further study of these anatomical changes in association with physiological and ultrastructural investigations may provide insight into which specific organelles are affected by nutrient deficiencies, and may help define the roles of particular elements in palm physiology.

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