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Trace Elements in Pandanus (*Pandanus tectorius*) from a Manganese-Enriched Wetland in Southern Guam: A Possible Lytico-Bodig Connection?

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Extremely high levels of manganese (Mn) were encountered in foliar tissue of the monocot tree *Pandanus tectorius* from southern Guam with values exceeding 10,000 μg/g dry weight in some wetland representatives. Historically, dried Pandanus leaves were used extensively as a source of domestic fiber in the local Chamorro culture. A possible link between the use of this plant and a neurodegenerative disease complex that once plagued the island and is symptomatically similar to the occupational disease "manganism" poses an intriguing question that merits further investigation.

Past studies generally point toward the environment as the cause of the neurodegenerative diseases amyotrophic lateral sclerosis (ALS) and Parkinsonism–dementia complex (PDC), that once plagued the island of Guam (Reed et al., 1975). This mysterious ailment, locally known as "Lytico-Bodig," is exclusively confined to the native Chamorro people and is reputed to have once accounted for the deaths of 1 person in 5 over the age of 25 (Ray, 1997). The declining incidence of ALS-PDC syndrome on Guam over the past half century or so has led to speculation that the disease complex may have been linked to an environmental factor that is no longer threatening (Plato et al., 2003). Both geochemical and biochemical factors have been considered responsible for the diseases (Perl et al., 1982; Yase, 1972; Steel & McGeer, 2003), but none have been confirmed. In this short study, the postulation of a link between these diseases and high levels of manganese (Mn) in the leaves of Pandanus (*Pandanus tectorius*), a monocot tree that once featured strongly in Chamorro culture as a source of food, fiber, and medicine, was examined. Manganese was suspected to have played a role in ALS-PDC as early as 1965 (Yase, 1972), although exposure pathways have never been established. While Mn is common in rocks and soils in southern Guam, it is present as biologically nonavailable Mn^{4+}. Under wetland conditions, however, Mn^{4+} may be reduced to soluble Mn^{2+} and make its way into biological resources that ultimately are harvested by humans. Such was the impetus behind the current investigation along with the fact that PDC ("Bodig") is symptomatically similar to the occupational disease "manganism" (Cotzias, 1953).

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MATERIALS AND METHODS

Pandanus samples were collected from an Mn-enriched wetland that straddles the lower reaches of the Taelayag River in southern Guam (Figure 1). The Mn deposits are heterogeneously distributed throughout the watershed as pyrolusite, an Mn^{4+} oxide mineral that occurs as metallic black lustrous coatings and layers between cracks, faults, and other cavities in the soft volcanic rock (saprolites) that characterize the area. Over time, erosional processes have transported upland soil and particulate pyrolusite into the wetland below. Dissolved Mn levels measured in the wetland soil pore waters can exceed 60 mg/L (Siegrist et al., 1997). Distal, mesial, and proximal portions of mature *P. tectorius* leaves were clipped from nine wetland trees and two adjacent upland specimens. A root, shoot, and fruit sample was also taken from a single wetland representative. All tissues were dried to constant weight at 65ºC prior to wet oxidation with hot concentrated HNO_3 and trace element analysis (iron [Fe], Mn, copper [Cu], and zinc [Zn]) by conventional flame atomic absorption spectroscopy.

RESULTS AND DISCUSSION

The compartmentation of excessively accumulated metals in foliar tissue is a common strategy employed by plants growing

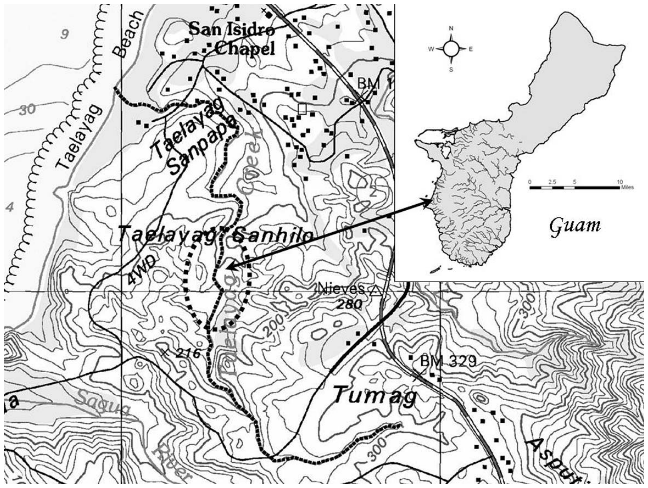

FIG. 1. Portion of a 1:24,000 U.S. Geological Survey topographical map of Guam. The dashed line and circle, respectively, delineate the location of the Taelayag River and wetland study area in the southern half of the island.

in metalliferous regions (Verkleij & Schat, 1990). Thus, the extraordinarily high Mn concentrations found in the leaves of *P. tectorius* from both wetland and upland sites (Table 1) undoubtedly reflect a physiological response that permits the plant to survive in this Mn-enriched locale. It is noteworthy that *P. tectorius* does not appear to accumulate excessive levels of trace elements in its shoots or fruits and is similar in this respect to other accumulator plants (Kabata-Pendias & Pendias, 1992). This characteristic ensures the protection of sensitive meristem and embryonic tissues from potentially toxic metal concentrations.

Pandanus tectorius is a savannah species that has adapted to wetland conditions, and its ablility to tolerate high levels of soluble Mn in the study area has clearly helped facilitate its survival in this environment. However, the fact that upland specimens share the same capability suggests this adaptive mechanism evolved in response to selection pressures other than those associated with waterlogged soil. Several soil types on Guam, including the ferruginous latisols that dominate the upland terrain of the study area, are known to have limited availability of one or more essential trace elements (Motavalli et al., 1996). Plants able to survive such conditions frequently do so by secreting metal-reducing and/or metal-chelating substances from their root system (Verkleij & Schat, 1990). It is postulated that *P. tectorius* has evolved such capabilities and is able to sequester sufficient amounts of essential trace elements from oxidic upland soils to satisfy its metabolic needs. In the Taelayag River uplands, however, it is frequently faced with oversupply of Mn, a problem it resolves by shunting the excess metal into subcellular foliar compartments away from sensitive

TABLE 1
Trace Metals in Pandanus (µg/g Dry Weight) from the Taelayag River Wetland and Upland Areas in Southern Guam

Area	Tissue	Statistic	Fe	Mn	Cu	Zn
Wetland	Leaf: distal	Range	115–500	3,995–12,251	5.47–32.5	192–922
		Mean[a] (± 95%conf.limits)	285 (196–415)	8,030 (6,195–10,410)	12.5 (8.65–18.0)	479 (332–691)
		n = 9				
Wetland	Leaf: mesial	Range	69.7–543	679–2,988	4.90–18.7	32.0–912
		Mean[a] (± 95% conf.limits)	239 (163–351)	1,363 (930–1,998)	11.0 (8.07–14.9)	449 (341–590)
		n = 9				
Wetland	Leaf: proximal	Range	31.2–801	280–1,011	2.93–20.2	13.8–296
		Mean[a] (± 95% conf.limits)	165 (93.4–290)	419 (322–545)	7.77 (4.58–13.2)	44.6 (21.9–91.0)
		n = 9				
Wetland	Shoot	n = 1	11.3	247	3.76	50.6
	Fruit	n = 1	127	292	2.22	9.8
	Root	n = 1	176	357	7.11	124
Upland	Leaf: distal	Range n = 2	89.8–481	430–7,322	5.60–8.47	79.6–426
	Leaf: mesial	Range n = 2	63.3–601	66.9–1,637	3.73–18.5	206–1,176
	Leaf: proximal	Range n = 2	373–421	41.5–334	5.21–17.8	45.8–390

[a]Mean = geometric mean

metabolic activities. How it does this and precisely where Mn deposition sites are located in leaves remain to be determined. Other Mn-resistant species have the ability to precipitate MnO_2 in leaf epidermis in close proximity to leaf stoma (Gonzalez & Lynch, 1999). This deposition process might also be expected to co-precipitate other elements and, if it occurs at all in *P. tectorius,* might account for the relatively high levels of foliar Fe and Zn in several specimens analyzed. It is noteworthy that levels of all three elements were generally higher in older leaf sections, suggesting that deposition is a continuous and irreversible process, with leaf fall marking the final elimination step.

The marked ability of *P. tectorius* to accumulate Mn is of particular interest from a human health standpoint because of the plant's many traditional uses throughout Micronesia, plus the fact that Mn poisoning ("manganism") is symptomatically similar to the PDC that was once so prevalent among the Chamorro people of Guam. Reported cases of manganism are confined almost exclusively to occupational exposures involving the inhalation of Mn oxide dust (Cotzias, 1953). Since dried Pandanus leaves were traditionally woven into rope, baskets, body ornaments, roofing, sleeping mats, household curtains and screens, food trays, skirts, and other miscellaneous items, exposure pathways from plant to human via pulmonary/enteric routes are easy to envisage. For now, however, any connection between the plant's predilection for Mn and the high incidence of the neurodegenerative diseases that once plagued the island remains an intriguing question. Studies are, therefore, continuing to determine: (a) whether or not *P. tectorius* from other parts of Guam display similar accumulator capabilities for this element; (b) the identification of mechanisms involved in the solubilization and sequestration of soil-bound Mn and other essential elements; (c) precisely where the primary Mn deposition sites are in the leaves and in what form the element is translocated and stored; and finally (d) whether or not traditional methods of working and weaving of *P. tectorius* leaves may have generated sufficient amounts of Mn dust in ancient Chamorro households to account for the ALS-PDC epidemic of the past.

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