

Ornamental Palms: Biology and Horticulture

T.K. Broschat and M.L. Elliott

Fort Lauderdale Research and Education Center
University of Florida,
Davie, FL 33314, USA

D.R. Hodel

University of California
Cooperative Extension Alhambra,
CA 91801, USA

ABSTRACT

Ornamental palms are important components of tropical, subtropical, and even warm temperate climate landscapes. In colder climates, they are important interiorscape plants and are often a focal point in malls, businesses, and other public areas. As arborescent monocots, palms have a unique morphology and this greatly influences their cultural requirements. Ornamental palms are overwhelmingly seed propagated, with seeds of most species germinating slowly and being intolerant of prolonged storage or cold temperatures. They generally do not have dormancy requirements, but do require high temperatures (30–35°C) for optimum germination. Palms are usually grown in containers prior to transplanting into a field nursery or landscape. Because of their adventitious root system, large field-grown specimen palms can easily be transplanted. In the landscape, palm health and quality are greatly affected by nutritional deficiencies, which can reduce their aesthetic value, growth rate, or even cause death. Palm life can also be shortened by a number of diseases or insect pests, some of which are lethal, have no controls, or have wide host ranges. With the increasing use of palms in the landscape, pathogens and insect pests have moved with the

palms, both between and within countries, with some having spread virtually worldwide.

KEYWORDS: Arecaceae; insect pests; nursery production; nutrient deficiencies; plant diseases; propagation; transplanting

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LITERATURE CITED

I. INTRODUCTION

Palms comprise a natural and distinctive, yet unusually diverse group of mostly tropical plants. The family includes ~2,500 species in 184 genera and is most diverse and rich in tropical Asia, the western Pacific, Central

and South America, Australia, and Madagascar (Dransfield et al. 2005, 2008; Govaerts 2013). Where palms occur naturally, they are typically among the most economically important plants, providing food, beverages, and cooking oil; fiber for clothing, rope, baskets, mats, hats, and other uses; material for furniture and construction; and medicine and narcotics (Balick 1988; Balick and Beck 1990). Several palms have been domesticated and are of international economic importance, including *Phoenix dactylifera* (date palm), *Bactris gasipaes* (peach palm), *Cocos nucifera* (coconut palm), and *Elaeis guineensis* (African oil palm). The latter two are considered two of the world's ten most important agronomic crops (Janick and Paull 2008).

Palms are also important as ornamentals and are widely used in the landscape in tropical, subtropical, and Mediterranean climates around the world (Table 1.1, Plate 1.1). They are often the featured plants in botanical glasshouses in temperate climates. Indeed, they are the quintessential plant of the tropics and few, if any other, plants can capture that tropical motif as do the palms (Ledin 1961). *C. nucifera* in Hawaii and south Florida and *Phoenix canariensis* (Canary Island date palm) and *Washingtonia robusta* (Mexican fan palm) in California are the iconic or signature trees of these respective regions, filling the skyline and providing the tropical ambience upon which these tourism-reliant regions depend to draw visitors to support their economies.

In warmer parts of the United States, especially Hawaii, Florida, and California but also in Arizona, Texas, and the Gulf Coast, palms are a significant and increasing component of ornamental wholesale production nurseries. Palms of all sizes are grown for landscape use in these areas but also for indoor use everywhere. The monetary value of palm extends from the seed to transplantation of mature palms into residential and commercial landscapes. For the Florida nursery industry alone, the monetary value of palms has almost doubled every 5 years for the past 10 years. The estimated total sales value for palm trees by Florida producers in 2010 was \$404 million, representing 9.5% of nursery growers' sales (Hodges et al. 2011). While this represents only a 2.5% increase in percentage of nursery sales from 2005, it is a near double of the monetary value (\$220 million) from 2005 (Hodges and Haydu 2006). The 2005 monetary value was a near double of the 2000 palm sales, which were \$123 million (Hodges and Haydu 2002). In 2010, the percentage of sales (9.5%) of palms was equal to the combination of deciduous shade trees, flowering and fruiting trees, and evergreen trees (9.8%).

Table 1.1. Common ornamental palms, along with their botanical and common names and information about their habit, size, uses, and environmental adaptations.

Botanical name (synonyms)	Common name	Habit/trunk diameter (cm)	Size (<i>h</i> × <i>w</i>) (m) ^z	Leaf type and length (m) ^y	Inflorescence length (m)	Length (cm)	Fruit		Exposure ^w / climate zone (USDA) ^v
							Color	Uses ^x	
<i>Acoelorrhaphe wrightii</i> (<i>Paurotis wrightii</i>)	Everglades palm	Clustered/10	7 × 6	Palmate, 1	1	0.3	Orange- brown	BG, H, S	Sun/9–11
<i>Acrocomia aculeata</i> (<i>A. media</i> , <i>A. mexicana</i> , <i>A. totai</i>)	Grū-grū palm, macaw palm	Solitary/30	12 × 4	Pinnate, 2	1.5	2	Brown	S	Sun/10–11
<i>Adonidia merrillii</i> (<i>Veitchia merrillii</i>)	Christmas palm, Manila Palm	Solitary/15	4 × 2	Pinnate, 1	0.5	2.5	Red	BG, B, S, C	Sun/10–11
<i>Archontophoenix alexandrae</i>	Alexandra palm	Solitary/20	14 × 4	Pinnate, 2	0.75	1	Red	BG, B, S	Sun/10–11
<i>A. cunninghamiana</i>	King palm	Solitary/20	14 × 4	Pinnate, 2	0.75	1	Red	BG, B, S	Sun/10–11
<i>Areca catechu</i>	Betel nut palm	Solitary/12	10 × 2.5	Pinnate, 1.3	0.60	5	Yellow- orange	BG, B, S, C	Part sun to sun/11
<i>A. triandra aliciae</i>	NCN ^u	Clustered/8	8 × 3	Pinnate, 1.5	0.30	2	Red	BG, B, S, C, I	Shade to part sun/11
<i>Arenga engleri</i>	Formosa palm	Clustered/15	2.5 × 5	Pinnate, 2	0.75	2	Purple- red	BG, B, H, S, C	Part sun/9–11
<i>A. pinnata</i>	Sugar palm	Solitary/45	15 × 6	Pinnate, 3	2.25	6	Yellow	BG, B, S	Sun/10–11
<i>Astrocaryum mexicanum</i>	NCN	Solitary/10	5 × 3	Pinnate, 1.5	0.75	5	Brown	BG, B, S	Part sun to sun/9–11 (continued)

Table 1.1. (Continued)

Botanical name (synonyms)	Common name	Habit/trunk diameter (cm)	Size (h × w) (m) ^z	Leaf type and length (m) ^y	Inflorescence length (m)	Length (cm)	Fruit		Exposure ^{w/} climate zone (USDA) ^v
							Color	Uses ^x	
<i>Bismarckia nobilis</i>	Bismarck palm	Solitary/40	10 × 5	Palmate, 2.5	2.25	5	Brown	BG, B, S	Sun/10-11
<i>Brahea armata</i>	Mexican blue palm	Solitary/30	8 × 3	Palmate, 1.5	5	2.5	Black	BG, B, S	Sun/9-11
<i>B. edulis</i>	Guadalupe palm	Solitary/=30	8 × 3	Palmate, 1.5	2	2.5	Black	BG, B, S	Sun/9-11
<i>Butia odorata</i> (<i>B. capitata</i>)	Pindo palm, jelly palm	Solitary/40	5 × 3	Pinnate, 1.5	1	2.5	Yellow- orange	BG, B, S, C	Sun/8-11
<i>Carpentaria acuminata</i>	NCN	Solitary/20	15 × 3	Pinnate, 1.5	1	1.5	Red	BG, B, S	Sun/10-11
<i>Caryota maxima</i>	Fishtail palm	Solitary/30	15 × 4	Pinnate, 2	3	2.5	Reddish	BG, B, S	Part sun to sun/9-11
<i>C. mitis</i>	Clustered fishtail palm	Clustered/12	10 × 4	Pinnate, 2	1.5	1.2	Black	BG, B, H, S, C, I	Shade to sun/ 10-11
<i>Chamaedorea benziei</i>	NCN	Solitary/4	3 × 1.5	Pinnate, 0.7	1	1	Black	BG, B, H, S, C, I	Shade/10-11
<i>C. cataractarum</i>	Cat palm	Clustered/3	1 × 3	Pinnate, 1	0.75	1	Black	FG, B, H, C, I	Shade/10-11
<i>C. elegans</i>	Parlor palm	Solitary/1.5	2 × 0.8	Pinnate, 0.4	1	0.7	Black	FG, B, C, I	Shade/10-11

<i>C. hooperiana</i>	Maya palm	Clustered/3	3 × 3	Pinnate, 1.5	0.75	1	Black	BG, B, S, C, I	Shade/10-11
<i>C. metallica</i>	NCN	Solitary/1.5	1 × 0.4	Bifid to pinnate, 0.2	0.25	1.2	Black	FG, B, H, C, I	Shade/10-11
<i>C. microspadix</i>	Bamboo palm	Clustered/1	3 × 2	Pinnate, 0.3	0.25	1.2	Red-orange	FG, B, C, I	Shade to part sun/9-11
<i>C. plumosa</i>	NCN	Solitary/3	3 × 1.5	Pinnate, 1	0.75	1	Black	BG, B, S, C	Part sun to sun/10-11
<i>C. radicalis</i>	NCN	Solitary/2.5	1 × 1	Pinnate, 0.6	1.25	1.2	Red	FG, M, B, C, I	Shade to part sun/9-11
<i>C. seifrizii</i> (<i>C. erumpens</i>)	Bamboo palm	Clustered/1.5	2.5 × 1	Pinnate, 0.3	0.20	0.8	Black	BG, B, H, S, C, I	Part sun to sun/10-11
<i>Chambeyronia macrocarpa</i>	NCN	Solitary/12	8 × 3	Pinnate, 1.5	1	4.5	Red	BG, B, S	Part sun to sun/10-11
<i>Coccothrinax argentata</i>	Thatch palm	Solitary/10	8 × 2	Palmete, 1	0.5	1.2	Black	BG, B, S, C	Part sun to sun/10-11
<i>C. crinita</i>	Old-man palm	Solitary/12	5 × 2	Palmete, 1	1.5	2.5	Pinkish	BG, B, S, C	Sun/10-11
<i>Cocos nucifera</i>	Coconut palm	Solitary/45	20 × 6	Pinnate, 3	1.25	30	Greenish yellow	BG, B, S	Sun/10-11
<i>Cyrtostachys renda</i>	Sealing wax palm	Clustered/8	8 × × 3	Pinnate, 1	0.9	1	Black	BG, B, H, S, C	Part sun to sun/11
<i>Dictyosperma album</i>	Princess palm	Solitary/15	14 × 3	Pinnate, 1.5	0.6	1.2	Black	BG, B, S	Sun/10-11
<i>Dypsis cabadae</i>	Cabada palm	Clustered/10	8 × 5	Pinnate, 1.5	1.25	1.2	Red	BG, B, S	Part sun to sun/10-11
<i>D. decaryi</i>	Triangle palm	Solitary/30	4 × 3	Pinnate 1.5	1.25	2.5	Greenish yellow	BG, S, C, I	Sun/10-11
<i>D. leptochelios</i>	Teddy bear palm	Solitary/20	10 × 4	Pinnate, 2	1.5	1.2	Brown	BG, B, S	Part sun to sun; 10-11

(continued)

Table 1.1. (Continued)

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							Color	Uses ^x	
<i>D. lutescens</i> (<i>Chrysalidocarpus</i> <i>lutescens</i>)	Areca palm	Clustered/10	10 × 5	Pinnate, 1.5	1.25	2.5	Yellow to black	BG, B, H, S, C, I	Part sun to sun/10-11
<i>Euterpe oleracea</i>	Assai palm	Clustered/20	15 × 5	Pinnate, 2	1	2	Black	BG, B, H, S	Sun/10-11
<i>Heterospatha elata</i>	Sagisi palm	Solitary/20	15 × 4	Pinnate, 2	1.25	1	White	BG, B, S	Sun/10-11
<i>Howea forsteriana</i>	Kentia palm, sentry palm	Solitary/20	15 × 4	Pinnate, 2	0.6	4	Red	BG, B, S, C, I	Shade to sun/ 10-11
<i>Hyophorbe</i> <i>lagenicaulis</i> (<i>Mascarena</i> <i>lagenicaulis</i>)	Bottle palm	Solitary/60	6 × 3	Pinnate, 1.5	0.9	2.5	Black	FG, B, S, C	Sun/10-11
<i>H. verschaffeltii</i> (<i>Mascarena</i> <i>verschaffeltii</i>)	Spindle palm	Solitary/30	8 × 4	Pinnate, 2	0.7	2	Black	FG, B, S, C	Sun/10-11
<i>Jubaea chilensis</i> (<i>J. spectabilis</i>)	Chilean wine palm	Solitary/200	25 × 8	Pinnate, 4	1.25	4	Yellow- orange	BG, B, S	Sun/9-10
<i>Latania loddigesii</i>	Blue latan palm	Solitary/25	7 × 4	Palmate, 2	2	8	Greenish brown	BG, B, S	Sun/10-11
<i>Licuala grandis</i>	NCN	Solitary/8	3 × 3	Palmate, 1.5	2	1.2	Red	FG, B, M, S, C, I	Shade to part sun/10-11
<i>L. spinosa</i>	NCN	Clustered/5	6 × 3	Palmate, 1	2.5	1.2	Red	BG, FG, H, S, Cs, I	Part sun to sun/10-11

<i>Livistona australis</i>	Australian fan palm	Solitary/30	20 × 5	Palmate, 2/5	1.25	2	Black	BG, B, S	Sun/9-11
<i>L. chinensis</i>	Chinese fan palm	Solitary/30	20 × 6	Palmate, 2.5	2	2.5	Bluish-green	BG, B, S, I	Sun/9-11
<i>L. decora</i> (<i>L. decipiens</i>)	Ribbon fan palm	Solitary/25	15 × 6	Palmate, 2.5	3	1.5	Black	BG, B, S	Sun/9-11
<i>Phoenix canariensis</i>	Canary Island date palm	Solitary/100	20 × 8	Pinnate, 4	2	1.2	Golden orange	BG, B, S	Sun/8-11
<i>P. dactylifera</i>	Date palm	Clustered or solitary/45	20 × 8	Pinnate, 3.5	2.5	2.5	Dark brown to black	BG, B, H, S	Sun/8-11
<i>P. reclinata</i>	Senegal date palm	Clustered/20	15 × × 15	Pinnate, 3	1	2	Black	BG, B, H, S	Sun/9-11
<i>P. roebelenii</i>	Pygmy date palm	Solitary/10	4 × 2.5	Pinnate, 1.2	0.6	1	Black	FG, B, M, S, C, I	Part sun to sun/9-11
<i>P. sylvestris</i>	Wild date palm	Solitary/45	15 × 6	Pinnate, 3	1	2.5	Purplish	BG, B, S	Sun/8-11
<i>Ptychosperma elegans</i>	Solitaire palm	Solitary/10	10 × 3	Pinnate, 1.5	0.75	1.2	Red	BG, B, S, C, I	Part sun to sun/10-11
<i>P. macarthurii</i>	Macarthur palm	Clustered/6	10 × 5	Pinnate, 1.5	0.75	1.2	Red	BG, B, H, S, C	Part sun to sun/10-11
<i>Ravenea rivularis</i>	Majesty palm	Solitary/45	15 × 3	Pinnate, 1.5	1	1.2	Red	BG, B, S	Sun/10-11
<i>Rhapis excelsa</i>	Lady palm	Clustered/3	4 × 4	Palmate, 0.7	0.3	0.8	White	BG, B, H, S, C, I	Shade to part sun/9-11
<i>R. humilis</i>	Slender lady palm	Clustered/3	5 × 5	Palmate, 0.7	0.3	0.8	White	BG, B, H, S, C, I	Shade to part sun/9-11
<i>Roystonea regia</i>	Royal palm	Solitary/50	25 × 8	Pinnate, 4-5	0.3	0.6	Reddish purple	BG, B, S	Sun/10-11
<i>Sabal mexicana</i>	Texas palmetto	Solitary/30	20 × 5	Palmate, 2.5	2	1.2	Black	BG, B, S	Sun/8-11

(continued)

Table 1.1. (Continued)

Botanical name (synonyms)	Common name	Habit/trunk diameter (cm)	Size (h × w) (m) ^z	Leaf type and length (m) ^y	Inflorescence length (m)	Fruit			Exposure ^{w/} climate zone (USDA) ^v
						Length (cm)	Color	Uses ^x	
<i>Sabal minor</i>	Dwarf palmetto	Solitary/15	2.5 × 3	Palmate, 2	3	0.8	Black	FG, M, C	Shade to sun/ 7-11
<i>S. palmetto</i>	Palmetto palm, cabbage palm	Solitary/40	20 × 4	Palmate, 2- 2.5	2.5	1.2	Black	BG, B, S	Sun/8-11
<i>Saribus rotundifolius</i> (<i>L. rotundifolia</i>)	Footstool palm	Solitary/25	20 × 5	Palmate, 2	2.5	2.5	Orange- red	BG, B, S	Sun/10-11
<i>Syagrus romanzoffiana</i>	Queen palm	Solitary/25	20 × 6	Pinnate, 3- 3.5	2.5	2.5	Yellow to orange	BG, B, S	Sun/10-11
<i>Thrinax radiata</i>	Thatch palm	Solitary/12	12 × 4	Palmate, 2	1	0.6	White	BG, FG, B, S, C	Sun/10-11
<i>Trachycarpus fortunei</i>	Windmill palm, Chinese windmill palm	Solitary/12	7 × 3	Palmate, 1	0.5	1.2	Bluish	BG, FG, B, S, C	Sun/8-11
<i>T. wagnerianus</i>	Windmill palm	Solitary/12	7 × 2	Palmate, 1	0.5	1.2	bluish	FG, B, S, C	Sun/8-11
<i>Veitchia arecina</i> (V. <i>montgomeryana</i>)	Montgomery palm, NCN	Solitary/20	20 × 5	Pinnate, 2.5	1.25	4	Red	BG, B, S	Sun/10-11
<i>V. joannis</i>	NCN	Solitary/40	30 × 6	Pinnate, 3	1	5	Red	BG, B, S	Sun/10-11
<i>Veitchia winin</i>	NCN	Solitary/30	25 × 5	Pinnate, 2.5	1.25	1	Red	BG, B, S	Sun/10-11

<i>Washingtonia filifera</i>	California fan palm	Solitary/100	20 × 6	Palmate, 2.5	5	0.6	Black	BG, B, S	Sun/8-11
<i>W. robusta</i>	Mexican fan palm	Solitary/50	30 × 5	Palmate, 2.5	4	0.6	Black	BG, B, S	Sun/8-11
<i>Wodyetia bifurcata</i>	Foxtail palm	Solitary/25	10 × 5	Pinnate, 2.5	3	5	Red	BG, B, S, C	Sun/10-11

The categories covering habit, size, uses, and environmental adaptation are annotated and described or defined at the end of the table. Information is derived mostly from Meerow (2006), Riffle et al. (2012), and Hodel (2012).

^zHeight and width are averages for typical landscape specimens; width is through canopy of solitary species or through canopies of clustered species at maturity.

^yLength includes leaf blade and petiole but not leaf base.

^xBG: Background; taller and/or wider plants that can interrupt a line of sight or in front of which smaller plants can be positioned; FG: foreground; smaller or slow-growing plants that do not block a line of sight and that can be positioned in front of larger plants; B: border—short or tall plants for an elongated or narrow area or for an area along a building or other structure or lining a street; H: hedge screen—typically densely clustered plants that can be managed as a hedge or to block a view; M: mass—mostly very small, dwarf, and/or trunkless plants that can be planted canopy to canopy to create a uniform block or groundcover effect; S: specimen—a plant that can stand alone on its own merits; C: container—typically a small or slow-growing plant that can remain in a container for several years, attaining or nearly attaining maturity, note that nearly all palms make suitable container subjects when young and that recommendations are made in this table for palms that are especially distinctive or exhibit adult characters when still relatively small plants; i: indoors—a plant tolerant of conditions typically encountered inside homes, offices, and other buildings where light and humidity are usually low.

^wShade: no direct sun; part sun: filtered sun or morning full sun and afternoon shade; sun: full sun all day.

^vUSDA climate zone recommendations are based mostly on Meerow (2006) and Riffle et al. (2012).

^uNo common name.

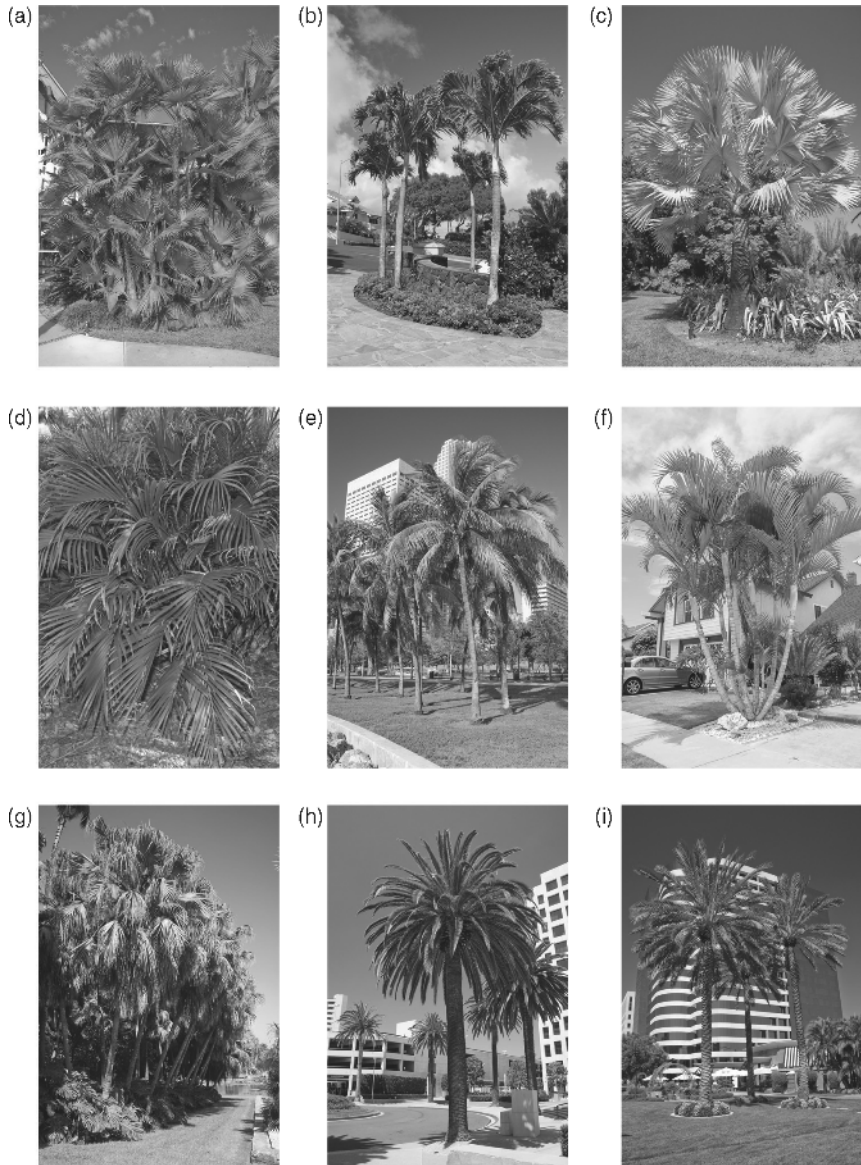


Plate 1.1. Ornamental palms. (a) *Acoelorrhaphe wrightii* (paurotis palm) (b) *Adonidia merrillii* (Christmas palm); (c) *Bismarckia nobilis* (Bismarck palm); (d) *Chamaedorea cataractarum* (cat palm); (e) *Cocos nucifera* (coconut palm); (f) *Dypsis lutescens* (areca palm); (g) *Livistona chinensis* (Chinese fan palm); (h) *Phoenix canariensis* (Canary Island date palm); (i) *P. dactylifera* (date palm); (j) *P. roebelenii* (pygmy date palm); (k) *P. sylvestris* (wild date palm); (l) *Ptychosperma elegans* (solitaire palm); (m) *Roystonea regia* (royal palm); (n) *Sabal palmetto* (cabbage palm); (o) *Syagrus romanzoffiana* (queen palm); (p) *Veitchia* sp. (Montgomery palm); (q) *Washingtonia robusta* (Mexican fan palm); (r) *Wodyetia bifurcata* (foxtail palm) (See the color version of this plate in Color Plates Section).



Plate 1.1. (Continued)

Along with this increase in popularity has come an increased interest in how to grow, plant, and manage landscape palms. However, palms are unique among landscape plants and have several unusual features that set them apart from other woody plants and affect their nursery production and landscape management. These features include the lack of a cambium and ability for secondary growth in the stem; typically only one growing point or apical meristem per stem; an adventitious root system composed of nonwoody roots, with all primary- or first-order roots arising separately from one another at or near the base of the stem; and an aggregation of photosynthetic and reproductive efforts into relatively few but large organs (leaves and inflorescences) (Tomlinson 1990; Hodel 2012).

Those who grow or manage landscape palms frequently do not understand these unique features, and this lack of understanding often leads to mismanagement of palms in the nursery and landscape. Also, until recently, most of the information about production and management of landscape palms was anecdotal in nature and little research-based information was available (Broschat and Meerow 2000). Thus, the need for research-based information on how to grow, plant, and manage landscape palms is real and urgent. This publication reviews the literature on the biology, production, planting and transplanting, nutrition, irrigation, pruning, interiorscape use, disorders, and pest and diseases of ornamental palms.

II. PALM BIOLOGY

A. What Is Palm?

Palms are unique among landscape plants and have several features that set them apart from other woody plants. Although until recently divided into two major groups, flowering plants (angiosperms) are now divided into three major groups: basal or primitive angiosperms (*Magnolia*, *Liriodendron*, etc.), monocotyledons (monocots), and eudicotyledons (eudicots). Monocots are distinguished from basal angiosperms and eudicots by having one cotyledon (seed leaf) rather than two, flower parts (sepals, petals, carpels, etc.) in threes or multiples of threes rather than in fours or fives, parallel rather than net leaf venation, and vascular bundles (phloem and xylem) dispersed throughout the stem rather than in two concentric rings with a cylindrical cambium between them. Palms are woody monocots, although they do not form wood in the same manner or have the same type of wood as other types of trees. A combination of characters distinguishes palms from all other monocots, including a woody stem, monopodial growth

habit, petiolate leaves with initially closed bases, the mode of leaf initiation and development (plication and later splitting into segments that arise from a prominent midrib, an inflorescence (flower stalk) that is always initially enclosed within a two-edged bract (modified leaf), one ovule per carpel, and relatively large seeds (Dransfield et al. 2008). Sago palms (*Cycas* spp., coniferous plants), ponytail palms (*Nolina* spp.), traveler's palm (*Ravenala madagascariensis*), and other palm-like plants (dracaenas, yuccas) are not palms, although they have a palm-like habit and are commonly referred to as palms.

B. Taxonomy and Distribution

Being a natural and well-defined group, taxonomists have placed palms in their own order, Arecales (formerly Principes), composed of one family, Areaceae or Palmae. The palm family is divided into five subfamilies based on DNA sequence data and morphological characters: Arecoideae, Calamoideae, Ceroxyloideae, Coryphoideae, and Nypoidae (Dransfield et al. 2005, 2008). The commonly cultivated genera of landscape palms in the United States occur in the Arecoideae and Coryphoideae subfamilies. These include *Archontophoenix*, *Butia*, *Chamaedorea*, *Cocos*, *Dypsis*, *Howea*, *Ptychosperma*, *Roystonea*, *Syagrus*, *Veitchia*, and *Wodyetia* of the Arecoideae and *Brahea*, *Bismarckia*, *Caryota*, *Chamaerops*, *Livistona*, *Phoenix*, *Pritchardia*, *Rhapis*, *Sabal*, *Trachycarpus*, and *Washingtonia* of the Coryphoideae.

Most species of palms naturally inhabit moist to wet tropical areas in Central and South America, Madagascar, Southeast Asia, Malaysia, Indonesia, Australia, and the western Pacific (Dransfield et al. 2005, 2008; Govaerts 2013). The cold intolerance across the entire family is the most limiting factor in where and how palms can be grown in the landscape. However, a small percentage of palms, ~5–10% of the species, originate in subtropical or even warm temperate regions and are much better adapted to cultivation in these or similar areas (Meerow 2005).

C. Growth and Development

Palms pass through several developmental growth phases from the embryo (seed) to reproductive adult, each of which has features that can affect their management in the nursery and landscape. Tomlinson (1990) identified five distinct phases, although the transition between each is smooth and continuous: (1) embryonic, (2) seedling, (3) establishment, (4) adult vegetative, and (5) adult reproductive. Nursery

production managers deal mostly with palms in the embryonic, seedling, and establishment phases while landscape managers deal mostly with palms in the adult vegetative and reproductive phases, although there is some overlap, especially in the establishment and adult vegetative phases and especially in nurseries that field-grown palms.

The embryonic phase refers to the development of the embryo within the seed, from fertilization to germination (Tomlinson 1990). Critical morphological changes that occur during the seedling phase include emergence of the apical meristem and the production of the first scale (rudimentary) and bladed (“true”) leaves, radicle (first and rudimentary root), and haustorium (specialized growth structure of the cotyledon that grows into the endosperm to absorb carbohydrates for growth and development) (Tomlinson 1990).

The establishment phase covers the time from the seedling phase until the stem has attained its maximum diameter and begins to elongate vertically (Tomlinson 1990). During this phase, stems increase in diameter with little vertical elongation, vascular bundles increase in number and size, roots become more numerous and larger, and leaves transition from strap-like or bifid juvenile foliage to pinnate or palmate adult foliage. The canopy attains its maximum size and number of leaves at the end of the establishment phase, essentially “fixing” the transport capacity of the stem for future growth. Once the stem has attained its maximum diameter and elongates vertically, there will be no further increase in its diameter or in the number of vascular bundles, primarily because of the lack of a vascular cambium and subsequent secondary growth. Thus, the stem is “overbuilt” during this phase because it must be sufficiently developed and constructed to accommodate all future growth, including increases in stem height, mass, strength, and transport requirements (Tomlinson 1990, 2006).

The establishment phase can be lengthy, several years or more, and, because most of the growth occurs at or near ground level, there is little, visible upward growth, (Tomlinson 1990). For most palms the establishment phase occurs with the apical meristem close to the ground. However, in some palms the establishment phase occurs mostly below ground and involves a radical reorientation of the apical meristem so that stem growth is initially downward prior to growing upward to resume the more typical, erect habit (Tomlinson 1990). This type of growth, which typically makes the establishment phase much longer, results in an underground, saxophone-shaped stem, usually with a low, above-ground “heel.” This saxophone-shaped stem occurs in some species of several genera, including *Chamaedorea*, *Dypsis*, *Ravenea*, *Rhopalostylis*, and *Sabal* (Tomlinson 1990; Hodel 2012).

The adult vegetative phase spans the time from the initial stem attaining maximum diameter and growing vertically until the emergence of the first inflorescence (Tomlinson 1990). Stems, roots, and leaves typically have attained their ultimate, more or less constant size. Stem elongation is most rapid in the early part of this phase with long internode lengths. Palms attain their ultimate habit during this phase and four general categories are recognized: tree (single- or multi-stemmed); shrub (single- or multistemmed); acaulescent (no visible above-ground stem, or if above-ground, then stem is very short and compact with exceedingly short internodes); and vine (stems slender with very long internodes, often climbing by hook-like modified leaves or inflorescences) (Tomlinson 1990).

Multistemmed tree or shrub palms attain their habit through basal or, rarely aerial, branching of stems. Basal branches develop adjacent to the “mother” stem, or they grow laterally for a considerable distance as rhizomes or stolons. In acaulescent palms the apical meristem is permanently fixed at or near ground level and there is little, if any, stem elongation, even in the adult phases (Tomlinson 1990). While there are ~400 species of vining, climbing palms, they are rarely encountered in the landscape because of their intractable and often spiny nature and cold intolerance.

The production of inflorescences and onset of flowering initiate the adult reproductive phase, and it lasts until the palm senesces and dies (Tomlinson 1990). Other than the appearance of inflorescences and an increase in overall size, there are few visible differences in gross morphology between this phase and the adult vegetative phase. However, toward the end of a palm’s natural life, leaf production tends to slow and leaves become smaller, stems may decrease in diameter, and internodes become shorter (Hodel 2012).

Two types of flowering—pleoanthy and hapaxanthy—occur in palms, and they are defined by the way in which the event terminates the growth of the stem (Tomlinson 1990; Tomlinson and Huggett 2012). In pleoanthy, which is the most common condition in palms, flowering is indeterminate to the stem because production of inflorescences and leaves continues indefinitely until the palm senesces and dies of old age.

In hapaxanthy, which is less common, flowering is determinate to the stem, signaling the eventual and fairly imminent death of that stem. With single-stemmed species, hapaxanthy results in the death of the palm. In multistemmed species, hapaxanthy results in the death of an individual stem, but the palm may live on through production of new stems. The most common landscape palms exhibiting hapaxanthy include *Arenga* sp. and *Caryota* spp., both with single- and multi-stemmed species.

D. General Architectural Model

Architecturally, palms usually consist of an elongated axis (stem) or a series of such axes with growth restricted to its extremities: roots at the bottom and leaves and inflorescences at the top (Tomlinson 1990). There is typically only one apical growing point per stem (apical meristem), and it is embedded and protected within a series of older, overlapping leaf bases. All growth is primary in nature: active root and shoot apical meristems directly produce all tissues (Tomlinson 1990, 2006).

Palms are unusual, then, in that they can become tall and long-lived woody plants without traditional secondary growth from a single peripheral vascular cambium, such as that in basal angiosperms, eudicotyledons, and conifers, which develop the vascular system and continually increase stem diameter and strength by producing xylem and wood on the inside and phloem and bark on the outside. The vascular system in palms is repetitive and redundant, composed of numerous individual bundles containing both phloem and xylem, and dispersed throughout the stem, with the result that movement of water and minerals is not restricted to a specific sector of the stem. Palm stems do become stronger and more rigid over time, however, by stem cells that thicken and strengthen with age (Tomlinson 1990, 2006).

While the unique structural biology of palms offers several features that protect vital organ systems from overt exposure to blunt force trauma, fire, wind, and pests and diseases (Tomlinson 2006; Hodel 2012), the lack of a peripheral, vascular cambium and capability for secondary growth does mean that there is no ability to repair damaged tissue, and wounds in palm stems are permanent as well as unsightly and potential entry sites for pests and diseases (Hodel 2012). Despite this apparent disadvantage and the lack of documented compartmentalization of decay processes, palm stems are remarkably resistant and resilient to decay.

E. Morphological and Anatomical Features

1. Stems. Other than the leaves, stems are the most conspicuous and characteristic feature of palms and are typically cylindrical, elongated, and aerially unbranched (Tomlinson 1990). They might retain old, dead persistent leaves or leaf bases or they might be free of leaves, but are often marked with circular or diamond-shaped scars where leaves were once attached. Palm stems are more or less uniform in diameter and can be good indicators of past and present health; stem constrictions

typically represent periods of abnormally reduced growth caused by environmental or physiological stresses (Broschat and Meerow 2000; Hodel 2012).

In transverse section the palm stem has two distinct regions—the cortex and central cylinder (Tomlinson 1990)—which, to the untrained eye, might appear similar to the bark and wood of nonpalm trees, although neither of these two regions is even remotely analogous. The cortex, a narrow band on the outside of the stem, has a thin outer covering composed primarily of thick-walled, sclerified (hardened) cells. It is sometimes referred to as pseudobark, although it has no relation to bark of other types of trees. Relatively unspecialized parenchyma cells, which become larger, more numerous, and lignified (woody) with age, compose most of the remainder of the cortex, although there may be some vascular tissues present connecting the leaf base and inflorescences with the vascular bundles in the central cylinder.

The central cylinder lies within the cortex and comprises a majority of the palm stem. It is composed primarily of numerous, dispersed, light- or dark-colored, hardened vascular bundles containing phloem and xylem embedded in a mostly homogeneous, light-colored, hardened ground tissue made up largely of unspecialized parenchyma cells, although intercellular air spaces and some specialized cells may also be present. The parenchyma cells, which store water and carbohydrates as starch, can become woody and strengthen with age, especially those toward the outer part of the central cylinder, while those toward the center of the central cylinder are mostly spongy and unligified (Tomlinson 2006).

A strong, hard, fibrous sheath partially or entirely encloses each vascular bundle and is the primary mechanical support for the stem (Tomlinson 1990, 2006). In most palms, the vascular bundles are concentrated toward the periphery of the central cylinder for maximum strength and support, and are interconnected with each other by bridges and with leaves and inflorescences by traces.

The inner part of the central cylinder contains a preponderance of spongy parenchyma cells and usually fewer vascular bundles. Because parenchyma cells are less resistant to decay, especially those that are unligified, the inner portions of the central cylinder and the cortex typically degrade faster than the outer portions of the central cylinder on cut palm stems because in the latter harder, more decay-resistant vascular bundles predominate.

Parenchyma cells and the fibers of the vascular bundles become woody with age and the latter thicken their cell walls, adding to the rigidity and

strength of the stem. (Tomlinson 1990, 2006). This unique strengthening process means that stems are typically more flexible and can bend more distally, yet are more rigid proximally, resulting in excellent mechanical resistance to strong lateral forces like wind.

The palm stem can be likened structurally to a steel-reinforced, concrete column (Tomlinson 1990). The vertically oriented vascular bundles are the steel rebar and the ground tissue is the concrete matrix. Stems are exceptionally hard, but can bend and yet rarely break.

Because palm stems lack a peripheral cambium for secondary growth, their stems thicken little if at all after they attain their maximum diameter and begin to grow vertically. However, stems can thicken slightly due to a phenomenon called “diffuse secondary thickening,” which results from division of parenchyma cells, cell expansion, cell wall thickening and lignification, and an increase in the diameter of vascular fibers (Tomlinson 1990).

Palm stems likely have the longest living cells of any organism, animal, or plant (Tomlinson and Huggett 2012). Among the plants, only palms, which lack secondary growth, retain living cells in their stems throughout their lifetime. The oldest stem cells are at the base of the stem, and if the palm is 100, 200, 400, or more years of age, the living and functioning cells at the stem base are of the same or similar age. In contrast, in other types of trees the stem is nearly entirely composed of dead tissues and functioning, living cells are confined to an inner ring near the periphery of the plant and have a relatively short life span. As noted earlier, the lack of secondary growth also means that there is no ability to repair damaged tissue, and wounds in palm stems are permanent.

2. Leaves. Leaves are the most conspicuous and characteristic feature of palms. They are produced sequentially at the apex of the stem, as a result of primary growth from the same apical meristem responsible for stem initiation, development, and thickening. Because they are produced sequentially, the newest leaves are always in the center or upper part of the canopy and, as they age, are displaced or “pushed” to the lower part of the canopy. Thus, the oldest leaves are the lowest leaves in the canopy. Annual leaf production varies among species, ranging from less than 1 in *Lodoicea maldivica* to as many as 50 in *W. robusta*.

The palm leaf is composed of three parts: the blade; the petiole; and the base. The petiole attaches the blade to the base or sheath, which supports and attaches the entire leaf to the stem.

The blade is the expanded, conspicuously enlarged, multiribbed or folded, typically divided, often flattened surface (Tomlinson 1990).

Blades are initially folded tightly in the apical bud and emerge from the center of the crown as a spear, eventually unfolding and expanding to their ultimate size with the aid of specialized expansion cells. Damage from insects and diseases or abiotic factors that occurred when the blade was still folded in the spear stage typically is inconspicuous until the blade fully expands. Orientation of the segment fold, whether adaxially or up (induplicate), or abaxially or down (reduplicate), can be useful in identification.

Leaf blades vary greatly in their size and shape, color, texture, orientation, and number in the crown. Variation is largely species dependent, although environment and management can play critical roles. Like many other parts of the palm, blades may be covered to various degrees with deciduous or permanent indumentum, primarily hair and waxes.

The multiribbed and folded nature of the blade increases its mechanical strength and allows for the development of unusually large leaves, the largest in the plant kingdom (Tomlinson 1990). Blade division into segments or pinnae is structurally related to expansion and reduces wind resistance.

There are two major types of palm leaves defined by the degree to which the petiole extends into the blade as a rachis. In palmate-leaved or fan palms, the rachis is short or nonexistent, the ribs (folds) or segments radiating from a more or less central point. In palmate-leaved palms, the segments may be united for varying distances from the base, and this solid or undivided area is referred to as the palman. In pinnate-leaved or feather palms, the rachis is extended and elongated, and the ribs (folds) or pinnae (leaflets) are attached along its length at equal and uniform or unequal distances. Each of the two major types of palm leaves has a variation on the theme. In some species of palmate-leaved palms, such as *Sabal*, there is a costapalmate condition where the petiole extends for some distance into the otherwise palmate leaf. In the pinnate-leaved palms, all species of *Caryota* have a bipinnate (twice pinnate or compound) leaf where each pinna or leaflet is divided again into pinnules or subpinnae. *Caryota* is the only genus of palms that has a bipinnate leaf.

The petiole is built to support the increasing weight of the leaf as it gradually moves from an erect to horizontal to downward or pendulous position in the crown (Tomlinson 1990). It is also sufficiently flexible to bend from the sail-like effect of wind on the blade. It is widest where it connects to the leaf base and then gradually, but uniformly, tapers to its attachment with the blade. Anatomically, the petiole somewhat resembles the palm stem with its dispersed vascular bundles.

Depending on the species and exposure to light, petioles may be short and nonexistent to 2 m. Like the blade, the petiole may be covered by various indumentum, including hairs, scales, and waxes. Margins are rounded or extremely sharp, like a knife blade, and in some species are armed with spines, and care must be taken when placing and managing these palms in the landscape. In species that retain their dead leaves, petioles frequently become woody and rigid as in *Butia odorata* and various *Phoenix* spp., and if not cut closely and neatly to the base, can pose a hazard to pedestrians and workers (Hodel 2012).

The leaf base attaches the leaf to the stem and contains leaf traces (vascular bundles) from the blade and petiole that traverse the base and enter the stem, crossing the cortex and connecting with vascular bundles in the stem central cylinder (Tomlinson 1990). Leaf bases may be protected by spines, as in *Acrocomia*, and, like the blade and petiole, covered with various types of indumentum, including hairs and waxes. Leaf bases are constructed to withstand mechanical stresses from several sources, including the wind load and increasing dead weight of the blade and petiole; the expansion of younger, enclosed leaves; stem thickening; and the expansion and weight of inflorescences (Tomlinson 1990). The base is initially cylindrical and completely encircles the stem at its attachment point and is closed except for an opening at the top through which the next newest leaves will emerge. However, expansion of younger, enclosed organs, such as leaves and, eventually, inflorescences, and stem thickening split the base longitudinally to varying degrees, resulting in a wide variety of leaf bases (Tomlinson 1990).

In some species, like *Archontophoenix cunninghamiana*, the base is elongate and remains tubular and closed until the leaf reaches the end of its natural life, senesces, and falls away. These tubular, concentric leaf bases form a conspicuous, sometimes swollen, structure called a crownshaft (Tomlinson 1990). In palms with a crownshaft, leaves typically abscise neatly and completely as a single, intact unit (base, petiole, and blade together), often thrust off by the expanding inflorescence in the leaf axil. Such species are commonly referred to as self-cleaning palms (Hodel 2012). In contrast, *Brahea*, *Butia*, *Phoenix*, *Syagrus*, and *Washingtonia*, among many other palms, have leaf bases that are so profoundly split longitudinally early in their life that they are closed and tubular only at the base and appear as a hoop-like or crescent-shaped structure. In these species the side of the base opposite the petiole is deeply split and open, with the remnants of the base margin where it splits extending on to the two sides of the petiole, often as hair, fibers, spines, teeth-like structures, or other appendages.

3. Inflorescences, Flowers, and Fruits. Palm flowers are small and individually insignificant. They are aggregated into larger clusters of numerous flowers called inflorescences. When inflorescences develop fruit, they are typically called infructescences.

Inflorescences. Depending on their size and placement on the palm, inflorescences can be conspicuous and even showy, greatly exceeding the leaves and up to 5–7 m long, as in *Brahea armata*, or hidden and mostly inconspicuous (<0.3 m long), as in *Chamaerops humilis* and *Chamaedorea* spp. (Hodel 2012).

The basic inflorescence consists of a typically elongated central axis with up to five, progressively smaller or more slender orders of branches (Tomlinson 1990). They are rarely unbranched and spike-like. The ultimate, most slender branches bear flowers and/or fruits and are called rachillae (singular: rachilla). The unbranched base of the central axis is called the peduncle and, at least initially, is sheathed in a two-edged bract (modified leaf) called the prophyll.

An inflorescence or, in some cases, multiple inflorescences can be produced in the axil of each leaf once the palm reaches the adult reproductive phase. However, sometimes and with some species, inflorescences will not be produced in the axils of all leaves (Hodel 2012). Unfortunately, the mechanism controlling inflorescence initiation and development is not well understood.

While inflorescence production can theoretically be continuous, especially in species from wet tropical areas, it is typically periodic in subtropical areas with distinct seasons defined by temperature, rainfall, and/or day length that trigger or otherwise influence production (Hodel 2012). Most species cultivated in subtropical areas tend to produce inflorescences in the spring with fruits maturing in the summer or fall.

Inflorescences emerging from the axils of living leaves (typically held among the leaves), as in *Brahea*, *Butia*, and *Washingtonia*, are called interfoliar and those that emerge from nodes where the leaf is no longer present (typically held below the leaves), as in *Archontophoenix*, are called infrafoliar. Sometimes inflorescences are interfoliar in flower, but infrafoliar in fruit (Hodel 2012). Inflorescences are typically erect, ascending, or spreading in flower, but can sag and assume a lower position when heavily laden with fruit.

Flowers. The palm family encompasses a remarkable variety and arrangement of flowers. Most palmate-leaved palms in the Coryphoideae subfamily, such as *Brahea*, *Sabal*, and *Washingtonia*, have perfect

(bisexual or hermaphroditic) flowers, meaning each flower has both functional staminate (male, pollen producing) and pistillate (female, seed or fruit producing) parts. Such palms can theoretically produce fruits with only one plant present, although this is not always the case because a lack of pollinators, self-incompatibility, differences in flower opening, or other factors may preclude successful pollination and fruit set (Hodel 2012).

Phoenix, *Arenga*, and *Caryota*, anomalies in the Coryphoideae because of their pinnate leaves, have imperfect (unisexual) flowers, meaning each flower has only staminate or pistillate parts. In the case of *Phoenix*, staminate and pistillate flowers are produced on separate plants (dioecious plants), whereas in *Arenga* and *Caryota* and nearly all Arecoideae genera, they are separate, but occur on the same plant, and most often on the same inflorescence (monoecious plants) (Dransfield et al. 2008).

Fruits. Palm fruits are botanically classified as a single-seeded berry or a drupe. They are fleshy, pulpy, mealy, or fibrous and contain one or rarely more hard seeds. Fruits are usually green when immature and typically progress through a maturation or ripening process, and may be yellow, orange, red, brown, or black when soft ripe. Palms fruits are variously shaped, ranging from spherical to elongate, and most are relatively small, ranging from 6 to 25 mm. in diameter. Several tropical species produce much larger fruits, for example, *C. nucifera*. In some palms, such as *Chamaedorea*, *Arenga*, *Roystonea*, and *Caryota*, fruits contain needle-like calcium oxalate crystals that can be highly irritating if ingested or if their juice contacts unprotected skin (Snyder et al. 1979; Broschat and Latham 1994).

4. Roots. The palm root system is composed of numerous, slender, fibrous, primary roots that initiate and grow independent of each other and periodically from the root initiation zone (RIZ) at the base of the stem (Tomlinson 1990). Roots actually initiate in the periphery of the central cylinder of the stem where they connect extensively with the stem's vascular bundles. Palm roots are adventitious, that is, primary palm roots arise not from other roots but directly from an organ, in this case the stem, from which roots are not normally expected to arise. The RIZ on the stem is typically confined to the lower 30–60 cm of trunk, but in some *Phoenix* spp. can extend up over 3 m from the ground (Hodel 2012). On mature trees, the emergence of new adventitious roots from the underlying trunk tissue results in splitting of the

pseudobark. If these emerging root initials are exposed to air, their development will be arrested until conditions favorable for further development are experienced. When the RIZ is conspicuously enlarged, as in *P. canariensis* or *W. robusta*, it is referred to as a “root boss” (Dransfield et al. 2008). Additional disjunct regions of root emergence may occasionally be found at any height on the trunks of some palms (Hodel 2012).

Not all roots that emerge from the RIZ grow into the soil, especially in arid regions (Hodel 2012). Essentially “air pruned” by low humidity, many roots simply stop growing once they have emerged and appear as short root initials or nubs.

Most palm roots are found in the upper 30 cm of soil and close to the base of the palm stem (Hodel et al. 2005). Indeed, primary roots typically branch into an extensive network of secondary, tertiary, and quaternary orders of roots that often forms a rather dense and compact system referred to as a “root mat” immediately around the base of the stem and spreading outward over a meter or more (Hodel 2012). In some instances, the root mat may push up above grade, exposing the roots.

Most water and nutrient absorption occurs in the fine tertiary and quaternary root orders, which typically are most extensively developed near the soil surface (Tomlinson 1990). Under optimal growing conditions, such as the presence of even or constant moisture and a humus layer, these absorptive roots achieve their greatest number and density.

In some species, such as *Phoenix* spp., there is a strong tendency to produce erect secondary roots called pneumatophores that can form an especially dense mat above the soil surface (Tomlinson 1990). These are thought to be an ecological adaptation to aid in gas exchange in unusually wet conditions. Pneumatophores, as well as tertiary and quaternary roots, will grow extensively into a moist, humus-rich layer formed when leaf litter is appropriately left at the base of palms.

Root density typically drops off dramatically below 30 cm deep and more than 60 cm away from the palm stem (Hodel et al. 2005). However, this relatively dense and compact root system does not preclude palm roots from growing considerable, sometimes impressive, distances from the stem, especially under optimal growing conditions. Roots of *P. dactylifera* in deeply irrigated, light sandy soil are readily permeable to moisture and oxygen and have been recorded from over 3 m deep and 33 m away from the stem (Hodel 2012).

Palm roots lack a mechanism for secondary growth and, thus, once formed, do not increase in diameter. However, cut roots frequently branch and, as noted earlier, palm roots typically branch into a system of lesser orders.

III. PALM PRODUCTION

A. Propagation

1. Seed Propagation. Because shoots of palms contain but a single meristem, the vast majority of ornamental palms are propagated only from seeds. Palm seeds are notorious for their slow and erratic germination (Koebernik 1971; Maciel and Mogollon 1995). Tomlinson (1990) estimated that 25% of all palm species require more than 100 days for seed germination, with final germination percentages below 20%. Riffle et al. (2012) provide approximate germination times for most genera of cultivated palms. Seeds of most palm species possess small or immature embryos that require time to develop before germination can occur. This type of dormancy is categorized as morphological by Baskin and Baskin (2004). Other species display some form of nondeep physiological dormancy or a combination of physiological and morphological dormancy (Baskin and Baskin 2004; Pérez et al. 2008a). Robinson (2009) and Meerow and Broschat (2012) provide a general overview of propagating palms from seeds.

Collecting Seed. With few exceptions, it is best to collect fully mature fruit that has changed color from green to the appropriate mature color for each species, which varies considerably with each species. Fully ripened fruits are typically red or black, but can be yellow, orange, white, brown, or even bluish, depending on the species (Hodel 1998; Rauch 2001; Meerow and Broschat 2012). Ripe fruit is often soft to touch, but may not soften upon ripening in some species.

Seeds from fully mature fruits are generally recommended for planting (Hodel 1998; Silva et al. 1999; Pivetta et al. 2005; Meerow and Broschat 2012). However, seeds from mature green fruits of *Livistona chinensis* and *Syagrus romanzoffiana* had higher germination percentages than those from fully mature fruits (Broschat and Donselman 1987b; Maciel 1996). Fruit color had little effect on germination percentage in *Pritchardia pacifica* if planted immediately, but if stored for 12 weeks, seed from red or dark blue fruits germinated better (Maciel 2003).

Palm seed is best collected from the tree as seed collected from the ground beneath fruiting trees may not be fresh and may be infested with seed weevils or fungi that can reduce its chances of germinating. Seed may also be purchased from dealers who may have specialized seed cleaning equipment, but the freshness of such seed may not be known. Because seed viability for most palm species declines rapidly

after harvest, it is best to plant them as soon as possible (Meerow and Broschat 2012).

Seed Viability Testing. Seed viability varies considerably among trees of the same species and from year to year from the same tree (Martins et al. 2000). Raja et al. (2004) found that seed collected from middle-aged trees of *Areca catechu* germinated faster and produced more vigorous seedlings than those from younger or older trees. Seed weight within a species has been shown to affect germination, with heavier seeds germinating better than lighter seeds (Myint et al. 2010). Palm seed viability has been tested using a “float test” method wherein floating seeds are believed to be nonviable. However, this method tends to underestimate viability since seeds of some species naturally float and a significant number of floating seeds will ultimately germinate if planted (Doughty et al. 1986; Meerow and Broschat 2012).

Because loss of palm seed viability has been associated with desiccation (Carpenter and Gilman 1988; Carpenter and Ostmark 1994; Martins et al. 2003), visual examination of the embryo in bisected seeds will reveal noticeable shrinkage of the embryo and endosperm in desiccated seeds (DeLeon 1958; Loomis 1958; Meerow and Broschat 2012). However, seed viability can also be determined by soaking bisected seeds in a 10% solution of tetrazolium chloride and then storing them in the dark for several hours. Viable seeds will show red or pinkish staining of the embryo (Moore 1972). Instruments that measure electrolyte leakage, and thus membrane integrity, from seeds as an indicator of seed viability have been tested in palm seeds and have shown high correlations with germination rate and speed in some species (Martins et al. 2003).

Cleaning Palm Seed. Most palm seeds are covered with a fleshy mesocarp [the term “pericarp”, which also includes the inner, often stony endocarp (Tomlinson 1990), has been misapplied in many papers] that generally must be removed prior to planting. For small lots of seeds with soft mesocarp, this can be achieved by rubbing and squeezing the fruits together by hand with frequent water rinses (Donselman 1982; Hodel 1998). When handling palm fruits, it is advisable to wear rubber gloves as the mesocarps of genera such as *Caryota*, *Roystonea*, *Carpentaria*, *Arenga*, *Hyophorbe*, and *Chamaedorea* contain high concentrations of oxalate crystals that are highly irritating to exposed skin (Snyder et al. 1979; Broschat and Latham 1994). Firm mesocarp may be removed with a knife, but for larger numbers of palm seeds, more innovative mechanical methods have been employed (Broschat 1994a; Markus and Banks

1999). In species such as *C. nucifera*, the entire fibrous mesocarp is left on the seed prior to planting.

The germination response to mesocarp removal depends on the maturity of the fruit and varies among palm species, but, in general, removal of mesocarp from mature fruit increases germination percentage, decreases germination time, or both. (Broschat and Donselman 1986b, 1987b; Martins et al. 1996; Ehara et al. 2001; Maciel 2001; Rauch 2001). The positive response of seeds from mature fruits to mesocarp removal suggests the presence of a germination inhibitor within the mesocarp (Broschat and Donselman 1987b; Rauch 2001). This was confirmed using lettuce seed bioassays for *Washingtonia filifera* and *Dypsis lutescens* (Rauch 2001; Khan 2006). Ehara et al. (2001) demonstrated that the endocarp and sarcotesta of *Metroxylon sagu* also contained germination inhibitors that must be leached from seeds before they germinate. Mature endosperm from *C. nucifera* has also been found to inhibit *in vitro* embryo growth of excised embryos of this species (Cutter and Wilson 1954).

When seeds from mature but green fruits were sown, mesocarp removal greatly decreased germination percentage in *D. lutescens* (Broschat and Donselman 1986b), suggesting that the mesocarp may be essential for maturation of the immature embryo. In contrast, seed from mature green fruit of *S. romanzoffiana* germinated faster and had a higher final germination percentage when cleaned (Broschat and Donselman 1987b).

Palm Seed Storage. The ability to store palm seeds varies widely among species and storage methods. DeLeon (1958) generalized that palms endemic to subtropical areas, from areas having distinct wet-dry or hot-cool season, or those having seeds with thick endocarps remain viable for 2–3 months. However, those from tropical areas where temperature and rainfall vary little may remain viable for only 2 or 3 weeks. Davies and Pritchard (1998) found that drought-tolerant species such as *Hyphaene thebaica*, *Hyphaene petersiana*, and *Medemia argun* had excellent germination after 2–3 years of storage at 21°C. Generally, seed desiccation is the primary reason for loss of viability in stored palm seeds. Seeds that can survive desiccation and storage are classified as being orthodox, while those that are intolerant of drying or storage are categorized as being recalcitrant (Hong and Ellis 1996; Orozco-Segovia et al. 2003). The percentage of water in palm seeds varies greatly among palm species (Carpenter and Gilman 1988; Carpenter and Ostmark 1994; Martins et al. 1999a, 2000, 2003; Andrade 2001; Bovi et al. 2004) and even among cultivars of species

such as *E. guineensis* (Ellis et al. 1991) and *Euterpe oleracea* (Martins et al. 1999b). Rakotondranony et al. (2006) found that drying seeds of four species of *Ravenea* to 5% moisture resulted in a complete loss of viability. Leonhardt et al. (1984) found that seeds of *B. armata* were little affected by drying to less than 30% of their initial moisture content, while germination of *Hyophorbe verschaffeltii* and *Adonidia merrillii* was greatly reduced when dried to 80 or 70% of their initial moisture content, respectively. *D. lutescens*, *Pritchardia thurstonii*, *Roystonea regia*, and *Sabal palmetto* showed intermediate reductions in germination due to drying. Pritchard et al. (2004) tested four species each of *Phoenix* and *Syagrus* and found that only *Phoenix roebelenii* and *Syagrus schizophylla* were intolerant of desiccation to less than 10% moisture. Wood and Pritchard (2003) found that dried and stored seed of *Hyophorbe lagenicaulis* had final germination percentages equivalent to undried and/or stored seed, but dried and/or stored seeds germinated much more slowly. Ferreira and Santos (1993) showed that the speed of drying also affected palm seed viability and vigor, with slow drying favoring seed viability.

Because palm seed drying is generally detrimental to seed survival during storage, use of moisture-retaining containers is critical for maintaining palm seed viability. Broschat and Donselman (1986b) found that germination percentage of seeds of *D. lutescens* stored in paper bags was reduced by half within 3 months, while those stored in polyethylene bags had similar reductions in germination after 15 months. LeSaint et al. (1989) showed that *C. nucifera* seeds could be stored for up to 4 months if sealed in plastic without atmospheric modification. Seeds of this species rapidly lost viability after 1 month when stored without any protective covering (Remison and Mgbeze 1988).

The possibility of storing dried palm seeds cryogenically has been investigated by Dickie et al. (1992, 1993). Of the 14 species they tested, only *W. filifera* and *Sabal mexicana* showed potential for long-term storage. Seeds of *Sabal causarium* also survived drying from 27% to ~7% moisture, although germination was delayed at 10% or lower moisture content (Carpenter 1989). This species also survived low temperatures of -20°C , making it a good candidate for cryogenic storage. *H. thebaica* and *H. petersiana* also survived extended storage at -20°C (Davies and Pritchard 1998). Al-Madeni and Tisserat (1986) concluded that *P. dactylifera* seeds could be stored under cryogenic conditions. Because these species are native to dry climates, their seeds tolerated the necessary drying better than those of more tropical species (Dickie et al. 1992). In *L. chinensis*, seeds did not survive cryoexposure at any moisture content, but embryos were successfully

stored for 2 years after desiccation to 20% moisture (Wen 2009). Leonhardt et al. (1984) examined the effects of seed drying for cryopreservation for seven species of palms and found that only *B. armata*, a drought-tolerant species, was able to tolerate drying and exposure to liquid nitrogen.

Moisture-retaining containers also promote fungal growth on seeds, so dusting stored seeds with seed-protectant fungicides has been recommended (Broschat and Donselman 1986b, 1987b, 1988; LeSaint et al. 1989). However, Meerow (1994c) demonstrated that treatment of *P. roebelenii* seeds with thiram or captan reduced germination speed, and captan also reduced final germination percentage compared with untreated seed.

Storage temperature also strongly affects seed viability. Germination rate for seeds of *D. lutescens* dropped by half after 450 days of storage at 23°C, but a similar reduction in germination rate occurred after 70 days of storage at 15°C. No seed stored at 5°C germinated after 10 days (Sento 1972; Broschat and Donselman 1986b). Storage of *Chamaedorea elegans* seed for up to 8 weeks at 5°C significantly reduced germination percentage compared with those stored at 23–25°C (Poole and Conover 1974). Seed of *E. guineensis* could be stored for 24 weeks at 28°C, but only 19 weeks at 20°C and 0 weeks at 5°C (Mok and Hor 1977). Ellis et al. (1991) showed that seeds of this species stored at 0 or –20°C had greatly reduced viability compared with those stored at 15°C. Seeds of *Rhapis excelsa* germinated well after 35 months at 3–5°C, but only 8 months at room temperature (Sento 1971a). Similarly, *Sabal minor* seeds germinated well after 2 years of storage at 3–5°C, but only 7 months at room temperature (Sento 1970).

Germination rate for *Attalea speciosa* seed dropped off rapidly after 3 months of storage at 15°C, compared with ambient tropical temperatures in Brazil and virtually no seed survived storage at 10°C (Carvalho et al. 1988). On the other hand, more cold hardy species such as *C. humilis* were able to tolerate 85 days of storage at 5, –18, and –80°C without significant loss of viability, while long-term storage (569 days) resulted in slower germination at 5 and –18°C than at 15°C (González-Benito et al. 2006). *S. causerianum*, another cold-tolerant species, survived storage well at –10 or –20°C and germinated significantly faster than seed stored at 0 or 5°C (Carpenter 1989). Chien and Chen (2008) found that seeds of *Phoenix loureiroi* survived 12 months of storage at 4°C with no loss of germinability, but those stored at –20°C had germination decreased by 15–44%. They also showed that seeds of this species retained their original viability when stored for 1 year at –196°C in liquid nitrogen.

Germination Environment. The primary function of a germination substrate is to provide a uniformly moist, but not saturated environment. Alternating cycles of wetness and dryness are usually detrimental to palm seeds during germination (Meerow and Broschat 2012). Those authors recommended a 1:1 blend of peat and perlite, but a wide range of well-aerated materials has been successfully used to germinate palm seeds (Donselman 1982; Hodel 1998; Markus and Banks 1999; Airo et al. 2011). Rauch (2001) evaluated seven different substrates for germinating seeds of *Ptychosperma macarthurii* and found that peat and peat-cinders (1:1) were less satisfactory than peat-vermiculite (1:1), peat, or vermiculite. Sento (1967, 1970, 1971a,b, 1972, 1974) germinated seeds of 20 species of palms in vermiculite, sand, or a clay-loam soil. Seeds of *H. verschaffeltii*, *R. regia*, *Trachycarpus fortunei*, *P. macarthurii*, and *Butia capitata* (nearly all material cultivated under this name is actually *B. odorata*) germinated best in the clay-loam soil, but most others performed better in vermiculite or sand. Three species of *Phoenix* were indifferent to germination substrate. Seeds of *C. nucifera* are typically germinated in ground beds, partially covered with wood chips or other well-drained materials. The optimum germination substrate will likely vary, depending on the drying potential of the germination environment (Broschat and Donselman 1986b).

Palm seeds can be sown in cell packs, tree cones, flats, large or small nursery containers, or in raised ground beds, with deeper containers providing better drainage and room for development of remote germinating seeds (Meerow and Broschat 2012). Seeds of palm species having remote germination (e.g., *Bismarckia*, *Borassus*) push a shoot down as deep as 30 cm before sending up the first leaf (Morton 1988; Markus and Banks 1999). These seeds are often planted singly near the surface of the substrate in deep containers to prevent damage to the seedling during transplanting.

One method that has been employed for small lots of seed is to mix the seeds with moist peat or coir and seal them in polyethylene bags (Corrado and Wuidart 1990; Carpenter et al. 1993b; Broschat 1998b; Markus and Banks 1999). Individual seedlings are removed periodically for transplanting as they germinate. This method eliminates the need for mist or irrigation to maintain substrate moisture that would be lost due to evaporation from open containers. These bags can also be placed in incubators to maintain constant high temperatures under cool ambient conditions.

The need for uniform moisture in the germination substrate can be met by intermittent mist or light irrigation, but also by varying the planting depth to compensate for substrate surface drying. Seeds of *D. lutescens*

germinated better under full sun if planted deeper, while shallow planted seeds germinated better under shade (Broschat and Donselman 1986b). Covering the top of the germination container with clear plastic sheeting can also help retain moisture in the substrate (Meerow and Broschat 2012). Donselman (1982) suggests planting seed of cocosoid palms, which have water-retentive fibers attached to the endocarp, such that the tops of the seeds are exposed, but other palms with smooth endocarps should be planted ~ 0.5 cm deep.

Orientation of the seed during germination is usually not considered when sowing palm seeds since those having elongated shapes naturally lay on their sides. However, in *C. nucifera*, seed orientation was evaluated and horizontally positioned seeds germinated slightly better than those planted vertically (Remison and Mgbeze 1988).

Exposure to light during germination did not affect germination in *Aiphanes aculeata* or *Calamus manan* (Mohamad and Said 1990; Silva et al. 1999), but seeds of *H. lagenicaulis* germinated under 12 h of light had a much higher germination percentage than those germinated in darkness (Wood and Pritchard 2003). Light strongly inhibited germination of *S. palmetto* seeds (Brown 1976). Light intensity also affects substrate temperature and drying potential of the substrate (Broschat and Donselman 1986b; Bernardes et al. 1996). High light intensity may not be favorable for growth of emerging seedlings of species adapted to low light understory environments (Meerow and Broschat 2012).

High temperatures are almost universally recommended for germinating palm seeds. Optimum germination temperatures for most species of palms are usually around 30–35°C, although some cold hardy species do better at 25°C (Hodel 1998) (Table 1.2). A few species such as *E. guineensis* are typically germinated at 38–40°C (Hussey 1958; Rees 1960). Alternating temperatures have sometimes performed better than constant temperatures. Carpenter et al. (1993a) showed that *Rhapidophyllum hystrix* germinated best with 6 h at 25°C and 18 h at 40°C. Continuous 40°C temperatures resulted in poor germination in this species. Alternating 25/35 or 30/40°C temperatures yielded the highest germination percentage in *Leucothrinax morrisii*, but continuous 35°C temperatures resulted in the most rapid germination (Carpenter 1988a). For *S. causerum*, 30/40°C alternating temperatures resulted in equivalent germination percentage but more rapid germination times than continuous 35°C (Carpenter 1989).

Soil salinity can also affect seed germination. Ramoliya and Pandey (2003) found that seed germination of *P. dactylifera* seeds was negatively correlated with soil salinity, with no seeds emerging at salinities above

Table 1.2. Optimum germination temperatures for several species of palm seeds.

Species	Temperature (°C)	Reference
<i>Acoelorrhaphe wrightii</i>	35–40	Carpenter 1988
<i>A. alexandrae</i>	30	Sento 1971a
<i>Areca catechu</i>	25–30	Sento 1971b
<i>Butia odorata</i>	30	Sento 1967
<i>B. odorata</i>	40	Carpenter 1988
<i>Caryota mitis</i>	30	Sento 1971b
<i>Chamaedorea elegans</i>	30	Carpenter and Ostmark 1994
<i>C. elegans</i>	27	Poole and Conover 1974
<i>C. microspadix</i>	25–30	Carpenter and Ostmark 1994
<i>C. radicalis</i>	30	Carpenter and Ostmark 1994
<i>C. seifrizii</i>	29–32	Donselman 1982
<i>C. seifrizii</i>	30	Carpenter and Ostmark 1994
<i>Chamaerops humilis</i>	20–25, 15/25	González-Benito et al. 2006
<i>C. humilis</i>	15–25	Chatty and Tissaoui 1999
<i>Coccothrinax argentata</i>	35	Carpenter 1988
<i>Cocos nucifera</i>	30–35	Sento 1974
<i>Dypsis lutescens</i>	30–35	Broschat and Donselman 1986a,b
<i>D. lutescens</i>	25	Sento 1972
<i>Elaeis guineensis</i>	38–40	Hussey 1958
<i>Hyophorbe verschaffeltii</i>	25–35	Sento 1972
<i>Leucothrinax morrisii</i>	35	Carpenter and Gilman 1988; Carpenter 1988
<i>Livistona chinensis</i>	30	Sento 1970
<i>L. chinensis</i>	15–35	Chatty and Tissaoui 1999
<i>Phoenix canariensis</i>	30–35	Sento 1967
<i>P. canariensis</i>	25–35	Chatty and Tissaoui 1999
<i>P. dactylifera</i>	25–35	Sento 1972
<i>P. loureiroi</i>	30	Sento 1974
<i>P. roebelenii</i>	30	Sento 1970
<i>P. sylvestris</i>	30–35	Sento 1974
<i>Pritchardia remota</i>	25–35	Pérez et al. 2008
<i>Ptychosperma macarthurii</i>	30–35	Sento 1971a
<i>Rhapidophyllum Hystrix</i>	25/40	Carpenter et al. 1993b
<i>R. hystrix</i>	30	Carpenter et al. 1993a
<i>Roystonea regia</i>	30	Sento 1971b
<i>R. regia</i>	30	Muñoz et al. 1992
<i>Rhapis excelsa</i>	30	Sento 1971a
<i>Sabal causiarum</i>	25 or 20/30	Carpenter 1989
<i>S. etonia</i>	30–35	Carpenter 1988
<i>S. mauritiiformis</i>	30	Briceño and Maciel 2004
<i>S. minor</i>	25	Chatty and Tissaoui 1999
<i>S. palmetto</i>	35	Carpenter 1987
<i>S. palmetto</i>	27–33 or 25/35	Brown 1976
<i>S. palmetto</i>	25	Sento 1970

(continued)

Table 1.2. (Continued)

Species	Temperature (°C)	Reference
<i>Serenoa repens</i>	35	Carpenter 1986, 1987
<i>Syagrus romanzoffiana</i>	30–35 or 25/35	Pivetta et al. 2005
<i>Trachycarpus fortunei</i>	30	Sento 1971a
<i>T. fortunei</i>	15–25	Chatty and Tissaoui 1999
<i>Washingtonia filifera</i>	25–35	Chatty and Tissaoui 1999
<i>W. robusta</i>	25–35	Sento 1967

12.8 dS m⁻¹. Khudairi (1958) found that germination in this species was not inhibited by NaCl until concentrations exceeded 0.5% and not greatly up to 1.5%. Interestingly, this author found that similar concentrations of sucrose were more inhibitory to germination than NaCl. *H. thebaica* seed was more tolerant of salinity with little reduction in final germination percentage at 12 dS m⁻¹, especially at optimal germination temperatures (Ali 2007). Final germination percentage was unaffected by substrate salinity up to 6.2 dS m⁻¹ for *P. canariensis*, but only 1.9 dS m⁻¹ for *S. palmetto* (Alemán et al. 1999). The percentage germination decrease per unit of salinity above these values was 4.2% for the former and 5.0% for the latter. Brown (1976) found that *S. palmetto* seeds germinated well at salinities below ~15.2 dS m⁻¹.

Germination Enhancement Treatments. Slow germination in many species of palms has been attributed to a thick, impervious endocarp and sarcotesta (Mousa et al. 1998; Ehara et al. 2001; Orozco-Segovia et al. 2003). However, Pérez (2009) and Robertson and Small (1977) have demonstrated that the endocarps of *Pritchardia remota* and *Jubaeopsis caffra* are in fact water permeable. In *P. remota*, growth of the embryo is believed to be mechanically restricted (Pérez 2009). Ehara et al. (2001) also suggested that restriction of embryo growth by the operculum was one of the factors inhibiting germination in *M. sagu*.

Several treatments have been used to overcome the various types of dormancies found in palm seeds (Odetola 1987). Mechanical scarification, including removal of the embryo cap, operculum, or endocarp, has been effective in improving both germination percentage and speed in some species, but has no effect on others (Table 1.3). Seed scarification using concentrated sulfuric acid has improved germination speed in a few species, but has no effect, or negative effects on other species. Morales-Payan and Santos (1997) used concentrated nitric acid to scarify seeds of seven species of palms and found it harmful to five species and beneficial only for *S. palmetto* seeds.

Table 1.3. Effects of seed germination enhancement treatments on germination speed and final germination percentage in several species of palms.

Species	Treatment	Germination ^z		Reference
		(%)	Speed	
<i>A. alexandrae</i>	Mechanical scarification	0	+	Nagao et al. 1980
<i>Ptychosperma macarthurii</i>	Mechanical scarification	0	+	Nagao et al. 1980
<i>Syagrus schizophylla</i>	Mechanical scarification	+	+	Pivetta et al. 2005
<i>Areca triandra</i>	Mechanical scarification	+	+	Yang et al. 2007
<i>Pritchardia</i> spp.	Mechanical scarification	0	+	Pérez et al. 2008b
<i>Rhapidophyllum hystrix</i>	Embryo cap removal	+	+	Carpenter et al. 1993a; Clancy and Sullivan 1988
<i>Copernicia</i> spp.	Operculum removal	+	+	Kitzke 1958
<i>Butia odorata</i>	Endocarp removal	+	0	Broschat 1998b
<i>Pritchardia remota</i>	Endocarp or operculum removal	0	+	Pérez et al. 2008a
<i>Livistona chinensis</i>	Endocarp removal	–	0	Maciel 1996
<i>Sabal palmetto</i>	Mechanical scarification	0	+	Dewir et al. 2011
<i>Thrinax morrissii</i>	Mechanical scarification	+	0	Dewir et al. 2011
<i>Phoenix roebelenii</i>	Mechanical scarification	+		Doughty et al. 1986
<i>P. reclinata</i>	Mechanical scarification	0	0	von Fintel et al. 2004
<i>Sabal mauritiiiformis</i>	Sulfuric acid scarification	–	+	Briceño and Maciel 2004
<i>S. palmetto</i>	Sulfuric acid scarification	0 or –	+	Dewir et al. 2011
<i>Chamaedorea Seifrizzii</i>	Sulfuric acid scarification 30 min	+		Daquinta et al. 1996
<i>Chamaerops humilis</i>	Mechanical and sulfuric acid scarification	+	+	Merlo et al. 1993
<i>C. humilis</i>	Sulfuric acid scarification 10 min		0	Airo et al. 2011
<i>Caryota urens</i>	Sulfuric acid scarification	–	0	Maciel 2002
<i>Areca Triandra</i>		–	–	Yang et al. 2007

(continued)

Table 1.3. (Continued)

Species	Treatment	Germination ^z		Reference
		(%)	Speed	
	Sulfuric acid scarification			
<i>Serenoa repens</i>	Sulfuric acid scarification	–	–	Carpenter 1986
<i>Acrocomia crispata</i>	Sulfuric acid scarification	0	0	Holmquist and Popenoe 1967
<i>Arenga engleri</i>	Sulfuric acid scarification	0	0	Holmquist and Popenoe 1967
<i>Phoenix reclinata</i>	Sulfuric acid scarification	0	0	von Fintel et al. 2004
<i>Euterpe Edulis</i>	Sulfuric acid scarification	0	0	Mullett et al. 1981
<i>Sabal palmetto</i>	Nitric acid scarification	+		Morales-Payan and Santos 1997
<i>Archontophoenix alexandrae</i>	Water soak 72 h	0	+	Nagao and Sakai 1979
<i>S. palmetto</i>	Water soak 7 days	+	+	Carpenter 1987
<i>S. repens</i>	Water soak 7 days	+	+	Carpenter 1987
<i>Dypsis lutescens</i>	Water soak 24 or 72 h	0	+	Schmidt and Rauch 1982; Morales-Payan and Santos 1997
<i>Roystonea oleracea</i>	Water soak 2 or 4 days	+	+	Maciel 2001
<i>Acrocomia standleyanum</i>	1 min soak in 100°C water	Lethal		Potvin et al. 2003
<i>P. reclinata</i>	1 min soak in 100°C water	Lethal		von Fintel et al. 2004
<i>D. lutescens</i>	1000 ppm GA ₃ 72 h	0	+	Schmidt and Rauch 1982
<i>A. alexandrae</i>	100 or 1000 ppm GA ₃	0	+	Nagao et al. 1980; Nagao and Sakai 1979
<i>Ptychosperma macarthurii</i>	1000 ppm GA ₃	0	+	Nagao et al. 1980
<i>Areca triandra</i>	100 or 200 ppm GA ₃	0	+	Yang et al. 2007
<i>A. triandra</i>	250 or 500 ppm GA ₃	0	0	Yang et al. 2007
<i>Phoenix roebelenii</i> (seed from green fruits)	1000 ppm GA ₃ 48 h	0	–	Broschat and Donselman 1987b
<i>P. roebelenii</i> (seed from ripe fruits)	1000 ppm GA ₃ 48 h	+	0	Broschat and Donselman 1987b
<i>Syagrus romanzoffiana</i>	1000 ppm GA ₃ 48 h	0	–	Broschat and Donselman 1987b
<i>Roystonea regia</i>	1000 ppm GA ₃ 48 h	–	0	Broschat and Donselman 1987b
<i>D. lutescens</i>	1000 ppm GA ₃ 48 h	0	+	Broschat and Donselman 1986b
<i>Howea forsteriana</i>	GA ₃ in organic solvents versus water		+	Chin et al. 1988

Table 1.3. (Continued)

Species	Treatment	Germination ^z		Reference
		(%)	Speed	
<i>Leucothrinax morrissii</i>	500 ppm GA ₃	–	–	Dewir et al. 2011
<i>Livistona chinensis</i>	500 ppm GA ₃ 72 h	0	0	Maciel 1996
<i>S. palmetto</i>	500 ppm GA ₃	+	0	Dewir et al. 2011
<i>S. repens</i>	GA ₃	0	0	Carpenter 1986
<i>S. repens</i>	10,000 ppm GA ₄ , 7–24 h	+	+	Makus 2008
<i>A. alexandrae</i>	BA or NAA	0	0	Nagao and Sakai 1979
<i>A. triandra</i>	BA, KNO ₃ , NaNO ₂	0 or –	0 or +	Yang et al. 2007
<i>A. triandra</i>	10 or 15% H ₂ O ₂ soaks 12 h	0	+	Yang et al. 2007
<i>Elaeis guineensis</i>	Pure oxygen environment	+	+	Hussey 1958
<i>Jubaeopsis caffra</i>	Pure oxygen environment	+	+	Robertson and Small 1977
<i>Euterpe edulis</i>	H ₂ O ₂ soak	–	–	Mullett et al. 1981

^z+, –, and 0 refer to significant positive, negative, and nonsignificant effects on seed germination, respectively.

Presoaking palm seeds in water for up to 7 days prior to planting has been effective in improving germination speed (Table 1.3) and has become a nearly universal recommendation (Rees 1963; Hodel 1998; Rauch 2001; Robinson 2009; Meerow and Broschat 2012). However, few studies have determined the optimum duration for these water soaks. Transient (1 min) soaking of seeds in water at 100°C was generally lethal to seeds of *Astrocaryum standleyanum* and *Phoenix reclinata* (Potvin et al. 2003; von Fintel et al. 2004).

Numerous studies have examined the effects of gibberellic acid (GA₃) in palm seed germination, but results varied widely by species. Germination speed has been accelerated in some species, but final germination percentage generally has been no better than for water-soaked seed (Table 1.3). Seed from green fruits of *P. roebelenii* germinated faster when soaked for 48 h in 1000 ppm GA₃, but this substance had no effect on half ripe or fully ripe seeds (Broschat and Donselman 1987b). While most studies have utilized aqueous solutions of GA₃, Chin et al. (1988) demonstrated that dissolving GA₃ in organic solvents such as dichloromethane, dimethylsulfoxide, or acetone significantly improved germination in *Howea forsteriana* seeds compared with aqueous solutions.

While presoaking seeds in GA₃ generally has a positive effect on palm seed germination, few studies have examined the effects of these

presoaks on subsequent seedling growth and morphology. Broschat and Donselman (1986b, 1987b) noted that seedlings of *D. lutescens*, *P. roebelenii*, *R. regia*, and *S. romanzoffiana* that had been soaked for 48 h in 1000 ppm GA₃ had weak, elongated, and sometimes distorted growth. These undesirable growth regulator effects were still apparent after a year of growth, thus negating any positive benefits of GA₃ during seed germination (Broschat and Donselman 1986b, 1987b). On the other hand, Maciel (1996, 2002) mentioned that presoaking seeds of *L. chinensis* and *Caryota urens* in 500 ppm GA₃ for 3–7 days had no effect on the appearance of the seedlings. Thus, concentration and duration of the soaks, as well the species, may determine how GA₃ affects seedling growth characteristics.

Benzyladenine (BA) and naphthalene acetic acid (NAA) have also been tested for their effects on palm seed germination but have shown no benefits (Table 1.3). Yang et al. (2007) evaluated the effects of various concentrations of BA, KNO₃, NaNO₂, and H₂O₂ on seed germination in *Areca triandra*. None of these compounds improved germination percentage and some resulted in reduced germination. However, KNO₃ at 0.2%, NaNO₂ at 0.1, 0.2, or 0.3%, and H₂O₂ at 10 or 15% significantly increased germination speed. The response to H₂O₂ suggests a benefit to oxidizing compounds. A germination atmosphere of pure oxygen greatly improved germination in *E. guineensis* and *J. caffra* seeds (Hussey 1958; Robertson and Small 1977). However, soaking seeds of *Euterpe edulis* in H₂O₂ did not enhance germination and resulted in stunted seedlings (Mullett et al. 1981).

Stratification, or subjection of seeds to warm or cold temperatures to overcome dormancy, is a common practice for seeds of temperate plants, but has received little attention in palms. In *E. guineensis*, maintaining seeds under dry or moist conditions at 38–40°C for 40–80 days promotes rapid and uniform germination at lower temperatures (Rees 1962; Addae-Kagyah et al. 1988; Corrado and Wuidart 1990; Martine et al. 2009). Seeds of *A. triandra* held for 60 days at 4°C germinated more rapidly than control seeds, although treatment did not affect final germination percentage (Yang et al. 2007). Seeds of *R. hystrix* stored for 1 year at 5°C germinated much better than freshly planted seeds, although scarification greatly enhanced this effect (Carpenter et al. 1993b). Seeds of *R. regia* appear to have immature embryos upon harvest, which requires a period of warm storage of 4–9 months before germination can occur (Broschat and Donselman 1987b; Muñoz et al. 1992). Carpenter (1988b) showed that an “after-ripening” period of 90–150 days at 5°, 15°, or 25°C was necessary for germination in *B. odorata*, however, Broschat (1998b) found no benefit to after-ripening

storage in this species. Since excised embryos of *B. odorata* germinated promptly, Carpenter (1988b) concluded that this delay in germination could not be attributed to immature embryos.

Embryo Culture. Due to the slow, sporadic, and often poor germination of some palm seeds, embryo culture has been suggested as a potentially useful method for rapid propagation of rare and difficult to germinate species of palms. Hodel (1977) successfully germinated excised embryos of *Pritchardia kaalae* and *Veitchia joannis* in a modified Vacin and Went medium under Gro-Lux lamps at 29°C. Zygotic embryos of *H. lagenicaulis* were germinated using Murashige and Skoog (MS) salts, sucrose, and activated charcoal under cool white fluorescent lighting at 26°C (Sarasan et al. 2005). *Jubaea chilensis* embryos were similarly propagated using MS salts and activated charcoal, but no hormones (Yuri 1987). Thawaro and Te-chato (2010) evaluated a number of culture media on the germination of *E. guineensis* embryos and obtained the best results with one-half MS medium. Zaid and Tisserat (1984) successfully germinated 17 of 38 species of palms from excised embryos *in vitro*.

2. Vegetative Propagation. While the majority of ornamental palms are propagated exclusively by seeds, division as a propagation method is usually successful in those species that possess rhizomes (e.g., *Rhapis* spp.) or multiple stems (McKamey 1999; Broschat and Meerow 2000). A modification of division is the separation of offshoots from the parent plant. This method is used primarily in the propagation of *P. dactylifera* clones for commercial date production or *B. gasipaes* for commercial heart-of-palm production (Tisserat 1983; Mora-Urpí et al. 1997; Hodel and Johnson 2007). With either method, mounding soil up around the base of the stem several months prior to separation encourages growth of root initials (Tisserat 1983). Application of IBA to offshoots of *B. gasipaes* increased root production and transplant survival, but suppressed subsequent shoot growth in the field (Pinedo-Panduro and Meléndez-Torres 1993). Application of IAA, IBA, or NAA has generally enhanced rooting in aerial offshoots of *P. dactylifera* (Al-Mana et al. 1996; Bakr et al. 2010; Zirari and Ichir 2010; Afzal et al. 2011).

The practice of marcottage or air layering has been successfully used on a few species of palms that possess aerial root initials along their stems. While technically not a propagation method for single stem palms, because the basal portion of the plant invariably dies, it can be used to rejuvenate excessively tall palms. Buhler (1974) demonstrated

its use on *Chamaedorea ernesti-augusti* and *Chamaedorea metallica*, but was less successful in *C. elegans*. This method has been employed on a larger scale in *C. nucifera* (Davis 1961) and has been suggested for rooting aerial offshoots in *P. dactylifera* (Tisserat 1983). Hodel and Pittenger (2003a,b) showed that offshoots of *P. dactylifera* that were 10–35 cm in diameter had the highest survival rate, while a minimum of 29 existing roots on the offshoot optimized survival.

3. Tissue Culture. Tissue culture has been widely used for rapid multiplication of many types of plants. However, palms have generally been difficult to establish in tissue culture. Although techniques for tissue culture developed for commercially important food, oil, and medicinal palms such as *B. gasipaes*, *C. nucifera* (Batugal and Engelmann 1998; Pérez-Núñez et al. 2006), *E. guineensis* (Krikorian and Kann 1986), *E. edulis* (Guerra and Handro 1988), *P. dactylifera* (Tisserat 1979, 1983), and *Serenoa repens* (Gallo-Meagher and Green 2002) and are widely used for clonal propagation of superior genotypes, they are beyond the scope of this book and will not be discussed in detail here. Although tissue culture is not used commercially for propagation of ornamental palms, techniques have been developed for *P. canariensis* (Rousseau et al. 1999), *H. lagenicaulis* (Sarasan et al. 2005), and *Geonoma gamiova* (Dias et al. 1994). Zaid and Tisserat (1984) found that 9 of 38 species of palms tested produced adventitious embryos from callous.

B. Nursery Production

1. Container Production. Meerow (1994a) described four basic production regimes for palms grown in containers. Three of these are limited to tropical or subtropical climates where palms can be grown without heated greenhouses. However, any palm intended for indoors use must be acclimatized for up to a year prior to exposure to a low light environment since palm leaves produced under full sun will not survive under typical interiorscape conditions (Broschat et al. 1989). Thus, palms destined for interior use are grown for all or the final phase of their production under shade.

Container-grown palms that will be used as liners for field production or as landscape plants are typically grown continuously under full sun conditions (Meerow 1994a). Others may be grown in full sun for several years to increase caliper or suckering in clustering species prior to acclimatization under 70–83% shade for up to a year for interior use. Small, shade-requiring species may be grown entirely in containers under shade, although less shade (50–63%) may be used during the

initial production stage to improve compactness, followed by acclimatization under 70–83% shade for the final phase (Meerow 1994a). Finally, some large species intended for use as interiorscape specimens may be field-grown for several years prior to digging, containerization, and acclimatization for up to a year under 70–80% shade.

Containers. Containers used in palm production are typically full-depth (as opposed to shallower “azalea” type containers) polypropylene nursery containers, although polyethylene bags are widely used outside of the United States (Broschat and Meerow 2000). Container shape has been found to affect palm growth, with square containers producing smaller stem diameters than round ones in *T. fortunei* (Beeson and Newton 1992). Excessively deep (relative to diameter) containers have also been shown to reduce palm growth and health in *R. excelsa* (Luz et al. 2006).

Wrapping roots in container-grown palms do not cause serious problems with girdling roots or plant stability following transplanting into landscapes or field nurseries as occurs with other woody, non-palm, trees. Still, several studies have examined the effects of various root-pruning chemicals or containers on palm root and shoot growth. Treatment of the inside surfaces of traditional nursery containers with cupric hydroxide-based paints had no effect on final stem diameter of *T. fortunei* seedlings (Beeson and Newton 1992). This treatment had no effect on root or shoot dry weight but reduced the weight and percentage of circling roots of *Carpentaria acuminata* seedlings (Svenson and Broschat 1992). Copper-treated containers had no effect on shoot growth or surface root coverage in *C. elegans*, but did reduce root dry weight (Henley 1995).

Several designs of “air-pruning” containers have been tested in palms. Most of these resulted in fewer new leaves, smaller stem caliper, and reduced overall quality in *H. forsteriana* and *A. cunninghamiana* (Hodel et al. 2012). However, root dry weight was unaffected in either species.

As containers tend to blow over in high winds, growth of *W. robusta* in 95 L containers buried in the soil was compared with direct planting in the ground or placing the containers on the soil surface. Palms growing in containers on the soil surface grew taller than when the containers were buried or the palms were directly planted in the soil. This result was attributed to warmer soil temperatures in the above-ground containers (Yeager et al. 1994).

Substrates. A wide range of substrates has been successfully utilized to produce palms in containers (Broschat and Meerow 2000; Klock-Moore

and Broschat 2001). Palm-growing substrates should be well drained, well aerated, and slow to decompose since palms may remain in a container for several years. Meerow (1994a) recommended a substrate with ~10–15% air space and 30–40% (by volume) water holding capacity. The components used to create these substrates vary according to local availability and cost. Most contain sand and organic components such as peat or bark, but coconut coir dust and various waste composts have been utilized as substitutes for peat (Conover and Poole 1990; Bovi et al. 1994; Demattê et al. 1994; Meerow 1995). Composted peanut shells were found to be superior to peat moss in the production of *Caryota mitis* (Habib 2012). However, some organic materials such as composted sewage sludge have been shown to bind Mn tightly and induce severe Mn deficiencies in palms (Broschat 1991a). In some areas volcanic cinders are the primary component of potting substrates (Cid et al. 1999; Broschat and Meerow 2000). Amendment of highly leached native sand soil with up to 20% (by volume) clinoptilolitic zeolite improved growth and quality of container-grown *D. lutescens*, but similar amendment of a pine bark, sedge peat and sand substrate had no effect (Broschat 2001).

Addition of mycorrhizal (*Glomus* spp.) inoculants to potting substrates was shown to benefit *P. roebelenii* growing in a sterilized potting substrate (Jaizme-Vega and Díaz-Pérez 1999). In *P. canariensis* mycorrhizal inoculation improved growth in sterilized potting substrate but only if the plants were not fertilized (Morte and Honrubia 2002). In both studies, infection rates were very low (28% and 8%, respectively for the two studies) and required up to 8 months for establishment. Since most potting substrates used for palm production are not sterilized and must be fertilized, the practical value of these inoculations may be limited. Inoculation with a commercial bacterial inoculant had no effect on *D. lutescens* in unsterilized potting substrate (Elliott and Broschat 2002). However, El-Khateeb et al. (2010) found that addition of algal extract, beneficial bacteria, or mycorrhizae to container-grown *C. elegans* improved root and shoot growth over the control treatment.

Transplanting. Palm seedlings growing in germination flats or other containers should be transplanted before significant root development has occurred to prevent damage to the root system when separating the plants. Murakami and Rauch (1984) found that seedlings of *D. lutescens* had increased growth and survival when transplanted at the spike leaf or single-leaf stage compared with plants with two leaves. Exposing separated seedlings to air for 30 min reduced growth and survival, especially for two-leaf seedlings.

Seedlings should be planted such that the bottom of the stem axis is no more than 1 cm below the substrate surface. Species having remote germination may require planting the seedling shallower than it was in the germination container (Broschat and Meerow 2000). If the seed is still attached to the seedling, it should not be removed. While most palms are planted one seedling per container, single stem or even clustering species are often planted as multiple plants per container. Newly transplanted palms should be placed under 40–50% shade for several weeks or until new growth becomes apparent (Poole and Conover 1977a; Broschat and Meerow 2000).

Palm seedlings should not be planted into excessively large containers since the bulk of the substrate will remain too wet for optimum palm growth (Broschat and Meerow 2000). They can be transplanted into larger containers once the entire container volume is densely filled with roots. Tightly wrapped root balls can be planted intact, since wrapping roots will quickly be replaced by new roots arising from the base of the seedling stem.

Irrigation. Palms have been successfully grown in containers using overhead irrigation, drip or trickle irrigation, or subirrigation (Broschat and Meerow 2000). Container substrates should be kept moist, but never saturated, for optimum palm growth. The frequency of irrigation will thus depend not only on substrate water holding capacity but also on species and size of the plant, temperature, relative humidity, light intensity, wind, and other environmental factors (Demattê et al. 1994; Klock-Moore and Broschat 2001). Klock-Moore and Broschat (2000) found that container-grown *D. lutescens* grew better with overhead irrigation than subirrigation. Since palms grow relatively slowly and may remain in a particular container for a long time, fertilizer salt buildup requires periodic overhead leaching of the substrate in subirrigated palms (Klock-Moore and Broschat 2001). Khurram and Miyamoto (2005) determined the tolerance of nine species of cold-hardy palms to saline irrigation water. Relative water demand for four species of container-grown palms was found to be lower than for most non-palm species tested (Fitzpatrick 1983).

Light. The light intensity under which container-grown palms should be grown depends upon the species, fertilization rate, and the purpose for which it is being grown. In general, the rate of photosynthesis increases with increasing light intensity until the light saturation point is reached (Broschat and Meerow 2000). Further increases in light intensity can cause sunburn or photooxidation of exposed leaf tissue (Elliott et al.

2004). The light intensity at which this occurs varies among species and is influenced by the light intensity under which a particular leaf developed. At lower light intensities, photosynthetic rates decrease until the light compensation point (LCP) is reached. LCP is also influenced by the light intensity under which a leaf developed (Reyes et al. 1996a,b). Palms grown under shade generally have darker green color and longer, thinner, and weaker petioles and leaves than those grown in full sun (Broschat et al. 1989). The total number of leaves is not affected by light intensity (Ingram and McConnell 1980; Broschat et al. 1989; Reyes et al. 1996a; Gutiérrez and Jiménez 2007).

Palms growing under high light intensities have high LCPs, and when these palms are moved into low light environments such as interior-scapes, their relatively inefficient sun-grown leaves quickly senesce and are gradually replaced by shade-adapted leaves with lower LCPs (Broschat et al. 1989). A similar process likely occurs when shade-grown palms are moved into high-light environments.

Light intensity strongly affects palm nutritional requirements, with sun-grown palms requiring much higher fertilization levels to achieve the same dark green coloration and growth rate. Light compensation point can also be affected by fertilization rate, with LCP decreasing with increasing fertilization rate in *C. elegans* but increasing with increasing fertilization rate in *D. lutescens* (Reyes et al. 1996a,b).

Newly transplanted palm seedlings are usually grown under 40–60% shade to prevent burning (Gutiérrez and Jiménez 2007), but those destined for use in the landscape or field nursery production are eventually moved into full sun. Those intended for interior usage are typically moved into 70–80% shade for acclimatization for the final 3–12 months of production (Broschat and Meerow 2000).

Light spectral quality has been little studied in palms. George et al. (2011) grew *Chamaedorea cataractarum* using red- or blue-colored plastic mulch or uncovered potting substrate, but found no significant differences in plant growth parameters or chlorophyll *a* or *b* contents.

Fertilization. Fertilization of container-grown palms is similar to that for other woody ornamental species (Conover et al. 1975; Broschat 2009). Because many container substrates contain organic components such as pine bark that are known to tie up nitrogen (N) (Ogden et al. 1987), high N fertilization rates are required. Conover et al. (1975) recommend application rates of 242 kg ha⁻¹ year⁻¹ for *C. elegans* growing under 73% shade and 303 kg ha⁻¹ year⁻¹ for *D. lutescens* and *Chamaedorea seifrizii* grown under 55% shade. When fertigation was used, Poole and Henley (1981) found that rates >250 ppm

N decreased growth of *C. elegans*. Palms growing in full sun generally require higher fertilization rates (Broschat 2002).

Controlled-release fertilizers having a ratio of $\sim 3\text{N}:0.4\text{P}:1.7\text{K}$ and a longevity of at least 6 months are widely used in container production of palms (Broschat 2009). Resin-coated products, such as Osmocote® or Nutricote®, have generally performed better than water-soluble or other types of controlled-release fertilizers (Neel and Donselman 1977; Poole and Conover 1977b, 1989; Rauch et al. 1988; Rauch and Murakami 1994), but controlled-release plus liquid fertilizer combinations were superior to controlled-release fertilizer alone in *C. elegans* and *H. forsteriana* (Conover and Sanders 1978). Optimum fertilization rates were determined for *D. lutescens* and *H. forsteriana* using Osmocote by Poole and Conover (1975, 1990) and Lamont et al. (1988) and with liquid fertilizer solutions for *D. lutescens* by Poole and Conover (1985). Broschat (1995a) compared growth of *D. lutescens* when fertilized at the same N rate using liquid, soluble granular, or controlled-release formulations and found that liquid and controlled-release fertilization produced better plants than soluble granular products. Broschat and Moore (2003) studied placement of controlled-release fertilizers (top-dressed, incorporated into the substrate, or layered beneath the transplanted liner root ball). They found that incorporation was the best method for *D. lutescens*, but was less effective for *A. alexandrae* and *Wodyetia bifurcata*. Placement made no difference for *P. macarthurii* and *C. mitis*.

Various organic fertilizer products have been evaluated in palms, with castor bean cake, with or without pyroligneous extract, performing better than a water-soluble inorganic fertilizer (Wanderley et al. 2012). Supplemental foliar sprays with an organic fertilizer resulted in superior growth of *R. excelsa* in clay soil, cow manure, and sand substrate (Luz et al. 2008). *D. lutescens* grown in containers using pasteurized poultry litter as a partial substitute for resin-coated fertilizer grew poorly compared with those grown with only resin-coated fertilizer (Broschat 2008a).

Broschat and Klock-Moore (2000) examined the shoot, root, and root to shoot ratio of *D. lutescens* fertilized with varying rates of P and found that increasing P fertilization rate decreased root growth relative to shoot growth. Use of superphosphate fertilizers that are high in fluorides has been shown to result in foliar necrosis in *D. lutescens*, *C. elegans*, and *C. seifrizii* due to fluoride toxicity (Poole and Conover 1981a,b, 1982a).

Broschat and Elliott (2005a) evaluated the effectiveness of various Fe sources in *W. bifurcata* and found that only the chelates FeDTPA,

FeEDTA + FeHEDTA, and especially FeEDDHA were capable of improving chlorosis. Poole and Conover (1982b) compared the phytotoxicity of foliar-applied copper compounds on *D. lutescens* and *C. seifrizii* and found that CuEDTA, as well as two copper fungicides, caused foliar necrosis on both the species.

2. Field Production of Palms. Field nurseries are the most efficient and economical means of growing large or slow-growing species of palms to marketable size (Broschat and Meerow 2000). Palms intended for exterior landscape use can be grown to any size in the field since they are easily transplanted as large specimens. Palms intended for interior usage are typically grown in the field until about a year prior to marketing when they are dug, containerized, and moved into a shadehouse for acclimatization. Other reasons for field production of ornamental palms include seed production and production of leaves for the cut foliage market (Meerow 1994b).

Production Site and Layout. Ornamental palms have been commercially grown on a wide range of soil types, but soils should be well drained to provide adequate aeration for root growth and to facilitate harvest during periods of heavy rainfall (Broschat and Meerow 2000). In soils with high water holding capacity and high water tables, planting beds may be raised up to 30 cm or more to provide better drainage and to facilitate digging (Meerow 1994b). A disadvantage of raised beds is reduced stability during high winds (Meerow 1994b). Deep soils are preferred, but palms have been produced in shallow soils 45–60 cm deep.

Palms can be planted at densities ranging 1,125–10,000 plants per hectare, depending on the species grown and the size to which they will be grown (Broschat and Meerow 2000). Palms that will be mechanically harvested are typically grown with row spacing of 3.0–3.6 m to facilitate movement of equipment, but those that will be hand dug can be grown in rows spaced as little as 2.4 m apart. For optimum use of space, palms may be planted in double rows with plants staggered creating a diamond pattern of planting (Meerow 1994b). They may be grown as monocultures or small shade-tolerant species can be interplanted under larger species to optimize the use of space. Palms may also be interplanted with non-palm trees or shrubs if consideration is given to growth rate, spread, shade tolerance, and age at marketing (Meerow 1994b).

Liners planted into field nurseries are typically grown in containers of 11–19 L. Smaller container-grown palms are less costly but often result

in lower survival rates (Meerow 1994b). While fabric root-control bags (grow bags) have been encouraged for branching in non-palm trees grown in field nurseries, the large diameter of primary palm roots results in wrapping roots rather than a branched root system when palms are grown in these bags (Meerow and Begeman 1991; Meerow 1994b).

Irrigation. Irrigation frequency depends on soil water holding capacity, water table, species grown and their age, and rainfall (Broschat et al. 2013). Those authors suggested that the duration of irrigation be sufficient to wet the soil to a depth of 0.6–0.9 m. Newly planted palms receiving no rainfall may require frequent irrigation in sandy soils during the first 6 months, with irrigation frequency reduced thereafter. Many field nurseries in southern Florida receive no supplemental irrigation due to a high water table and high water-holding-capacity soil (Meerow 1994b). Migliaccio et al. (2008) have shown that *R. regia* planted in a poorly drained marl soil with a high water table in southeastern Florida grew as well when they were irrigated only when soil water tension reached 15 kPa as they did using a standard grower irrigation schedule. This method reduced water usage by 96%. Pittenger et al. (2009) demonstrated that leaf production and visual quality of *W. filifera* and *C. humilis* grown in coastal California were unaffected as total water provided (rainfall plus irrigation) was decreased from 50% to 0% of crop evapotranspiration (ET). However, visual quality of *S. romanzoffiana*, *T. fortunei*, and *A. cunninghamiana* was decreased significantly when no supplemental irrigation was provided.

Water can be supplied using overhead irrigation, low volume emitters, or flood irrigation. Low-volume emitters and flood irrigation are particularly useful in soils having good lateral water movement. Low-volume emitters can also be used to deliver liquid fertilizer (Meerow 1994b).

Fertilization. Fertilizer requirements for field-grown palms vary widely depending on soil type and rainfall. For palms growing in the predominantly sandy soils of the Atlantic Coastal Plain of the southeastern United States, a fertilizer having an analysis of 8N- 0 or 2P₂O₅- 12K₂O- 4Mg plus micronutrients is recommended for field-grown palms (Broschat 2009). Use of fertilizers having higher N:K ratios than this have exacerbated K and Mg deficiencies in field-grown palms and even resulted in their deaths (Broschat et al. 2008). Due to the low cation exchange capacity of these soils and high leaching potential, Broschat (2009, 2011a) recommended that 100% of the N, K, Mg, and B be in controlled-release form. However, micronutrients such as Fe and Mn should be in water-soluble sulfate or chelate (Fe only) form (Broschat 1991b). Because soils and

climates in other palm-growing regions of the world differ from those in Florida, different fertilizer formulations will be required for those areas. Unfortunately, there is little published research on the fertilization of ornamental palms in field nurseries outside of Florida. Downer et al. (2007) reported that *S. romanzoffiana* grown on a loam soil in California benefited primarily from N and only in the ammonium form. Fertilization programs developed for commercial oil, fruit, or heart of palm plantations may or may not be the most appropriate for ornamental palms in those areas since the objectives of those fertilization programs are solely to optimize product yield and quality at the lowest cost. Foliar aesthetic quality, the primary objective for ornamental palm fertilization, may not be optimal under such fertilization regimes, as mobile macronutrients such as K and Mg are often resorbed from older leaves to provide for the nutrient requirements of developing fruits.

There has been no research on optimum fertilization rate for field production of ornamental palms. Broschat (2009) stated that the 8N-0.9P-10K-4Mg fertilizer recommended for palms in Florida is typically applied at a rate of $\sim 730 \text{ kg ha}^{-1}$ every 3 months ($=234 \text{ kg N ha}^{-1} \text{ year}^{-1}$), but there is no research to indicate whether this rate is optimal or not.

Harvesting. The digging and transplanting of field-grown palms destined for landscape use is discussed in the section on Transplanting. Field-grown palms intended for interior usage should be dug with a root ball slightly smaller than the container in which they are to be placed (Broschat and Meerow 2000). If they are to be transported out of state, they may need to have their root balls rinsed free of any native soil.

Harvesting Leaves for Cut Foliage. Leaves from palms grown for cut foliage production will be harvested on a regular basis over a period of years. The oldest blemish-free leaves should be selected, since older leaves generally have longer vase lives due to greater carbohydrate reserves than younger leaves (Broschat and Meerow 2000). The number of leaves that can be harvested will depend on the species and the interval between harvests, but in general, no more than one-third of the canopy should be removed at any one time (Broschat and Meerow 2000). Particular attention should be paid to K nutrition as even mild K deficiency symptoms can greatly reduce the number of unblemished leaves in the canopy (Broschat and Meerow 2000). Routine removal of K-deficient leaves can result in a net reduction in the number of healthy leaves in the canopy or even result in death of the palm (Broschat 1994e). In the short term, removal of most or all leaves can accelerate the rate of leaf production, but the resulting leaves will be smaller than those from

untrimmed palms (Mendoza et al. 1987; Oyama and Mendoza 1990; Endress et al. 2004; Downer et al. 2009a).

Harvesting of cut leaves should be done early in the morning when leaf water potentials are the greatest and vase life maximum (Broschat and Meerow 2000). Cut leaves should be immediately placed in water and held until packing for shipping. Cut leaves of most palm species naturally have long vase lives and holding or pulsing cut leaves in solutions of silver thiosulfate or floral preservatives containing 8-hydroxyquinoline citrate generally has not improved vase life (Broschat and Donselman 1987a). However, pulsing cut leaves of *C. elegans* for 4 h in 2 mM silver thiosulfate increased vase life to 92 days compared with 30 days for deionized water (Broschat and Donselman 1987a). Palm leaves should be maintained at temperatures between 10 and 24°C to prevent possible chilling injury. They are usually shipped dry, but should be soaked for 1 or 2 h in warm water upon receipt to rehydrate the leaves (Broschat and Meerow 2000).

IV. LANDSCAPE MANAGEMENT

A. Transplanting

Palms differ from most other arborescent plants in that large, mature specimens are relatively easy to transplant. This subject has been reviewed previously by Broschat (1994b), Pittenger et al. (2005), and Hodel et al. (2009). The success or failure of transplanting depends on a number of factors, both above and below ground.

1. Root Regeneration in Palms. Since water balance is the most critical factor in palm transplanting, an understanding of the fate of cut palm roots is central to developing optimum digging strategies. Tomlinson (1961) stated that if a palm root apex is destroyed, it will usually be replaced by one or more branch roots arising immediately behind the dead apex. Hodel and Pittenger (2003a) found that a majority of severed roots of *P. dactylifera* respouted when roots were cut during removal of offshoots from the mother plant. However, Broschat and Donselman (1984) showed that in some species, severing palm roots stimulated the production of new adventitious roots from the root initiation zone at the base of the stem (Table 1.4). In *S. palmetto*, virtually all cut roots die back to the trunk and are replaced by large numbers of new adventitious roots (Broschat and Donselman 1984). In contrast, about half of all severed roots in *C. nucifera* branched and

Table 1.4. Average percentage of cut roots branching into four different root length classes.

Species	Root stub length (cm)				No. new roots
	<15	15–30	30–60	60–90	
<i>C. nucifera</i>	47	61	50	50	20
<i>P. reclinata</i>	0	2	8	32	62
<i>R. regia</i>	1	6	24	36	97
<i>S. palmetto</i>	1	1	3	1	196
<i>S. romanzoffiana</i>	3	41	49	57	13
<i>W. robusta</i>	2	14	31	59	144

Data from Broschat and Donselman (1984, 1990b).

continued growing with very few new roots being initiated from the root initiation zone (Broschat and Donselman 1984). However, in all other species of palms studied, the percentage of cut roots surviving was proportional to the distance from the trunk at which they were cut (Table 1.4) (Broschat and Donselman 1984; 1990b).

2. Palm Maturity Effects. Landscapers transplanting *S. palmetto* have long known that while mature specimens can readily be transplanted, juvenile palms lacking a trunk rarely survive digging and transplanting. Conversely, juveniles of *C. nucifera* and other species are easily transplanted. Broschat and Donselman (1990a) found that when the roots of ten species of juvenile palms were cut off, no new roots were produced in any species. However, in the two species for which mature specimens were similarly treated (*C. elegans* and *P. roebelenii*), all palms produced new roots from the root initiation zone. They concluded that juvenile palm stems lacked a functional root initiation zone, whereas palms with trunks had them. Because *S. palmetto* roots all die back to the trunk when cut, but juvenile specimens lack a functional root initiation zone, this could explain why it is so difficult to transplant juvenile *S. palmetto*. On the other hand, since about half of all *C. nucifera* roots branch and continue growing, an active root initiation zone is not essential for survival of transplanted juveniles of this species. Similarly, Hodel and Pittenger (2003b) found that offshoots of *P. dactylifera* that were 10–35 cm in diameter had higher survival rates when removed from the mother plant than smaller sizes, probably because of a better developed root initiation zone with more roots.

3. Auxin Effects on Rooting. In an attempt to stimulate adventitious root production in transplanted palms, several studies have examined

the effects of exogenous auxins on root production. Broschat and Donselman (1990a) soaked stem bases of *C. elegans* and *P. roebelenii* in indolebutyric acid (IBA) at 3 g L^{-1} for 5 min after all roots had been cut off. They found no increase in the number of roots produced in either species in response to IBA treatment. Al-Mana et al. (1996) treated aerial and ground offshoots of *P. dactylifera* with naphthaleneacetic acid (NAA) or catechol and found no improvement in rooting of ground offshoots, but NAA or catechol increased total fresh root weight and length of the longest root in aerial offshoots. Bakr et al. (2010) injected *P. dactylifera* offshoots with NAA or IBA and found that 3 mL of a 3000 ppm solution of either auxin resulted in the highest survival rate, number of roots, root length, and leaf length. Afzal et al. (2011) observed enhanced rooting in aerial offshoots of this species with quick dips or injection with indoleacetic acid IAA, IBA, or NAA at rates of $1\text{--}3 \text{ g L}^{-1}$. These studies suggest that the different responses may be due to species' differences.

4. Seasonal Effects. Although most recommendations for transplanting palms imply that time of year can affect transplant success, these recommendations are based primarily on observations rather than published scientific studies. Because palm leaf and root growth rates are more rapid during warmer months (Broschat 1998a; Pittenger et al. 2000; Hodel et al. 2005), late spring planting has been recommended for subtropical, temperate, or Mediterranean climates (Hodel et al. 2005; Pittenger et al. 2005). In climates where temperature is not a limiting factor, wet–dry seasonality may be more important. In South Florida, where late spring months are very warm and dry, *S. palmetto* transplanted from unirrigated natural areas were observed to have much lower transplant survival rates than those transplanted at other times of the year (Broschat and Meerow 2000; Broschat 2012).

5. Root Ball Size. While large root balls usually result in better transplant survival, the slight increase in survival may not be justified due to greater costs and difficulty in handling larger root balls. Thus, the optimum root ball size is the smallest root ball that results in an acceptable survival rate (Broschat and Meerow 2000). However, quantifying that optimum size has been a bit more difficult. Hodel et al. (2005) suggested that root balls need not be any larger than 30 cm from the trunk or 30 cm deep for most species because the greatest root density is concentrated within this volume. Broschat (2012) suggested that for those species whose transplant survival depends primarily on the survival of cut roots, minimum root ball size can be inferred from root survival versus cut root

length data (Broschat and Donselman 1984, 1990b). Thus, for a species such as *S. palmetto*, in which no cut roots survive, root balls need only be large enough to prevent injury to the root initiation zone itself. For *S. romanzoffiana*, it can be as little as 15 cm from the trunk, but for *P. reclinata*, it would need to be a minimum of 60 cm from the trunk (Table 1.4) (Broschat 2012). For other species that produce significant numbers of new adventitious roots in addition to cut root survival, a combination of roots derived from both sources should be considered in the equation (Hodel et al. 2005). Because root balls are three dimensional, root ball depth must also be taken into consideration when determining minimum root ball size. This is especially important in drought-tolerant species (e.g., *P. dactylifera* and *Washingtonia* spp.) that tend to have deeper root systems than those from wetter climates.

6. Digging Palms. Large specimen palms may be dug by hand, with backhoes, or with various designs of mechanical tree spades or trenchers (Broschat and Meerow 2000). It may be useful to irrigate the soil thoroughly prior to digging, both to insure optimum palm water status and to promote soil cohesion (Broschat and Meerow 2000; Broschat 2012). Palms dug from sandy soils should have their root balls wrapped with burlap or similar material to prevent them from falling apart during handling.

Palms are lifted from the ground using a crane with the cable attached to a self-cinching wide nylon sling. When cables, ropes, or chains are attached directly to palm trunks, even over carpet or burlap padding, trunk compression wounds usually result. They may be permanently visible and are known to provide entry sites for *Thielaviopsis paradoxa*, a lethal trunk rotting fungus (Elliott et al. 2004).

Root pruning prior to digging is a common practice when transplanting non-palm trees, but most palms can be successfully transplanted without this extra step. For valuable, but difficult to transplant species such as *Bismarckia nobilis*, root pruning 4–6 weeks prior to digging has been recommended (Broschat 2012). With this method, about one-third to one-half of the roots are severed with a spade at a length just inside the future root ball dimensions. However, in order to prevent newly emerging roots from being damaged during final digging, wrapping the root-pruned roots with polypropylene weed control fabric will prevent new roots from growing beyond the intended root ball dimensions (Broschat 2012).

7. Transport and Handling. When palms are dug, it is common practice to remove one-third to two-thirds of the lower leaves and tie the remaining leaves in a bundle to facilitate handling and prevent damage

to the leaves. For slender-stemmed or weak-wooded species, it is recommended to attach a splint to the leaves and stem to prevent the crown from flexing excessively and potentially damaging the meristem. Ideally, palms should be laid flat on a flat bed trailer such that the crown is fully supported by the bed (Broschat 2012).

For long distance transport, wrapping root balls in polyethylene film can help reduce drying, but clear film must be shaded to keep root balls cool (Hodel et al. 2009). Burlap-wrapped root balls should be kept moist during transport to prevent root loss due to desiccation. Costonis (1995) showed that wrapping the root ball of *S. palmetto* significantly improved shoot regrowth rate and visual quality.

Palms can be temporarily planted in a holding area as though they were being planted in their final site. Keeping the roots wrapped with polypropylene root barrier fabric, or even planting them into large containers at that time, can help establish new roots that will aid in rapid establishment once the palms are moved into their final site.

8. Planting. Planting sites for palms should have good drainage, with hardpan layers drilled through for drainage. Palms can also be planted on builtup mounds or berms to improve drainage. Poor drainage and/or excessive irrigation can result in poor establishment rates and subsequent growth (Broschat and Donselman 1987c).

Planting holes should be about twice the diameter of the root ball, but no deeper than the root ball. It is important to wash soil down under and around the root ball to eliminate air pockets because palm roots have been observed not to grow into voids in the soil (Broschat 1998a).

Deep planting of large palms has been used to alleviate the need for supporting transplanted palms and to create plantings of uniform height when using palms of unequal heights. Over time, deeply planted palms often exhibit chronic micronutrient deficiencies, stunting, wilting, increased insect pest pressure, and mortality (Broschat 1995b, 2012; Broschat and Meerow 2000). Broschat (1995b) demonstrated that *P. roebelenii* transplanted at depths greater than 30 cm had significantly greater mortality, fewer leaves, more severe Mn deficiency symptoms, and lower foliar Mn concentrations. When these palms were planted deeply, arrested aerial root initials visible at the base of the trunk resumed growth; however, no new roots emerged from the trunk above the root initiation zone (Broschat 1995b). Costonis (1995) documented mortality rates up to 99% for *S. palmetto* planted 25–130 cm deep in Florida.

9. Planting Hole Amendments. It is a common practice in California to use builder's sand as the sole backfill material when transplanting palms

in an attempt to improve drainage. Hodel et al. (2013a) found that *A. cunninghamiana* and *T. fortunei* had significantly higher transplant survival rates and plant quality with sand backfill than with native soil. *S. romanzoffiana* did not respond to sand backfill. On the other hand, amendment of backfill with varying percentages of composted douglas-fir wood shavings had no effect on the growth and quality of five species of palms (Hodel et al. 2006b).

10. Leaf Removal and Tying. Because water stress is the primary cause of transplant failure in palms, it is a standard practice to remove one-third to two-thirds of the lower leaves to reduce transpirational water loss (Brochat and Meerow 2000). While in some cases this practice might be unnecessary (Hodel et al. 2003, 2006a, 2013b; Downer et al. 2013b), it is necessary for palms transplanted in extremely hot, arid conditions, even if palms are irrigated regularly (Hodel et al. 2013c). Brochat (1994d) demonstrated that regularly irrigated *P. roebelenii* transplanted with more leaves had more living leaves and greater root dry weight than palms with few or no leaves left on. They also had significantly more dead leaves, suggesting that transplanted palms could not support a full canopy of leaves. However, under conditions of severe water stress, palms with no leaves left on had significantly higher survival rates than palms transplanted with full or partial canopies. Survival rates of regularly irrigated *P. roebelenii*, *P. canariensis*, *S. romanzoffiana*, and *W. robusta* were unaffected by number of leaves at the time of transplanting (Brochat 1994b; Hodel et al. 2003, 2006a). Removal of all leaves in *S. romanzoffiana* significantly reduced root dry mass (Hodel et al. 2003). Hodel et al. (2003, 2006a) concluded that the primary benefit from leaf removal was an improvement in aesthetic appearance. However, for *S. palmetto*, a species in which virtually all cut roots die back to the trunk and must be replaced by new roots, removal of all leaves resulted in a survival rate of 95% compared with 66% for palms with one-third of their leaves left on (Brochat 1991c). Shoot visual quality and regrowth rates in this species were also improved by removal of all leaves (Brochat 1991c; Costonis 1995). Leaf removal is known to stimulate production of new leaves in palms (Mendoza et al. 1987; Oyama and Mendoza 1990).

Another practice used to reduce transpirational water loss in transplanted palms is tying them into a tight bundle. This is normally done to reduce leaf damage during shipping and handling, but the practice of keeping the leaves tied up for up to 6 months following transplanting has been controversial. Keeping leaves tied provided no benefit to transplanted *P. roebelenii* in Florida (Brochat 1994d) or *P. canariensis*, *S. romanzoffiana*, or *W. robusta* in California (Hodel et al. 2003, 2006a;

Downer et al. 2013b). There was also no benefit to irrigating transplanted *P. roebelenii* with overhead sprinklers compared with irrigating the soil only, but overhead irrigation increased the incidence of *Gliocladium* pink rot disease if the leaves were kept tied up (Broschat 1994d).

11. Transplanting Container-Grown Palms. Since there is no loss of root mass when transplanting palms from containers, no special treatments beyond irrigation are required to achieve a high survival rate. Circling roots in containers can cause serious problems in container-grown non-palm trees. However, there is no need to cut circling roots in palms since palm roots have no secondary thickening and any circling roots will eventually be replaced by straight new roots originating from the stem.

One problem that can occur when transplanting container-grown palms is planting them too shallowly. It is important that the base of the stem be ~2–3 cm below the surface of the soil to encourage new root development. If this area is not buried, new root growth will be arrested (Broschat 2012).

Various mycorrhizal and bacterial inoculants have been promoted for use on transplanted palms. Positive responses to inoculation with freshly prepared mycorrhizae have been reported for several species of container-grown palms when using sterilized soil or potting substrates (Janos 1977; Jaizme-Vega and Díaz-Pérez 1999; Morte and Honrubia 2002; Fisher and Jayachandran 2008). However, when four commercially available formulations of mycorrhizae and beneficial bacteria were added to the backfill of a phosphorus-deficient native soil in Florida, neither *S. romanzoffiana* nor *W. robusta* showed any positive responses (Broschat and Elliott 2009a). Any benefits obtained from these products were shown to be due to the fertilizer included in some products.

Container-grown palms often exhibit reduced growth rates and nitrogen deficiency symptoms during the first year following transplanting (Broschat et al. 2008). This is thought to be due to competition for N by microbes that degrade organic container substrate components such as pine bark (Prasad 1980). While the palm's roots are largely confined to this N-deficient environment, root growth into the surrounding soils is retarded until sufficient numbers of roots become established outside the root ball. Broschat and Moore (2010) found that *D. lutescens* transplanted from containers had the largest size and darkest color when fertilized with high N controlled-release fertilizer during the first 6 months in Florida. Fertilizer rate or placement of the fertilizer on the surface of the root ball, incorporated into the backfill, or at the bottom of

the planting hole did not affect palm growth and quality, but any fertilizer was superior to no fertilizer (Broschat and Moore 2013).

Use of mulch to cover the root ball of transplanted palms has been recommended to reduce water evaporation from the soil. Downer and Hodel (2001) found that transplanted container-grown *S. romanzoffiana* and *W. robusta* were unaffected by mulch application, but *A. cunninghamiana*, a difficult to transplant species, responded favorably to mulching with turfgrass clippings or *Eucalyptus* wood chips.

B. Fertilization and Irrigation

Research on fertilization of landscape palms has largely been restricted to Florida where soils vary from acidic to alkaline sands to limestone, peat, or muck. In many parts of south Florida, landscapes are planted on land built up with dredged limestone and sand fill. These soil types generally have very low cation exchange capacity and are highly leached, resulting in widespread deficiencies of K, Mg, Fe, Mn, B, and occasionally N and P in palms (Dickey 1977; Broschat and Donselman 1985; Broschat, 1999 Broschat 2011e). Fertilizers developed for palms growing in these soils have 100% of their N, K, Mg, and B in controlled-release form and P, Fe, Mn, Zn, and Cu in water-soluble form for maximum efficiency (Broschat 1991b, 1996, 1997b, 2008b; Broschat and Elliott 2005a). Broschat (2011a) found that an analysis of 8N-0.9P-10K-4Mg plus micronutrients was most effective for landscape palms growing in Florida's sandy and limestone soils. Use of materials with higher N:K ratios has been shown to exacerbate K and/or Mg deficiency symptoms and has even resulted in the death of landscape palms (Broschat et al. 2008; Broschat 2011a). In southern California, Downer et al. (2007) showed that *S. romanzoffiana* responded favorably to N fertilization, with the N in ammonium form, but not to Mg, Ca, or K. *A. cunninghamiana*, *W. robusta*, *T. fortunei*, and *C. humilis* did not respond to any fertilization treatment.

Fertilizers have been applied by banding the material in a ring around the trunk, by broadcasting on the soil surface under the palm canopy, by drilling holes into the soil under the canopy and filling them with fertilizer, by controlled-release fertilizer spikes similarly placed, by trunk injection, or by injecting liquid fertilizer into the soil under pressure. Because they are highly leachable, liquid- or water-soluble fertilizers are not recommended for sandy highly leached soils (Broschat 2011a). Similarly, concentrating granular fertilizers in holes, spikes, or as bands around the trunk is less effective than broadcasting due to the greater proportion of roots in contact with fertilizer applied by broadcasting

(Broschat 2011a). Broschat and Docola (2010) found that injecting MnSO_4 into the trunks of *C. nucifera* was more effective than soil applications of the same product. However, this method is not recommended for routine application of Mn or any other element since injection wounds in palm trunks are permanent and could be potential entry sites for insect pests or pathogens. Dwivedi et al. (1981) showed that radioactive P and Rb were taken up by *C. nucifera* even faster by immersing a cut root in the nutrient solution than by trunk injection. Applying these highly mobile elements to the leaf axils was slightly slower in their uptake. On the other hand, Rajaratnam (1972c) demonstrated that B, an immobile element, applied to leaf axils or as foliar sprays on *E. guineensis*, had to be rinsed in the soil for root uptake before it could be translocated into new growth. Broschat (2011d) similarly found that application of B to the soil was much more effective than to leaf axils in *C. nucifera*.

Landscape palms are typically irrigated using lawn or shrub sprinklers or low-volume emitters. Once established, many palms do not require supplemental irrigation, especially in areas such as southern Florida that have high water tables. Pittenger et al. (2009) concluded that in coastal southern California, many established landscape palms can maintain minimally acceptable appearance for extended periods of time with little or no irrigation. Use of mulch has been recommended to reduce evaporation from the surface of landscape soils and to reduce root competition from weeds or turfgrass. Downer and Hodel (2001) showed that turfgrass growing up to the trunk reduced growth and number of leaves in *S. romanzoffiana* and *A. cunninghamiana* compared with palms mulched with grass clippings or *Eucalyptus* chip mulch or unmulched control palms in southern California. *W. robusta* did not respond to mulching or turfgrass growing up to the trunk. Mulching with either material reduced transplant mortality in *A. cunninghamiana* over unmulched palms or those with turfgrass near the trunk.

C. Pruning

Palms are pruned differently than other woody, non-palm trees, where removal of branches is normal. Because most palms do not branch, pruning typically consists of the removal of leaves, inflorescences and infructescences, or occasionally entire stems in multistemmed species (Hodel 1999, 2012). While landscape palms are pruned primarily for aesthetic reasons, leaves are also removed during the transplanting process to reduce water stress and to improve survival rates. This pruning is discussed in the section on transplanting palms. Overviews

on the topic of palm pruning can be found in Robinson (2004), Downer et al. (2009a), Rosenfield (2009), Broschat (2011c), and Hodel (2012).

As palm leaves age, their position within the canopy moves from the top center to the bottom of the canopy. If the palm is not K deficient, the oldest leaves eventually senesce naturally, typically changing from completely green one day to uniformly orange-brown the second day, and completely necrotic the third or fourth day (Broschat and Gilman 2013). If the palm has a crownshaft, the dead leaf will abscise and fall off naturally (self-cleaning), but in species without crownshafts, the dead leaves may fall off (self-cleaning) or they may remain firmly attached until the leaf base eventually rots off or is manually removed (non-self-cleaning).

It is normal for leaf bases or entire leaves of some palms species to persist for many years or even decades following senescence. Dry climates generally favor dead leaf or leaf base retention, but genetics may also play a role since *S. palmetto* in Florida may naturally retain their leaf bases for decades or shed them within a year of leaf senescence (Broschat and Elliott 2007; Hodel 2012). In *Washingtonia* spp. old leaf bases or leaves may suddenly begin to drop after a decade or more of persistence and they may drop first from the bottom of the skirt, the top, or from the middle (Broschat and Elliott 2007; Hodel 2012). Once shedding begins, the entire skirt usually drops off over the course of a couple of years and the palms become “self-cleaning” thereafter (Broschat and Elliott 2007; Broschat 2011c).

Due to the large size of palm leaves, K-deficient older leaves are conspicuous and detract from the aesthetic appearance of the palm, and they are typically removed from palms during pruning. However, because K is highly mobile within palm canopies (Broschat 1997a), these symptomatic older leaves serve as a supplementary source of K for the palm in the absence of sufficient K in the soil and thus should not be removed. Broschat (1994e) demonstrated that routine removal of K-deficient leaves in *P. roebelenii* resulted in a net reduction in the number of green leaves in the canopy.

Pruning, or more importantly, overpruning, can affect palms in a number of ways. If palms are overpruned, the reduction in canopy size results in reduced photosynthetic capacity. In the short term, some studies have shown that overpruning can result in greater leaf production rates (Mendoza et al. 1987; Oyama and Mendoza 1990; Chazdon 1991; O'Brien and Kinnaird 1996; Endress et al. 2004). However, repeated overpruning has been shown to reduce leaf size (O'Brien and Kinnaird 1996; Endress et al. 2004; Jimenez 2004; Downer et al. 2009a), leaf number (Downer et al. 2009a), and trunk diameter (Broschat and Meerow 2000; Hodel 2012).

Pruning of living leaves has been demonstrated to be the primary means of transmission of diseases such as Fusarium wilt of *P. canariensis* (Feather 1982; Summerell et al. 2001) and may be a means of spreading Fusarium wilt in *S. romanzoffiana* and *W. robusta* (Elliott et al. 2010). Any trunk wounds caused by careless pruning, climbing spikes, or pulling off old leaves before they completely abscise or rot off can result in unsightly scars and provide entry sites for Thielaviopsis trunk rot (Elliott et al. 2004). However, selective pruning of severely infected leaves has been suggested for managing other diseases such as petiole/rachis blight or Graphiola leaf spot (Elliott et al. 2004). Entire stems of multistemmed palms are sometimes removed to reduce clump height, width, and/or density or to eliminate dead stems of hapaxanthic palms. In areas where *Ganoderma* butt rot occurs, stumps left by stem removal are often colonized by this fungus, which then moves into healthy stems and ultimately kills the palm (Elliott et al. 2004; Elliott and Broschat 2012). Leaf removal in *P. canariensis* and *S. palmetto* has also been shown to attract serious insect pests such as palm weevils (*Rhynchophorus* spp.), which are attracted by volatile chemicals emitted by cut leaf bases (Giblin-Davis and Howard 1989).

Overpruning palm canopies to just a few leaves has been promoted as a means of reducing wind resistance and improving survival of palms during hurricanes. However, Broschat (2011c) and Caldwell (2006) observed that overpruned palms were more likely to fail during hurricanes than those with their canopies intact. Pfalzgraf (2000) concluded that the remaining younger leaves had not yet hardened off yet and were unsupported by older leaves. Research on *E. guineensis* by Calvez (1976) and Chan and Duckett (1978) supports these observations.

The number of leaves that can be removed at each pruning is a function of K status (Broschat 2011c). Because older leaves serve as supplemental sources of K in K-deficient palms, only completely dead leaves should be removed (Broschat 2011c). However, arborists and landscapers routinely remove not only dead and K-deficient leaves, but also some green leaves as well, knowing that they can extend the time before dead older leaves again appear at the bottom of the canopy. Broschat and Gilman (2013) demonstrated that severely pruned K-deficient *S. palmetto* had no symptomatic leaves until the number of leaves in the canopy again exceeded the number that could be supported by the K reserves in the palm. Dead leaves did not appear until the severity of the K deficiency increased to the point where leaves died from K deficiency. If these palms were heavily fertilized with K fertilizers, the total number of leaves and number of symptom-free

leaves increased, but the number of symptomatic leaves remained constant over time until the palm achieved a full 360° canopy (Broschat and Gilman 2013). If fertilization is continued once a full canopy is achieved, palms will remain symptom-free and older leaves will senesce via natural senescence rather than via K deficiency. ANSI (ANSI 2001) pruning standards specify that no leaves with tips above the horizontal should be removed.

Timing of pruning in palms does not appear to be critical, although several factors may influence when they are pruned in different areas. In areas subject to hurricanes or other strong seasonal storms, pruning of dead leaves, inflorescences, and infructescences (especially coconuts) just prior to the windstorm season may be optimum. In areas where cold damage could occur, pruning before the winter months should be avoided on cold-sensitive palms as a full canopy provides more insulation than an overpruned one (Broschat and Meerow 2000). In California, pruning prior to winter is similarly discouraged due to concerns about pink rot fungus (*Nalanthamala vermoesonii*) during winter months (Downer et al. 2009b). In species having a relatively short flowering season, pruning of inflorescences should be timed to remove the entire year's production of inflorescences before they develop fruit.

D. Growth Regulator Effects

There is great interest in using growth regulating chemicals to control palm height, flowering, suckering, and rooting. Fisher (1980) studied the effects of gibberellins and several growth retardants on the morphology of several species of juvenile palms. He found that in most species, leaves emerging following treatment with gibberellic acid (GA_3) assumed a more juvenile form, with leaflets failing to split normally. Application of GA_3 had no effect on palm height of *C. seifrizii* (Broschat and Donselman 1986a), although when seeds of several species of palms were soaked in GA_3 , the resulting seedlings exhibited excessively elongated or even twisted growth during their first year (Broschat and Donselman 1987b, 1988). Fisher and Theobald (1989) injected GA_3 into the trunks of *C. nucifera* and noted elongation of the ovaries, fruits, leaves, and internodes. Gibberellins had no effect on suckering in palms (Fisher 1980; Broschat and Donselman 1986a).

Growth retardants such as daminozide or chlormequat had no effect on size or shape of leaves, or on suckering in *E. guineensis*, *C. mitis*, *C. seifrizii*, or *D. lutescens*, but chlormequat darkened the green color of the leaves in all species (Fisher 1980). Leaf size was reduced in all of

these species by ethephon (Fisher 1980), but Broschat and Donselman (1986a) found that this material significantly reduced overall height in *C. seifrizii*. When paclobutrazol was applied as a soil drench to mature *R. regia*, vertical growth, but not trunk caliper, was significantly reduced over a 3-year period (Ali and Bernick 2010), and similar results were reported for *A. merrillii* and *S. romanzoffiana* (Hensley and Yogi 1996). Leaf length and number were reduced and palm canopies became very compact and stunted in 3-year old *P. dactylifera* seedlings receiving soil drenches of paclobutrazol or uniconazole P (Aloni et al. 2010). However, the effects on mature, fruiting specimens of this species were less pronounced. Hodel et al. (2012) showed that glyphosate could be used successfully to reduce or inhibit regrowth of pruned basal shoots of the multistemmed *C. humilis*.

Foliar sprays of benzyladenine (BA) or the auxin naphthalene acetic acid (NAA) had no effect on number of lateral shoots or flowers or total plant height in *C. seifrizii* (Broschat and Donselman 1986a). Fisher and Theobald (1989) reported no effects of BA on trunk-injected *C. nucifera*.

V. INTERIORESCAPE MANAGEMENT

Some palms are among the best plants for use in interiorscapes because of their tolerance of low light and low humidity, leaves that do not readily abscise in response to environmental changes, relatively slow rate of growth, and fibrous, nonwoody roots that make them amenable to container culture or other situations with limited root space. Since palms capture the desirable tropical motif that few other plants can match, they are among the most popular and common interiorscape plants. However, an understanding of the palms' cultural requirements and environmental conditions in interiorscapes is necessary to manage palms appropriately and achieve their maximum function and benefit. The most critical environmental factors in interiorscapes are light, relative humidity, temperature, water quality and quantity, and soil or planting substrate.

Little growth can be expected, or is desired, in most interiorscape situations, especially those with low light, and few palms can be expected to perform adequately in such poorly lit situations (Broschat and Meerow 2000). Thus, palms are primarily in a static state in most interiorscapes, and the management objective is to maintain the quality of the palm as it was when it entered the interiorscape for as long as possible without producing much, if any growth. About 5–7 years is the maximum life span for most medium to large palms in the average

low-light interiorscapes (Broschat and Meerow 2000). In situations with higher light, where more growth is expected, expected life spans of palms can be considerably longer, although size limitations then become critical.

A. Palm Selection for Interiorscape Use

Factors to consider when evaluating palms for interiorscape use include growth characteristics and habitat and ecology of the species, acclimatization and health of individual plants, and intended use and design (see Table 1.1). While green is the predominant color, a few palms offer various shades of yellow, orange, red, and gray in stems, leaves, inflorescences, or flowers and fruits that might impact use and design.

The best species for interiorscape use are found in the understory of forests where light levels are naturally low. Species from moist, dry, or monsoon forests will likely be more tolerant of low humidity in interiorscapes than species from wet or cloud forests. Species from middle and higher elevations and/or higher latitudes will likely be more tolerant of cooler temperatures; however, in many cases, species from higher altitudes also occur in wet forests or cloud forests where tolerance of low humidity is limited.

B. Installation

Palms should be protected from rough handling, which can irreparably damage the apical meristem or leave permanent, unsightly wounds on the stem. Palms should be protected from cold when installing them in cold-winter areas; temperatures below 10°C for even a few hours can damage some palms. Also, palms should be protected from direct sun during installation, especially on warm, summer days; only a few minutes of exposure of shade-grown leaves to full, midday sun can burn them.

C. Soil or Planting Substrate

Most interiorscape plants are displayed in containers or in specialized planting beds where the use of a soilless substrate is beneficial. Such substrates should hold water and nutrients, yet be porous and well aerated. Water holding capacity should be 30–40% and air space should be 15–25% (Broschat and Meerow 2000). Typically, such substrates are composed of an organic fraction to provide water and nutrient holding

capabilities and an inorganic fraction to provide aeration and drainage. Substrates with excessively high amounts of organic components will degrade rapidly, reducing porosity and aeration and lead to poor growth (Broschat and Meerow 2000). Substrates with more than 1.5 dS m^{-1} soluble salts can damage plants, causing leaf-tip and leaf-margin burn (Conover and McConnell 1981).

D. Light

Light is the most critical factor affecting the success of palms in interiorscapes. Light intensity and its relationship with the light compensation point (LCP), the point at which the palm is not growing, accumulating, or consuming stored carbohydrates, is critical to understanding the selection, growth, and management of plants in interiorscapes (Conover and McConnell 1981). Light intensity above the LCP means that the palm will be photosynthesizing, producing carbohydrates, and actively growing. In contrast, light intensity below the LCP means that the palm will not be photosynthesizing and producing carbohydrates and must rely on carbohydrate reserves produced and stored during cultivation in higher light prior to entering the low-light interiorscape. If light intensity continues below the LCP, the palm will eventually use up all its stored carbohydrates, decline, and die. Although each species has its own LCP, the LCP for most plants used in interiorscapes, including palms, ranges from 0.8 to 1.6 klx (Conover and McConnell 1981). Although light intensity is generally low in most interiorscapes, it averages $\sim 1.6 \text{ klx}$ (Broschat and Meerow 2000), meaning that it is at or near the LCP for most species commonly used in interiorscapes.

Light duration is also important. At least 8–12 h of light at or slightly above the LCP per day is recommended for plants in the interiorscape (Conover 1975). If natural light is insufficient, supplemental lighting can boost light intensity up to 6.5 klx (Broschat and Meerow 2000). Supplemental lighting is especially important in regions with many cloudy winter days where light levels may be only 10% of clear summer days (Broschat and Meerow 2000).

Plants respond mostly to blue and red ranges of the visible spectrum, and cool or warm white fluorescent lights efficiently provide this quality of light (Conover and McConnell 1981; Broschat and Meerow 2000). Other suitable lights include Gro-Lux fluorescent, high-intensity discharge mercury, metal halide, and high- and low-pressure sodium (Broschat and Meerow 2000). Incandescent, incandescent mercury, and other types of fluorescent lamps are not recommended (Cathey and Campbell 1977).

Palms, even species naturally occurring in low-light situations, must be properly grown and acclimatized prior to use in interiorscapes. The objective in acclimatization is to prepare palms for conditions typically encountered in interiorscapes, primarily low light but also low humidity and, in some cases, low temperatures (Conover and McConnell 1981). Shade-grown palms tend to have larger, thinner, softer, darker green leaves with longer petioles and more slender stems with longer internodes (Conover and McConnell 1981; Broschat and Meerow 2000). Leaves grown in excessively high light will decline rapidly in low-light interiorscapes (Broschat and Meerow 2000).

Light levels also affect internal leaf tissues. Leaves grown in high light tend to have multiple epidermal layers that reduce the amount of potentially damaging sunlight reaching the interior of the cell. Chloroplasts and grana within chloroplasts assume vertical orientation to reduce chloroplast damage and minimize heating due to excessive light (Conover and McConnell 1981). In contrast, shade-grown leaves have a single epidermal layer to permit more light to enter the cell, and chloroplasts and grana have an open stack, rather than vertical, arrangement.

While some plants, especially non-palm trees, have the ability to reorient chloroplasts and grana in sun- or high-light-grown leaves to a low-light arrangement in ~6 weeks (Conover and McConnell 1981), this process seems lacking in palms. For maximum durability in the low-light interior, a palm must replace all sun- or high-light-grown leaves in its canopy with shade-grown leaves (70–80% shade) (Broschat et al. 1989). Because this process of replacing the canopy of sun- or high-light-grown leaves with shade-grown leaves can take several years or even longer in the interior where growth is much reduced, it is important to select shade-grown palms initially. Light levels should be at or slightly above the LCP, at least 1.6 klx, during acclimatization to ensure that some storage of carbohydrates occurs (Conover and McConnell 1981). The degree of acclimatization when the plant is moved into the interior is especially critical and appears more important than stored carbohydrates for future plant success (Milks et al. 1979). Properly acclimated palms will also have lower respiration rates and lower carbohydrate requirements, helping to preserve stored reserves and further enhance their success in low-light interiorscapes (Fonteno and McWilliams 1978).

E. Relative Humidity

Relative humidity levels in interiorscapes are generally low, usually below 50%, but they can drop to as low as 10–20%, especially during

intense heating and cooling. Most plants suitable for the interiorscape, including palms, can typically tolerate relative humidity down to 50% without damage, but at 10% leaf tip burn can occur (Conover and McConnell 1981).

F. Temperature

Temperatures in interiorscapes, which can range from 20 to 24°C on workdays, are generally suitable for most palms. However, temperatures below 18°C can reduce growth (Conover and McConnell 1981; Broschat and Meerow 2000), although most palms might not sustain damage until temperatures drop to ~10°C.

G. Water

Excessive irrigation is a common problem in interiorscapes (Conover and McConnell 1981) and can lead to root damage, disease, nutritional problems, and other disorders. The root ball, backfill, and surrounding soil of newly planted palms should be kept evenly moist, not saturated, for 4–6 weeks to encourage roots to grow out of the root ball and into the surrounding soil (Broschat and Meerow 2000). After this establishment period, it is best to allow the soil to dry out slightly between irrigations. In many areas water quality is poor, primarily because of soluble salts. Soluble or total salts in water should be less than 0.78 dS m⁻¹ (500 ppm) (Henley and Poole 1981). Higher levels can cause leaf-tip and leaf-margin necrosis. However, higher levels, up to 2.25 dS m⁻¹, can be tolerated if horticultural and irrigational practices are modified by using a well aerated and porous planting substrate, applying sufficient water at each irrigation to moisten the entire root zone, spacing irrigations to maintain the planting substrate in an evenly moist state and not allow it to become excessively dry, and occasionally leaching the planting substrate with an extra heavy irrigation. Irrigation water temperatures in the winter can be 5° to 10°C, well below the minimal soil temperature of 18°C at which most palm root growth slows or stops (Broschat and Meerow 2000).

H. Fertilization

Because little or no growth occurs or is desired in interiorscapes, nutritional needs of palms are correspondingly low (Conover and Poole 1977; Broschat and Meerow 2000). Fertilizer rates are generally 10–20% of production rates under higher light (Conover and Poole 1977).

Conover et al. (1992) provided annual nitrogen rates at various light levels for interiorscape plants. A controlled-release, complete fertilizer with micronutrients is commonly used, but fertigation has also been used in the interiorscape (Broschat and Meerow 2000).

VI. PALM PROBLEMS

Broschat and Elliott (2005b), Broschat et al. (2010, 2013), and Hodel (2012) provide illustrated, annotated keys to disorders, diseases, and pests of ornamental palms grown in the United States, including Hawaii, and the Caribbean Basin.

A. Physiological Disorders

1. Chemical Toxicities

Micronutrient Toxicities. While excess macronutrients in the soil tend to result in elemental imbalances or salt injury symptoms, some high concentrations of micronutrients such as B and Cu can be toxic to palms. Excessive B in the soil causes leaflet tip necrosis in all but the youngest leaves (Marlatt 1978; Elliott et al. 2004).

Copper toxicity in the soil results in necrosis and dieback of root tips, but because Cu is not readily translocated within the palm, Cu toxicities in soil usually do not result in foliar symptoms. However, foliar applications of soluble Cu compounds cause necrotic spotting and leaflet tip necrosis in tissue contacted by the spray (Poole and Conover 1982b; Chase and Poole 1984; Elliott et al. 2004). Insoluble “fixed” Cu compounds used as fungicides cause similar symptoms in palms, but are less severe (Chase and Poole 1984). Chelates of other micronutrients such as Fe can also be phytotoxic when applied to the foliage of palms at recommended rates or at excessive rates to the soil (Chase and Poole 1984; Elliott et al. 2004). Symptoms of soil-applied Fe chelate toxicity include leaflet tip necrosis and necrosis of the central veinal regions of the leaflets (Elliott et al. 2004).

Fluoride Toxicity. Leaflets of palms exposed to F show necrotic lesions, usually arranged in parallel rows along the longitudinal axis (Elliott et al. 2004). Leaflet tip necrosis occurs in more severely affected palms and symptoms are most severe on older leaves (Poole and Conover 1981a,b, 1982a). Poole and Conover (1981a,b) demonstrated that equivalent concentrations of F from superphosphate fertilizer were more toxic to

C. elegans, *C. seifrizii*, and *D. lutescens* than those from NaF. Addition of dolomite reduced the solubility of F in the soil and reduced foliar necrosis in these species. Woltz and Waters (1978) demonstrated that palms are moderately to severely susceptible to foliar injury caused by HF fumes.

Other Air Pollutant Toxicities. Airborne sulfur dioxide has been shown to cause red-orange necrosis parallel to the veins and leaflet margins in *D. lutescens* (Howe and Woltz 1981). Mid-canopy leaves were most susceptible in this species.

Herbicide Toxicities. Toxicity symptoms for a wide range of postemergent herbicides applied to the soil around palms or directly to their foliage have been reported for field-grown *C. nucifera* and *E. guineensis* (Romney 1964, 1965; Kee and Brown 1968; Kasasian et al. 1968; Huat and Leong 1994) and ornamental palms are likely to respond similarly. Broschat and Busey (2010) showed that metsulfuron applied to the soil of container-grown *W. bifurcata* produced a single crumpled and kinked new leaf ~6 months after application. Donselman and Broschat (1986) showed that any effects of foliar-applied glyphosate to nine species of container-grown ornamental palms were confined to one or two new distorted leaves, with subsequent new leaves emerging symptom-free. Toxicity symptoms of preemergent herbicides were generally similar, with leaf necrosis, stunting, and distortion appearing only on new leaves that may not emerge for 6–8 months following application (Donselman and Broschat 1986; Broschat 2000; Elliott et al. 2004). Among preemergent herbicides studied, only metolachlor produced auxin-like symptoms of branching and lateral growth (Meerow and Broschat 1991).

2. Temperature-Related Disorders

Cold Damage. Root and shoot growth occur year-round in southern Florida, and their rates were found to be highly correlated with air and soil temperatures in *R. regia*, *C. nucifera*, and *S. romanzoffiana*, but only for primary root growth in *P. roebelenii* (Broschat 1998a). However, at temperatures below 10°C, chilling injury can occur in tropical species. Symptoms of chilling injury include leaflet necrosis and/or yellow or reddish blotches on the surface of the leaflets but not the rachis or petiole. Symptoms occurred on all but the youngest expanding or unexpanded leaves (Broschat 2010a). Temperatures below freezing cause similar symptoms, but can also affect the petiole, rachis,

younger leaves, inflorescences, roots, and the apical meristem. Larcher and Winter (1981) have shown experimentally that palm tissues such as the apical meristem, spear leaf tip, newly expanding leaves, and petioles are much hardier than inflorescences, roots, leaflets, and the base of the spear leaf. Based on these findings, Broschat (2010a) concluded that the status of the apical meristem could be predicted based on the similar cold tolerance of the petioles of a palm. Because the base of the spear leaf is one of the most cold-sensitive tissues and is usually degraded by secondary bacteria and fungi, spear leaf basal rot is not a good indicator of the viability of the apical meristem even though the two tissues are in proximity within a palm canopy. Partially developed young leaves within the canopy are the most susceptible to cold injury, but damage to these leaves does not become apparent until they emerge several months after the cold event. These leaves typically have truncated tips, but are usually followed by progressively more normal-appearing leaves. In *C. Nucifera*, prolonged chilling or freezing temperatures can cause permanent damage to trunk tissue in the top 2 m of the trunk. This injured trunk tissue can become infected with secondary microorganisms that can ultimately kill the palm (Broschat 2010a).

Numerous studies have documented the relative cold hardiness of various species of ornamental palms (Smith 1958, 1964; Barry 1961; Kellett 1969; Martens 1970; Anderson 1971; Hintz 1978; Larcher and Winter 1981; Goldstein 1989; Doughty et al. 1992; Campbell 1997; Noblick 1998; Francko and Wilhoite 2002; Meerow 2005, 2006; Riffle et al. 2012). However, the temperature at which damage occurs in a palm is strongly influenced by the palm's acclimation, its environment, the duration of the cold, windy conditions, and other factors (Francko 2000; Hodel 2012). Broschat (2010b) observed that fertilized *C. nucifera* exhibited less chilling injury than unfertilized palms.

Due to concerns that apical meristems might be affected by secondary bacterial and/or fungal rots of cold-killed spear leaf bases, some investigators have recommended drenching the bud area of cold-injured palms with broad-spectrum fungicides such as copper compounds (Chase and Broschat 1991; Meerow 1994b; Broschat and Meerow 2000; Elliott et al. 2004; Broschat 2010a; Hodel 2012). However, there is no research that conclusively demonstrates that fungicides are effective in preventing invasion of healthy meristematic tissue or even that healthy meristems are susceptible to attack by these secondary microbes.

Ornamental palms may be protected to varying degrees from cold injury by shelters or covers of various designs, trunk wrapping, fans, applying water via flood or overhead irrigation, portable heaters, or

heavy mulching for small palms (Broschat and Meerow 2000; Hodel 2008, 2012).

Excessive Heat Injury. Hodel (2012) describes new leaves emerging chlorotic or necrotic under hot dry conditions in southern California and attributes these symptoms to excessively high temperatures. Palms native to high elevations such as *Ceroxylon* spp. grow poorly in warm to hot climates (Hodel 2012).

3. Water-Related Problems

Drought. Although palm foliage rarely exhibits “wilt” symptoms, palms under severe water stress may show folded leaflets or necrosis of the central or peripheral parts of the leaves (Chase and Broschat 1991; Broschat and Meerow 2000; Elliott et al. 2004; Hodel 2012). Unless it is necrotic, dehydrated palm foliage can often rehydrate with no visible symptoms (Chase and Broschat 1991; Elliott et al. 2004). In severely water-stressed *R. regia*, upper parts of the trunk may buckle inward. When dissected, the affected portions of the trunk show extensive contraction of the parenchyma tissue and hollowing of the trunk (Elliott et al. 2004). Water-stressed *W. robusta* trunks may also become hollow, with only loose dried vascular bundles remaining in the central portion of the trunk. Other species may show only mild shriveling of the trunk surface.

Excessive Water Uptake. The thin-walled parenchyma cells that predominate in the central portion of palm trunks can expand and contract in response to changes in water potential (Holbrook and Sinclair 1992a, b). However, over time, lignified fibers associated with vascular bundles, which are concentrated near the periphery of the trunk in most species (Tomlinson 1990), render the outer cylinder much more rigid. When excess amounts of water are taken up by the parenchyma cells, the hydraulic pressure exerted within the palm trunk can result in vertical splitting of the more rigid outer cylinder of the stem (Chase and Broschat 1991; Broschat and Meerow 2000; Hodel 2012).

4. Salt Injury. Salts, whether from seawater, applied fertilizers, or irrigation water, can cause desiccation of root or leaf tissue in palms through osmotic action. In coastal areas subject to strong onshore winds, salt spray can cause extensive leaflet tip necrosis in susceptible species (Chase and Broschat 1991; Broschat and Meerow 2000; Elliott et al. 2004; Hodel 2012). High soluble salts concentrations in the soil can similarly

cause injure palm roots in many species. Symptoms of soil salt injury are extensive root tip necrosis, leaflet tip necrosis on all but the youngest leaf, wilting, and eventually, death (Chase and Broschat 1991; Broschat and Meerow 2000; Elliott et al. 2004). Newly emerging leaves of affected palms may show Fe chlorosis symptoms due to reduced root surface area for uptake of Fe (Broschat and Meerow 2000; Elliott et al. 2004).

A number of papers present observational data on the relative salt tolerance of various palm species, although some do not differentiate between foliar salt tolerance and root salt tolerance (Koebernik 1966; Broschat and Meerow 1991; Bezona et al. 1996; Meerow 2006; Hodel 2012; Riffle et al. 2012). Experimental determination of salt tolerance of the roots has been published for 11 species of cold-tolerant palms (Furr and Ream 1968; McConnell et al. 1976, 1978; Perry and Williams 1996; Miyamoto et al. 2004). In all of these studies, increasing salinity decreased palm growth rate.

5. Root Suffocation. Palms planted too deeply or growing in poorly aerated soils typically exhibit symptoms of chronic Fe, or occasionally Mn, deficiency, poor growth, wilting of the foliage, shriveling of the trunk, and even death (Broschat 1995b; Broschat and Meerow 2000; Elliott et al. 2004; Hodel 2012). Insufficient oxygen in the root zone reduces root respiration and activity and can ultimately kill the roots. Palms stressed by root suffocation may be invaded by secondary root pathogens or insect pests (Elliott et al. 2004).

6. Shallow Planting (Inverted Root Cone). If container-grown palms are planted too shallow (i.e., the bottom of the stem is not in direct contact with the soil), newly emerging roots from the stem base may cease their development and thus never penetrate the soil (Broschat and Meerow 2000; Elliott et al. 2004; Hodel 2012). Because the base of most palm stems is shaped like a “V” or inverted cone, palms planted too shallow will reveal this profile. Another cause of inverted root cone, especially in palms in turfgrass, is damage from mowers and monofilament line trimmers, which sever or inhibit roots growing on the stem periphery, preventing them from reaching the soil (Hodel 2012). These palms will be anchored and supplied with water and nutrients only from those roots originating from the very bottom of the stem axis and may eventually topple over. This situation is easily corrected by mounding up soil around the stem base.

7. Lightning Injury. Palms are highly susceptible to lightning strikes and, unlike non-palm, such strikes to palms are invariably fatal.

Symptoms include a near total collapse of the leaves in the canopy against the trunk, often with only the spear leaf intact (Chase and Broschat 1991; Elliott et al. 2004). Vertical splitting of the trunk is occasionally observed (Elliott et al. 2004). Typically, rust-colored, sometimes bleeding, exit wounds will be visible on the bottom meter of the trunk even if the canopy is initially unaffected. Secondary rots occurring in the vicinity of these exit wounds ultimately kill the vascular system and the canopy wilts and die as a result. Although canopy collapse in lightning-struck palms is immediate, in cases where only the trunk shows injury, death may be delayed for up to 6 months. It is not unusual for a single lightning strike to kill multiple palms.

8. Powerline Decline. Unlike broadleaf trees, palms are highly sensitive to electromagnetic fields present near high-voltage power lines (Chase and Broschat 1991; Broschat and Meerow 2000; Elliott et al. 2004; Hodel 2012). Symptoms occur on all leaves within the palm canopy, not just those closest to or touching the wires. Leaf tips will be chlorotic or necrotic, while the basal 3/4 of the leaf remains green. Death from powerline decline is rare.

9. Sunburn. Sunburn can occur on shade-grown leaves when exposed to high light intensities. Symptoms appear as necrotic lesions in the central portions of a leaf that is held in a horizontal position (Chase and Broschat 1991; Broschat and Meerow 2000; Elliott et al. 2004; Hodel 2012). Leaves grown under shade conditions cannot acclimate to high light intensities, but will eventually be replaced by leaves that developed under high light.

10. Wind Damage. Palm trunks are generally quite tolerant of high winds, but occasionally will snap at some height above the ground, or even uproot. Leaves subjected to high winds may show tattered leaflets, snapped petioles, or “flagging” of leaf tips (Elliott et al. 2004; Hodel 2012). Strong winds may produce chlorotic new leaves that are the result of the spear leaf being forced open prematurely (Broschat and Meerow 2000; Hodel 2012). These typically green up within a couple of days. Griffith et al. (2008) have correlated cyclone tolerance in palm species with the frequency of such storms in their country of origin.

11. Other “Disorders”. A number of conditions that would be considered abnormalities in most plants are in fact normal for some species of palms. Broschat and Elliott (2007) have termed these “normal abnormalities.” The pseudobark on the lower portions of palms can slough

or erode away, exposing the vascular bundles of the central cylinder (Broschat and Elliott 2007; Hodel 2012). No pathogens have ever been isolated from such areas and it is not known why this occurs (Broschat and Elliott 2007). It is often severe in palms exposed to eroding forces such as wind-driven sand or irrigation heads (Hodel 2012), but can occur in landscapes or natural forest stands that are totally protected from such forces. It does not appear to affect the health of palms even though a substantial proportion of the trunk cross-sectional area may have eroded.

On multistemmed palms, the first leaf or leaves emerging as offshoots or branches are typically crumpled and are similar in appearance to those produced by B-deficient palms (Broschat and Elliott 2007; Hodel 2012). Subsequent leaves on the new shoot will emerge normal in appearance.

B. Nutritional Problems

1. Diagnosis of Nutrient Deficiencies. Since sufficiency ranges for foliar nutrient elemental concentrations have been published only for *C. elegans*, *Chamaedorea erumpens*, *D. lutescens*, *H. forsteriana*, *P. roebelenii*, *R. excelsa*, and *E. guineensis* (Chase and Broschat 1991; Jones et al. 1991; Mills and Jones 1996; Broschat and Meerow 2000; Elliott et al. 2004), diagnosis of nutritional problems by leaf analysis is not as useful for the wide range of palm species grown as ornamentals as it is for other crops. Mills and Jones (1996) provided survey results for nutrient concentrations for six additional species, but these values do not define critical concentrations for essential elements and nutrient sufficiency levels are unknown for the vast majority of cultivated palm species. Standards for all elements are based on the central leaflets collected from the youngest fully expanded leaf. However, for mobile elements such as N, P, K, and sometimes Mg and Mn, older leaves may be better indicators of palm nutritional status (Broschat 1997a).

Soil analysis is frequently used for determination of nutrient requirements in many agronomic crops, but because data on sufficiency levels of the various nutrients in the numerous soil types, climates, and palm species involved do not exist, soil analysis as a diagnostic technique is less useful for ornamental palms.

The primary method by which nutritional deficiencies are diagnosed is visual symptom identification. Broschat and Elliott (2009b), Broschat and Meerow (2000), Chase and Broschat (1991), and Elliott et al. (2004) published full color photographic illustrations of all known nutrient

deficiency symptoms. Interactive keys for identifying nutritional, physiological, and disease problems in ornamental palms are available online (Broschat et al. 2010, 2013).

2. Nitrogen Deficiency. Nitrogen deficiency begins as an overall light green discoloration that affects the oldest leaves first, but eventually all but the spear leaf will be affected. As the deficiency progresses, growth virtually stops, with very light green foliage and tapering of the trunk (pencil-pointing) (Bull 1961a; Manciot et al. 1979; Broschat 1984).

Nitrogen deficiency is rather uncommon in landscape or field nursery situations, but is often observed in *S. romanzoffiana* in California and in *Ravenea rivularis* in both California and Florida (Broschat 2011e; Hodel 2012). It is also common in *D. lutescens* in Florida where it results in golden-colored leaf bases, petioles, and rachises (Broschat 2011e).

Because microbes degrading organic potting substrate components such as pine bark strongly compete with plant roots for N and most forms of N are highly leachable, N deficiency is the most common nutrient deficiency in container production (Broschat 2011b). Palms transplanted from containers into the landscape are highly prone to N deficiency during the first 6–12 months or until their roots become established in the mineral soil of the landscape (Broschat and Moore 2010).

3. Phosphorus Deficiency. Phosphorus (P) deficiency is relatively rare in palms in the United States, but may be more common than thought due to the similarity of its symptoms to N or K deficiency (Broschat and Meerow 2000). Symptoms in most species include a pale olive green to yellow discoloration of all leaves with leaflet tip necrosis on the oldest most severely affected leaves (Bull 1958; Broschat 1984). Purplish-brown spots may occur on the older leaves of *E. guineensis*, *C. elegans*, and *B. odorata* (Bull 1958; Chase and Broschat 1991; Hodel 2012). However, the most important symptom of P deficiency is a nearly complete cessation of growth (Broschat 1984). Phosphorus deficiency has not been reported from container-grown palms, but occurs in some landscape soils in Florida (Broschat and Elliott 2009a).

4. Potassium Deficiency. Potassium deficiency is the most widespread nutrient deficiency of landscape- and field-grown palms in North America and the West Indies, being most prevalent in highly leached sandy or limestone soils (Chase and Broschat 1991; Elliott et al. 2004). In California it is most common in palms grown in turfgrass subjected to frequent irrigation and high-N fertilizers, especially *Phoenix* and *Sabal* spp.

(Hodel 2012). It is relatively uncommon in container-grown palms (Broschat 2011b). Symptoms are most severe on the oldest leaves and appear as translucent yellow-orange and/or necrotic spotting, followed by leaflet tip necrosis and frizzling (Bull 1961a; Broschat 1984, 1990). In some species such as *Roystonea* spp., leaflet tip necrosis and frizzling are the only symptoms. Potassium deficiency symptoms are most severe toward the tip of older leaves and least so toward the base (Elliott et al. 2004). Potassium deficiency results in premature leaf senescence and is a strong determinant of the number of leaves that a palm can support (Elliott et al. 2004; Broschat and Gilman 2013). Because K is highly mobile within palms, under deficiency conditions, it is resorbed from older leaves and translocated to the newly developing leaves so that growth continues in the absence of sufficient K in the soil (Broschat 1997a). Routine removal of K-deficient leaves has been shown to accelerate the rate of decline from this deficiency in *P. roebelenii* (Broschat 1994e). In severely K-deficient palms, where all leaves are symptomatic, new leaves will emerge chlorotic, frizzled, and reduced in size. Trunk diameter tapers and death of the meristem typically follows (Chase and Broschat 1991; Elliott et al. 2004). Treatment with K fertilizers over a long period of time will gradually increase the total number of leaves in the canopy, but the lowest leaves in the canopy will remain symptomatic until the canopy reaches its normal full size (Broschat and Gilman 2013). Then symptomatic leaves will eventually be replaced with green leaves. Treatment of moderate K deficiency in Florida requires 3 or more years of intensive fertilization utilizing controlled-release K fertilizers. High N:K ratio fertilizers are known to induce or exacerbate K deficiency symptoms in palms (Broschat 2009).

5. Magnesium Deficiency. Magnesium deficiency is relatively common in landscape palms throughout the world's tropics and subtropics, being most common in highly leached soils (Elliott et al. 2004; Hodel 2012). It can occur in container-grown palms if insufficient Mg from dolomite is present in the substrate or if palms remain in a container long enough to exhaust substrate Mg supplies (Elliott et al. 2004; Broschat 2011b).

Symptoms of Mg deficiency appear on the oldest leaves unless K deficiency is also present, in which case K deficiency symptoms will be present on the oldest leaves and Mg deficiency symptoms on mid-canopy leaves (Broschat 2009). Magnesium-deficient leaves have broad yellow bands along the margins of the leaves or individual leaflets with the central portions of the leaves or leaflets remaining distinctly green (Bull 1961a; Dickey 1977; Broschat 1984; Elliott et al. 2004). In

severe cases, the entire leaf except for the rachis becomes chlorotic and leaflet tip necrosis may also be present. Magnesium deficiency is rarely fatal to palms. Magnesium deficiencies can be induced or exacerbated by high N:Mg or K:Mg ratio fertilizers (Broschat 2009).

6. Iron Deficiency. Iron (Fe) deficiency in palms is often the result of soil or root problems that affect the uptake of Fe. Poor root zone aeration due to poorly drained soils, deep planting, or excessive irrigation typically causes chronic Fe deficiency symptoms (Broschat and Donselman 1985; Elliott et al. 2004; Broschat 2009). High soil pH can also induce Fe deficiencies in palms, although to a much lesser degree than in other types of plants (Broschat 1994c, 2009; Elliott et al. 2004). Iron deficiency is common in container-grown palms where the organic substrate components have degraded, resulting in reduced aeration in the root zone. Root rot diseases in container-grown palms will also exhibit Fe deficiency symptoms above ground (Broschat and Donselman 1985; Broschat 2009).

Symptoms of Fe deficiency include interveinal or uniform chlorosis of the youngest leaves (Bull 1961b; Broschat 1984, 2009; Elliott et al. 2004). In a few species such as *S. romanzoffiana* and *Rhapis* spp., new leaves will often show diffuse green spotting superimposed upon a chlorotic background (Elliott et al. 2004; Broschat 2009). Although chlorotic Fe-deficient new leaves often eventually regain their green color, in chronic cases the entire canopy can become chlorotic. In severe cases, new leaves may emerge nearly white in color with necrotic tips (Elliott et al. 2004; Broschat 2009).

7. Manganese Deficiency. Manganese deficiency is a common problem in palms growing in alkaline soils, but binding of Mn by composted sewage sludge products has also been shown to induce severe Mn deficiencies in palms (Broschat 1991a; Elliott et al. 2004). Cold soil temperatures can also cause transient Mn deficiencies in palms due to the effects of temperature on root metabolic rates (Broschat and Donselman 1985).

Symptoms of Mn deficiency develop on newly developing leaves as chlorosis with longitudinal necrotic streaking. As symptoms progress, leaflet tips become necrotic and curled or frizzled, hence the common name “frizzle-top” (Bull 1961b; Broschat 1984; Elliott et al. 2004). Eventually only necrotic petiole stubs may emerge and the palm may die. Manganese deficiency symptoms are most severe toward the base of leaves, in contrast to K deficiency, which causes similar leaflet frizzling on leaf tips (Broschat 2009).

8. Boron Deficiency. Boron deficiency is a common disorder of palms in both humid and desert climates throughout the world (Manciot et al. 1980; Elliott et al. 2004; Patnude and Nelson 2012). Leaching of B out of the root zone by heavy rainfall is a common cause of transient B deficiencies in wet climates, but drying of soils can bind B and result in chronic B deficiencies in dry climates (Broschat 2009). Boron deficiency is rare in container-grown palms unless no B-containing fertilizers have been used.

Symptoms of B deficiency are extremely variable, even within a single species. Mild symptoms include transverse or longitudinal translucent streaks in the leaflets, puckering of the leaflets, and sharply hooked leaflet tips (hookleaf) (Rajaratnam 1972b; Brunin and Coomans 1973; Marlatt 1978; Dufour and Quencez 1979; Broschat 1984, 2009; Corrado et al. 1992; Elliott et al. 2004; Hodel 2012). Transient B deficiency is typically expressed as angular truncation of the leaf tips and can be the result of heavy rainfall leaching B out of the root zone for as little as 1 day (Broschat 2009). This transient B deficiency affects tiny developing leaves, so the symptoms do not become visible until that leaf emerges ~4 or 5 months after the deficiency occurred. The palm may have gone through multiple phases of B deficiency and sufficiency in the mean time. More severe B deficiency may be manifested by crumpling of leaves (accordion leaf), reduction in leaf size, epinasty and loss of geotropism, multiple and incompletely opened spear leaves, branching, floral necrosis, premature fruit drop, and death of the palm (Broeshart et al. 1957; Bull 1961b; Ollagnier and Valverde 1968; Rajaratnam 1972a; Brunin and Coomans 1973; Manciot et al. 1980; Corrado et al. 1992; Kamalakshamma and Shanavas 2002; Broschat 2007a,b). Leaves of B-deficient palms are often brittle, hence the name “brittleleaf.” Epinastic growth in B-deficient palms is believed to be the result of excess accumulation of auxin (indoleacetic acid) (Rajaratnam 1972a).

9. Other Nutrient Deficiencies. Calcium deficiency symptoms have been induced in sand culture for *C. elegans*, *E. guineensis*, and *H. forsteriana*, but have never been documented in palms in production or landscape situations (Bull 1958; Broschat 1984; Chase and Broschat 1991; Elliott et al. 2004). Symptoms include stunted, deformed new leaves that fail to open normally. Leaflets become necrotic with only the petiole base remaining alive. The petiole bases have a water-soaked appearance. Death of the meristem follows.

Chlorine deficiency symptoms have been induced in sand culture for *C. mitis* where they appear as mildly chlorotic new leaves and in

P. roebelenii where the chlorosis was more severe and was accompanied by incomplete separation of the leaflets. This incomplete separation gives the leaves a ladder-like appearance (Broschat 1984; Elliott et al. 2004). Fruit size and production and plant vigor were reduced in Cl-deficient *C. nucifera* and *E. guineensis* (Ollagnier and Ochs 1971; Magat et al. 1988).

Copper deficiency has been documented on *E. guineensis* growing in peat soils in Malaysia (Ng and Tan 1974), but has never been observed in ornamental palms. Symptoms have been induced in sand culture by Broschat (1984) for *C. elegans*, *H. forsteriana*, and *P. roebelenii*. Symptoms include new leaves that are reduced in size, malformed, and have necrotic margins. Chlorosis of the youngest leaves is prominent in *P. roebelenii*, and *E. Guineensis*, but is less so in *C. elegans* and nonexistent in *H. forsteriana*. As symptoms progress, only necrotic petiole stubs emerge and death of the meristem follows (Broschat 1984; Chase and Broschat 1991; Elliott et al. 2004).

Molybdenum deficiency has never been documented under natural growing environments, but has been induced in sand culture for *C. elegans* and *P. roebelenii* (Broschat 1984). New growth of Mo-deficient palms was chlorotic with large necrotic areas near the leaflet tips and margins. Leaves were deformed and reduced in size and, in severe cases, only petiole stubs emerged followed by death of the meristem (Broschat 1984; Elliott et al. 2004).

Sulfur deficiency appears to be relatively rare in ornamental palms, but it may be underdiagnosed due to the similarity of its symptoms to those of N or Fe deficiency. It has been documented in *C. nucifera* in Madagascar and Papua New Guinea (Southern 1969; Ollagnier and Ochs 1972). Symptoms have been induced in sand culture for *C. elegans*, *C. mitis*, *D. lutescens*, *H. forsteriana*, and *E. guineensis* (Broeshart et al. 1957; Bull 1961a; Broschat 1984). Uniform chlorosis or chlorosis of leaflet tips occurs in the new leaves of *C. elegans*, *C. mitis*, *E. guineensis*, and *D. lutescens*, but in *H. forsteriana* this chlorosis affects oldest leaves first. Severely affected leaves are reduced in size, extremely chlorotic, and have necrotic leaflet tips.

Zinc deficiency has not been documented in ornamental or agronomic palms, but has been induced in sand culture for *C. elegans*, *P. roebelenii*, *D. lutescens*, *H. forsteriana*, and *E. guineensis* (Bull 1961b; Marlatt and McRitchie 1979; Broschat 1984). Symptoms appear on new leaves as an interveinal chlorosis in *C. elegans* and *P. roebelenii*, but not in *D. lutescens* and *H. forsteriana* (Broschat 1984; Elliott et al. 2004). As symptoms progress, leaflet tips become necrotic, the necrosis increasing until only necrotic petiole stubs remain. Death of the meristem follows.

C. Diseases

Since this chapter concerns ornamental palms, the diseases and arthropod pests of palms discussed below are focused on palms grown and used in the landscape or interiorscape. Zaid (2002), Corley and Tinker (2003), and Batugal et al. (2005) have reviewed diseases and pests of *C. nucifera*, *E. guineensis*, and *P. dactylifera* in production settings, respectively. Because palms are used for food and oil, as well as ornamentals, and have moved far beyond their endemic range, the importance of diseases varies with the use and location of the palm. Thus, while Fusarium wilt is the primary lethal disease of *P. dactylifera* in some date-producing countries of North Africa, this disease does not occur in the United States, where *P. dactylifera* is used as a landscape plant as well as in date production.

The palm diseases discussed below do not include every disease known to occur in palms, nor is it a complete literature review. Instead, it concentrates on the diseases associated with palms used as ornamentals or diseases that could become serious threats in the landscape. The diseases are presented based on the pathogen group and not on the portion of the palm affected by the pathogen.

For ornamental palms especially, there are many reports of a “potential” pathogen being isolated from diseased palm tissue but no follow-up regarding its pathogenicity on healthy palms (e.g., contrast Ligoxigakis et al. (2013b) with Liu et al. (2010)). Thus, while the USDA ARS database (Farr and Rossman 2013) lists 557 fungus–host combinations for *C. nucifera*, many of these are based simply on reports of isolations from country or state databases, such as the one in Florida (Alfieri et al. 1994) and not necessarily on completion of Koch’s postulates, which establishes pathogenicity.

1. Virus and Viroid Diseases. Only three viruses are known to affect palms: coconut foliar decay nanavirus, limited to *C. nucifera* in the Republic of Vanuatu (Labouisse et al. 2011); African oil palm ringspot virus, limited to South America oil palm production (Lozano et al. 2010); and potyviruses. The latter have only been documented in two ornamental species: *R. regia* in Australia (Thomas et al. 1993) and *W. robusta* in California (Mayhew and Tidwell 1978).

Two viroids that affect palms are coconut cadang–cadang viroid (CCCVd) and coconut tinangaja viroid. While they primarily cause serious diseases of *C. nucifera* (Hodgson et al. 1998; Hanold and Randles 1991b) and *E. guineensis* (Randles et al. 2009) in Oceania and southeast Asia, CCCVd has been detected in other palm species in this region (Hanold and Randles 1991a; Rodriguez et al. 2003).

2. Bacterial Diseases. The number of palm diseases caused by bacteria is limited, as is the number of palm species affected and the geographic range of the diseases. Bacterial leaf disease pathogens include *Acidovorax avenae* ssp. *avenae* of *C. mitis* in Florida (Knauss et al. 1978) and *Burkholderia andropogonis* of *D. lutescens* in Australia (Young et al. 2007) and of *A. catechu* in Taiwan (Hseu et al. 2007). Sudden decline in the disease of *P. dactylifera* is caused by *Erwinia chrysanthemi* in Saudi Arabia (Abdalla 2001). A bacterial bud rot disease of *W. filifera* in Egypt is reported to be caused by *Ralstonia solanacearum* (El-Mougy and Abd-El-Kareem 2004), while bud rot disease of *R. regia* and *A. catechu* in Mauritius is caused by *Xanthomonas axonopodis* pv. *vasculorum* (Orian 1947, 1948).

3. Phytoplasma Diseases. Phytoplasmas are unculturable, cell wall-less bacteria. They are transmitted from plant to plant by insect vectors of the order Hemiptera, primarily leafhoppers, planthoppers, and psyllids. Lethal diseases of *C. nucifera* that we now associate with phytoplasma pathogens were first described in the Caribbean as early as 1834. While these diseases do occur in production fields of *C. nucifera*, they are just as important in the landscape because *C. nucifera* is a dominant palm in tropical and subtropical landscapes. All of the phytoplasmas identified thus far from palms in the Caribbean Basin and the Gulf of Mexico belong to the 16SrIV group (coconut lethal yellows group), which is comprised of six subgroups (Ntushelo et al. 2013). Phytoplasmas are divided into 28 major 16Sr groups based on analysis of the 16Sr RNA gene (Wei et al. 2007).

The dominant disease is lethal yellowing (LY), which specifically refers to the disease caused by subgroup 16SrIV-A, a pathogen detected in the Caribbean Islands (eight countries), Central America (four countries), and the Florida peninsula (Ntushelo et al. 2013). While the pathogen has been confirmed in over 35 palm species, some are more susceptible than others, with *C. nucifera* being the dominant susceptible species (Harrison and Jones 2004). Recently, subgroup 16SrIV-D has been detected more widely, both in palm hosts and geographic area, in Florida and Texas, Puerto Rico, the Yucatan peninsula of Mexico, and Central America (Harrison et al. 2002, 2008, 2009; Rodrigues et al. 2010; Aviña-Padilla et al. 2011; Vázquez-Euán et al. 2011). While this subgroup was initially identified as pathogenic to *Phoenix* spp., it has been detected in a number of palm species, including indigenous palms such as *S. palmetto*, *S. mexicana*, *Pseudophoenix sargentii*, *Roystonea* sp., and *Thrinax radiata*. Three other subgroups, 16SrIV-B, 16SrIV-E, and 16SrIV-F, occur in palms in the Caribbean Basin, but their geographic

range has been very limited (Harrison and Oropeza 1997; Roca et al. 2006; Martinez et al. 2007; Harrison et al. 2008; Ntushelo et al. 2013).

C. nucifera breeding programs screening for LY resistance have been ongoing for over 50 years. Initial results from a program based in Jamaica indicated Maypan and Malayan Dwarf cultivars were highly resistant to LY (Whitehead 1968; Harries and Romney 1974). Thus, they became popular as ornamental palms. However, it became clear over time that these coconut cultivars were not as resistant as originally believed (Broschat et al. 2002; Baudouin et al. 2008; Lebrun et al. 2008). The primary management scheme used to protect phytoplasma-susceptible palms in the landscape is injection of the antibiotic oxytetracycline every 3 or 4 months (McCoy 1982).

Other lethal-yellowing-type diseases of *C. nucifera* occur in sub-Saharan Africa under a wide variety of common names, but they are caused by phytoplasma groups other than the 16SrIV group. These diseases occur in Kenya, Tanzania, Cameroon, Ghana, Mozambique, Nigeria, and Togo (Tyman et al. 1998; Mpunami et al. 1999). Phytoplasmas recently detected in *C. nucifera* (India, Malaysia, Papua New Guinea, and Sri Lanka), *P. dactylifera* (Saudi Arabia and Sudan), and *A. catechu* (India) also do not belong to the 16SrIV group (Cronjé et al. 2000a,b; Alhudaib et al. 2007; Nejat et al. 2008; Manimekalai et al. 2010a,b; Kelly et al. 2011; Perera et al. 2012).

4. Algal Diseases. Algal leaf spot is most commonly caused by the filamentous green algae *Cephaleuros* and *Trentepohlia* (Joubert and Rijkenberg 1971). It is important to differentiate between algae that are present on leaf tissue simply as epiphytes and those that actually infect living tissue as parasites. While parasitic algae can be found in association with palms, they are not restricted to palms (Marlatt and Alfieri 1981).

5. Protozoan Diseases. The protozoans associated with palm diseases are single-flagellated, phloem-limited trypanosomatids that are currently placed in the genus *Phytomonas*. The protozoans causing lethal wilt diseases of *C. nucifera* (heartrot or fatal wilt) and *Elaeis* spp. (marchitez sorpresiva or sudden wilt) are vectored by a true bug in the genus *Lincus* and occur only in the tropical regions of Central and South America, including Trinidad and Tobago (Dollet 1984, 2001).

6. Nematode Diseases. Red ring disease, caused by *Bursaphelenchus cocophilus*, is the most important nematode disease of *C. nucifera* and *E. guineensis* (Griffith 1987). Seventeen palm species are considered plant

hosts for this nematode. However, some of these palms are classified as hosts based on successful artificial inoculation via roots and not on natural infection (Giblin-Davis 2004a). The nematode is thus far restricted to the Americas, from Mexico southward into the northern countries of South America and the islands of the Lesser Antilles (Griffith 1987; Giblin-Davis et al. 2013). It is vectored by the palm weevils *Rhynchophorus palmarum*, *Dynamis borassi*, and *Metamasius hemipterus*, with *R. palmarum* the primary vector (Giblin-Davis 2004a).

The burrowing nematode (*Radopholus similis*) has a very broad plant host range, but only eight genera of palms are documented as hosts. This nematode is found throughout the tropics, as it was most likely spread with banana corms. It is considered an important pest of *A. catechu* and *C. nucifera* in southern India (Giblin-Davis 2004b).

Other nematodes reported in association with palms include root-knot nematodes (*Meloidogyne* spp.), reniform nematode (*Rotylenchulus reniformis*), lesion nematode (*Pratylenchus penetrans*), stunt nematode (*Tylenchorhynchus* sp.), and spiral nematode (*Helicotylenchus* sp.). While the extent of damage is not clear for these pathogens, their presence can still be problematic due to regulatory issues (Giblin-Davis 2004c).

7. Oomycete Diseases. The class Oomycota is no longer classified under Kingdom Fungi, as Oomycetes have more in common with protists than fungi. The only Oomycete genus causing diseases in palms is *Phytophthora*, with the primary disease being bud rot. Two *Phytophthora* species are implicated in *C. nucifera* bud rot: *Phytophthora katsuræ* in Hawaii and Africa (Ivory Coast), where it also causes a nut rot, and *Phytophthora palmivora* elsewhere in the world (Quillec et al. 1984; Uchida et al. 1992; Rasmi and Iyer 2010). While *P. palmivora* is implicated as the bud rot pathogen in *E. guineensis* in Colombia (Torres et al. 2010), there is still considerable debate regarding the etiological agent(s) causing bud rot in this palm species in Central and South America (see de Franqueville (2003) for an overview). Since this palm species is used for oil production and seldom as an ornamental, no further discussion regarding the etiological agent will be presented. However, bud rot caused by *P. palmivora* is not limited to just *C. nucifera* and *E. guineensis*. The complete host range of this disease is unknown, but over 30 palm species are reported as hosts from around the world (Farr and Rossman 2013). However, it is unlikely that pathogenicity experiments have been completed for all palm hosts listed.

Phytophthora species are also implicated in causing a leaf disease of *C. elegans* and *D. lutescens*, as well as seedling blights, stem rots, and

petiole rots of numerous palm species (e.g., Nagata and Aragaki 1989; Faedda et al. 2011). Root rots caused by *Phytophthora* are limited, with only a few well documented and always associated with palms grown in containers (Ploetz and Mitchell 1989; Cacciola et al. 2011; Faedda et al. 2011).

8. Fungal Diseases. Fungi in the class Ascomycota are consistently associated with palms in the tropics, but most are not pathogenic to palms (Fröhlich and Hyde 2000; Hyde et al. 2000). Fungi associated with a palm in its native habitat are not necessarily the same ones observed when the palm is moved into the landscape on the other side of the world. Taylor et al. (2000) demonstrated that the fungi associated with palms in their native habitat were consistently associated with palms (multiple species), especially in the tropics. However, the fungi associated with these same palms outside of tropical regions were composed of fungi considered relatively ubiquitous with a much wider plant family host range.

Seedling blights, leaf spot, and leaf blight diseases are ubiquitous in palms in production and in the landscape, and the fungi that cause these diseases are numerous. However, most of these diseases are more problematic in young palms (Forsberg 1985), which may only have a few and smaller leaves (e.g., palm seedling versus mature tree) or in food production (e.g., *Pestalotiopsis palmivora* on *C. nucifera* in production fields in the tropics). Fungal pathogens with a wide host range, both within the palm family and other plant families, include but are not limited to the following: *Alternaria*, *Bipolaris*, *Botryosphaeria*, *Botrytis*, *Cercospora*, *Colletotrichum*, *Curvularia*, *Cylindrocladium*, *Exserohilum*, *Fusarium*, *Gloeosporium*, *Pestalotia*, *Pestalotiopsis*, *Phaeotrichon*, *Phyllostica*, *Pseudocercospora*, *Rhizoctonia*, and *Sclerotium* (Elliott et al. 2004; Farr and Rossman 2013).

Leaf pathogens with a host range limited to palms include *Annellophora phoenicis* (Vann and Taber 1985; Farr and Rossman 2013), with a relatively limited geographic range [Malaysia, New Guinea, Sierra Leone, the United States (Texas)], and *Stigmata palmivora* (Simone 2004; Farr and Rossman 2013) and *Graphiola* spp. (Piepenbring et al. 2012), which have a wider geographic range. False smut is the common name often used for the disease caused by *Graphiola phoenicis*, which is found throughout the world affecting primarily *Phoenix* spp. The other *Graphiola* spp. often have only one palm host with only a few known geographic locations (Piepenbring et al. 2012). *Graphiola* is the only genus of palm leaf pathogens in the Basidiomycota class of fungi (Oberwinkler et al. 1982).

A group of Ascomycete pathogens referred to as “tar spot” fungi, due to the highly melanized stromata formed within leaves and petioles, are also restricted to the palm family, sometimes just one palm species, and their geographic range is also quite limited (Hyde and Cannon 1999). The taxonomy of these fungi has been problematic, in part because most are unculturable and only historical specimens are available. Molecular analysis may aid in identification and likely lead to continued renaming and reclassification of these fungi in the future (Barr et al. 1989; Hyde et al. 1997; Silva-Hanlin and Hanlin 1998; Hyde and Cannon 1999; Wanderlei-Silva et al. 2003).

The pathogens in the “tar spot” fungal group that infect only leaf blades include *Broddingnagia nigeriensis*, *Camarotella* spp., *Coccostromopsis* spp., *Malthomyces* spp., *Ophiodothella calamicola*, *Oxodeora petrakii*, *Phaeochora* spp., *Phaeochoropsis* spp., *Phyllachora* spp., and *Sphaerodothis arengae*. The exceptions to the limited host and geographic range are *Phyllachora palmicola* (= *Catacauma sabal*) and *Camarotella acrocomiae* (= *Sphaerodothis acrocomiae*), although both appear to be restricted to the Neotropics (Hyde and Cannon 1999).

A “tar spot” fungus that affects both the leaves and petioles is *Phaeochoropsis neowashingtoniae*, which causes diamond scale, but only in *W. filifera* and to a lesser extent in *W. robusta* and hybrids of the two species, and only in Arizona, California (USA), and Sonora, Mexico (Shear 1931; Ohr 1991; Hyde and Cannon 1999; Downer et al. 2009b). The remaining “tar spot” fungi, *Cocoicola* and *Serenomyces* spp., infect only the petiole and rachis and not the leaf blade, although symptoms are also observed in the blade due to disruption of vascular tissue in the petiole or rachis. The disease is called petiole blight or rachis blight, depending on the palm species being affected. *Cocoicola* spp. have only one plant host per species, with each limited to very specific regions of the world (Barr et al. 1989; Hyde and Cannon 1999; Elliott and Des Jardin 2006a). Most *Serenomyces* spp. also have a very limited host and geographic range, with *Serenomyces phoenicis* the exception, as it has a wide geographic range (Hyde and Cannon 1999). As observed in palms growing in Florida, there may be more *Serenomyces* species than currently documented (Elliott and Des Jardin 2006b).

As indicated above, there is a disease called petiole blight or rachis blight, and two of the pathogens causing it are *Cocoicola* and *Serenomyces* spp. While these two pathogens are palm specific, other fungal pathogens with host ranges that often extend beyond the palm family have also been implicated in this disease, meaning “potential pathogens” have been isolated from symptomatic palms, but pathogenicity studies have not always been completed (contrast Ligoigakis et al.

2013b with Liu et al. 2010). Most of these fungi belong to Botryosphaeriaceae family, whose taxonomy is in flux (Phillips et al. 2008; Liu et al. 2012) and are often listed in the databases under their anamorphs (asexual state) because the teleomorph (sexual state) was not observed and molecular techniques were not available for identification purposes at the time they were first observed.

A lethal disease that affects specific palm species is *Fusarium* wilt. Currently, there are four formae speciales of *Fusarium oxysporum* that cause this vascular wilt disease of palms, with the host range and geographic range of these formae speciales varying widely. The only natural host of *Fusarium oxysporum* f. sp. *elaeidis* is *E. guineensis* (Flood 2006). This pathogen is present in Africa, from Ivory Coast to Democratic Republic of Congo. The localized disease outbreaks in South America were probably due to pathogen-infested seed, either palm seed or plants used for understory growth (Flood 2006). *F. oxysporum* f. sp. *albedinis* occurs only in *P. dactylifera* and, thus far, only officially documented in Algeria, Mauritania and Morocco (EPPO/CABI 1997; EPPO 2003). Strict quarantines on movement of date palm material have probably helped to limit the spread of this pathogen beyond these countries. See Hodel and Johnson (2007) for a description of almost 20-year process required to import and then release the Medjool variety, now one of the most popular ornamental date palms in the United States, into the United States from Morocco.

In contrast, *F. oxysporum* f. sp. *canariensis* occurs virtually worldwide in *P. canariensis*, probably due to this movement of palm as a popular ornamental palm. The disease was first described in France (Mercier and Louvet 1973), but has now been confirmed in Argentina (Palmucci 2006), Australia (Priest and Letham 1996), Canary Islands (Hernández-Hernández et al. 2010), Greece (Elena 2005), Italy (Migheli et al. 2005), Japan (Arai and Yamamoto 1977), and five states in the United States (California, Florida, Louisiana, Texas, South Carolina, and Nevada) (Feather et al. 1989; Plyler et al. 1999; Summerell et al. 2001; Elliott et al. 2011; Singh et al. 2011). It has been suggested that *W. filifera* is also susceptible, based on information from California and Australia (Summerell et al. 2001). It is important to note that thus far this pathogen has not been observed or detected in *P. canariensis* in natural palm groves in the Canary Islands, where this palm is endemic, only in gardens and public parks (Hernández-Hernández et al. 2010). Downer et al. (2013a) has determined that the pathogen can survive in California soils for up to 25 years.

The newest *Fusarium* wilt pathogen is *F. oxysporum* f. sp. *palmarum*, which was observed first in Florida, USA, in *S. romanzoffiana* and

W. robusta (Elliott et al. 2010). It has now been isolated from \times *Butiagrus nabonnandii* (*B. odorata* \times *S. romanzoffiana*) (single site) (Elliott et al. 2010) and *P. canariensis* (Elliott 2011) (single site) in Florida and from *W. robusta* in coastal Texas, USA (single site) (Giesbrecht et al. 2013).

Fusarium proliferatum is another *Fusarium* species associated with palm diseases, causing a variety of symptoms and, in some cases, death of the palm. It has been associated with numerous palm species in Saudi Arabia (Abdalla et al. 2000), Canary Islands (Hernández-Hernández et al. 2010), Italy (Polizzi and Vitale 2003), Spain (Armengol et al. 2005), and the United States (Nevada) (Munoz and Wang 2011). This fungus was isolated in Florida from *S. romanzoffiana* symptomatic for Fusarium wilt, but it was determined not to be pathogenic in this palm species (Elliott et al. 2010).

Three fungal pathogens that appear capable of infecting multiple parts of the palm, even mature palms, are *N.* (= *Gliocladium*) *vermoesenii* (Schroers et al. 2005), *Thielaviopsis paradoxa* (= *Ceratocystis paradoxa*), and *T. punctulata* (= *Ceratocystis radicicola*). *N. vermoesenii* is primarily a palm pathogen, while *T. paradoxa* causes diseases in multiple plant families.

N. vermoesenii has been associated with diseases of leaf sheath, rachis, leaf blade, stem, and bud (apical meristem), with the stem and bud infections resulting in palm death. The disease is often referred to as pink rot due to the massive number of pink conidia produced in the palm host (Downer et al. 2009b). While this fungus is considered cosmopolitan, the actual host and geographic range of this pathogen seems somewhat limited (Farr and Rossman 2013). This may be due to lack of official reports or due to a presumed temperature limitation; *in vitro*, the fungus did not grow at 33°C and growth was reduced by 50% at 18 and 30°C (Atilano et al. 1980; Downer et al. 2009b). In Florida, the disease has been documented on nursery material, especially if injured, but not on mature palms (Atilano et al. 1980). However, in coastal California (Downer et al. 2009b) and more recently in Crete, Greece (Ligoxigakis et al. 2013a), it is considered a serious disease of mature palms—again, more so in injured or stressed palms. The relationship of this fungus with Fusarium wilt of *P. canariensis* in California is still unclear (Downer et al. 2009b).

T. paradoxa has been associated with diseases of many palm parts of *C. nucifera*, *E. guineensis*, and *P. dactylifera* in production fields throughout the world. However, in ornamental palms, *T. paradoxa* primarily causes a lethal trunk rot in trunk tissue that is not yet highly lignified. For some palm species, notably *C. nucifera*, the palm trunk often exudes a fluid from the point of infection, often referred to as “stem

bleeding” (Nambiar et al. 1986). Again, while the list of palms reported to have been affected by *T. paradoxa* is relatively small (Farr and Rossman 2013), this pathogen has been observed in numerous other palms in the landscape as a trunk disease of mature palms (M.L. Elliott, pers. observ.). Completing pathogenicity studies with mature palms is difficult and expensive, which may explain the short list of official host palms. The pathogen can infect only wounds; thus, the trunk tissue decay usually occurs in only one side of the palm (Nambiar et al. 1986; Polizzi et al. 2007; Warwick and Passos 2009).

A second species of *Thielaviopsis*, *T. radicola*, causes a lethal root disease of *P. dactylifera* called rhizosis. It is only documented as a pathogen of *P. dactylifera* in countries in the Arabian peninsula (Al-Sadi 2013), California, USA (Bliss 1941), and South Africa (Linde and Smit 1999).

The only other root pathogen identified in palms is *Armillaria*, but this has not been a common occurrence, even in production fields (Farr and Rossman 2013). Two recent reports include one from Italy (Grasso et al. 2007) and the United States (South Carolina) (Schnabel and Bryson 2006), and this fungus is listed from a few palms in Florida (Alfieri et al. 1994).

Another lethal trunk disease of palms is caused by *Ganoderma* spp., primarily *Ganoderma zonatum* and *Ganoderma boninense*, although other species have been implicated (Steyaert 1967; Moncalvo 2000). In the United States, only *G. zonatum* is considered pathogenic to palms, and it is thus far restricted geographically to the southeastern United States (Florida and coastal areas of adjoining states), a range that coincides with that of *S. palmetto* (Elliott and Broschat 2001). In Florida, all palms that develop lignified trunks are considered susceptible (see Elliott and Broschat 2001 for a partial host list). While the fungus may be observed as a saprophyte on dead hardwood trunks or stumps, it appears to be specific as a pathogen to the palm family. The same is true for *G. boninense*, which is the primary *Ganoderma* species pathogenic to *E. guineensis* on plantations in Southeast Asia (Flood et al. 2000), with *G. zonatum* and *Ganoderma miniatotinctum* now implicated (Wong et al. 2012). Other palm species, such as *C. nucifera* and *A. catechu*, are affected in Asia, but exact *Ganoderma* sp. or spp. is still not clearly defined (e.g., Rolph et al. 2000), although *Ganoderma lucidum* has been documented as the pathogen of *C. nucifera* in multiple states in India (Bhaskaran 2000). Although *Ganoderma* spp. are present in association with palms in Africa (Farr and Rossman 2013), Cameroon is supposedly the only African country where this pathogen is problematic on *E. guineensis* (Tengoua and Bakoume 2005).

D. Arthropod Pests

The phylum Arthropoda includes two groups of palm pests: insects (class Insecta) and mites (class Acari). As with palm diseases, some arthropod pests are more problematic in production of palms for food, oil, and fiber and less so or not at all in ornamental palms. While some insects directly affect palms (e.g., caterpillars that destroy leaf tissue), others are vectors of pathogens (e.g., planthoppers that transmit phytoplasmas) and still others are both (e.g., weevils that directly affect palms and transmit nematodes that cause a disease) (Howard et al. 2001).

Since this chapter cannot possibly examine all arthropod pests of palms in great detail, we refer the reader to two resources. One is a book that thoroughly examines all insects associated with palms worldwide, including beneficial insects, such as pollinators (Howard et al. 2001). The other is a web resource that provides identification keys and fact sheets for the known arthropod pests of palms in the United States, including Hawaii, and the Caribbean Islands, and arthropod pests that are likely to move into these regions: http://itp.lucidcentral.org/id/palms/sap/about_palm_resource.html (Redford et al. 2010). For the purposes of this chapter, the arthropod pests are first separated by the type of damage they cause in palms (defoliators, sap feeders, or borers), and then by the orders or families of arthropods that cause the damage.

1. Defoliators. This group of pests primarily chew and consume plant tissue. While they can attack the palm roots, they are more likely to consume the leaf tissue, which reduces photosynthesis and, in the case of ornamental palms, reduces their aesthetic value. While the defoliation is unattractive but rarely harmful in large palms, complete defoliation can have adverse effects on seedlings and young palms, which have fewer and smaller leaves.

Order Lepidoptera. This order includes moths and butterflies. While the adults do not harm palms, the larvae (caterpillars) can be voracious defoliators. Some larvae, in addition to being plant defoliators, are also harmful to people due to their stinging setae or spines. Examples of the latter include *Acharia stimulea* (saddleback caterpillar), *Darna pallivitta* (nettle caterpillar), and *Automeris io* (io moth) (Howard and Abad 2001a; Nagamine and Epstein 2007; Redford et al. 2010). Problematic species, which appear to have only palm hosts, include but are not limited to the following: *Litoprosopus futilis* (cabbage palm caterpillar), *Asbolis capucinus* (monk skipper), *Homaledra sabalella* (palm leaf skeletonizer),

Brassolis sophorae (brush-footed butterfly), and *Omiodes blackburni* (coconut leaf roller) (Howard and Abad 2001a; Redford et al. 2010).

Order Coleoptera. This order includes the beetles and weevils. Wood-boring weevils associated with palms will be discussed in the borer section. The most important group of beetles as defoliators of palms are species within the family Chrysomelidae, in particular the Hispinae subfamily, which are primarily associated with monocot hosts, including palms (Howard and Abad 2001b). In general, species within this subfamily have not spread much beyond their natural geographic range. The most well-known genus is *Promecotheca*, leaf miners of many palm species in Australasia and southwest Pacific. *Brontispa longissima* (coconut leaf beetle) is a species that has spread the farthest beyond its natural range, although still limited to Australasia and southwest Pacific. While primarily a pest of *C. nucifera*, it is known to affect over 20 other palm species (Redford et al. 2010). A beetle species common to Florida, USA, is *Hemisphaerota cyanea* (palmetto tortoise beetle), easily found on *S. palmetto* and *S. repens*, common native palms. A weevil that is a defoliator is *Myloccerus undatus* (Sri Lanka weevil or Asian gray weevil), a new pest in Florida, USA since 2000, which has many plant hosts, including numerous palm hosts (Thomas 2005; Mayer and Mannion 2011).

Order Orthoptera. This order includes the grasshoppers, which occur worldwide, but which are not host specific to palms (Moore and Howard 2001). However, dense populations of grasshoppers can easily devour a small palm.

2. Sap Feeders. Sap feeders are able to harm palms, primarily the foliage, with their piercing-sucking mouth parts. They may harm the palm directly, or they may act as vectors of plant pathogens, phytoplasmas and protozoans. All sap feeders in the class Insecta belong to the order Hemiptera, which is currently divided into four suborders; however, the suborder *Coleorrhyncha* is not associated with palms. The other group of sap feeders is mites, which belong to the arthropod class Acari (Howard 2001).

Suborder Heteroptera. This suborder includes the “true bugs.” One very host-specific bug, *Xylastodoris luteolus*, causes damage only in the popular ornamental palm *R. regia*. It is documented as occurring only in Cuba and Florida, USA (Howard 2001), although this is surprising since this palm is used extensively in the landscape throughout the

Caribbean Basin and other tropical areas (M.L. Elliott, pers. observ.). This bug seems to be cyclic in its appearance in Florida, altering between quiescent and active years (Howard 2001). Although not yet an issue in ornamental palms in the landscape, the Heteroptera genus *Lincus* is the vector of protozoans belonging to the genus *Phytomonas*, which cause lethal diseases of *C. nucifera* and *E. guineensis* in plantation settings in the tropical Americas (Dollet 1984, 2001). Exactly which *Lincus* species is the vector has yet to be determined (Howard 2001).

Suborder Auchenorrhyncha. The importance of this suborder of insects, which includes planthoppers, treehoppers, and leafhoppers, is reflected not in the direct physical damage that these insects might cause, but rather in that species may be vectors of palm phytoplasmas (Howard 2001; Weintraub and Beanland 2006; Gitau et al. 2009). *Haplaxius* (= *Myndus*) *crudus* (American palm cixiid) is considered the primary vector of the phytoplasma that causes lethal yellowing disease in Florida, USA (Howard et al. 1983; Harrison and Oropeza 1997). This planthopper is quite likely the vector of this disease in other areas of the Caribbean Basin, but confirmation is still required. Unfortunately, these insects are difficult to maintain in the laboratory for transmission tests (Howard 2001). While adults of *H. crudus* are associated with numerous palm species, the larvae develop in the root zone of grasses (Howard et al. 1983). Other *Haplaxius* spp. are suspect vectors of a phytoplasma disease of *C. nucifera* in Ghana, but results have not been conclusive (Dery et al. 1996).

Other planthoppers in this suborder include the derbids (Family Derbidae), which can be found worldwide in palms, and flatids (Family Flatidae), which has a limited number of species associated with palms. Neither family is considered a serious pest of palms (Howard 2001; Redford et al. 2010).

Suborder Sternorrhyncha. Included in this suborder are aphids, whiteflies, mealybugs, and scales. The only important aphid genus associated with palms is *Cerataphis*, with species found worldwide. This aphid is often confused for a scale because its legs are short and hidden beneath its body and a white waxy fringe surrounds the usually sessile body (Howard 2001; Redford et al. 2010).

While whiteflies are noted in association with palms, and species of whiteflies have been found in *C. nucifera* throughout the world, they have only occasionally been serious pests. *Aleurodicus* is a genus of note as the most serious whitefly population explosions have been in this genus and because of its diagnostic characteristic of laying eggs in spirals

(Howard 2001). *Aleurodicus dispersus* was initially only known in the neotropics, but is now found throughout the tropics. In southern Florida, USA, *Aleurodicus rugiperculatus*, which appears to have originated in Central America, has infested hundreds of plants, including many palm species (Stocks and Hodges 2012). While damage to the palm by *A. rugiperculatus* may not be all that extensive, the whiteflies produce copious amounts of honeydew excretion (literally dripping from the palm), which then leads to development of sooty mold, a fungus that uses the honeydew for a food source. Together, the honeydew and sooty mold are considered the real nuisance (Mannion 2010).

Mealybugs are widely reported in palms, but only a few are considered palm specific. *Nipaecoccus nipae* (coconut mealybug) is native to Oceania and Southeast Asia, but is found in the Americas and Europe, especially in glasshouse and containerized palms (Howard 2001; Redford et al. 2010). *Palmicultor palmarum*, *Pseudococcus longispinus*, and *Dymicoccus* spp. are also widely distributed (Howard 2001). While mealybug infestations of mature palms often go unnoticed, infestations can kill seedling palms, especially under greenhouse and shadehouse conditions (Howard 2001).

The scale insects are commonly divided into soft scales and armored scales. Three soft scale species with a wide host range and distribution are *Ceroplastes floridensis* (a wax scale), *Coccus hesperidum*, and *Eucalymnatus tessellatus* (tessellated scale) (Howard 2001; Redford et al. 2010). The first two are more likely to be a problem in nurseries and greenhouses, whereas the third has been observed to be problematic in the landscape. As with whiteflies and aphids, the honeydew excretions of soft scales can be more problematic than the insects.

The four primary armored scales that are pests in ornamental palms have unique and easily identifiable features. The females of *Phoenicococcus marlatti* (red date scale) embed their red bodies in a cottony, waxy secretion (Redford et al. 2010). This scale is found almost everywhere *Phoenix dactylifera* is grown, but it has been successfully intercepted and eradicated in the southwestern United States (Howard 2001; Espinosa et al. 2011). It is present in Florida, USA, in multiple *Phoenix* spp. used in the landscape, with serious infestations observed in *P. dactylifera* and *P. roebelenii* (M.L. Elliott, pers. observ.). The coconut scale, *Aspidiotus destructor*, is unique because the scales are transparent (Redford et al. 2010). While common in *C. nucifera*, it is often found in other palm species (Howard 2001). The females of *Ischnaspis longirostris*, the black thread scale, have a body with a shiny, black, and extremely long and narrow scale cover (Redford et al. 2010). This scale is most likely to be found under greenhouse conditions.

Chrysomphalus aonidum (Florida red scale), once a major pest in Florida, USA, but under biocontrol now (Fasulo and Brooks 2010), is still a pest in the rest of the world (Gitau et al. 2009). The adult female's armor is made of three rings and is dark reddish brown with a light brown center (Fasulo and Brooks 2010).

Order Thysanoptera. The two most common plant-feeding thrips species in palms worldwide are *Heliothrips haemorrhoidalis* and *Parthenothrips dracaenae*. Thrips are not typically problematic in palms and some species feed on fungal spores in older palm leaves.

Class Acari. The red palm mite, *Raoiella indica*, is unique because all life stages are red, including the eggs (Redford et al. 2010). Originally a pest in Asia and the Middle East in *C. nucifera*, *Acacia Catechu*, and *P. dactylifera*, it has been introduced into the Caribbean Basin, including Florida, USA (Welbourn 2006). In the Caribbean Basin, it has been observed feeding on 42 palm species (Welbourn 2006). Although not a sap feeder, the coconut mite, *Aceria guerreronis*, is perhaps the most well-known mite of palms and is found in the Americas and West Africa. It feeds on the developing fruit surface, under the perianth. The distorted, imperfect fruit is a cosmetic issue in the landscape (Moore 2001).

3. Borers. This group of insects can bore into any part of the plant, but for pest purposes, insects that bore into inflorescences and fruits will not be discussed as they seldom create aesthetic issues. As defined by Giblin-Davis (2001), a borer is an “insect that makes a tunnel by chewing or burrowing.” In most cases, it is the larvae, not the adult, which bores into the palm tissue. Since the apical meristem is often the tissue destroyed by the larvae, the palm usually dies. Hence, these are some of the most serious insect pests of palms.

Order Coleoptera. Weevils are beetles that have an elongated rostrum or snout; there are a number of weevils that are palm pests. The weevil uses the rostrum to prepare openings to deposit eggs, and then the larvae bore into the palm tissue.

Species of *Rhynchophorus* and *Dynamis* are only known in association with palms; hence, their common name of palm weevils (Giblin-Davis 2001). Of major concern is the red palm weevil, *Rhynchophorus ferrugineus*, because it has spread dramatically in the past 30 years as *P. dactylifera* has been moved as an ornamental, along with another favorite host, *P. canariensis*. Until the 1980s, *R. ferrugineus* had been limited to south and southeast Asia (Giblin-Davis et al. 2013). Since then,

it has moved with infested palms to the Middle East, then southern Europe, and most recently to the islands of Curacao and Aruba (EPPO 2008). The recent infestation in California, USA, initially attributed to *R. ferrugineus* (Hodel et al. 2011; Nisson et al. 2013), which might even have been eradicated, has now been determined to be *Rhynchophorus vulneratus*, a similar looking but less aggressive and damaging species (M. Hoddle pers. commun.). A complete list of countries where this weevil is found, along with pertinent references, can be found in Bertone et al. (2010). While reported on over 20 palm hosts, *R. ferrugineus* is primarily a pest of *C. nucifera*, *P. dactylifera*, and *P. canariensis*. This weevil, like all the *Rhynchophorus* species, is normally attracted to wounded, stressed, or dying palms, but it appears to be capable of infesting healthy *P. canariensis*.

With the arrival of *R. ferrugineus* in the Caribbean Basin, there are now three species of *Rhynchophorus* in the New World, with *Rhynchophorus cruentatus* found in Florida, the coastal southeastern United States, and the Bahamas and *R. palmarum* found in Mexico, Central and South America, and the southernmost Antilles (Giblin-Davis et al. 2013). While all three species cause direct damage to the palm by their boring, *R. palmarum* is also the vector of the nematode *B. cocophilus*, which causes red ring disease of *C. nucifera* and *E. guineensis* (Giblin-Davis 2004a). *D. borassi* and *M. hemipterus* may also vector this nematode (Giblin-Davis 2004a). Plant parasitic nematodes are not known to be associated with any of the other *Rhynchophorus* species (Giblin-Davis et al. 2013).

R. palmarum is primarily a serious pest in palm plantations. However, *R. cruentatus* is a serious pest of ornamental palms in the United States and Bahamas. It will infest healthy *P. canariensis*, but other palm species appear to become attractive to the weevil only after they have been stressed or wounded (Giblin-Davis 2001). For example, *R. cruentatus* is not a serious pest *S. palmetto*, a native palm throughout Florida and the coastal southeastern United States, except during transplanting and establishment in the landscape, when the palms are stressed.

In addition to being a vector of the red ring nematode, *Metamasius hemipterus* (sugar cane weevil) can also cause direct damage to certain palm species, specifically *P. canariensis*, *R. rivularis*, *Roystonea* spp., and *Hyophorbe* spp. This weevil is found throughout Central and South America, the Caribbean Basin, and Florida, USA (Giblin-Davis 2001). Another sugarcane weevil that attacks a similar list of ornamental palms, but which also includes *C. nucifera*, occurs in the Pacific—New Guinea, Queensland (Australia), Polynesia, Micronesia, and

Hawaii, USA—is *Rhabdosceles obscurus*. As with the *Rhynchophorus* species, *M. hemipterus* and *R. obscurus* are attracted to wounded palms where they oviposit their eggs. Another genus of borers that can kill ornamental palms is *Diocalandra*, limited to tropical countries bordering the western Pacific Ocean and the Indian Ocean (Giblin-Davis 2001).

Ambrosia beetles within the genera *Xyleborus* and *Platypus* are common throughout the world, but the ones observed in palms are considered secondary pests — i.e., they primarily seem to attack palms that are stressed and are not considered lethal to palms (Giblin-Davis 2001).

Dinapate wrightii, the giant palm borer, is also attracted to stressed palms, and never healthy palms, as this borer does not produce cellulase and restricts its feeding to sugars and starch in dead wood (Giblin-Davis 2001). This species attacks *W. filifera* (>20 years old) and *P. dactylifera* in California, USA, and Baja California (Mexico). It is the larvae that are damaging the palms (Giblin-Davis 2001; Redford et al. 2010).

Rhinoceros beetles, *Oryctes* and *Scapanes* species, are the largest (30–60 mm) beetles affecting palms. Unlike the other beetle pests, it is the adult *Oryctes* beetle, not the larvae, which damage the palm. Adults burrow into the crown of the palm, near where the spear and young leaves are emerging, and feed on plant juice and tissues. Species of rhinoceros beetles can be found throughout the tropics and in date-producing areas of the Middle East and Africa. Depending on the beetle species, *C. nucifera*, *P. dactylifera*, and *E. gunineensis* are the primary palms noted as damaged, but many ornamental palm species are also hosts (Giblin-Davis 2001).

Order Lepidoptera. Probably the two most harmful Lepidopterans to ornamental palms are *Opogona sacchari* (banana moth) (Giblin-Davis 2001; Nelson and Wright 2005) and *Paysandisia archon* (CABI 2013), as both can lead to the death of the palm. In Hawaii, *Pritchardia* spp., *W. bifurcata*, *A. merrillii*, and *C. nucifera* have died due to the larvae of *O. sacchari* (Nelson and Wright 2005). In addition to these hosts, *O. sacchari* has been observed in Florida in *D. lutescens*, *Chamaedorea* sp., *Syagrus* sp., and *B. gasipaes* (Giblin-Davis 2001). In California it has been observed in *R. rivularis* and *T. fortunei* (Hodel 2012).

While *O. sacchari* has a wider host range than palms (e.g., sugar cane), the host range of *P. archon* is limited to palms. *P. archon* was introduced into Europe in the 1990s from South America, where it is indigenous, and has since spread, especially along the Mediterranean coast (CABI 2013). While damage from *P. archon* larvae is seldom observed in South America, this moth is considered an invasive species in France, Italy,

and Spain where considerable damage has occurred. It has been reported from the following palm genera in Europe: *Brahea*, *Butia*, *Chamaerops*, *Livistona*, *Phoenix*, *Sabal*, *Syagrus*, *Trachycarpus*, *Trithrinax*, and *Washingtonia* (CABI 2013).

Although not a problem in ornamental palms, *Sagalassa valida* must be mentioned as it is the only root borer of palms, specifically young *E. guineensis* in plantations in some regions of South America (Howard et al. 2001).

Order Isoptera. There is only one genus of termites that appears to attack living palm wood, *Neotermes rainbowi* (coconut termite), and this species is found only in a few islands in the South Pacific (Tuvalu and Cook Islands) (Giblin-Davis 2001). However, under certain conditions, termites may become problematic. Examples include high termite populations coinciding with stressed palms, or termites utilizing woody material buried in the soil in the same area where palms are planted (Giblin-Davis 2001).

E. Weed Management

While manual removal of weeds in small container-grown palms may be necessary to prevent growth suppression (Utulu 1986), both pre- and postemergence herbicides are routinely employed in the production and landscape management of ornamental palms. Most postemergent herbicides are applied as directed sprays around the base of larger palms because only grass-selective herbicides such as fluzifop-butyl and sethoxydim can be safely applied to palm foliage (Broschat and Meerow 2000). While *C. nucifera* was unaffected by foliar application of glyphosate, eight other species similarly treated produced one or two deformed or necrotic leaves 4–6 weeks after application (Donselman and Broschat 1986). Subsequent leaves emerged without damage in all cases. When atrazine, dicamba, imazaquin, metsulfuron, sulfosulfuron, 2,4-D amine, or mesoprop were applied at rates up to three times the label rate to the soil and base of juvenile *W. bifurcata*, only metsulfuron caused any damage and that affected only a single leaf 6 months after application (Broschat and Busey 2010). Interestingly, metsulfuron applied to the foliage of *E. guineensis* caused no injury while soil drenches did (Huat and Leong 1994). Soil applications of 2,4-D amine, diquat, paraquat, dalapon, atrazine, monuron, and diuron were also found to be safe around juvenile *C. nucifera* (Romney 1965; Kasasian et al. 1968; Hoyle 1969). However, when sprayed over the top of *C. nucifera* seedlings, all of these herbicides caused phytotoxicity or even death (Romney 1964).

Preemergent herbicides used in ornamental palms have generally been found to be safe when used at label rates on palms, with only metolachlor consistently causing injury (Neel 1977; Meerow and Broschat 1991; Broschat 2000). Symptoms of preemergent herbicide toxicity appear as distortion and/or partial necrosis of leaves emerging 2 to as long as 9 months following application (Meerow and Broschat 1991; Broschat 2000; Broschat and Meerow 2000).

LITERATURE CITED

- Abdalla, M.Y. 2001. Sudden decline of date palm trees caused by *Erwinia chrysanthemi*. Plant Dis. 85:24–26.
- Abdalla, M.Y., A. Al-Rokibah, A. Moretti, and G. Mulè. 2000. Pathogenicity of toxigenic *Fusarium proliferatum* from date palm in Saudi Arabia. Plant Dis. 84:321–324.
- Addae-Kagyah, K.A., D.M. Osafo, N.S. Olympio, and O.K. Atubra. 1988. Effect of storage, heat pretreatment and its duration on germination and growth of nursery stock of the *idolatraca* palm, *Elaeis guineensis* var. *idolatraca* (Chevalier). Trop. Agric. (Trinidad) 65:77–83.
- Afzal, M., M.A. Khan, M.A. Pervez, and R. Ahmed. 2011. Root induction in the aerial offshoots of date palm (*Phoenix dactylifera* L.) cultivar, Hillawi. Pak. J. Agric. Sci. 48:11–17.
- Airo, M., G. Giardina, G. Farruggia, G.V. Zizzo, and A. Giovino. 2011. Preliminary study on *Chamaerops humilis* L. propagation. Acta Hort. 898:39–43.
- Alemán, N.M., A.M.L. Hernández, and J.A.R. Pérez. 1999. Effect of salinity on germination of *Phoenix canariensis* and *Sabal palmetto* (Arecaceae). Acta Hort. 486:209–213.
- Alfieri, S.A., Jr., K.R. Langdon, J.W. Kimbrough, N.E. El-Gholl, and C. Wehlburg. 1994. Diseases and disorders of plants in Florida. Bull. No. 14. Florida Dept. Agric. and Consumer Services, Div. Plant Industry, Gainesville, FL.
- Alhudaib, K., Y. Arocha, M. Wilson, and P. Jones. 2007. First report of a 16SrI, *Candidatus Phytoplasma asteris* group phytoplasma associated with a date palm disease in Saudi Arabia. New Dis. Rep. 15:12.
- Ali, Y.S.S. 2007. Interaction of salinity and temperature on the germination of doum (*Hyphaene thebaica*) seed in Saudi Arabia. Asian J. Plant Sci. 6:962–966.
- Ali, A.D., and S.C. Bernick. 2010. Effects of paclobutrazol on royal palm (*Roystonea regia*) trunk and height growth. Arboric. Urban For. 36:221–223.
- Al-Madeni, M.A., and B. Tisserat. 1986. Survival of palm seeds under cryogenic conditions. Seed Sci. Technol. 14:79–85.
- Al-Mana, F.A., M.A. Ed-Hamady, M.A. Bacha, and A.O. Abdelrahman. 1996. Improving root development on ground and aerial date palm offshoots. Principes 40:179–181 217–219.
- Aloni, D.D., H. Hazon, E. Edom, D. Sendelham, C. Karp, R. Pumeranc, and Y. Cohen. 2010. Effects of growth retardants on vegetative growth of date palms. Acta Hort. 884: 207–213.
- Al-Sadi, A.M. 2013. Phylogenetic and population genetic analysis of *Ceratocystis radicola* infecting date palms. J. Plant Pathol. 95:49–57.
- Anderson, L. 1971. California cold effects. Principes 15:140.

- Andrade, A.C.S. 2001. The effect of moisture content and temperature on the longevity of heart of palm seeds (*Euterpe edulis*). *Seed Sci. Technol.* 29:171–182.
- ANSI (American National Standards Institute). 2001. Tree, shrub, and other woody plant maintenance: Standard practices (pruning). National Arborist Assoc., Manchester, NH.
- Arai, K., and A. Yamamoto. 1977. New Fusarium disease of Canary Island date palm in Japan. *Bull. Faculty Agric. Kagoshima Univ.* 27:31–37.
- Armengol, J., A. Moretti, G. Perrone, A. Vicent, J.A. Bengoechea, and J. García-Jiménez. 2005. Identification, incidence and characterization of *Fusarium proliferatum* on ornamental palms in Spain. *Eur. J. Plant Pathol.* 112:123–131.
- Atilano, R.A., W.R. Llewellyn, and H.M. Donselman. 1980. Control of *Gliocladium* in *Chamaedorea* palms. *Proc. Fla. State Hort. Soc.* 93:194–195.
- Aviña-Padilla, K., L.A. Rodríguez-Páez, A.I. Nava-Castrejón, J.C. Ochoa-Sanchez, R. Rivera-Bustamante, and J.P. Martínez-Soriano. 2011. Epidemic of lethal yellowing disease affecting *Phoenix dactylifera* and *Sabal mexicana* in Central Mexico. *Bull. Insectology* 64 (Suppl.): S221–S222.
- Bakr, E.I., G.M.M. Haseeb, S.E. El-Kosary, and M.A.M. Bakir. 2010. Using date palm suckers as material for vegetative propagation by growth regulators injection. *Bull. Fac. Agric. Cairo Univ.* 61:63–78.
- Balick, M.J. 1988. The palm—tree of life: Biology, utilization and conservation. *Adv. Econ. Bot.* 6:1–282.
- Balick, M.J., and H.T. Beck. (eds.), 1990. Useful palms of the world: A synoptic bibliography. Columbia Univ. Press, New York.
- Barr, M.E., H.D. Ohr, and M.K. Murphy. 1989. The genus *Serenomyces* on palms. *Mycologia* 81:47–51.
- Barry, D. 1961. Notes on the hardiness of palms on the French Riviera. *Principes* 5:100–103.
- Baskin, J.M., and C.C. Baskin. 2004. A classification system for seed dormancy. *Seed Sci. Res.* 14:1–16.
- Batugal, P., and F. Engelmann. (eds.), 1998. Coconut embryo *in vitro* culture. Papers presented at a workshop on embryo culture, October 1997, Serdang, Malaysia.
- Batugal, P., V.R. Rao, and J. Oliver (eds.), 2005. Coconut genetic resources. International Plant Genetic Resources Institute, Regional Office for Asia, the Pacific, and Oceania (IPGRI-APO), Selangor DE, Malaysia.
- Baudouin, L., P. Lebrun, A. Berger, W. Myrie, B. Been, and M. Dollet. 2008. The Panama Tall and Maypan hybrid coconut in Jamaica: Did genetic contamination cause a loss of resistance to lethal yellowing? *Euphytica* 161:353–360.
- Beeson, R. C., Jr., and R. Newton. 1992. Shoot and root responses of eighteen southeastern woody landscape species grown in cupric hydroxide-treated containers. *J. Environ. Hort.* 10:214–217.
- Bernardes, M.S., V.U. Cromber, L.R.R. Furia, and A.N. Martins. 1996. Influence of nursery conditions on germination and initial development of pejibaye (*Bactris gasipaes*). *Rev. Biol. Trop.* 44:499–505.
- Bertone, C., P.S. Michalak, and A. Roda. 2010. New pest response guidelines: Red palm weevil. USDA-APHIS.
- Bezona, N., D. Hensley, J. Yogi, J. Tavares, F. Rauch, R. Iwata, M. Kellison, and M. Wong. 1996. Salt and wind tolerance of landscape plants for Hawaii. CTHAR, Univ. Hawaii, Coop. Ext. Serv. Publ., L-19.
- Bhaskaran, R. 2000. Management of basal stem rot disease of coconut caused by *Ganoderma lucidum*. p. 121–128. In: J. Flood, P.D. Bridge, and M. Holderness (eds.), *Ganoderma diseases of perennial crops*. CABI Publ., Wallingford, UK.

- Bliss, D.E. 1941. A new species of *Ceratostomella* on the date palm. *Mycologia* 33:468–482.
- Bovi, M.L.A., C.C. Martins, and S.H. Spiering. 2004. Desidratação de sementes de quatro lotes de pupunheira: efeitos sobre a germinação e o vigor. *Hortic. Bras.* 22 (1): 109–112.
- Bovi, M.L.A., P.F. de A. Tedrus, and S.H. Spiering. 1994. Nursery growth of *Euterpe oleracea* as a function of substrate and container size. *Acta Hortic.* 360:195–209.
- Briceño, A., and N. Maciel. 2004. Efectos de la madurez del fruto, escarificación de la semilla y temperatura de siembra en la emergencia de *Sabal mauritiiformis*. *Proc. Intl. Am. Soc. Trop. Hortic.* 48:184–188.
- Broeshart, H., J.D. Ferwerda, and W.G. Kovachich. 1957. Mineral deficiency symptoms of the oil palm. *Plant Soil* 8:289–300.
- Broschat, T.K. 1984. Nutrient deficiency symptoms of five species of palms grown as foliage plants. *Principes* 28:6–14.
- Broschat, T.K. 1990. Potassium deficiency of palms in south Florida. *Principes* 34:151–155.
- Broschat, T.K. 1991a. Manganese binding by municipal waste composts used as potting media. *J. Environ. Hortic.* 9:97–100.
- Broschat, T.K. 1991b. Effects of manganese source on manganese uptake by pygmy date palms. *HortScience* 26:1389–1391.
- Broschat, T.K. 1991c. Effects of leaf removal on survival of transplanted sabal palms. *J. Arboric.* 17:32–33.
- Broschat, T.K. 1994a. Palm seed germination. *Acta Hortic.* 360:141–147.
- Broschat, T.K. 1994b. Transplanting large specimen palms in the landscape. *Acta Hortic.* 360:189–193.
- Broschat, T.K. 1994c. Nutrition of ornamental palms. *Acta Hortic.* 360:217–222.
- Broschat, T.K. 1994d. Effects of leaf removal, leaf tying, and overhead irrigation on transplanted pygmy date palms. *J. Arboric.* 20:210–213.
- Broschat, T.K. 1994e. Removing potassium-deficient leaves accelerates rate of decline in *Phoenix roebelenii*. *HortScience* 29:823.
- Broschat, T.K. 1995a. Nitrate, phosphate, and potassium leaching from container-grown plants fertilized by several methods. *HortScience* 30:74–77.
- Broschat, T.K. 1995b. Planting depth affects survival, root growth, and nutrient content of transplanted pygmy date palms. *HortScience* 30:1031–1032.
- Broschat, T.K. 1996. Release rates of soluble and controlled-release potassium fertilizers. *HortTechnology* 6:128–131.
- Broschat, T.K. 1997a. Nutrient distribution, dynamics, and sampling in coconut and Canary Island date palms. *J. Am. Soc. Hortic. Sci.* 122:884–890.
- Broschat, T.K. 1997b. Release rates of controlled-release and soluble magnesium fertilizers. *HortTechnology* 7:58–60.
- Broschat, T.K. 1998a. Root and shoot growth patterns in four palm species and their relationship to air and soil temperatures. *HortScience* 33:995–998.
- Broschat, T.K. 1998b. Endocarp removal enhances *Butia capitata* (Mart.) Becc. (pindo palm) seed germination. *HortTechnology* 8:586–587.
- Broschat, T.K. 1999. Nutrition and fertilization of palms. *Palms* 43:73–76.
- Broschat, T.K. 2000. Phytotoxicity and longevity of twenty-two preemergent herbicides used on three species of container-grown palms. *HortTechnology* 10:597–603.
- Broschat, T.K. 2001. Substrate nutrient retention and growth of container-grown plants in clinoptilolitic zeolite-amended substrates. *HortTechnology* 11:75–78.
- Broschat, T.K. 2002. Influence of light intensity on optimum fertilization rate in five species of tropical ornamental plants. *HortTechnology* 12:226–229.

- Broschat, T.K. 2007a. Boron deficiency symptoms in palms. *Palms* 51:115–126.
- Broschat, T.K. 2007b. Boron deficiency, phenoxy herbicides, stem bending, and branching in palms: Is there a connection? *Palms* 51:161–163.
- Broschat, T.K. 2008a. Effectiveness of pasteurized poultry litter as a partial substitute for controlled-release fertilizers in the production of container-grown ornamental plants. *HortTechnology* 18:671–677.
- Broschat, T.K. 2008b. Release rates of soluble and controlled release boron fertilizers. *HortTechnology* 18:471–474.
- Broschat, T.K. 2009. Palm nutrition and fertilization. *HortTechnology* 19:690–694.
- Broschat, T.K. 2010a. Cold damage on palms. Univ. Fla. Environ. Hortic. Dept. Publ. ENH-92. <http://edis.ifas.ufl.edu/mg318>
- Broschat, T.K. 2010b. Fertilization improves cold tolerance in coconut palm. *HortTechnology* 20:852–855.
- Broschat, T.K. 2011a. Fertilization of field-grown and landscape palms in Florida. Univ. Fla. Environ. Hortic. Publ. ENH1009. <http://edis.ifas.ufl.edu/ep261>
- Broschat, T.K. 2011b. Nutrition and fertilization of palms in containers. Univ. Fla. Environ. Hortic. Dept. Circ. ENH1010. <http://edis.ifas.ufl.edu//EP262>
- Broschat, T.K. 2011c. Pruning palms. Univ. Fla. Environ. Hortic. Publ. ENH1182. <http://edis.ifas.ufl.edu/ep443>
- Broschat, T.K. 2011d. Uptake and distribution of boron in coconut and paurotis palms. *HortScience* 46:1683–1686.
- Broschat, T.K. 2011e. Nutrient deficiencies of landscape and field-grown palms in Florida. Univ. Fla. Environ. Hortic. Dept. Publ. ENH1018. <http://edis.ifas.ufl.edu/ep273>
- Broschat, T.K. 2012. Transplanting palms in the landscape. Univ. Fla. IFAS Extension Cir 1047. <http://edis.ifas.ufl.edu/ep001>
- Broschat, T.K., and P. Busey. 2010. Toxicity of turfgrass postemergence herbicides to *Wodyetia bifurcata*. *Palms* 53:137–140.
- Broschat, T.K., and J.J. Docola. 2010. Effects of soil-applied and trunk and petiole-injected manganese on manganese content of coconut palm (*Cocos nucifera*). *Arboric. Urban For.* 36:272–274.
- Broschat, T.K., and H. Donselman. 1984. Root regeneration in transplanted palms. *Principes* 28:90–91.
- Broschat, T.K., and H. Donselman. 1985. Causes of palm nutritional disorders. *Proc. Fla. State Hortic. Soc.* 98:101–102.
- Broschat, T.K., and H. Donselman. 1986a. Effects of several growth substances on height, flowering, and lateral shoot development in *Chamaedorea seifrizii*. *Principes* 30:135–137.
- Broschat, T.K., and H. Donselman. 1986b. Factors affecting storage and germination of *Chrysalidocarpus lutescens* seeds. *J. Am. Soc. Hortic. Sci.* 111:872–877.
- Broschat, T.K., and H. Donselman. 1987a. Potential of 57 species of tropical ornamental plants for cut foliage use. *HortScience* 22:911–913.
- Broschat, T.K., and H. Donselman. 1987b. Effects of fruit maturity, storage, presoaking, and seed cleaning on germination in three species of palms. *J. Environ. Hortic.* 5:6–9.
- Broschat, T.K., and H. Donselman. 1987c. Factors affecting palm transplant success. *Proc. Fla. State Hortic. Soc.* 100:396–397.
- Broschat, T.K., and H. Donselman. 1988. Palm seed storage and germination studies. *Principes* 32:3–12.
- Broschat, T.K., and H. Donselman. 1990a. IBA, plant maturity, and regeneration of palm root systems. *HortScience* 25:232.

- Broschat, T.K., and H. Donselman. 1990b. Regeneration of severed roots in *Washingtonia robusta* and *Phoenix reclinata*. *Principes* 34:96–97.
- Broschat, T.K., H. Donselman, and D.B. McConnell. 1989. Light acclimatization in *Ptychosperma elegans*. *HortScience* 24:267–268.
- Broschat, T.K., and M.L. Elliott. 2005a. Effects of iron source on iron chlorosis and *Exserohilum* leaf spot severity in *Wodyetia bifurcata*. *HortScience* 40:218–220.
- Broschat, T.K., and M.L. Elliott. 2005b. A key to common landscape palm disorders and diseases in the continental United States. *Palms* 49:143–148.
- Broschat, T.K., and M.L. Elliott. 2007. Normal “abnormalities” in palms. Univ. Fla. Environ. Hortic. Dept. Publ. ENH1077. <http://edis.ifas.ufl.edu/ep344>
- Broschat, T.K., and M.L. Elliott. 2009a. Effects of fertilization and microbial inoculants applied at transplanting on the growth of Mexican fan palm and queen palm. *HortTechnology* 19:324–330.
- Broschat, T.K., and M.L. Elliott. 2009b. Diseases and disorders of ornamental palms. 2nd edition. Card Deck SP-360. Univ. Fla. Coop. Ext. Serv.
- Broschat, T.K., M.L. Elliott, and I. Maguire. 2010. A resource for pests and diseases of cultivated palms: Symptoms of diseases and disorders. A Resource for Pests and Diseases of Cultivated Palms, Univ. Florida, Identification Technology Program, CPHST, PPQ, APHIS, USDA, Fort Collins, CO. Accessed June 15, 2013. <http://itp.lucidcentral.org/id/palms/symptoms/>
- Broschat, T. K., M.L. Elliott, and I. Maguire. 2010. Palm problems. IFAS, Fort Lauderdale Research and Education Center, Univ. Florida. Accessed June 1, 2013. http://frec.ifas.ufl.edu/palm_prod/palm_problems.shtml
- Broschat, T.K., and E.F. Gilman. 2013. Effects of fertilization and severe pruning on canopy size and potassium deficiency symptom severity in *Sabal palmetto*. *Palms* 57: 84–88.
- Broschat, T.K., N.A. Harrison, and H. Donselman. 2002. Losses to lethal yellowing cast doubt on coconut cultivar resistance. *Palms* 46:185–189.
- Broschat, T.K., and K.A. Klock-Moore. 2000. Root and shoot growth responses to phosphate fertilization in container-grown plants. *HortTechnology* 10:765–767.
- Broschat, T.K., and W.G.L. Latham. 1994. Oxalate content of palm fruit mesocarp. *Biochem. Syst. Ecol.* 22:389–392.
- Broschat, T.K., and A.W. Meerow. 1991. Betrock’s guide to Florida landscape plants. Betrock Info. Systems, Davie, FL.
- Broschat, T.K., and A.W. Meerow. 2000. Ornamental palm horticulture. Univ. Press of Florida, Gainesville, FL.
- Broschat, T.K., A.W. Meerow, and J. Miller. 2013. Field production of palms. Univ. Fla. Environ. Hortic. Dept. Circ. 877. <http://edis.ifas.ufl.edu/ep036>
- Broschat, T.K., and K.K. Moore. 2003. Influence of fertilizer placement on plant quality, root distribution, and weed growth in container-grown tropical ornamental plants. *HortTechnology* 13:305–308.
- Broschat, T.K., and K.A. Moore. 2010. Effects of fertilization on the growth and quality of container-grown areca palm and Chinese hibiscus during establishment in the landscape. *HortScience* 20:389–394.
- Broschat, T.K., and K.A. Moore. 2013. Fertilization rate and placement effects on areca palms transplanted from containers or a field nursery. *Arboric. Urban For.* 38:146.
- Broschat, T.K., D.R. Sandrock, M.L. Elliott, and E.F. Gilman. 2008. Effects of fertilizer type on quality and nutrient content of established landscape plants in Florida. *HortTechnology* 18:278–285.

- Brown, K.E. 1976. Ecological studies of the cabbage palm, *Sabal palmetto*: III. Seed germination and seedling establishment. *Principes* 20:98–115.
- Brunin, C., and P. Coomans. 1973. La carence en bore sur jeunes cocotiers en Côte D'Ivoire. *Oléagineux* 28:229–234.
- Buhler, T.C. 1974. Notes on marcottage of certain palms. *Principes* 18:111–112.
- Bull, R.A. 1958. Symptoms of calcium and phosphorus deficiency in oil palm seedlings. *Nature* 182:1749–1750.
- Bull, R.A. 1961a. Studies on the deficiency diseases of the oil palm: 2. Macronutrient deficiency symptoms in oil palm seedlings grown in sand culture. *J. West African Inst. Oil Palm Res.* 3:254–260.
- Bull, R.A. 1961b. Studies on the deficiency diseases of the oil palm: 3. Micronutrient deficiency symptoms in oil palm seedlings grown in sand culture. *J. West Afr. Inst. Oil Palm Res.* 3:254–272.
- CABI. 2013. *Paysandisia archon* (original text by P. Riola and S. Nardi). Invasive species compendium. CAB International, Wallingford, UK. www.cabi.org/isc.
- Cacciola, S.O., A. Pane, R. Faedda, C. Rizza, F. Badala, and G.M. di San Lio. 2011. Bud and root rot of windmill palm (*Trachycarpus fortunei*) caused by simultaneous infections of *Phytophthora palmivora* and *P. nicotianae* in Sicily. *Plant Dis.* 95:769.
- Caldwell, D. 2006. Hurricane cuts compromise palm tree structure in high winds. Univ. Fla. Collier Co. Horticulture fact sheet. <http://collier.ifas.ufl.edu/CommHort/CommHortPubs/Hurricane%20Cuts%20Compromise%20Palm%20Tree%20Structure.pdf>
- Calvez, C. 1976. Influences on oil palm yield of pruning at different levels. *Oléagineux* 1:57–58.
- Campbell, K. 1997. The effects of the freeze of 1997 on palms in central and south Florida. *Palm Rev.* 17 (2): 7–9.
- Carpenter, W.J. 1986. Seed germination in *Serenoa repens*. *Proc. Fla. St. Hortic. Soc.* 99:158–159.
- Carpenter, W.J. 1987. Temperature and imbibition effects on seed germination of *Sabal palmetto* and *Serenoa repens*. *HortScience* 22:660.
- Carpenter, W.J. 1988a. Temperature affects seed germination of four Florida palm species. *HortScience* 23:336–337.
- Carpenter, W.J. 1988b. Seed after-ripening and temperature influence *Butia capitata* germination. *HortScience* 23:702–703.
- Carpenter, W.J. 1989. Influence of temperature on germination of *Sabal causiarum* seed. *Principes* 33:191–194.
- Carpenter, W.J., and E.F. Gilman. 1988. Effect of temperature and desiccation on the germination of *Thrinax morrisii*. *Proc. Fla. State Hortic. Soc.* 101:288–290.
- Carpenter, W.J., and E.R. Ostmark. 1994. Temperature and desiccation effect the germination of *Chamaedorea* palm seed. *Proc. Fla. State Hortic. Soc.* 107:183–186.
- Carpenter, W.J., E.R. Ostmark, and J.A. Cornell. 1993a. Embryo cap removal and high temperature exposure stimulate rapid germination of needle palm seeds. *HortScience* 28:904–907.
- Carpenter, W.J., E.R. Ostmark, and K.C. Ruppert. 1993b. Promoting the rapid germination of needle palm seed. *Proc. Fla. State Hortic. Soc.* 106:336–338.
- Carvalho, J.H., F.G.A. Filho, and J.L.D. Moraes. 1988. Effects of different conditions and duration of storage on the germination of Babassu seeds (*Orbignya phalerata*). *Principes* 32:55–58.
- Cathey, H. M., and L. E. Campbell. 1977. Choose the best light source. *Florists Rev.* 161 (4161): 27–28.

- Chan, S.K., and J.E. Duckett. 1978. Crown fracture and palm type: Initial findings. *Planter (Kuala Lumpur)* 54:142–148.
- Chase, A.R., and T.K. Broschat. (eds.) 1991. Diseases and disorders of ornamental palms. *Am. Phytopathological Soc.*, St. Paul, MN.
- Chase, A.R., and R.T. Poole. 1984. Influence of foliar applications of micronutrient and fungicides on foliar necrosis and leaf spot disease of *Chrysalidocarpus lutescens*. *Plant Dis.* 68:195–197.
- Chazdon, R.L. 1991. Effects of leaf and ramet removal on growth and reproduction of *Geonoma congesta*, a clonal understorey palm. *J. Ecol.* 79:1137–1146.
- Chien, C.T., and S.Y. Chen. 2008. Effects of seed moisture content and temperature on the storability of *Phoenix hanceana* (Arecaceae). *Seed Sci. Technol.* 36:781–787.
- Chin, H.F., B. Krishnapillay, and Z.C. Alang. 1988. Breaking dormancy in kentia palm seeds by infusion technique. *Pertanika* 11:137–141.
- Cid, M.C., M. Caballero, M.A. Diaz, and P. Mansito. 1999. Increase of *Phoenix roebelenii* growth rates by hydroculture on volcanic cinder. *Acta Hort.* 486:169–173.
- Clancy, K.E., and M.J. Sullivan. 1988. Some observations on seed germination, the seedling, and polyembryony in the needle palm *Rhapidophyllum hystrix*. *Principes* 32:18–25.
- Conover, C.A. 1975. Handling foliage plants in the retail shop. *Am. Florists* 7 (12): 6–7.
- Conover, C. A., and D. B. McConnell. 1981. Utilization of foliage plants. p. 519–543. In: J.N. Joiner (ed.), *Foliage plant production*. Prentice Hall, Englewood Cliffs, NJ.
- Conover, C.A., and R.T. Poole. 1977. Fertilization of indoor foliage plants. *Proc. 1977 Nat. Trop. Foliage Short Course*, Orlando, FL, Florida Foliage Association, Apopka FL, p. 1:130–133.
- Conover, C.A., and R.T. Poole. 1990. Utilization of Agrisoil® compost in production of foliage plants. *Proc. Fla. State Hort. Soc.* 103:163–165.
- Conover, C.A., R.T. Poole, and R.W. Henley. 1975. Growing acclimatized foliage plants. *Fla. Foliage Grower* 12 (9): 1–4.
- Conover, C.A., R.T. Poole, and R.W. Henley. 1992. Light and fertilizer recommendations of interiorscape maintenance of acclimated foliage plants. *South. Nurs. Dig.* 52–53.
- Conover, C.A., and G.A. Sanders. 1978. Influence of liquid and slow release fertilizer combinations on three foliage plants. *Foliage Dig.* 1 (4): 5–6.
- Corley, R.H.V., and P.B. Tinker. 2003. *The oil palm*. John Wiley & Sons, Inc., Hoboken, NJ.
- Corrado, F., P. Quincez, and B. Tailliez. 1992. La déficience en bore chez le palmier à huile. *Symptômes et corrections*. *Oléagineux* 47:719–725.
- Corrado, F., and W. Wuidart. 1990. Germination of oil palm (*E. guineensis*) seeds in polythene bags “dry heat” method. *Oleagineux* 45:511–518.
- Costonis, A.C. 1995. Factors affecting the survival of transplanted sabal palms. *J. Arboric.* 21:98–102.
- Cronjé, P., A.J. Dabek, P. Jones, and A.M. Tymon. 2000a. First report of a phytoplasma associated with a disease of date palms in North Africa. *New Dis. Rep.* 1:4.
- Cronjé, P., A.J. Dabek, P. Jones, and A.M. Tymon. 2000b. Slow decline: a new disease of mature date palms in North Africa associated with a phytoplasma. *New Dis. Rep.* 1:7.
- Cutter, V.M., and K.S. Wilson. 1954. Effect of coconut endosperm and other growth stimulants upon the development *in vitro* of embryos of *Cocos nucifera*. *Bot. Gaz.* 115:234–240.
- Daquinta, M., O. Concepcion, I. Capote, I. Cobo, M. Escalona, and C. Borroto. 1996. *In vitro* germination of *Chamaedorea seifrizii*. *Principes* 40:112–113.
- Davies, R.I., and H.W. Pritchard. 1998. Seed storage and germination of the palms *Hyphaene thebaica*, *H. petersiana* and *Medemia argun*. *Seed Sci. Technol.* 26:823–828.

- Davis, T.A. 1961. Rejuvenate your coconut palm. *Indian Farmer* 1961:272–274.
- de Franqueville, H. 2003. Oil palm bud rot in Latin America. *Exp. Agric.* 39:225–240.
- DeLeon, N.J. 1958. Viability of palm seeds. *Principes* 2:96–98.
- Dematté, J.B.I., T.T. Graziano, C.A. Volpe, D. Perecin, and M.E.S.P. Dematté. 1994. Interaction between substrates and irrigation on early development of *Rhapis excelsa* (Lady palm). *Acta Hortic.* 360:211–216.
- Dery, K.S., R. Philippe, and D. Mariau. 1996. Auchenorrhyncha (Homoptera), suspected vectors of coconut lethal yellowing disease in Ghana. *Plant. Rech. Dév.* 3:355–362.
- Dewir, Y.H., M.E. El-Mahrouk, and Y. Naidoo. 2011. Effects of some mechanical and chemical treatments on seed germination of *Sabal palmetto* and *Thrinax morrisii* palms. *Aust. J. Crop Sci.* 5:248–253.
- Dias, A.C., M.P. Guerra, A.S. Cordoba, and E.L. Kemper. 1994. Somatic embryogenesis and plant regeneration in the tissue culture of *Geonoma gamiova* (Arecaceae). *Acta Hortic.* 360:167–171.
- Dickey, R.D. 1977. Nutritional deficiencies of woody ornamental plants used in Florida landscapes. *Univ. Fla. Coop. Ext. Serv. Bull.* 791.
- Dickie, J.B., M.J. Balick, and I.M. Linington. 1992. Experimental investigations into the feasibility of *ex situ* preservation of palm seeds: An alternative strategy for biological conservation of this economically important plant family. *Biodivers. Conserv.* 1:112–119.
- Dickie, J.B., M.J. Balick, and I.M. Linington. 1993. Studies on the practicality of *ex situ* preservation of palm seeds. *Principes* 37:94–98.
- Dollet, M. 1984. Plant diseases caused by flagellate protozoa (*Phytomonas*). *Annu. Rev. Phytopathol.* 22:115–132.
- Dollet, M. 2001. Phloem-restricted trypanosomatids form a clearly characterised monophyletic group among trypanosomatids isolated from plants. *Int. J. Parasitol.* 31:459–467.
- Donselman, H. 1982. Palm seed germination. *Proc. Fla. St. Hortic. Soc.* 95:256–257.
- Donselman, H., and T.K. Broschat. 1986. Phytotoxicity of several pre- and postemergent herbicides on container grown palms. *Proc. Fla. State Hortic. Soc.* 99:273–274.
- Doughty, S.C., D.J. Gill, and D.C. Blouin. 1992. Freeze survival survey of 21 palm species in New Orleans and vicinity. *HortTechnology* 2:460–465.
- Doughty, S.C., E.N. O'Rourke, E.P. Barrios, and R.P. Mowers. 1986. Germination studies of pygmy date palm seed. *Principes* 30:85–87.
- Downer, A.J., and D. Hodel. 2001. The effects of mulching on establishment of *Syagrus romanzoffiana* (Cham.) Becc., *Washingtonia robusta* H. Wendl. and *Archontophoenix cunninghamiana* (H. Wendl.) H. Wendl. & Drude in the landscape. *Scientia Hortic.* 87:85–92.
- Downer, A.J., D.R. Hodel, D. M. Mathews, and D.R. Pittenger. 2013a. Effect of fertilizer nitrogen source on susceptibility of five species of field-grown palms to *Fusarium oxysporum* f. sp. *canariensis*. *Palms* 57:89–92.
- Downer, A.J., D.R. Hodel, and M. Mochizuki. 2007. Effects of preplant incorporation and postplanting application of a palm special fertilizer on five species of landscape palms. *HortScience* 42:878.
- Downer, A.J., D. Hodel, and M.J. Mochizuki. 2009a. Pruning landscape palms. *HortTechnology* 19:695–699.
- Downer, A.J., D.R. Hodel, and D.R. Pittenger. 2013b. Effect of leaf tie-up and pre-plant storage on growth and transpiration of transplanted Mexican fan palms. *Palms* 57:58–63.
- Downer, A.J., J. Uchida, D.R. Hodel, and M.L. Elliott. 2009b. Lethal diseases common in the United States. *HortTechnology* 19:710–716.
- Dransfield, J., N.W. Uhl, C.B. Asmussen, W.J. Baker, M.M. Harley, and C.E. Lewis. 2005. A new phylogenetic classification of the palm family, Arecaceae. *Kew Bull.* 60:559–569.

- Dransfield, J., N.W. Uhl, C.B. Asmussen, W.J. Baker, M.M. Harley, and C.E. Lewis. 2008. *Genera palmarum: The evolution and classification of palms*. Kew Publ., Richmond, Surrey, UK.
- Dufour, F., and P. Quencez. 1979. Étude de la nutrition en oligo-éléments du palmier à huile et du cocotier cultivés sur solutions nutritives. *Oléagineux* 34:323–330.
- Dwivedi, R.S., P.K. Ray, and S. Ninan. 1981. Studies on the methods of inorganic nutrient application in coconut. *Plant Soil* 63:449–456.
- Ehara, H., O. Morita, C. Komada, and M. Goto. 2001. Effect of physical treatment and presence of the pericarp and sarcotesta on seed germination in sago palm (*Metroxylon sagu* Rottb.). *Seed Sci. Technol.* 29:83–90.
- Elena, K. 2005. *Fusarium* wilt of *Phoenix canariensis*: first report in Greece. *Plant Pathol.* 54:244.
- El-Khateeb, M.A., E. El-Madaawy, and A. El-Attar. 2010. Effect of some biofertilizers on growth and chemical composition of *Chamaedorea elegans* Mart. Seedlings. *J. Hortic. Sci. Ornam. Plants* 2:123–129.
- Elliott, M.L. 2011. First report of *Fusarium* wilt caused by *Fusarium oxysporum* f. sp. *palmarum* on Canary Island date palm in Florida. *Plant Dis.* 95:356.
- Elliott, M.L., and T.K. Broschat. 2001. Observations and pathogenicity experiments on *Ganoderma zonatum* in Florida. *Palms* 45:62–72.
- Elliott, M.L., and T.K. Broschat. 2002. Effects of a microbial inoculants on plant growth and rhizosphere bacterial populations of container-grown plants. *HortTechnology* 12:222–225.
- Elliott, M.L., and T.K. Broschat. 2012. *Ganoderma* butt rot of palms. *Univ. Fla. Plant Pathol. Publ.* PP-54. <http://edis.ifas.ufl.edu/pp100>
- Elliott, M.L., T.K. Broschat, J.Y. Uchida, and G.W. Simone. (eds.), 2004. *Compendium of ornamental palm diseases and disorders*. Am. Phytopathol. Soc., St. Paul, MN.
- Elliott, M.L., and E.A. Des Jardin. 2006a. First report of *Coccoloba californica* on *Washingtonia robusta* in Florida. doi:10.1094/PHP-2006-0227-01-BR.
- Elliott, M.L., and E.A. Des Jardin. 2006b. First report of a *Serenomyces* sp. from *Copernicia x burretiana*, *Latania loddigesii*, and *Phoenix canariensis* in Florida and the United States. doi:10.1094/PHP-2006-1213-02-BR.
- Elliott, M.L., E.A. Des Jardin, K. O'Donnell, D.M. Geiser, N.A. Harrison, and T.K. Broschat. 2010. *Fusarium oxysporum* f. sp. *palmarum*, a novel forma specialis causing a lethal disease of *Syagrus romanzoffiana* and *Washingtonia robusta* in Florida. *Plant Dis.* 94:31–38.
- Elliott, M.L., E. Honeycutt, J. West, and P. Franklin. 2011. First report of *Fusarium* wilt caused by *Fusarium oxysporum* f. sp. *canariensis* on Canary Island date palm in Texas and South Carolina. *Plant Dis.* 95:358.
- Ellis, R.H., T.D. Hong, E.H. Roberts, and U. Soetisna. 1991. Seed storage behavior in *Elaeis guineensis*. *Seed Sci. Res.* 1:99–104.
- El-Mougy, N.S., and F. Abd-El-Kareem. 2004. Occurrence of apical bud rot disease on ornamental palm (*Pritchardia filifera*) in Egypt and its control. *Egypt. J. Microbiol.* 39:15–28.
- Endress, B.A., D.L. Gorchov, and M.B. Peterson. 2004. Harvest of the palm *Chamaedorea radicalis*, its effects on leaf production, and the implications for sustainable management. *Conserv. Biol.* 18:822–830.
- EPPO. 2003. *Fusarium oxysporum* f. sp. *albedinis*. *EPPO Bull.* 33:265–269.
- EPPO. 2008. *Rhynchophorus ferrugineus*. *EPPO Bull.* 38:55–59.
- EPPO/CABI. 1997. *Fusarium oxysporum* f. sp. *albedinis*. p. 758–763. In: *Quarantine pests for Europe*. 2nd edition. CAB International, Wallingford, UK.

- Espinosa, A., A. Hodges, G. Hodges, and C. Mannion. 2011 Red Date Scale, *Phoenicococcus marlatti* (Cockerell) (Insecta: Hemiptera: Phoenicococcidae). EENY-454. Fla. Coop. Ext. Serv., Univ. Florida, Gainesville, FL. <http://edis.ifas.ufl.edu/in816>
- Faedda, R., A. Pane, G. Granata, and G.M. di San Lio. 2011. First report of *Phytophthora nicotianae* as pathogen of blue Mediterranean fan palm. New Dis. Rep. 23:3.
- Farr, D.F., and A.Y. Rossman. 2014 Fungal Databases, Systematic Mycology and Microbiology Laboratory, ARS, USDA. Retrieved Apr. 24, 2014, from <http://nt.ars-grin.gov/fungal-databases/>
- Fasulo, T.R., and R.F. Brooks. 2010. Scale Pests of Florida Citrus. ENY814. Fla. Coop. Ext. Serv., Univ. Florida, Gainesville, FL. <http://edis.ifas.ufl.edu/ch059>
- Feather, T.V. 1982. Occurrence, etiology and control of wilt and dieback of *Phoenix canariensis* in California. Ph.D. Diss., Univ. California, Riverside.
- Feather, T.V., H.D. Ohr, D.E. Munnecke, and J.B. Carpenter. 1989. The occurrence of *Fusarium oxysporum* on *Phoenix canariensis*, a potential danger to date production in California. Plant Dis. 73:78–80.
- Ferreira, S.A.N., and L.A. Santos. 1993. Efeito da velocidade de secagem sobre a emergência e vigor de sementes de pupunha (*Bactris gasipaes* Kunth). Acta Amazon. 23 (1): 3–8.
- Fisher, J.B. 1980. Morphogenetic effects of gibberellins and other growth regulators on palms. p. 21–32. In: C.D. Brickell, D.F. Cutler, and M. Gregory (eds.), Petaloid monocotyledons. Linn. Soc. Symp. Ser. 8, Academic Press, London.
- Fisher, J.B., and K. Jayachandran. 2008. Beneficial role of arbuscular mycorrhizal fungi on Florida native palms. Palms 52:113–123.
- Fisher, J.B., and W.F. Theobald. 1989. Long term effects of gibberellins and cytokinin on coconut trees. Principes 33:5–17.
- Fitzpatrick, G.E. 1983. Relative water demand in container-grown ornamental plants. HortScience 18:760–762.
- Flood, J. 2006. A review of Fusarium wilt of oil palm caused by *Fusarium oxysporum* f. sp. *elaeidis*. Phytopathology 96:660–662.
- Flood, J., P.D. Bridge, and M. Holderness (eds.), 2000. Ganoderma diseases of perennial crops. CABI Publ., Wallingford, UK.
- Fonteno, W.C., and E.L. McWilliams. 1978. Light compensation points and acclimatization of four tropical foliage plants. J. Am. Soc. Hortic. Sci. 103:52–56.
- Forsberg, L.I. 1985. Foliar diseases of nursery-grown ornamental palms in Queensland. Aust. Plant Pathol. 14:67–71.
- Francko, D.A. 2000. Effect of microclimate on cultivation of cold-hardy palms in southwestern Ohio. Palms 44:37–46.
- Francko, D.A., and S.L. Wilhoite. 2002. Cold-hardy palms in southwestern Ohio: Winter damage, mortality, and recovery. Palms 46:5–13.
- Fröhlich, J., and K.D. Hyde. 2000. Palm microfungi. Fungal Diversity Press, Hong Kong.
- Furr, J.R., and C.L. Ream. 1968. Salinity effects on growth and salt uptake of seedlings of the date, *Phoenix dactylifera* L. Proc. Am. Soc. Hortic. Sci. 92:268–273.
- Gallo-Meagher, M., and J. Green. 2002. Somatic embryogenesis and plant regeneration from immature embryos of saw palmetto, an important landscape and medicinal plant. Plant Cell, Tissue Organ Cult. 68:253–256.
- George, G., S. Reed, B. Tansel, and G. Gordon. 2011. Growth profile of *Chamaedorea cataractarum* (cascade palm) seedlings with different colored plastic mulch. J. Agric. Sci. 3:39–49.
- Giblin-Davis, R.M. 2001. Borers of palms. p. 267–304. In: F.W. Howard, D. Moore, R.M. Giblin-Davis, and R.G. Abad (eds.), Insects on palms. CABI Publ., Wallingford, UK.

- Giblin-Davis, R.M. 2004a. Red ring. p. 43–45. In: M.L. Elliott, T.K. Broschat, J.Y. Uchida, and G.W. Simone (eds.), Compendium of ornamental palm diseases and disorders. Am. Phytopathol. Soc., St. Paul, MN.
- Giblin-Davis, R. M. 2004b. Burrowing nematode. p. 4–46. In: M.L. Elliott, T.K. Broschat, J.Y. Uchida, and G.W. Simone (eds.), Compendium of ornamental palm diseases and disorders. Am. Phytopathol. Soc., St. Paul, MN.
- Giblin-Davis, R.M. 2004c. Other nematodes. p. 46–47. In: M.L. Elliott, T.K. Broschat, J.Y. Uchida, and G.W. Simone (eds.), Compendium of ornamental palm diseases and disorders. Am. Phytopathol. Soc., St. Paul, MN.
- Giblin-Davis, R.M., J.R. Faleiro, J.A. Jacas, J.E. Peña, and P.S.P.V. Vidyasagar. 2013. Biology and management of the red palm weevil, *Rhynchophorus ferrugineus*. p. 1–34. In: J. Peña (ed.), Potential invasive pests of agricultural crops. CABI Publ., Wallingford, UK.
- Giblin-Davis, R.M., and F.W. Howard. 1989. Vulnerability of stressed palms to attack by *Rhynchophorus cruentatus* (Coleoptera: Curculionidae) and insecticidal control of the pest. J. Econ. Entomol. 82:1185–1190.
- Giesbrecht, M., M. McCarthy, M. Elliott, and K. Ong. 2013. *Fusarium oxysporum* f. sp. *palmarum* found in Texas causing Fusarium wilt of *Washingtonia robusta*. Plant Dis. 97:1.511.3. <http://apsjournals.apsnet.org/doi/abs/10.1094/PDIS-05-13-0488-PDN>
- Gitau, C.W., G.M. Gurr, C.F. Dewhurst, M.J. Fletcher, and A. Mitchell. 2009. Insect pests and insect-vectored diseases of palms. Aust. J. Entomol. 48:328–342.
- Goldstein, L. 1989. Cold weather experiences in south Florida. Principes 33:56–62.
- González-Benito, M.E., M. Huertas-Micó, and F. Pérez-García. 2006. Seed germination and storage of *Chamaerops humilis* (dwarf fan palm). Seed Sci. Technol. 34:143–150.
- Govaerts, R. 2013. Arecaceae. World checklist of selected plant families. <http://apps.kew.org/wcsp/home.do>
- Grasso, F.M., A. Pane, and S.O. Cacciola. 2007. First report of *Armillaria* butt rot caused by *Armillaria mellea* on *Phoenix canariensis* in Italy. Plant Dis. 91:1517.
- Griffith, R. 1987. Red ring disease of coconut palm. Plant Dis. 71:193–196.
- Griffith, M.P., L.R. Noblick, J.L. Dowe, C.E. Husby, and M.A. Calonje. 2008. Cyclone tolerance in new world Arecaceae: Biogeographic variation and abiotic natural selection. Ann. Bot. 102:591–598.
- Guerra, M.P., and W. Handro. 1988. Somatic embryogenesis and plant regeneration in embryo cultures of *Euterpe edulis* Mart. (Palmae). Plant Cell Rep. 7:550–552.
- Gutiérrez, M.V., and K. Jiménez. 2007. Crecimiento de nueve especies de palmas ornamentales cultivadas bajo un gradiente de sombra. Agronomía Costarricense 31:9–19.
- Habib, A.M. 2012. Effect of NPK and growing media on growth and chemical composition of fishtail palm (*Caryota mitis* Lour). Life Sci. J. 9:3159–3168.
- Hanold, D., and J.W. Randles. 1991a. Detection of coconut cadang–cadang viroid-like sequences in oil and coconut palm and other monocotyledons in the south-west Pacific. Ann. Appl. Biol. 118:139–151.
- Hanold, D., and J.W. Randles. 1991b. Coconut cadang–cadang disease and its viroid agent. Plant Dis. 75:330–335.
- Harries, H.C., and D.H. Romney. 1974. Maypan: An F1 hybrid coconut variety for commercial production. World Crops 26:10–11.
- Harrison, N.A., E.E. Helmick, and M.L. Elliott. 2008. Lethal yellowing-type diseases of palms associated with phytoplasmas newly identified in Florida, United States. Ann. Appl. Biol. 153:85–94.
- Harrison, N.A., E.E. Helmick, and M.L. Elliott. 2009. First report of a phytoplasma-associated lethal decline of *Sabal palmetto* in Florida, United States. Plant Pathol. 58:792.

- Harrison, N.A., and P. Jones. 2004. Lethal yellowing. p. 39–41. In: M.L. Elliott, T.K. Broschat, J.Y. Uchida, and G.W. Simone (eds.), *Compendium of ornamental palm diseases and disorders*. Am. Phytopathol. Soc., St. Paul, MN.
- Harrison, N.A., and C. Oropeza. 1997. Recent studies on detection of lethal yellowing disease phytoplasmas in the Americas. p. 221–234. In: S.J. Eden-Green and F. Ofori (eds.), *Proceedings of an international workshop on lethal yellowing-like diseases of coconut*, Elmina, Ghana, November 1995. Natural Resources Institute, Chatam, UK. 1995
- Harrison, N.A., M. Womack, and M.L. Carpio. 2002. Detection and characterization of a lethal yellowing (16SrIV) group phytoplasma in Canary Island date palms affected by lethal decline in Texas. *Plant Dis.* 86:676–681.
- Henley, R.W. 1995. Growth responses of 35 ornamental plants to propagation in liner trays coated with a product containing copper hydroxide. *Proc. Fla. State Hortic. Soc.* 108:16–22.
- Henley, R.W., and R.T. Poole. 1981. Water and foliage plants. p. 203–228. In: J.N. Joiner (ed.), *Foliage plant production*. Prentice Hall, Englewood Cliffs, NJ.
- Hensley, D., and J. Yogi. 1996. Growth regulation of some tropical trees. *J. Arboric.* 22: 244–247.
- Hernández-Hernández, J., A. Espino, J.M. Rodríguez-Rodríguez, A. Pérez-Sierra, M. León, P. Abad-Campos, and J. Armengol. 2010. Survey of diseases caused by *Fusarium* spp. on palm trees in the Canary Islands. *Phytopathol. Mediterr.* 49:84–88.
- Hintz, G. 1978. Effects of the winter of 1976–77 on certain palm species in Dallas, Texas. *Principes* 22:94–98.
- Hodel, D.R. 1977. Notes on embryo culture of palms. *Principes* 21:103–108.
- Hodel, D.R. 1998. Propagating palms from seeds. *Comb. Proc. Int. Plant Prop. Soc.* 48: 56–61.
- Hodel, D.R. 1999. Pruning palms. *Principes* 43:99–100.
- Hodel, D.R. 2008. Cold protection strategies for palms. *Palm J.* 188:4–9.
- Hodel, D.R. 2012. The biology and management of landscape palms. The Britton Fund, Porterville, CA.
- Hodel, D.R., A.J. Downer, and M. Mochizuki. 2012. Effect of container type on the nursery growth of kentia palms and king palms. *Palms* 56:65–71.
- Hodel, D.R., J. Downer, and D.R. Pittenger. 2006b. Effect of leaf tie-up on transplanted large Mexican fan palms (*Washingtonia robusta*). *Palms* 50:76–81.
- Hodel, D.R., J. Downer, and D.R. Pittenger. 2009. Transplanting palms. *HortTechnology* 19:686–689.
- Hodel, D.R., J. Downer, and D.R. Pittenger. 2013a. Effects of sand backfill on transplanted king, queen, and windmill palms. *Palms* 57:63–66.
- Hodel, D.R., J. Downer, and D.R. Pittenger. 2013b. Effect of leaf removal and tie-up on water loss and estimated crop coefficients for juvenile, trunkless, containerized queen palms. *Palms* 57:79–83.
- Hodel, D.R., A.J. Downer, D.R. Pittenger, and P.J. Beaudoin. 2006a. Effect of amended backfill soils when planting five species of palms. *HortTechnology* 16:457–460.
- Hodel, D.R., and D.V. Johnson. 2007. Imported and American Varieties of Dates (*Phoenix dactylifera*) in the United States. UC ANR Publ. 3498. Univ. California, Oakland, CA.
- Hodel, D.R., M. Marika, and M. Mochizuki. 2012. Use of glyphosate to suppress basal suckers on Mediterranean fan palm (*Chamaerops humilis* L.). *Palms* 56:109–115.
- Hodel, D.R., and D.R. Pittenger. 2003a. Studies on the establishment of date palm (*Phoenix dactylifera* ‘Deglet Noor’) offshoots: Part 1. Observations on root development and leaf growth. *Palms* 47:191–200.

- Hodel, D.R., and D.R. Pittenger. 2003b. Studies on the establishment of date palm (*Phoenix dactylifera* 'Deglet Noor') offshoots: Part 2. Size of offshoot. *Palms* 47:201–205.
- Hodel, D.R., D.R. Pittenger, and A.J. Downer. 2005. Palm root growth and implications for transplanting. *J. Arboric.* 31:171–181.
- Hodel, D.R., D.R. Pittenger, A.J. Downer, and M. Mochizuki. 2013c. Effect of leaf removal and tie-up on date palms transplanted in extremely hot, arid conditions. *Palms* 57:72–78.
- Hodel, D.R., D.R. Pittenger, A.J. Downer, and W.E. Richie. 2003. Effect of leaf removal and tie up on juvenile transplanted Canary Island date palms (*Phoenix canariensis*) and queen palms (*Syagrus romanzoffiana*). *Palms* 47:177–184.
- Hodel, D.R., C.A. Wilen, and N. Nisson. 2011. The red palm weevil: a devastating pest and serious threat to palms in California and the desert southwest. *West Arb.* 37 (2): 34–50.
- Hodges, A.W., and J.J. Haydu. 2002. Economic impacts of the Florida environmental horticultural industry, 2000. *Univ. Fla. Econ. Inform. Rep.* EI 02–3.
- Hodges, A.W., and J.J. Haydu. 2006. Economic impacts of the Florida environmental horticultural industry in 2005. FE 675. *Univ. Fla., IFAS, Food Resource Econ. Dept., Gainesville, FL.* Accessed June 15, 2013. <http://www.fred.ifas.ufl.edu/economic-impact-analysis/publications>
- Hodges, A.W., T.J. Stevens, M. Rahmani, and H. Khachatryan. 2011. Economic contributions of the Florida environmental horticulture industry in 2010. *Univ. Fla., IFAS, Food Resource Econ. Dept., Gainesville, FL.* <http://www.fred.ifas.ufl.edu/economic-impact-analysis/publications>
- Hodgson, R.A.J., G.C. Wall, and J.W. Randles. 1998. Specific identification of coconut tinangaja viroid for differential field diagnosis of viroids in coconut palm. *Phytopathology* 88:774–781.
- Holbrook, N.M., and T.R. Sinclair. 1992a. Water balance in the arborescent palm, *Sabal palmetto*: I. Stem structure, tissue water release properties and leaf epidermal conductance. *Plant Cell Environ.* 15:393–399.
- Holbrook, N.M., and T.R. Sinclair. 1992b. Water balance in the arborescent palm, *Sabal palmetto*: II. Transpiration and stem water storage. *Plant Cell Environ.* 15:401–409.
- Holmquist, J.D., and J. Popenoe. 1967. Germination experiments: The effect of scarification on the germination of seed of *Acrocomia crispata* and *Arenga engleri*. *Principes* 11:23–25.
- Hong, T.D., and R.H. Ellis. 1996. A protocol to determine seed storage behavior. In: J.M.M. Engels and J. Tolls (eds.), IPGRI. *Technol. Bull. No. 1. Intern. Plant Genetic Resources Inst., Rome, Italy.*
- Howard, F.W. 2001. Sap-feeders on palms. p. 109–232. In: F.W. Howard, D. Moore, R.M. Giblin-Davis, and R.G. Abad (eds.), *Insects on palms.* CABI Publ., Wallingford, UK.
- Howard, F.W., and R.G. Abad. 2001a. Lepidoptera. p. 34–81. In: F.W. Howard, D. Moore, R.M. Giblin-Davis, and R.G. Abad (eds.), *Insects on palms.* CABI Publ., Wallingford, UK.
- Howard, F.W., and R.G. Abad. 2001b. Coleoptera. p. 81–104. In: F.W. Howard, D. Moore, R.M. Giblin-Davis, and R.G. Abad (eds.), *Insects on palms.* CABI Publ., Wallingford, UK.
- Howard, F.W., D. Moore, R.M. Giblin-Davis, and R.G. Abad. 2001. *Insects on palms.* CABI Publ., Wallingford, UK.
- Howard, F.W., R.C. Norris, and D.L. Thomas. 1983. Evidence of transmission of palm lethal yellowing agent by a planthopper, *Myndus crudus* (Homoptera, Cixiidae). *Trop. Agric. (Trinidad)* 60:168–171.
- Howe, T.K., and S.S. Woltz. 1981. Symptomology and relative susceptibility of various ornamental plants to acute airborne sulfur dioxide exposure. *Proc. Fla. State Hortic. Soc.* 94:121–123.

- Hoyle, J.C. 1969. The effect of herbicides on the growth of young coconut palms. *Trop. Agric. (Trinidad)* 46:137–143.
- Hseu, S.H., W.C. Lai, Y.P. Pan, and C.Y. Lin. 2007. Occurrence of bacterial leaf spot of betel palm caused by *Burkholderia andropogonis* and inhibition of bacterial growth by agrochemicals. *Plant Pathol. Bull.* 16:131–139.
- Huat, T.C., and C.C. Leong. 1994. Injury symptoms on young oil palms induced by topical and basal applications of herbicides. *Planter (Kuala Lumpur)* 70:341–358.
- Hussey, G. 1958. An analysis of the factors controlling the germination of the seed of the oil palm, *Elaeis guineensis* (Jacq.). *Ann. Bot.* 22:259–284.
- Hyde, K.D., and P.F. Cannon. 1999. Fungi causing tar spots on palms. *Mycol. Pap.* 175.
- Hyde, K.D., P.F. Cannon, and M.E. Barr. 1997. Phaeochoaraceae, a new ascomycete family from palms. *Systema Ascomycetum* 15:117–120.
- Hyde, K.D., J.E. Taylor, and J. Fröhlich. (eds.), 2000. *Genera of Ascomycetes from palms*. Fungal Diversity Press, Hong Kong.
- Ingram, D.L., and D.B. McConnell. 1980. Effect of production shade and fertilization levels on establishment of palms in the landscape. *Proc. Fla. State Hortic. Soc.* 93:72–74.
- Jaizme-Vega, M.C., and M.-A. Díaz-Pérez. 1999. Effect of *Glomus intraradices* on *Phoenix roebelenii* during the nursery stage. *Acta Hortic.* 486:199–202.
- Janick, J., and R.E. Paull. 2008. *Encyclopedia of fruits and nuts*. CABI, Oxfordshire, UK.
- Janos, D.P. 1977. Vesicular-arbuscular mycorrhizae affect the growth of *Bactris gasipaes*. *Principes* 21:12–18.
- Jimenez, K. 2004. Efecto de la densidad de siembra y la poda en la producción de hojas comerciales de *Phoenix roebelenii* (dwarf date palm) en Alajuela, Costa Rica. *Rev. Agric. Trop.* 34:53–60.
- Jones, J.B., Jr., B. Wolf, and H.A. Mills. 1991. *Plant analysis handbook*. Micro–Macro Publ., Athens, GA.
- Joubert, J.J., and F.H.J. Rijkenberg. 1971. Parasitic green algae. *Ann. Rev. Phytopathol.* 9:45–64.
- Kamalashiamma, P.G., and M. Shanavas. 2002. Boron deficiency in coconut: symptoms and correction. *Indian Coconut J.* 32 (11): 1–5.
- Kasasian, L., J. Seeyave, and R.W. Smit. 1968. The effects of weeding and of several herbicides on the growth of young coconuts. *Int. J. Pest Manag. Part C* 14:375–379.
- Kee, D.L.H., and D.A.L. Brown. 1968. Effect of herbicides on oil palm (preliminary screening trial). *J. Pest Manag. Part C* 14:71–77.
- Kellett, J. 1969. Looking back on the Florida freeze of 1962. *Principes* 13:23–25.
- Kelly, P.L., R. Reeder, P. Kokoa, Y. Arocha, T. Nixon, and A. Fox. 2011. First report of a phytoplasma identified in coconut palms (*Cocos nucifera*) with lethal yellowing-like symptoms in Papua New Guinea. *New Dis. Rep.* 23:9.
- Khan, M.I. 2006. Allelopathic potential of dry fruits of *Washingtonia filifera*: inhibition of seed germination. *Physiol. Plant.* 54:323–328.
- Khudairi, A.K. 1958. Studies on the germination of date-palm seeds: The effect of sodium chloride. *Physiol. Plant.* 11:16–22.
- Khurram, S., and S. Miyamoto. 2005. Seedling growth, leaf injury and ion uptake response of cold-resistant palm species to salinity. *J. Environ. Hortic.* 23:193–198.
- Kitzke, E.D. 1958. A method for germinating *Copernicia* seeds. *Principes* 2:5–8.
- Klock-Moore, K.A., and T.K. Broschat. 2000. Use of subirrigation to reduce fertilizer runoff. *Proc. Fla. State Hortic. Soc.* 113:149–151.
- Klock-Moore, K.A., and T.K. Broschat. 2001. Effect of four growing substrates on growth of ornamental plants in two irrigation systems. *HortTechnology* 11:456–460.

- Knauss, J.F., J.W. Miller, and R.J. Virgona. 1978. Bacterial blight of fishtail palm, a new disease. *Proc. Fla. State Hortic. Soc.* 91:245–247.
- Koebornik, J. 1966. Salt tolerance in young palms. *Principes* 10:130–132.
- Koebornik, J. 1971. Germination of palm seed. *Principes* 15:134–137.
- Krikorian, A.D., and R.P. Kann. 1986. Oil palm improvement via tissue culture. *Plant Breed. Rev.* 4:175–202.
- Labouisse, J.-P., T. Sileye, F. Bonnot, and L. Baudouin. 2011. Achievements in breeding coconut hybrids for tolerance to coconut foliar decay disease in Vanuatu, South Pacific. *Euphytica* 177:1–13.
- Lamont, G.P., G.C. Cresswell, and L.J. Spohr. 1988. Response of kentia palm (*Howea forsteriana*) to controlled-release fertilizer. *Sci. Hortic.* 36:293–302.
- Larcher, W., and A. Winter. 1981. Frost susceptibility of palms: Experimental data and their interpretation. *Principes* 25:143–152.
- Lebrun, P., L. Baudouin, W. Myrie, A. Berger, and M. Dollet. 2008. Recent lethal yellowing outbreak: Why is the Malayan Yellow Dwarf coconut no longer resistant in Jamaica? *Tree Genet. Genom.* 4:125–131.
- Ledin, B.R. (ed.) 1961. Cultivated palms. *Am. Hortic.* 40:1–189.
- Leonhardt, K.W., P.C. Stanwood, and K.T. Taniguchi. 1984. Generic conservation of palm germplasm in liquid nitrogen with emphasis on seed moisture content as a function of survival. *Proc. 2nd Fert. Ornamentals Short Course, Honolulu, HI.*
- LeSaint, J.P., G. de Taffin, and G. Bénard. 1989. Coconut seed preservation in sealed packages. *Oléagineux* 44:15–25.
- Ligoxigakis, E.K., I.A. Papaioannou, E.A. Markakis, and M.A. Typas. 2013a. First report of pink rot of *Phoenix* and *Washingtonia* species caused by *Nalanthamala vermoesenii* in Greece. *Plant Dis.* 97:285.
- Ligoxigakis, E.K., E.A. Markakis, I.A. Papaioannou, and M.A. Typas. 2013b. First report of palm rot of *Phoenix* spp. caused by *Neodeightonia phoenicum* in Greece. *Plant Dis.* 97:286.
- Linde, C., and W.A. Smit. 1999. First report of rhizosis caused by *Ceratocystis radicola* on date palms in South Africa. *Plant Dis.* 83:880.
- Liu, J.-K., P. Chomnunti, L. Cai, R. Phookamsak, E. Chukeatirote, E.B.G. Jones, M. Moslem, and K.D. Hyde. 2010. Phylogeny and morphology of *Neodeightonia palmicola* sp. nov. from palms. *Sydowia* 62:261–276.
- Liu, J.-K., R. Phookamsak, M. Doilom, S. Wikee, Y.-M. Li, H. Ariyawansa, S. Boonmee, P. Chomnunti, D.-Q. Dai, J.D. Bhat, A.I. Romero, W.-Y. Zhuang, J. Monkai, E.B.G. Jones, E. Chukeatirote, T.W.K. Ko, Y.-C. Zhao, Y. Wang, and K.D. Hyde. 2012. Towards a natural classification of Botryosphaerales. *Fungal Divers.* 57:149–210.
- Loomis, H.F. 1958. The preparation and germination of palm seeds. *Principes* 2:98–102.
- Lozano, I., F.J. Morales, A.K. Martinez, and E.A. Peña. 2010. Molecular characterization and detection of African oil palm ringspot virus. *J. Phytopathol.* 158:167–172.
- Luz, P.B. da., F.F.A. Aguiar, A.R. Tavares, S. Kanashiro, J. Aguiar, and T.D.R. do Nascimento. 2006. Desenvolvimento de *Rhapis excelsa* (Thunberg) Henry ex. Rehder (Palmeira-Rafia): Influência da altura do recipiente na formação de mudas. *Ciencia Agrotechnol. (Lavras)* 30:31–34.
- Luz, P.B. da., P.D. de O. Paiva, and A.R. Tavares. 2008. Effect of foliar and substrate fertilization on lady palm seedling growth and development. *J. Plant Nutr.* 31:1311–1318.
- Maciel, N. 1996. Efectos de la madurez y el almacenamiento del fruto, la escarificación y el remojo de las semillas sobre la emergencia de la palma china de abanico. *Agron. Trop.* 46:155–170.

- Maciel, N. 2001. Emergencia de la palma real Venezolana (*Roystonea oleracea* (Jacq.) O.F. Cook) en función de condiciones variables del fruto y la semilla. *Bioagro* 13:105–110.
- Maciel, N. 2002. Efectos del almacenamiento del fruto, romojo y escarificación de la semilla y ácido giberélico en la emergencia de *Caryota urens*. Proc. In. Am. Soc. Trop. Hortic. 46:106–109.
- Maciel, N. 2003. Efectos de la madurez del fruto y almacenamiento de la semilla en la emergencia de *Pritchardia pacifica*. Proc. In. Am. Soc. Trop. Hortic. 47:13–15.
- Maciel, N., and N. Mogollon. 1995. Variables de la emergencia de semillas germinadas de seis palmas ornamentales. *Bioagro* 7:10–16.
- Magat, S.S., R.Z. Margate, and J.A. Habana. 1988. Effects of increasing rates of sodium chloride (common salt) fertilization on coconut palms grown under an island soil (Tropudalfs), of Mindanao, Philippines. *Oléagineux* 43:13–19.
- Makus, D.J. 2008. Seed germination methods and establishment of saw-palmetto, *Serenoa repens*, in south Texas. *Acta Hortic.* 782:381–385.
- Manciot, E., M. Ollagnier, and R. Ochs. 1979. Mineral nutrition of the coconut around the world. *Oléagineux* 34:511–515, 563–580.
- Manciot, E., M. Ollagnier, and R. Ochs. 1980. Mineral nutrition of the coconut around the world: II. Study of the different elements. *Oléagineux* 35:23–37.
- Manimekalai, R., V.P. Soumya, R.S. Kumar, R. Selvarajan, K. Reddy, G.V. Thomas, M. Sasikala, G. Rajeev, and V.K. Baranwal. 2010a. Molecular detection of 16SrXI group phytoplasma associated with root (wilt) disease of coconut (*Cocos nucifera*) in India. *Plant Dis.* 94:636.
- Manimekalai, R., R.S. Kumar, V.P. Soumya, and G.V. Thomas. 2010b. Molecular detection of phytoplasma associated with yellow leaf disease in areca palms (*Areca catechu*) in India. *Plant Dis.* 94:1376.
- Mannion, C. 2010. Rugose spiraling whitefly. Univ. Fla., Trop. Res. Ed. Ctr., Homestead, FL. Accessed June 15, 2013. <http://trec.ifas.ufl.edu/mannion/pdfs/Rugose%20spiraling%20whitefly.pdf>
- Markus, J., and K. Banks. 1999. A practical guide to germinating palm seeds. *Palms* 43:56–59.
- Marlatt, R.B. 1978. Boron deficiency and toxicity symptoms in *Ficus elastic* and *Chrysalidocarpus lutescens*. *HortScience* 13:442–443.
- Marlatt, R.B., and S.A. Alfieri, Jr. 1981. Hosts of a parasitic alga, *Cephaleuros* Kunze, in Florida. *Plant Dis.* 65:520–522.
- Marlatt, R.B., and J.J. McRitchie. 1979. Zinc deficiency symptoms of *Chrysalidocarpus lutescens*. *HortScience* 14:620–621.
- Martens, O. 1970. Observations of frost damage at a palm nursery. *Principes* 14:66–68.
- Martine, B.M., K.K. Laurent, B.J. Pierre, K.K. Eugene, K.T. Hilaire, and K.Y. Justin. 2009. Effect of storage and heat treatments on the germination of oil palm (*Elaeis guineensis* Jacq.) seed. *Afr. J. Agric. Res.* 4:931–937.
- Martinez, R.T., M. Narváez, S. Fabre, N. Harrison, C. Oropeza, M. Dollet, and E. Hichez. 2007. Coconut lethal yellowing on the southern coast of the Dominican Republic is associated with a new 16Sr IV group phytoplasma. *New Dis. Rep.* 15:39.
- Martins, C.C., M.L.A. Bovi, and J. Nakagawa. 2003. Desiccation effects on germination and vigor of king palm seeds. *Hortic. Bras.* 21 (1): 88–92.
- Martins, C.C., W.R. da Silva, and M.L.A. Bovi. 1996. Tratamentos pré-germinativos de sementes da palmeira inajá. *Bragantia* (Campinas) 55:123–128.
- Martins, C.C., J. Nakagawa, and M.L.A. Bovi. 1999a. Tolerância à dessecação de sementes de palmito-vermelho (*Euterpe espirotosantensis* Fernandes). *Rev. Bras. Botânico, São Paulo* 22:391–396.

- Martins, C.C., J. Nakagawa, M.L.A. Bovi, and H. Stanguerlim. 1999b. Teores de água crítico e lethal para sementes de açaí (*Euterpe oleracea* Mart.-Palmae). Rev. Bras. de Sementes 21 (1): 125–132.
- Martins, C.C., J. Nakagawa, M.L.A. Bovi, and H. Stanguerlim. 2000. Desiccation tolerance of four seedlots from *Euterpe edulis* Mart. Seed Sci. Technol. 28:101–113.
- Mayer, H., and C. Mannion. 2011. Weevil problems in the landscape with emphasis on *Myllocerus undatus* (Sri Lanka weevil). Proc. Fla. State Hortic. Soc. 124:301–302.
- Mayhew, D.E., and T.E. Tidwell. 1978. Palm mosaic. Plant Dis. Rep. 62:803–806.
- McConnell, D.B., C.R. Johnson, and J.N. Joiner. 1976. Salt tolerance of *Livistona chinensis*. Proc. Fla. State Hortic. Soc. 89:303–305.
- McConnell, D.B., J.N. Joiner, and C.R. Johnson. 1978. Influence of salinity levels on growth and chemical composition of *Livistona chinensis*. HortScience 13:706–707.
- McCoy, R. E. 1982. Use of tetracycline antibiotics to control yellows diseases. Plant Dis. 66:539–542.
- McKamey, L. 1999. Propagation by division. Palms 43:60–61.
- Meerow, A.W. 1994a. Container production of palms. Acta Hortic. 360:173–179.
- Meerow, A.W. 1994b. Field production of palms. Acta Hortic. 360:181–188.
- Meerow, A.W. 1994c. Fungicide treatment of pygmy date palm seeds affects seedling emergence. HortScience 29:1201.
- Meerow, A.W. 1995. Growth of two tropical foliage plants using coir dust as a container medium amendment. HortTechnology 5:237–239.
- Meerow, A.W. 2005. Betrock's cold hardy palms. Betrock Info. Syst., Davie, FL.
- Meerow, A.W. 2006. Betrock's landscape palms. Betrock Info. Syst., Hollywood, FL.
- Meerow, A.W., and J. Begeman. 1991. Observations on palms produced in grow-bags. Proc. Fla. State Hortic. Soc. 104:367–368.
- Meerow, A.W., and T.K. Broschat. 1991. Toxicity of the pre-emergent herbicide metolachlor on containerized palms. Foliage Dig. 17 (9): 6.
- Meerow, A.W., and T.K. Broschat. 2012. Palm seed germination. Fla. Coop. Ext. Serv. Bull. 274. <http://edis.ifas.ufl.edu/ep238>
- Mendoza, A., D. Piñero, and J. Sarukhan. 1987. Effects of experimental defoliation on growth, reproduction, and survival of *Astrocaryum mexicanum*. J. Ecol. 75: 545–554.
- Mercier, S., and J. Louvet. 1973. Recherches sur les fusarioses - X. Une fusariose vasculaire (*Fusarium oxysporum*) du palmier des Canaries (*Phoenix canariensis*). Ann. Phytopathol. 5:203–211.
- Merlo, M.E., M.M. Alemán, J. Cabello, and J. Peñas. 1993. On the Mediterranean fan palm (*Chamaerops humilis*). Principes 37:151–158.
- Migheli, Q. V. Balmas, M. Muresu, L. Otgianu, and B. Fresu. 2005. First report of *Fusarium oxysporum* f. sp. *canariensis* causing Fusarium wilt on *Phoenix canariensis* in Sardinia, Italy. Plant Dis. 89:773.
- Migliaccio, K.W., B. Schaffer, Y.C. Li, E. Evans, J.H. Crane, and R. Muñoz-Carpena. 2008. Assessing benefits of irrigation and nutrient management practices on a southeast Florida royal palm (*Roystonea elata*) field nursery. Irrig. Sci. 27:57–66.
- Milks, R.A., J.N. Joiner, L.A. Garrard, C.A. Conover, and B.O. Tjia. 1979. Effects of shade, fertilizer, and media on production and acclimatization of *Ficus benjamina* L. J. Am. Soc. Hortic. Sci. 104:410–413.
- Mills, H.A., and J.B. Jones, Jr. 1996. Plant analysis handbook II: A practical sampling, preparation, analysis, and interpretation guide. Micro-Macro Publ., Athens, GA.

- Miyamoto, S., I. Martinez, M. Padilla, A. Portillo, and D. Ornales. 2004. Landscape plant lists for salt tolerance assessment. Texas Agric. Exp. Station. http://www.plantanswers.com/Landscape_Plant_Lists_for_Salt_Tolerance_Assessment.pdf
- Mohamad, A.B., and S.H.M. Said. 1990. Influence of light on seed germination of *Calamus manan*. *Pertanika* 13:327–330.
- Mok, C.K., and Y.L. Hor. 1977. The storage of oil palm (*Elaeis guineensis*) seed after high temperature treatment. *Seed Sci. Technol.* 5:499–508.
- Moncalvo, J.-M. 2000. Systematics of *Ganoderma*. p. 23–45. In: J. Flood, P.D. Bridge, and M. Holderness (eds.), *Ganoderma* diseases of perennial crops. CABI Publ., Wallingford, UK.
- Moore, D. 2001. Insects of palm flowers and fruits. p. 233–266. In: F.W. Howard, D. Moore, R.M. Giblin-Davis, and R.G. Abad (eds.), *Insects on palms*. CABI Publ., Wallingford, UK.
- Moore, D., and F.W. Howard. 2001. Orthoptera. p. 104–106. In: F. W. Howard, D. Moore, R. M. Giblin-Davis, and R. G. Abad (eds.), *Insects on palms*. CABI Publ., Wallingford, UK.
- Moore, R.P. 1972. Tetrazolium staining for assessing seed viability. p. 347–366. In: W. Heydecker (ed.), *Seed ecology*. Penn. St. Univ., University Park, TX.
- Morales-Payan, J.P., and B.M. Santos. 1997. Influence of seed treatments on germination and initial growth of ornamental palms. *HortScience* 32:604.
- Mora-Urpí, J., J.C. Weber, and C.R. Clement. 1997. Peach palm, *Bactris gasipaes* Kunth: Promoting the conservation and use of underutilized and neglected crops 20. *Int. Plant Genet. Resour. Inst., Rome*.
- Morte, A., and M. Honrubia. 2002. Growth response of *Phoenix canariensis* to inoculation with arbuscular mycorrhizal fungi. *Palms* 46:76–80.
- Morton, J.F. 1988. Notes on the distribution, propagation, and products of *Borassus* palms (Arecaceae). *Econ. Bot.* 42:420–441.
- Mousa, H., H.A. Margolis, P.A. Dubé, and J. Odongo. 1998. Factors affecting the germination of doum palm (*Hyphaene thebaica* Mart.) seeds from the semi-arid zone of Niger, West Africa. *For. Ecol. Manag.* 104:27–41.
- Mpunami, A.A., A. Tymon, P. Jones, and M.J. Dickinson. 1999. Genetic diversity in the coconut lethal yellowing disease phytoplasmas of East Africa. *Plant Pathol.* 48: 109–114.
- Mullett, J.H., D.V. Beardsell, and H.M. King. 1981. The effect of seed treatment on the germination and early growth of *Euterpe edulis* (Family Palmae). *Sci. Hortic.* 15:239–244.
- Munoz, A., and S. Wang. 2011. Detection of *Fusarium oxysporum* f. sp. *canariensis* and *F. proliferatum* from palms in southern Nevada. *Phytopathology* 101:S125 (Abstract).
- Muñoz, B., R. Orta, and E. Medero. 1992. Algunos aspectos de la germinación de las semillas de *Roystonea regia* (H.B.K.) O.F. Cook 1. var. *regia*. *Cienc. Biol.* 24:119–123.
- Murakami, P.K., and F.D. Rauch. 1984. Effects of age and handling on subsequent growth and development of areca palm, *Chrysalidocarpus lutescens*, seedlings. *J. Environ. Hortic.* 2:91–93.
- Myint, T., W. Chanprasert, and S. Srikul. 2010. Effect of seed weight on germination potential of different oil palm (*Elaeis guineensis* Jacq.) crosses. *Seed Sci. Technol.* 38:125–135.
- Nagamine, W.T., and M.E. Epstein. 2007. Chronicles of *Darna pallivitta* (Moore 1887) (Lepidoptera: Limacodidae): Biology and larval morphology of a new pest in Hawaii. *Pan-Pacific Entomol.* 83:120–135.
- Nagao, M.A., K. Kanegawa, and W.S. Sakai. 1980. Accelerating palm seed germination with gibberellic acid, scarification, and bottom heat. *HortScience* 15:200–201.
- Nagao, M.A., and W.S. Sakai. 1979. Effect of growth regulators on seed germination of *Archontophoenix alexandrae*. *HortScience* 14:182–183.

- Nagata, N. M., and M. Aragaki. 1989. Etiology and control of *Phytophthora* leaf blight of golden-fruited palm. *Plant Dis.* 73:661–663.
- Nambiar, K.K.N., Y. Joshi, M.N. Venugopal, and R.C. Mohan. 1986. Stem bleeding disease of coconut: Reproduction of symptoms by inoculation with *Thielaviopsis paradoxa*. *J. Plant. Crops* 14:130–133.
- Neel, P.L. 1977. Effects of oxadiazon preemergence herbicide on weed control and growth of 16 species of containerized ornamental plants. *Proc. Fla. State Hort. Soc.* 90: 353–355.
- Neel, P.L., and H.M. Donselman. 1977. Growth of five species of containerized ornamentals as influenced by six commercial fertilizer sources. *Proc. Fla. State Hort. Soc.* 90: 350–353.
- Nejat, N., K. Sijam, S.N.A. Abdullah, G. Vadamalai, and M. Dickinson. 2008. First report of a 16SrXIV, '*Candidatus Phytoplasma cynodontis*' group phytoplasma associated with coconut yellow decline in Malaysia. *New Dis. Rep.* 17:19.
- Nelson, S., and M. Wright. 2005. Banana moth: A potentially fatal pest of *Pritchardia* and other palms. IP-24. Coop. Ext. Serv., Univ. Hawaii at Manoa, Honolulu. <http://www.ctahr.hawaii.edu/oc/freepubs/pdf/IP-24.pdf>
- Ng, S.K., and Y.P. Tan. 1974. Nutritional complexes of oil palms planted on peat in Malaysia: I. Foliar symptoms, nutrient composition, and yield. *Oléagineux* 29:1–8.
- Nisson, N., D. Hodel, and M. Hoddle. 2013. Red palm weevil. http://cisr.ucr.edu/red_palm_weevil.html
- Noblick, L.R. 1998. Predicting hardiness in palms. <http://www.bg-map.com/noblick.html>
- Ntushelo, K., N.A. Harrison, and M.L. Elliott. 2013. Palm phytoplasmas in the Caribbean basin. *Palms* 57:93–100.
- Oberwinkler, F., R.J. Bandoni, P. Blanz, G. Deml, and L. Kisimova-Horovitz. 1982. Graphiolales: Basidiomycetes parasitic on palms. *Plant. Syst. Evol.* 140:251–277.
- O'Brien, T.G., and M.F. Kinnaird. 1996. Effect of harvest on leaf development of the Asian palm *Livistona rotundifolia*. *Conserv. Biol.* 10:53–58.
- Odetola, J.A. 1987. Studies on seed dormancy, viability, and germination in ornamental palms. *Principes* 31:24–30.
- Ogden, R.J., F.A. Pokorny, H.A. Mills, and M.G. Dunavent. 1987. Elemental status of pine bark-based potting media. *Hortic. Rev.* 9:103–131.
- Ohr, H.D. 1991. Diamond scale. p. 10–11. In: A.R. Chase and T.K. Broschat (eds.), *Diseases and disorders of ornamental palms*. Am. Phytopathol. Soc., St. Paul, MN.
- Ollagnier, M., and R. Ochs. 1971. Le chlore, nouvel élément essentiel dans la nutrition du palmier à huile: Et la nutrition en chlore du palmier à huile et du cocotier. *Oléagineux* 26:367–373.
- Ollagnier, M., and R. Ochs. 1972. Sulphur deficiencies in the oil palm and coconut. *Oléagineux* 27:193–198.
- Ollagnier, M., and G. Valverde. 1968. Contribution a l'étude de la carence en bore du palmier à huile. *Oléagineux* 23:359–366.
- Orian, G. 1947. Bud rot of the royal palm in Mauritius. *Revue Agricole Sucrière de l'Île Maurice* 26:223–258.
- Orian, G. 1948. Bud rot of the areca nut palm in Mauritius. *Revue Agricole Sucrière de l'Île Maurice* 27:271–275.
- Orozco-Segovia, A., A.I. Batis, M. Rojas-Aréchiga, and A. Mendoza. 2003. Seed biology of palms: A review. *Palms* 47:79–94.
- Oyama, K., and A. Mendoza. 1990. Effects of defoliation on growth, reproduction, and survival of a neotropical palm, *Chamaedorea tepijilote*. *Biotropica* 22:119–123.

- Palmucci, H.E. 2006. *Fusarium oxysporum*-causal agent of wilt on crops of *Phoenix canariensis* in Argentina. *Plant Pathol.* 55:304.
- Patnude, E., and S. Nelson. 2012. Boron deficiency of palms in Hawaii. Univ. Hawaii CTHAR Publ. PD-83.
- Perera, L., M.K. Meegahakumbura, H.R.T. Wijesekara, W.B.S. Fernando, and M.J. Dickinson. 2012. A phytoplasma is associated with Weligama coconut leaf wilt disease in Sri Lanka. *J. Plant Pathol.* 94:205–209.
- Pérez, H.E. 2009. Promoting germination in ornamental palm seeds through dormancy alleviation. *HortTechnology* 19:682–685.
- Pérez, H.E., R.A. Criley, and C.C. Baskin. 2008a. Promoting germination in dormant seeds of *Pritchardia remota* (Kuntze) Beck., an endangered palm endemic to Hawaii. *Nat. Areas J.* 28:251–260.
- Pérez, H.E., A.B. Shiels, H.M. Zaleski, and D.R. Drake. 2008b. Germination after simulated rat damage in seeds of two endemic Hawaiian palm species. *J. Trop. Ecol.* 24: 555–558.
- Pérez-Núñez, M.T., J.L. Chan, L. Sáenz, T. González, J.L. Verdeil, and C. Oropeza. 2006. Improved somatic embryogenesis from *Cocos nucifera* L. plumule explants cultured *in vitro*. *In Vitro Cell. Dev. Biol. Plant.* 42:37–43.
- Perry, L., and K. Williams. 1996. Effects of salinity and flooding on seedlings of cabbage palm (*Sabal palmetto*). *Oecologia* 105:428–434.
- Pfalzgraf, K. 2000. On the pruning of palms. *Palms* 44:47–49.
- Phillips, A.J.L., A. Alves, S.R. Pennycook, P.R. Johnston, A. Ramaley, A. Akulov, and P.W. Crous. 2008. Resolving the phylogenetic and taxonomic status of dark-spored teleomorph genera in the Botryosphaeriaceae. *Persoonia* 21:29–55.
- Piepenbring, M., F. Nold, T. Trampe, and R. Kirschner. 2012. Revision of the genus *Graphiola* (Exobasidiales, Basidiomycota). *Nova Hedwigia* 94:67–96.
- Pinedo-Panduro, M., and W. Meléndez-Torres. 1993. Sobrevivencia de hijuelos basales de pijuayo (*Bactris gasipaes* H.B.K.) en vivero y campo definitivo con pretratamientos enraizantes. p. 145–153. In: J. Mora-Urpí, L.T. Szott, M. Murillo, and V.M. Patiño (eds.), IV Congreso Internacional Sobre Biología, Agronomía e Industrialización del Pijuayo. Editorial Univ., San Jose, CA.
- Pivetta, K.F.L., R.C. de Paula, G.S. Cintra, D.R. Pedrinho, L.P. Casali, P.U.C. Pizetta, I. Sarzi, and R.R. Pimenta. 2005. Effects of maturation and scarification on seed germination of *Syagrus schizophylla* (Mart.) Glass. (Arecaceae). *Acta Hort.* 683:375–378.
- Pittenger, D.R., A.J. Downer, and D.R. Hodel. 2000. Palm root regeneration and its significance in transplanting. In: T.G. Ranney (ed.), Proc.11th Conf. Metropolitan Tree Improvement Alliance, Gresham, OR.
- Pittenger, D.R., A.J. Downer, D.R. Hodel, and M. Mochizuki. 2009. Estimating water needs of landscape palms in Mediterranean climates. *HortTechnology* 19:700–704.
- Pittenger, D.R., D.R. Hodel, and A.J. Downer. 2005. Transplanting specimen palms: A review of common practices and research-based information. *HortTechnology* 15: 128–132.
- Plötz, R.C., and D.J. Mitchell. 1989. Root rot of bamboo palm caused by *Phytophthora arecae*. *Plant Dis.* 73:266–269.
- Plyler, T.R., G.W. Simone, D. Fernandez, and H.C. Kistler. 1999. Rapid detection of the *Fusarium oxysporum* lineage containing the Canary Island date palm wilt pathogen. *Phytopathology* 89:407–413.
- Polizzi, G., I. Castello, D. Aiello, and A. Vitale. 2007. First report of stem bleeding and trunk rot of Kentia palm caused by *Thielaviopsis paradoxa* in Italy. *Plant Dis.* 91:1057.

- Polizzi, G., and A. Vitale. 2003. First report of Fusarium blight on majesty palm caused by *Fusarium proliferatum* in Italy. *Plant Dis.* 87:1149.
- Poole, R.T., and C.A. Conover. 1974. Germination of 'Neanthe Bella' palm seeds. *Proc. Fla. State Hortic. Soc.* 87:429–430.
- Poole, R.T., and C.A. Conover. 1975. Media, shade and fertilizer influence production of the areca palm, *Chrysalidocarpus lutescens* Wendl. *Proc. Fla. State Hortic. Soc.* 88: 603–605.
- Poole, R.T., and C.A. Conover. 1977a. Influence of media, shade, and fertilization on production of areca palm. *Fla. Foliage Growers* 14 (4): 3–6.
- Poole, R.T., and C.A. Conover. 1977b. Influence of fertilizer source and level on growth and foliar content of *Philodendron oxycardium* and *Chrysalidocarpus lutescens*. *Proc. Fla. State Hortic. Soc.* 90:314–316.
- Poole, R.T., and C.A. Conover. 1981a. Influence of fertilizer, dolomite, and fluoride levels on foliar necrosis of *Chamaedorea elegans* Mart. *HortScience* 16:203–205.
- Poole, R.T., and C.A. Conover. 1981b. Dolomite and fluoride affect foliar necrosis of *Chamaedorea seifrizii* and *Chrysalidocarpus lutescens*. *Proc. Fla. State Hortic. Soc.* 94:107–109.
- Poole, R.T., and C.A. Conover. 1982a. Foliar necrosis of parlor palm. *Foliage Dig.* 5 (4): 11–12.
- Poole, R.T., and C.A. Conover. 1982b. Phytotoxicity of palms induced by foliar applications of copper. *Foliage Dig.* 5 (6): 10.
- Poole, R.T., and C.A. Conover. 1985. Nitrogen, phosphorus, and potassium fertilization of *Brassaia actinophylla*, *Calathea makoyana*, and *Chrysalidocarpus lutescens*. *J. Environ. Hortic.* 3:1–3.
- Poole, R.T., and C.A. Conover. 1989. Fertilization of four indoor foliage plants with osmocote or nutricote. *J. Environ. Hortic.* 7:102–108.
- Poole, R.T., and C.A. Conover. 1990. Fertilization of *Araucaria heterophylla* (Salisb.) Franco and *Chrysalidocarpus lutescens* H. Wendl. *Proc. Fla. State Hortic. Soc.* 103:212–214.
- Poole, R.T., and R.W. Henley. 1981. Constant fertilization of foliage plants. *J. Am. Soc. Hortic. Sci.* 106:61–63.
- Potvin, C., R. Cansari, J. Hutton, I. Caisamo, and B. Pacheco. 2003. Preparation for propagation: Understanding germination of giwa (*Astrocaryum standleyanum*), wagara (*Sabal mauritiformis*), and eba (*Socratea exorrhiza*) for future cultivation. *Biodivers. Conserv.* 12:2161–2171.
- Prasad, M. 1980. Retention of nutrients by peats and wood wastes. *Sci. Hortic.* 12:203–209.
- Priest, M.J., and D.B. Letham. 1996. Vascular wilt of *Phoenix canariensis* in New South Wales caused by *Fusarium oxysporum*. *Aust. Plant Pathol.* 25:110–113.
- Pritchard, H.W., C.B. Wood, S. Hodges, and H.J. Vautier. 2004. 100-seed test for desiccation tolerance and germination: A case study on eight tropical palm species. *Seed Sci. Technol.* 32:393–403.
- Quilicq, G., J.-L. Renard, and H. Ghesquiere. 1984. Le Phytophthora heveae du cocotier: son role dans la pourriture du Coeur et dans la chute des noix. *Oléagineux* 39:477–485.
- Raja, K., V. Palanisamy, and P. Selvaraju. 2004. Effect of palm age on seed germination and seedling vigour in arecanut (*Areca catechu* L.). *Madras Agric. J.* 91:326–328.
- Rajaratnam, J.A. 1972a. Observations on boron-deficient oil palms (*Elaeis guineensis*). *Exp. Agric.* 8:339–346.
- Rajaratnam, J.A. 1972b. 'Hook leaf' and 'fish-tail leaf': Boron deficiency symptoms of the oil palm. *Planter* 48:120.

- Rajaratnam, J.A. 1972c. The distribution and mobility of boron within the oil palm, *Elaeis guineensis* L: II. The fate of applied boron. *Ann. Bot.* 36:299–306.
- Rakotondranony, G.J., M. Sacande, C.B. Wood, and H.W. Pritchard. 2006. Seed storage responses in four species of the threatened genus *Ravenea* (Arecaceae). *Seed Sci. Technol.* 34:513–517.
- Ramoliya, P.J., and A.N. Pandey. 2003. Soil salinity and water status affect growth of *Phoenix dactylifera* seedlings. *New Zealand J. Crop Hortic. Sci.* 31:345–353.
- Randles, J.W., J.M.B. Rodriguez, D. Hanold, and G. Vadamalai. 2009. Coconut cadang–cadang viroid infection of African oil palm. *Planter* 85:93–101.
- Rasmi, A.R., and R. Iyer. 2010. Bud rot disease of coconut: An overview. *Indian Coconut J.* 52 (10): 7–13.
- Rauch, F.D. 2001. Palm seed germination. *Hortic. Dig.* 107:1–6. http://www.ctahr.hawaii.edu/TPSS/digest/hd107/hd107_3.html
- Rauch, F.D., and P.K. Murakami. 1994. Comparison between two controlled-release fertilizers on selected foliage plants in an artificial potting mix. *Fertilizer Res.* 39:89–95.
- Rauch, F.D., P. Yahata, and P.K. Murakami. 1988. Influence of slow-release fertilizer source on growth and quality of areca palm, *Chrysalidocarpus lutescens* Wendl. *J. Environ. Hortic.* 6:7–9.
- Redford, A.J., T.W. Walters, A.C. Hodges, F.W. Howard, and M.D. Trice. 2010. Screening aid to pests. A resource for pests and diseases of cultivated palms. Identification Technology Program, CPHST, PPQ, APHIS, USDA; Fort Collins, CO. <http://itp.lucidcentral.org/id/palms/sap/>
- Rees, A.R. 1960. The germination of oil palm seeds: a review. *J. West Afr. Sci. Assoc.* 6:55–62.
- Rees, A.R. 1962. High temperature pre-treatment and the germination of seed of the oil palm, *Elaeis guineensis* (Jacq.). *Ann. Bot.* 26:569–581.
- Rees, A.R. 1963. Germination of palm seeds using a method developed for the oil palm. *Principes* 7:27–28.
- Remison, S.U., and G.C. Mgbeze. 1988. Effects of storage and planting methods on the germination of coconut. *Niger. J. Palms Oil Seeds* 9:59–70.
- Reyes, T., T.A. Nell, J.E. Barrett, and C.A. Conover. 1996a. Irradiance level and fertilizer rate affect acclimatization of *Chamaedorea elegans* Mart. *HortScience* 31:839–842.
- Reyes, T., T.A. Nell, J.E. Barrett, and C.A. Conover. 1996b. Testing the light acclimatization potential of *Chrysalidocarpus lutescens* Wendl. *HortScience* 31:1203–1206.
- Riffle, R.L., P. Craft, and S. Zona. 2012. An encyclopaedia of cultivated palms. Timber Press, Portland, OR.
- Robertson, B.L., and J.G.C. Small. 1977. Germination of *Jubaeopsis caffra* seed. *Principes* 21:114–122.
- Robinson, M.L. 2004. Pruning palm trees. *Univ. Nev. Coop. Ext. Publ.* SP-04-16.
- Robinson, M.L. 2009. Cultivated palm seed germination. *Univ. Nevada Coop. Ext.* SP-02-09.
- Roca, M.M., M.G. Castillo, N.A. Harrison, and C. Oropeza. 2006. First report of a 16SrIV group phytoplasma associated with declining coyol palms in Honduras. *Plant Dis.* 90:526.
- Rodrigues, J.V., A.M. Vitoreli, and A.L. Ramirez. 2010. Association of a phytoplasma with dieback in palms in Puerto Rico confirmed by nested-PCR assays. *Phytopathology* 100: S110.
- Rodriguez, M.J.B., D. Hanold, J.P. Morin, J.P. Labouisse, and J.W. Randles. 2003. Coconut and other palm trees. p. 567–596. In: G. Loebenstein and G. Thottappill (eds.), *Virus and*

- virus-like diseases of major crops in developing countries. Kluwer Academic Publ., Dordrecht, The Netherlands.
- Rolph, H., R. Wijesekara, R. Lardner, F. Abdullah, P.M. Kirk, M. Holderness, P.D. Bridge, and J. Flood. 2000. Molecular variation in *Ganoderma* isolates from oil palm, coconut and betelnut. p. 205–221. In: J. Flood, P.D. Bridge, and M. Holderness (eds.), *Ganoderma* diseases of perennial crops. CABI Publ., Wallingford, UK.
- Romney, D.H. 1964. Observations on the effects of herbicides on young coconut palms. *Weed Res.* 4:24–30.
- Romney, D.H. 1965. Further experiments with herbicides on young coconut palms. *Trop. Agric. (Trinidad)* 42:177–181.
- Rosenfield, E. 2009. Effects of pruning on the health of palms. *Arboric. Urban For.* 35: 294–299.
- Rousseau, M., S. Monfort, and M. Ferry. 1999. *In vitro* vegetative propagation of the Canary Island date palm (*Phoenix canariensis*). *Acta Hortic.* 486:155–158.
- Sarasan, V., M.M. Ramsay, and A.V. Roberts. 2005. Rescue of endangered palms by *in vitro* methods: The case of 'bottle palm'. p. 267–274. In: S.M. Jain and P.K. Gupta (eds.), *Protocol for somatic embryogenesis in woody plants*. Springer, The Netherlands.
- Schmidt, L., and F.D. Rauch. 1982. Effects of presoaking seed of *Chrysalidocarpus lutescens* in water and gibberellic acid. *Foliage Dig.* 5 (12): 4–5.
- Schnabel, G., and P.K. Bryson. 2006. First report of *Armillaria tabescens* causing Armillaria root rot of Pindo palm in South Carolina. *Plant Dis.* 90:1106.
- Schroers, H.J., M.M. Geldenhuis, M.J. Wingfield, M.H. Schoeman, Y.F. Yen, W.C. Shen, and B.D. Wingfield. 2005. Classification of the guava wilt fungus *Myxosporium psidii*, the palm pathogen *Gliocladium vermoesonii* and the persimmon wilt fungus *Acremonium diospyri* in Nalanthamala. *Mycologia* 97:375–395.
- Sento, T. 1967. Studies on the germination of seed of the palms: I. On the *Butia capitata* (Becc.), *Phoenix canariensis* (Chaub.) and *Washingtonia robusta* (Wendl.). *J. Jpn. Soc. Hortic. Sci.* 36:235–242.
- Sento, T. 1970. Studies on the germination of seed of the palms: II. On the *Livistona chinensis* (R. Brown), *Phoenix roebelenii* (O'Brien) and *Sabal* species. *J. Jpn. Soc. Hortic. Sci.* 39:261–268.
- Sento, T. 1971a. Studies on the germination of seed of the palms: III. On the *Archontophoenix alexandrae* (Wendl. et Drude), *Ptychosperma macarthurii* (Wendl.) and *Trachycarpus* species. *J. Jpn. Soc. Hortic. Sci.* 40:246–254.
- Sento, T. 1971b. Studies on the germination of seed of the palms: IV. On the *Areca catechu* (Linn.), *Caryota mitis* (Lour.) and *Roystonea regia* (O.F. Cook). *J. Jpn. Soc. Hortic. Sci.* 40:255–261.
- Sento, T. 1972. Studies on the seed germination of palms: V. On *Chrysalidocarpus lutescens*, *Mascarena verschaffeltii*, and *Phoenix dactylifera*. *J. Jpn. Soc. Hortic. Sci.* 41:76–82.
- Sento, T. 1974. Studies on the seed germination of palms: VI. On *Cocos nucifera* L., *Phoenix humilis* var. *hanceana* Becc. and *Phoenix sylvestris* Roxb. *J. Jpn. Soc. Hortic. Sci.* 42:380–388.
- Shear, W. 1931. Leaf disease of palms in California. *Plant Dis. Rep.* 15:17–18.
- Silva, M.A.S., E.D. Castellani, and M.E.S.P. Demattê. 1999. Effect of fruit maturation stage and light on seed germination of *Aiphanes aculeata*. *Acta Hortic.* 486:229–231.
- Silva-Hanlin, D.M.W., and R.T. Hanlin. 1998. The order Phyllachorales: Taxonomic review. *Mycoscience* 39:97–104.
- Simone, G.W. 2004. Stigmata leaf spot. p. 35. In: M.L. Elliott, T.K. Broschat, J.Y. Uchida, and G.W. Simone (eds.), *Compendium of ornamental palm diseases and disorders*. Am. Phytopathol. Soc., St. Paul, MN.

- Singh, R., A. Castro, D.M. Ferrin, R.S. Harris, III, and B. Olson. 2011. First report of *Fusarium* wilt of Canary Island date palm caused by *Fusarium oxysporum* f. sp. *canariensis* in Louisiana. *Plant Dis.* 95:1192.
- Smith, D. 1958. Cold tolerance of the cultivated palms based on observations made at Daytona Beach, Florida, during the winter of 1957–1958. *Principes* 2:116–126.
- Smith, D. 1964. More about cold tolerance: Effects of a hard freeze upon cultivated palms during December, 1962, at Daytona Beach, Florida. *Principes* 8:26–39.
- Snyder, D.S., G.M. Hatfield, and K.F. Lampe. 1979. Elimination of the itch response from the raphide of the fishtail palm *Caryota mitis*. *Toxicol. Appl. Pharmacol.* 48: 287–292.
- Southern, P.J. 1969. Sulphur deficiency in coconuts. *Oléagineux* 24:211–220.
- Steyaert, R.L. 1967. Les *Ganoderma* palmicoles. *Bull. du Jardin Botanique National de Belgique* 37:465–492.
- Stocks, I.C., and G. Hodges. 2012. The rugose spiraling whitefly, *Aleurodicus rugioperculatus* Martin, a new exotic whitefly in South Florida (Hemiptera: Aleyrodidae). DACS-P-01745. Fla. Dept. Agric. Consumer Serv., Div. Plant Ind., Gainesville, FL.
- Summerell, B.A., H.C. Kistler, and L.V. Gunn. 2001. *Fusarium* wilt of *Phoenix canariensis* caused by *Fusarium oxysporum* f. sp. *canariensis*. p. 263–270. In: B.A. Summerell, J.F. Leslie, D. Backhouse, W.L. Bryden, and L.W. Burgess (eds.), *Fusarium: Paul E. Nelson memorial symposium*. Am. Phytopathol. Soc. Press, St. Paul, MN.
- Svenson, S.E., and T.K. Broschat. 1992. Copper hydroxide controls root circling in container-grown West Indies mahogany and Carpentaria palm. *Proc. Fla. State Hortic. Soc.* 105:219–220.
- Taylor, J.E., K.D. Hyde, and E.B.G. Jones. 2000. The biogeographical distribution of microfungi associated with three palm species from tropical and temperate habitats. *J. Biogeogr.* 27:297–310.
- Tengoua, F.F., and C. Bakoume. 2005. Basal stem rot and vascular wilt, two treats for the oil palm sector in Cameroon. *Planter* 81:97–105.
- Thawaro, S., and S. Te-chato. 2010. Effect of culture medium and genotype on germination of hybrid oil palm zygotic embryos. *ScienceAsia* 36:26–32.
- Thomas, M.C. 2005. *Myllocerus undatus* Marshall, a weevil new to the Western Hemisphere. DACS-P-01635. Fla. Dept. Agric. Consumer Serv., Div. Plant Ind., Gainesville, FL.
- Thomas, J.E., A.F. Kessling, M.N. Pearson, and J.W. Randles. 1993. A potyvirus isolated from Cuban royal palm (*Roystonea regia*) in Queensland. *Aust. Plant Pathol.* 22: 68–71.
- Tisserat, B. 1979. Propagation of date palm (*Phoenix dactylifera* L.) in vitro. *J. Exp. Bot.* 30:1275–1283.
- Tisserat, B. 1983. Tissue culture of date palms: a new method to propagate an ancient crop—and a short discussion of the California date industry. *Principes* 27:105–117.
- Tomlinson, P.B. 1961. *Palmae*. Vol. II. In: C.R. Metcalfe (ed.), *Anatomy of the monocotyledons*. Clarendon Press, Oxford, UK.
- Tomlinson, P.B. 1990. *The structural biology of palms*. Clarendon Press, Oxford, UK.
- Tomlinson, P.B. 2006. The uniqueness of palms. *Bot. J. Linnean Soc.* 151:4–14.
- Tomlinson, P.B., and B.A. Huggett. 2012. Cell longevity and sustained primary growth in palm stems. *Am. J. Bot.* 99:1891–1902.
- Torres, G.A., G.A. Sarria, F. Varon, M.D. Coffey, M.L. Elliott, and G. Martinez. 2010. First report of bud rot caused by *Phytophthora palmivora* on African oil palm in Colombia. *Plant Dis.* 94:1163.

- Tymon, A.M., P. Jones, and N.A. Harrison. 1998. Phylogenetic relationships of coconut phytoplasmas and the development of specific oligonucleotide PCR primers. *Ann. Appl. Biol.* 132:437–452.
- Uchida, J.Y., M. Aragaki, J. Ooka, and N.M. Nagata. 1992. Phytophthora fruit and heart rots of coconut in Hawaii. *Plant Dis.* 76:925–927.
- Utulu, S.N. 1986. Effects of duration of weed interference on growth and development of polybag oil palm seedlings. *J. Nigerian Inst. Oil Palm Res.* 7 (2): 175–182.
- Vann, S.R., and R.A. Taber. 1985. Anellophora leaf spot of date palm in Texas. *Plant Dis.* 69:903–904.
- Vázquez-Euán, R., N. Harrison, M. Narvaez, and C. Oropeza. 2011. Occurrence of a 16SrIV group phytoplasma not previously associated with palm species in Yucatan, Mexico. *Plant Dis.* 95:256–262.
- von Fintel, G.T., P. Berjak, and N.W. Pammenter. 2004. Seed behavior in *Phoenix reclinata* Jacquin, the wild date palm. *Seed Sci. Res.* 14:197–204.
- Wanderlei-Silva, D., E.R. Neto, and R. Hanlin. 2003. Molecular systematics of the Phylachorales (ascomycota, Fungi) based on 18S ribosomal DNA sequences. *Braz. Arch. Biol. Technol.* 46:315–322.
- Wanderley, C. da S., R.T. de Faria, and M.U. Ventura. 2012. Chemical fertilization, organic fertilization and pyroligneous extract in the development of seedlings of areca bamboo palm (*Dyopsis lutescens*). *Acta Sci., Agron.* 34:163–167.
- Warwick, D.R.N., and E.E.M. Passos. 2009. Outbreak of stem bleeding in coconuts caused by *Thielaviopsis paradoxa* in Sergipe, Brazil. *Trop. Plant Pathol.* 34:175–177.
- Wei, W., R.E. Davis, I.-M. Lee, and Y. Zhao. 2007. Computer-simulated RFLP analysis of 16S rRNA genes: identification of ten new phytoplasma groups. *Int. J. Syst. Evol. Microbiol.* 57:1855–1867.
- Weintraub, P.G., and L. Beanland. 2006. Insect vectors of phytoplasmas. *Annu. Rev. Entomol.* 51:91–111.
- Welbourn, C. 2006. Red palm mite *Raoiella indica* Hirst (Acari: Tenuipalpidae). Fla. Dept. Agric. Consumer Serv., Div. Plant Ind., Gainesville, FL. <http://www.freshfromflorida.com/pi/pest-alerts/raoiella-indica.html>
- Wen, B. 2009. Storage of recalcitrant seeds: A case study of the Chinese fan palm, *Livistona chinensis*. *Seed Sci. Technol.* 37:167–179.
- Whitehead, R.A. 1968. Selecting and breeding coconut palms (*Cocos nucifera* L.) resistant to lethal yellowing disease. A review of recent work in Jamaica. *Euphytica* 17:81–101.
- Woltz, S.S., and W.E. Waters. 1978. Airborne fluoride effects on some flowering and landscape plants. *HortScience* 13:430–432.
- Wong, L.-C., C.-F.J. Bong, and A.S. Idris. 2012. *Ganoderma* species associated with basal stem rot disease of oil palms. *Am. J. Appl. Sci.* 9:879–885.
- Wood, C.B., and H.W. Pritchard. 2003. Germination characteristics of fresh and dried *Hyophorbe lagenicaulis* seeds. *Palms* 47:45–50.
- Yang, Q.-H., W.-H. Ye, and X.-J. Yin. 2007. Dormancy and germination of *Areca triandra* seeds. *Sci. Hortic.* 113:107–111.
- Yeager, T., C. Larsen, R. Newton, and J.C. Tort. 1994. Container production system comparison for pine, oak, and palm. *Proc. South. Nurserymen's Assoc. Res. Conf.* 39: 78–80.
- Young, A.J., K.R.E. Grice, P.R. Trevorrow, and L.L. Vawdrey. 2007. *Burkholderia andropogonis* blight of golden cane palms in north Queensland. *Aust. Plant Dis. Notes* 2: 131–132.

- Yuri, J.A. 1987. Propagation of Chilean wine palm (*Jubaea chilensis*) by means of *in vitro* embryo culture. *Principes* 37:183–186.
- Zaid, A. (ed.), 2002. Date palm cultivation. FAO Plant Production and Protection Paper 156, Rev. 1. FAO, Rome, Italy.
- Zaid, A., and B. Tisserat. 1984. Survey of the morphogenetic potential of excised palm embryos *in vitro*. *Crop Res.* 24:1–9.
- Zirari, A., and L.L. Ichir. 2010. Effect of exogenous indole butyric acid (IBA) on rooting and leaf growth of small date palm offshoots (*Phoenix dactylifera* L.) derived from adult vitroplants of 'Najda' cultivar. *Acta Hort.* 882:839–844.