Sustainability in Plant and Crop Protection 16

Imran Ul Haq
Siddra Ijaz *Editors*

Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms

Springer

Sustainability in Plant and Crop Protection

Volume 16

Series Editor

Aurelio Ciancio, Sezione di Bari, Consiglio Nazionale delle Ricerche Istituto per la Protezione delle Piante, Bari, Italy

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ISSN 2567-9805 ISSN 2567-9821 (electronic)
Sustainability in Plant and Crop Protection
ISBN 978-3-030-56329-5 ISBN 978-3-030-56330-1 (eBook)
https://doi.org/10.1007/978-3-030-56330-1

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Ornamental palms are common in tropical regions, where they dominate the landscape. All palms belong to the family Arecaceae (syn. Palmae) comprising of thousands of species distributed throughout the tropical and sub-tropical ecological zones. The family ranks third globally after the grass and legume families. About 200 palm genera are currently recognized. The species richness is much less precise because of conflicting concepts by taxonomists as to what constitutes a distinct species, and the need to revise a number of large genera. Actually, the number of species recognized in the literature is more than 2400, which shows the taxonomic complexity of Palmae. Scientists have brought some ornamental palms under the category of "False Palm", which are cultivated as ornamental or for aesthetic purposes, but they are not true palms. As the horticultural industry is flourishing rapidly, ornamental palms occupy a key status for landscape purposes. Their great demand in landscape as well as for products makes ornamental palms perfect candidates for the horticultural industry. Nevertheless, they are prone to different biotic stresses including fungal diseases, which are a major threat. However, there is little and scattered information available along few reports on fungal diseases, although reality is otherwise. We came to know about this fact while conducting a survey to document the different diseases of ornamental plants under project (#2762) "Etiology and integrated management of perennial declining evergreen ornamental plants in Pakistan", funded by the Higher Education Commission (HEC) of Pakistan. The ornamental palms are exposed to stress by a variety of fungal pathogens and their associated diseases. With this perspective, we decided to compile information in the form of a compendium, which will serve as a reference for scientists and researchers dealing either directly or indirectly with ornamental horticultural research. The volume is organized into three distinct parts, comprised of 16 chapters in total. Part I consists of three chapters. The first one provides information about the economic importance of ornamental horticulture, describing the current scenario and future prospects. Chapter 2 focuses on molecular taxonomy, ecology and distribution of ornamental palms, whereas the third chapter deals with cultivation and growth constraints. Part II includes eleven chapters on the etiology and management strategies of economically important fungal diseases. Part III comprises of two chapters, which describe the etiology and management of “False Palms”. The production of this book gave us great pleasure with the hope that it will provide essential information on biology, diversity, taxonomy and, majorly, fungal diseases of ornamental palms. At the end we acknowledge Higher Education Commission, Pakistan, for providing funds under HEC project # 2762, titled; “Etiology and integrated managment of perennial ornamental plants”. that became ignition for aspiration to edit this book based on the information gathered while working on this project.

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Contents

Part I Biology and Horticultural Aspects of Ornamental Palms

1 Ornamental Horticulture: Economic Importance, Current Scenario and Future Prospects 3
Iftikhar Ahmad, Hafiz Atta-ur-Rehman Saeed, and Muhammad Abdul Salam Khan

2 Ornamental Palms: Molecular Taxonomy, Ecology and Distribution 41
Siddra Ijaz and Maria Babar

3 Cultivation and Growth Constraints of Ornamental Palms 73
Muhammad Azam, Rashad Qadri, Muhammad Tahir Akram, and Shaghef Ejaz

Part II Economically Important Fungal Diseases of Ornamental Palms: Etiology and Management

4 Fungi: Cynosure of Ornamental Palms Diseases 85
Imran Ul Haq, Siddra Ijaz, Qaiser Shakeel, Guoqing Li, Long Yang, and Ifrah Rashid

5 Fungal Diseases of Foxtail Palm (*Wodyetia bifurcata*) 115
Rana Muhammad Sabir Tariq, Saleem Shahzad, and Abdul Qayoom Rajput

6 Fungal Diseases of Cat Palm (*Chamaedorea cataractarum*), Bamboo Palm (*Chamaedorea seifrizii*) and Cluster Palm (*Chamaedorea costaricana*) 125
Qaiser Shakeel, Mingde Wu, Jing Zhang, and Zia-Ul-Haq

7 Fungal Diseases of Washingtonia Palm (*Washingtonia robusta*) 141
Iqra, Nabeeha Aslam Khan, Muhammad Zunair Latif, and Yasir Iftikhar

8 Fungal Diseases of Golden Palm (*Dypsis lutescens*) 149
Muhammad Taimoor Shakeel, N. I. Katis,
Muhammad Mohsin Alam, Rashida Atiq, and Qaiser Shakeel

9 Fungal Diseases of Bismarckia Palm (*Bismarckia nobilis*) 159
Rana Muhammad Sabir Tariq, Saboohi Raza, and Tanveer Ahmad

10 Fungal Diseases of Date Palm (*Phoenix dactylifera*): Etiology and Management 169
Imran Ul Haq and Nabeeha Aslam Khan

11 Fungal Diseases of Alexandra Palm (*Archontophoenix alexandrae*) and Queen Palm (*Syagrus romanzoffiana*) 197
Adnan Ahmad, Muhammad Raheel, Qaiser Shakeel,
Anjum Faraz, and Khalid Pervaiz Akhtar

12 Fungal Diseases of Ravenea Palm (*Ravenea rivularis*); Etiology and Management 203
Muhammad Zunair Latif

13 Fungal Diseases of Royal Palm (*Roystonea regia*) 221
Rabia Tahir Bajwa, Qaiser Shakeel, Muhammad Raheel,
and Ifrah Rashid

14 Fungal Diseases of Lady Palm (*Rhapis excelsa*) and Fishtail Palm (*Caryota mitis*). 237
Muhammad Kaleem Sarwar, Rashda Naheed, Siddra Ijaz,
and Imran Ul Haq

Part III Fungal Diseases of False Palms

15 Fungal Diseases of Traveler's Palm (*Ravenala madagascariensis*) 253
Rana Muhammad Sabir Tariq and Tanveer Ahmad

16 Fungal Diseases of Kangi Palm (*Cycas revoluta*) 265
Anjum Faraz, Muhammad Zunair Latif, and Owais Yaseen

Index. 275

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Part I
Biology and Horticultural Aspects of Ornamental Palms

Chapter 1
Ornamental Horticulture: Economic Importance, Current Scenario and Future Prospects

Iftikhar Ahmad, Hafiz Atta-ur-Rehman Saeed, and Muhammad Abdul Salam Khan

Abstract Ornamental horticulture comprises production of cut flowers, potted plants and cut foliage crops, which is highly competitive on account of advances in infrastructure availability, improved varieties development, postharvest handling and marketing options. With rise in production costs, floriculture production is shifting from the three most important global producers, The Netherlands, USA and Japan to some Latin American, African and Asian countries, where growing conditions are favorable and resources are cheaper. Among ornamental plant production for landscape and interioscapes, ornamental palm production is a high demanding segment, which has high value all over the world. In this chapter, ornamental palm types, economic importance, and future prospects are described along with their basic characteristics and growing requirements.

Keywords Horticulture · Economic importance · Ornamental palms · Interioscapes

1.1 Introduction

Floriculture consists of four major components, viz. cut flowers, potted plants (including potted flowers and potted greens), cut foliage, and bedding/garden plants. Compared to fruits and vegetables, floricultural products require higher initial investment, efficient management and a high-tech production technology. Therefore, their profitability per unit area is much higher than other agricultural commodities. According to a report, value per ha in The Netherlands has reached to $138,000

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_1

followed by Colombia having $100,000 (BIOX 2005). Floricultural production ranks among top four export earning commodities, that include petroleum, coffee, and bananas (BCMAFF 2003). The Netherlands, Japan, and USA are global leaders in floriculture production with approximately $44 billion value (Marques and Caixeta Filho 2003). Moreover, per capita consumption of floriculture products varies greatly in different countries with developed countries generally having a higher consumption, such as Switzerland €136, which ranked first in all countries, followed by Norway at €14 per capita (IFTS 2004). Presently, the Netherlands, the US and Japan are the leading floricultural producers in the world followed by Colombia, Kenya, Equador, Ethiopia and Zimbabwe, which are emerging floricultural economies during last two decades (Wijk 1994; Kenya Flower Council 2005).

There are more than 120 countries in the world which are actively involved in floriculture production. Japan, leading with a production value worth $3.7 billion, whereas The Netherlands, with $3.6 billion and the USA, with $3.3 billion accounted for more than half of the world total (Papademetriou and Dadlani 1998). In 2004, the total production value was around $75 billion, of which The Netherlands had a €3.6 billion share (FCH 2004), USA had $5.18 billion (USDA 2005), while Japan had $3.47 billion (MAFFJ 2002–2006). In terms of areas under floriculture crops, China and India are leading with more than 75,000 ha in China and 65,000 ha in India (Yang et al. 1998; CMA 2005). The proportion of different floriculture products varies greatly among countries (IFTS 2004; USDA 2004; 2005). The main floriculture products are cut flowers (45.3% in Germany, 48.5% in The Netherlands, 15.7% in USA, 31.6% in China and 99.3% in Colombia), potted flowers (34.8% in The Netherlands and 39.1% in China), and bedding and garden plants (51.8% in USA) (MAFFJ 2002–2006). Among these, cut flowers are the leading product in world floriculture trade. In 2001, fresh cut flowers shared 50.5% of the world trade value of floriculture (Laws 2004), the top four crops, in decreasing order, being roses, chrysanthemums, carnations and lilies. Production of huge amounts of high quality flowers all year around, with lower labor and other production costs, induced some floriculture production shifts towards Southern Hemisphere countries. The Global production of floriculture products will likely continue to expand, especially in developing countries in Africa, Latin America and Asia, whose productivity is expected to increase further. Traditional large producing countries such as The Netherlands, Japan and the USA continue to lead global production, increasing productivity per worker and unit area. Total area under production will remain stable or drop slightly in these three countries. Production of highly labor-intensive cut flowers will shift in areas with lower labor and other production costs.

During last two decades, floriculture production has shifted to many developing countries having favorable climatic conditions and fertile soils, with cheap labor and friendly export/import policies. These countries include Kenya, Colombia, Ecuador, Ethiopia, Zimbabwe, Malaysia etc., whose exports are rising day by day to European countries. Around the globe, there are three significant floriculture consumption regions, viz. Europe (66.7%), USA (19.3%) and Japan (10.7%). From a country perspective, USA is the biggest consumer at $6.99 billion, sharing 19.3% of the world total value. Germany is second largest (18.8%), followed by Japan

(10.7%), France (8.5%), United Kingdom (8.5%), Italy (6.8%), The Netherlands (4.1%), Spain (4.1%), Switzerland (2.6%), and Poland (2.6%). These ten countries account for 85% of the world total floriculture consumption. On a per capita basis, generally European countries have a higher floriculture consumption with Switzerland ($136), Norway ($114), The Netherlands ($93), Denmark ($83), Germany ($83), Austria ($78), Sweden ($77), and Belgium ($69) having higher per capita consumption. Outside Europe, Japan ($31) and the USA ($51) have relatively lower consumption per capita (Xia et al. 2006). Cut flower use is expected to still rise in coming years, particularly in Asian countries, where floriculture markets will experience increasingly global competition. A number of traditional markets are showing signs of saturation, while new countries are trying to get their place on the market. At the same time, with increased living standards, new markets will develop in some regions of the world such as Eastern Europe and Asia.

Floriculture, now a visible and growing section of Horticulture, encompasses production, propagation and marketing of ornamentally important trees, shrubs, palms, indoor plants as well as flowers that address the demand of cut flowers and potted plants in market. As the greenhouse technology developed, a positive competition in three big centers of floriculture market (Europe-Africa, America and Asia-Pacific) increased globally, especially in three big producers as well as consumers of floriculture items (The Netherlands, Japan and America). World floriculture trade has been exceeded up to 50 billion US $ while increasing daily. The Netherlands is the biggest exporter as well as importer of floriculture products, due to their distinctive way of trade. After Netherlands, Kenya, Ethiopia and Colombia are next biggest exporters (Ogawa 2004).

Pakistan is a country whose GDP depends up to 21% on agriculture. However, floriculture is a developing industry in the country but still occupies only 0.5% of arable land. Floriculture includes a vast range of commercially grown crops in all climatic regions of the country, whereas agronomic crops such as wheat, rice, maize and cereals are limited to specific regions of country. Floriculture in Pakistan is still limited to developed cities such as Karachi, Lahore, Islamabad, Peshawar and Faisalabad, while Pattoki (Kasur district) is biggest producing region as well as national market hub for floricultural crops. In Pakistan most of farmers are small land owners, they grow agronomic crops and depend on yields. Conventional crops are economical for larger areas but a solution for small land owners may be represented by floriculture.

On the other hand, floriculture products generate high cash value as well as aesthetic food for soul. Inexpensive labor, favorable climatic conditions and easiest availability of land are key benefits for local producers. Most common constraints to producers include lack of irrigation sources, expensive hybrid seeds and corms, lack of knowledge about fertilizers, high post-harvest losses, lack of cold store facilities, no greenhouse technology, low quality of products and lack of knowledge about packaging. Unfortunately, Pakistani farmers are not producing export quality products due to the above mentioned constraints and lack of cooperation with research and business officials. Moreover, producers are not aware about export standards of world floriculture markets. Pakistan has opportunities in nearest

Chinese, Japanese, Gulf and other Asian markets, but due to continuous negligence towards floriculture, national products have negligible shares in these markets. Pakistan needs to create awareness among farmers about standards of export quality products, providing greenhouse technology, managing continuous flights, and adopting postharvest treatments and packaging, according to the world trade demand. Most of evergreen plants also require less water and fertilizer. In floriculture products, demand of cut flowers is continuously emerging and contributes a big share in Pakistan floriculture market. The requirement of evergreen plants was low until the development of housing societies while nowadays a huge number of dracaenas, dieffenbachias, colorful shrubs, exotic trees and most graceful species of ornamental palms are in the demand of every developing and developed housing scheme. Among green plants, palms have their own aesthetic, historic and economic value.

1.2 Trends and Prospects

1.2.1 New Style and High Quality

In order to fulfil the trends set by the market for fresh cut flowers, bedding plants, ornamental palms, and potted flowering plants, and to compete with low-cost production and labor countries, production systems often have to be optimized, especially in large greenhouse areas in localities around the world where climate is less than optimal. Computer systems that monitor and regulate the growth environment, movable tables for enhancing production area, supplemental lighting and mechanization (for reduced labor costs), and re-use of irrigation water are all means of achieving these production goals.

1.2.2 Transition of the Producing and Consuming Center

Traditionally wholesalers play several roles (product sourcing, brokering and handling, providing product information, credit source, identifying emerging market trends, tracking of difficult-to-find material) for retail florist customers, and have served as middle-men for a long time, providing a bulk source (local or imported) from which redistribution occurs in smaller lots to retailers. These will continue to play a major part of global cut flower markets. However, distribution centers and grower-direct-auctions are becoming increasingly popular due to greater demands to reduce costs, cuts of the middle-men and speed up purchases in a more efficient way, allowing thus for a superior quality product (longer vase life). High-tech driven markets (USA, EU, Japan, S. Korea and increasingly China) are starting to move towards online grower auctions. This tends to cut the wholesale agent and the importer out of the picture, altogether. Retailers are also getting smarter, avoiding middle steps, and increasing purchases/sales by both traditional retailers (including large floral chains), street and special locality vendors such as supermarkets, stores, warehouses and internet sites. Retailers can be broadly categorized into three sectors: (a) specialty i.e. florist shops, garden centers, mail catalogues, craft/art specialty, toll-free numbers, farmer's markets, street vendors (accounting for 59.5% of the cut-flower market), (b) mass merchandisers i.e. supermarkets, discount chain stores, warehouse clubs, convenience stores (accounting for 36% of the cut-flower market), (c) others (4.5% of market) (van den Broek et al. 2003). This balance is definitely going to change, with a greater tendency towards (b), but this depends strongly on the national consumer market.

1.2.3 Use of the New Technologies and Advanced Facilities

A greater understanding of the physiological, genetic and ecological mechanisms underlying plant growth, flower initiation and development, and subsequent post-harvest conditions will lead to the launch of much more superior quality products onto the market, which is increasingly demanding, and reliant on novel ideas for its growth and expansion. At the same time, mass production units (either *in vitro* systems or bioreactors for mass production of micropropagules) will be essential to satisfy growing demands, which might otherwise, through conventional propagation practices, could not be fulfilled. Moreover, a greater ease, consistency and reliability of genetic transformation methods will allow the introduction of novel characters such as new colors, manipulated growth patterns and development, and also strengthen plants' responses to environmental (biotic and abiotic) stresses. There is no single factor that determines the efficiency of a production site or unit, and several aspects must be considered simultaneously: sufficient working capital, availability of suitable plant material, green or shade housing, location, ease of cultivation, well drained or suitable soil, species selection, flowering period, planting density, irrigation design, drainage, shelter or windbreaks, insects, diseases, climate, supply of labor, access to the market, weed control, spray equipment, mechanical equipment, cool room storage, and packaging facilities.

1.2.4 New Marketing System

Successful marketing and profitable exports depend on different factors such as: understanding and meeting market and customers' demands; understanding specific cultural and social customs, fashion and trends affecting buying patterns, quality of the product on arrival, product presentation and promotion. Successful marketing goes hand-in-hand with assured supply, quality product, packaging, cool chain transport and cool storage facilities, pre- and post-harvest treatments and

IPM. Marketers must be aware of color preference, stem length, bunch weights, bunching, sleeving, box size, product description sales as a consignment or as a fixed price basis. Moreover, knowledge of the export logistics (freight forwarder services, domestic transport, direct flights, customs clearance system, export documentation, packaging, pressure cooling, cool storage, distance from international airport, fumigation services), and legislative requirements (permits and authorities, quarantine, inspection, and phytosanitary certification for specified markets, import permits, duties, tariffs and customs requirements, and plant quarantine clearances of arrival in some export markets) will all ensure a sound marketing strategy.

1.3 Ornamental Palms

After cut flowers, second major segment of floriculture industry is the production of live potted plants, which accounts for around 43% of total trade. Among these, there are ornamental trees and shrubs, climbers, bedding and house plants. In this chapter, we will focus on ornamental palms. Symbolically, palm trees depicted victory, peace and productivity in many cultures in the past, while nowadays the palm is considered as a symbol of tropics and tourism.

Palms (Arecales), members of family Palmae (Arecaceae), are quite popular ornamentals in tropics and subtropics. They are placed in six subfamilies with approximately 4000 species and more than 200 genera. Palm trees have great diversity in morphology and ecology, and are commonly found in tropical, subtropical and Mediterranean climatic regions. These also have high economic value being source of food and oil, fiber, wine and other beverages, active compounds, rattan—used in furniture production—and thatch—used as roofing material—, tannins, and lumber. Moreover, palms are integral part of modern landscapes, interiorscapes, and are grown in many national and international tropical gardens, such as The Palm House at the Royal Botanical Gardens, Kew Gardens (England). In USA, primarily in California, Florida and Hawaii, palms are produced for the ornamental industry as potted, greenhouse-grown plants for interior use, or container- and field-grown plants for landscape use. While in other parts of the world, they are grown in fields for food, oil and other commercial uses.

Generally, palms are naturally distributed in tropical regions, but now the majority of them has been transported to new locations, different from their native habitats. For example, *Phoenix dactylifera*, commonly grown for its edible dates, probably originated in the Persian Gulf, but now it is commonly found throughout subtropical Florida, employed as landscape centerpieces. However, new cultivars of ornamental palms have not been bred for new environments but are transported to new locations in which they often fail to survive. This movement of palms to new environments poses great challenges to ornamental palm growers. Palms are basically monocots and their anatomical structure has important implications for their health. Each stem of a palm has a single apical meristem (bud or heart). Once the meristem is damaged—due to any pathogen, nutritional deficiency, herbicide, mechanical or environmental factors—the plant may die. This vulnerability is particularly known in single-stem palms. Since palm stems have no vascular cambium, they are essentially devoid of secondary growth. Therefore, palms cannot repair injuries to their stems, and diligent effort must be made to prevent lesions that provide opportunities for insect and/or pathogen invasions of the trunk.

Palms are integral part of the green vegetation in many developed countries. There are almost 4000 species of palms in the world, most of which are native to warm tropical regions. However, there are a number of species native to subtropical and lower hilly areas e.g., the Chinese windmil palm (*Trachycarpus fortunei*) which is outstandingly cold-resistant and hardy. Nowadays, species of palms are available for all landscape attributes such as indoor, outdoor, potted, green belts, group plantation and corner plantation as well.

People from old age era were directly dependent on many palm trees for several important products, such as natural waxes, oils, kernels, wood, fibers, leaves and fruits etc. Nowadays, there are few economically important species, for commercial purposes. History of palm trees is as old as man itself. Although controversial, it is thought that palms were first cultivated by Mesopotamians and other Middle East civilizations around 5000 years ago. History also guides us about useful benefits and distinctive traits of palms, i.e. the date palm (*Phoenix dactylifera*), that produces high yields of energy rich fruit, the coconut palm (*Cocos nucifera*) that produces delicious fruit coconuts (while its outer covering is used as organic substrate for raising of plant seedlings), the traveler's palm (*Ravenala madgascariensis*), which is a false palm that stores water in its branches during rain that later is useful for water supply, the rattan (climbing palms) that were broadly used to make furniture chairs and handicrafts, and many others. Many palm species bear edible fruit that remained as a survival food during famines, i.e. the Southern Paitue, or the California *Washingtonia filifera* that provides fruit to feed people in starvation.

As a testimony of the historical value of palms, the word "dates" is cited 26 times in the Holy Quran.

> Does any of you wish that he should have a garden with date-palms and vines and streams flowing underneath, and all kinds of fruit, while he is stricken with old age, and his children are not strong (enough to look after themselves)—that it should be caught in a whirlwind, with fire therein, and be burnt up? Thus doth Allah make clear to you (His) Signs; that ye may consider. (**Surah Al-Baqara, 266**)

Dates were also mentioned 30 times in the Bible. Palms remain as an important part of every civilization in old and middle ages, and even nowadays for many religion such as Islam, Christianity etc.

1.4 Biology of Palms

Palms are flowering angiosperms, and appeared almost 80 million years ago. Being monocots they have only a single cotyledon produced by each seed after germination. This character of palms relates very closely to bamboos and grass plants. Palms are now growing all around the world. Even if they attain the size of trees, in relation with their growth and basic structure, palms are more relevant to other monocots such as corn, grasses, bamboos and rice etc. rather than tropical trees such as maple, oak and others (Broschat et al. 2014). In monocots there are very rare species which attain the size of a palm, i.e. a date palm that may reach up to 40 m. One of the main characteristics of monocots is the lack of a distinctive and useful layer of productive cells known as vascular cambium, which in dicots appears between the xylem (that transfers water) and the phloem (that transfers carbohydrates). It also makes new phloem towards the inside of the stem, while the xylem is opposite to it.

As in palms there is no vascular cambium, water and carbohydrate conducting tissues become dispersed in whole internal stem. Woody dicots are able to expand their stem diameter and produce new vascular tissues, which is known as secondary growth. Horticulturists perform successful grafting and budding in closely related varieties and species of dicots due to the regenerative ability of cambium that also makes it able to fix injuries. On the other hand, palms lack cambium and therefore grafting and budding cannot be performed, as well as secondary growth. This means that once a palm tree reaches its maximum girth size it cannot raise stem size or diameter. Scattered xylem and phloem in palms stem last for the whole plant life. For this reason palms are also unable to fix their injuries. Most of the palms have only a single growing bud/node on the apical meristem. This apical meristem is hence vital for palms because it has only one single growing point. If it is damaged then the plant dies (Broschat et al. 2014).

Propagation of palms for commercial agricultural and ornamental objectives is achieved through seeds. However, there are certain species (*Phoenix dactylifera* and *Rhapis* spp.), which can be propagated through suckers (baby plants produced at the base of the mother plant) and tissue culture (Corley 1980). Seed propagation has certain serious problems such as the very low seed germination percentage and the long time needed for growth of seedlings. This is a challenge to produce uniform seedlings, with higher germination percentages.

Palm seeds usually take 90–120 days to germinate with only a 15–20% germination rate, which represent a great loss to producers. Palm seeds vary greatly in size, with the smallest seed measuring only 5 mm, while the biggest weighs up to 20 kg (this is the coco-de-mer Will Apse (Biologist from UK) palms *Lodoicea maldivica*). Germination in palms usually occurs in two ways: one is called remote germination, while the second is known as adjacent germination. In remote germination, a shoot from the cotyledon grows away from the seed, seedling shoot and radicle root develop, while the main cotyledon remains inside to provide food from endosperm in the form of nutrients. *Phoenix dactylifera*, *Livistona chinensis* and *Chamaerops humilis* are true examples of remote germination. On the other hand, if we see the adjacent procedure, a round button-like cotyledon grows, root develops from radicle and shoot emergence starts. *Syagrus romanzoffiana* and *Butia capitata* are best examples of this process.

Considering problems in palm seeds, the maturity of seeds stands on top. Most of the time seeds are immature, with an embryo that is not fully mature, causing a poor germination percentage. Also happens that all seeds are not synchronous, and do not mature at a single time, originating a mixed germination frequency. There is an exception where maturity does not matter, as in *Dypsis lutescens*. The second major problem is the collection of fallen seeds. It is observed that fallen seeds always carry spores of disease causing agents, that do not let the seed to emerge. Thirdly, usually farmers treat seeds with higher concentrations of fungicides that cause low germination percentages and even a delay in the process. Suitable substrate selection is another problem in nursery raising, requiring good sanitation and disease-free growing media.

There are some easy tests to check the viability of seeds including float test, tetrazolium chloride test and the physical cut method. To perform float test, seeds must be placed in a container filled with water. Dead seeds will float while viable ones will soak. However, this method is old and scientists do not recommend it any more. In the tetrazolium chloride test, a selected population of seeds are cut in half and the embryos are coated with 1% or 10 g L^{-1} of tetrazolium chloride (TTC), before being placed in the dark for 2–24 h. If the embryos become pink or red, they are viable otherwise they can be considered as non-viable. In the third test, the seeds are cut in half and the embryo and endosperm are observed. If the embryo is firm and colored and the endosperm fills all of its space in the seed coat, the seed may be considered as viable. If the embryo is discolored and the endosperm is dis-shaped, it is non-viable.

After seed selection, pre sowing treatments of palm seeds should be finalized. Growers and nurserymen commonly use scarification, stratification, soaking in water, removal of fruit remnants and application of chemical boosters such as gibberellic acid (GA) as pre sowing, or priming techniques (Nagao et al. 1980; Broschat and Donselman 1987).

Scarification-mechanical treatments to seeds are highly risky and require an experienced skill. Hard seed coat is a common problem in almost all palm species, and scarification is recommended for the hardest ones. In *Hyphaene* spp., only the upper husk, that is of a leathery type, should be removed mechanically. Mechanical treatments are harmful for the embryo, because a minute damage to the embryo turns the seed into waste. However, hammer hit, cutting of upper side to allow water access to endosperm, and levigation with stones are used which are being helpful to improve germination (Nagao et al. 1980).

Stratification-storage of seeds at a specific low temperature may help to break their dormancy. However, in case of palms, dormancy is usually not a problem. The main problem is instead with the hard seed coats, and suitable temperature during the germination period. It is recommended not to store palm seeds for years. If storage is necessary, then first remove fleshy fruits from seeds and wash with water to ensure the total removal of fruit residues. Secondly dry them, at temperatures higher than 15 °C, avoiding storage for more than 6 months (Broschat and Donselman 1987).

Soaking in water for a few days gives better germination rates. But if seeds are soaked in water and heated from below, the germination rates will be much higher. This procedure is even more effective than the use of chemical boosters/enhancers. Gibberellic acid, sulphuric acid and other chemical enhancers show good results, while hot water treatment showed the best results (Broschat and Donselman 1987).

Removal of flesh/fibrous fruit residue from the seed is necessary to boost up the germination rate. This procedure enhances the germination speed while the final germination percentage remains the same for both practices. However, fruits should be removed immediately because they may contain spores of different pathogens (Marcus and Banks 1999).

1.5 Pruning of Palms

Pruning is a judicious removal of plant parts performed to get specific objectives and goals, based on clear objective for each cut. In Pakistan, pruning is often limited to just cutting off branches, while this operation should be a totally scientific, experienced and skill-required job. Generally, it is thought that palms are slow growing plants and they do not require any pruning. Although they are slow growing, they need pruning to remain attractive and avoid diseases. As pruning requires certain goals, there are some objectives to achieve for members of this family. Palms are pruned to remove old dried fronds, collect fruits and remove suckers to maintain a solitary, main trunk. Old dried fronds are not a burden on plants, but when their cluster get wet by rain, they produce a conducive environment for fungal diseases (Pfalzgraf 2000). Insects are also observed in the skirt (old dried fronds that remain attached) of *Washingtonia robusta* that are lethal to the palm. It is also observed that when palms are planted on green belts, their old dried fronds often fall on vehicles that cause a severe damage. Approximately, all palm species produce fruits but few of them are edible, with a very little amount of commercial importance.

Date and coconut palms are two important commercial species in the world, and throughout history. Their fruits contribute a big cash value in the Horticulture sector of world trade. When we use these palms in landscapes, fallen dates produce a debris that cause hazards and may incubate insects as well as spores of pathogens. On the other hand, coconut palms produce a drupe of almost 2–3 lbs in weight that may cause serious injury to people. Fruit pruning of these palms is then also a necessary practice. Palms often produce basal suckers on their main trunk that affect the palm's look as well as snatching its single straight stem look. These suckers develop initially on the root system of palm, to later produce their own. Furthermore, these suckers are removed to maintain solitary straight trunk and to propagate more palms (Robinson 2004).

There are some important do's and do not's of pruning palms:

- Do not injure the living part of main trunk while pruning its frond or removing the sucker. This is advised because this damage cannot be healed up.
- Do avoid to damage the root ball of palm while pruning basal suckers because most of the nutrients available to palms are from upper surface of soil.
- Do not allow the flowers as well as fruits to develop because they use energy, cause mineral deficiency and create a messy debris when falling around the tree.

- Do pruning in the correct season, preferably in spring or summer months because it will differentiate growing and stagnant growth branches.
- Do not let the brown or paled leaves remain attached to trees because they cause certain mineral deficiency and induce this deficiency to newly growing leaves.
- Do pruning on newly growing parts, only if necessary, i.e. if planted indoor and/or space becomes limited.
- Do not over prune the palms. You must keep a desired and suitable shape that creates an attention in landscapes.
- Do pruning of 3 to 4 year older fronds. Palm's fronds may take 3–5 years to become mature, if you observe the new growth of current year, you must leave the last two growth of fronds and prune older than these. This helps palm to remain attractive until new growth becomes mature and protects new growth from heavy winds.
- Do pruning close to the main trunk but take care of living green part.

1.6 Common Ornamental Palms

*1.6.1 Areca Palm (***Areca catechu***)*

Origin This palm is also known as Areca palm, betel palm, or Indian nut. It is indigenous to Philippines. However, it now expanded over Asia and some islands of the Pacific Ocean and West Indies.

Growth and Botany *Areca catechu* is a small to medium sized species that grows almost up to 6–7 m height. Main trunk expands only 5-10 cm in diameter and leaves are medium green and assembled leaflets are attached. Areca palm also produce flowers which make a small, round fruit.

Propagation Seeds are the main source to propagate these palms, while suckers are also used for propagation. Seeds are sown in spring and seedlings are ready for transplant within 6–8 months. A low germination rate is a common problem of almost all species of palms especially in the case of Areca palms with rates lower than 25%, even after 100 days of sowing. Seed priming with bio-membrane and solvents is the best solution.

Economic Importance Suitable for symmetric gardening and for open indoor areas, i.e. super stores, malls and hotels. Fresh fruit is also used for some addictive beverages while its fruit is famous in Chinese people for chewing. Its fronds and trunks are used in local construction, in the making of weapons, and as sources of wax. *Areca* seeds are also widely used in traditional Chinese medicine as an anti-parasitic agent and antihypertensive agent. Its leaves and nuts are also used to cure diarrhea, throat inflammations, dropsy, sunstroke, beriberi, edema, bronchial catarrh, and urinary disorders (Badet 2011).

Future Prospects Areca palms contain polyphenols, fibre, fat polysaccharides, protein, and alkaloids. Moreover, their content may reach 8–12% in fats, which may be used in preparation of confectionery. There are bright prospects of using Areca palm fruits in pharmaceutical industry, as a digestive and carminative anti-diabetic, against certain skin diseases, relieving asthma and low blood pressure. Its husk may also be used for preparing paperboards, hard boards, cushions and non-woven fabrics besides being a good source of furfural. Its leaf sheath has the potential to be used for preparation of single use cups, plates, plyboards, tea chest, packing cases and suitcases, which can be commercially exploited.

*1.6.2 Toddy Palm (*Borassus flabellifer*)*

Origin Toddy palm, also known with the common name Palmyra palm, is used to make wine, from flower sap sugar and other local products. Areng (*Arenga pinnata*), nipa palm (*Nypa fruticans*) and coconut (*Cocos nucifera*) are other palm species known as toddy palms. *Borassus flabellifer* originated from subcontinent India and Pakistan and other Asian countries.

Growth and Botany Grey trunk, rounded signs of leaf scars and a straight upright single stem growth increase its beauty, as it attains more than 30 m height. Leaves look like fans, with reasonable difference in two leaves. They remain attached to the trunk for several years. Growth in earlier stages is very slow, while in later stages it grows rapidly. Toddy is a dioecious palm in which male flowers are very short (only 1 cm long) while female florescence is long and round like a golf ball. After pollination these flowers produce edible fruits.

Propagation Off shoots and seed are the right way of propagation. Seeds are present in jelly type sockets of fruit. They have a slow growth and low germination rates, while offshoots grow smoothly with high survival rate. Seeds are sown in garden soil and become able to transplant after 5–6 month. First year of plant from germination to forward should be under semi shade, later growth needs sunlight for further metabolism.

Economic Importance Toddy palm is one of the best choice among flowering shrubs, lawn sides and other formal and informal landscapes. Older leaves of toddy remain attached to the palm for long time, where the dry and green leaves combination gives a different look in garden. In ancient times its fruit were stored unripen and roasted later. The fruit was used in the past as raw, cooked or pickled, with a taste like the coconut, so that it was usually offered to guests. The soft juicy part of the fruit (toddy) is used to make sweet dishes.

Future Prospects Toddy palm has several medicinal uses and may be used commercially in the pharmaceutical industry. Moreover, its leaves have potential to be used as thatching for house floor and walls, weaving into baskets, mats and many other items. A number of fibers can also be obtained which can be used for making hats, boxes, baskets, fans, etc.

*1.6.3 Coconut Palm (***Cocos nucifera***)*

Origin Most common known nut but actually it is a drupe fruit. The word coconut was derived from "coco" (Spanish and Portuguese) which means "skull" or "head". *Cocos nucifera* is native to America. Old Sri Lankan, Indian and Malayan civilizations have great evidence of this palm in their history and religions. Its fruit, water, juices, milk, husk, oil, and coir are the main products being used for centuries.

Growth and Botany Coconut palm is one of the long and heighted palm trees. They are mainly of two types: dwarf and tall. Leaves are long up to 6 m. They do not leave any scar on stem when become old and fall. Fruit is mainly a round drupe almost 18–20 cm inches in diameter. The fruit contains a medicinally and economically important juice when harvested. Coconut palms need warm, humid areas to produce an economical crop, otherwise they have an ornamental use. Peak produce from a coconut palm tree is 70–80 fruits per year, from plants that need 10–12 years to reach this stage.

Propagation Coconut palms are conventionally propagated through seed. Recent research has shown that a coconut itself when having husk on it can be used to propagate further. Moreover, in recent days keeping in view the importance and demand of coconut trees they are being tissue cultured. Edible seeds or coconut with husk and water are placed in well drained media that finally raise seedlings. Seedlings need warm humid environment for better growth.

Economic Importance Coconut is used as food and oil as well as for ornamental purposes, in suitable coastal and warm humid areas. Landscapes in coastal areas are incomplete without coconut palms. It produces fruit and a list of by products which are important for their economic and medicinal value. Fruit itself is one of most demanded drupe in the world. Water in fruit has great medicinal value for stomach and renal care. Husk on fruit has a distinctive role in handicraft industry while hairy coir on husk is a very nutritive substrate for nursery production (Rajan and Abraham 2007).

Future Prospects As a cash crop, major components of coco palm include crude coconut oil (CNO) and copra (dried coconut kernel) (Mittaine and Mielke 2012). As a food crop, it is a source of coconut milk, sugar, coconut water, fibers, fuels, raw or virgin oil for cooking and cosmetics, while some varieties are also used in popular medicines (Batugal et al. 1998). However, with value addition, new non-traditional products have entered into global markets, which include but not limited to virgin coconut oil (VCO), cold pressed from the fresh kernel, coconut water extracted from mature or immature nuts, or coconut sugar, taken from the sap flowing out of the flower, which have great prospects for future developments in the coco industry (Prades et al. 2016).

***Areca catechu* (Areca palm)**

***Borassus flabellifer* (Toddy palm)**

***Cocos nucifera* (Coconut palm)**

***Cycas revoluta* (Sago palm)**

*1.6.4 Sago Palm (*Cycas revoluta*)*

Origin This palm is also known as Japanese sago, king sago, kanghi and cycad palm. The species belongs to the Cycadaceae family, therefore it is considered as false palm, but its growth resembles to the palms, originated from Ryukyu Island of Japan. There are several species that are known as sago. Cycads are also drought tolerant. They shed their leaves in winter in temperate areas.

Growth and Botany Very symmetrical, straight and deep dark brown trunk of palm makes graceful old look. Trunk, when reaching 45–50 cm in diameter does not expand more in later ages. Height may reach up to 5 m, after 15–20 years of growth. Leaves are deep to semi dark green in color, emerge from main trunk and remain attached to plants for 3 years after emergence. Leaf petiole is covered with thorns and leaflets have very sharp head, that may punch a human hand while caring them. Cycads are dioecious, where male inflorescence have cones and female produces mega sporophylls. Insects, wind and men are carrier of pollens. Small orange round non-edible fruits are formed, that contain seeds.

Propagation Cycads produce suckers in their base, a most suitable, fast and easy way to propagate them as compared to seeds. Although, seeds are also being used in commercial propagation. Seeds need special priming strategies before sowing. Soaking in distilled water for a week before sowing lifts germination rates from 30% to 80%. Seedlings become ready for transplant within 120–150 days after sowing.

Economic Importance Formal landscapes always contain cycads as accent plant. Corner plantation and indoor gardening has cycads as prime plant. Horticulturists must know before planting that cycads may shed their leaves in temperate winter and a permanent indoor conditions. They need bright light in indoor conditions. Their leaves are **highly toxic** to pets and children. High amount of alkaloids extracted from their leaves are used in pharmaceutical industry. In some cultures, cycas leaves are used after cooking and their seed kernels are used in cakes.

Future Prospects Cycas has a potential as food and in medicine, and also as oil, fiber, and gum source. However, all plant parts are toxic. Cycas is one of most demanding cut foliage crop being used worldwide for its decorative leaves, which further has scope to expand its market demand. Some cycads also help in nitrogen fixing, which may be used for improving soil health and lowering fertilizers requirements for crop production. Metroxylon sago is real sago palm from family Arecaceae which is used to make sago daana, used to cure several digestive system ailments.

1.6.5 *Fish Tail Palm (*Caryota mitis*)*

Origin *Caryota* is a genus of almost 13 species of palm trees. They are commonly popular as fish tail palm just because of their leaves look like the tail of a fish. All are originated from India, China and Indonesian forests from where they spread to Florida and the Americas. *Caryota furfracea*, *Caryota griffithii*, *Caryota urens* and *Caryota javanica* are the most famous species in this genus. *Caryota mitis* grows well in hilly areas. On the other hand, adaptation to subtropical areas is very good than to tropical one.

Growth and Botany *Caryota mitis* has a cluster type habit created by multiple stems. Bipinnate leaves are long up to 1–2 m, while leaflets, less than a 30 cm, end in a shape reminiscent of a fish tail. Main trunk does not exceed than 15 cm in diameter while in height may reach up to 15 m. The purple flowers of *Caryota* grow below the leaves and produce a dark red to purplish, non-edible fruit.

Propagation By seeds, which show first germination after 90–120 days. Seedlings become ready after 60 days from germination. They need a 25–30 °C temperature with 60–70% humidity to grow quick. A bright light is good for initial years while full sun in tropical areas is sufficient to dry the leaves.

Economic Importance It is suitable for sub-tropical and tropical climates and will do well in containers or indoors. It is also used as accent plant in parks, is a very nice choice in group plantations and performs well in semi shaded areas. Its purple inflorescence is graceful while fruits are non-edible. However, it is rich in carbohydrates and proteins. Inflorescence is tapped for toddy and the pith of the trunk is extracted for a kind of sago flour (Burkill 1993; Whitmore 1998). The fruit wall and sap contains irritant, needle-like crystals.

Future Prospects Being rich in carbohydrates and proteins, it might be used as replacement of vegetable oil. Moreover, it has great demand in modern landscapes for its unique plant structure and is popular in Indo-Pakistan and other Asian countries.

1.6.6 *Chinese Fan Palm (*Livistonia chinensis*)*

Origin Chinese Fan Palm is one of the purely subtropical species of palm trees. It is also known as fountain palm. It originated to China and Japanese islands. Furthermore, they are now naturalized in Indo-Pakistan region, America, Middle East, Bermuda and Dominican Republic.

Growth and Botany Trunk has light wooden colored, non-even but clean surface and does not cross 30 cm in diameter while in height it reaches up to 8 m. Fresh and lush green leaves look like Chinese traditional hand fan, and may lengthen up to

1 m. The petioles have spines and leaves are half straight and half hanging. Fruits are blue in color while equals to size of an olive. It grows best in loam to sandy loam soil, with moist conditions and frequent irrigation.

Propagation Livistonia palm produces many seeds every year that is the only way to raise new plants. Seeds are placed in vermiculite or garden soil mixed with coco coir to get best germination percentage. Seedlings become ready for transplanting after 6 months of sowing.

Economic Importance It's the best choice for open space landscapes in subtropical and tropical areas. As accent plant in flowering shrubs it gives an informal attractive look. Aesthetic beauty is also expressed when placed in group of three or five palms. Accent plant in formal parks and lawns is another best placement of Chinese Fan Palm. It is generally planted in parks, parking lots, and on avenues. Moreover, its leaves are used for making fans, brooms, hats and raincoats in some Asian countries (Dowe 2009; Flora of China Editorial Committee 2016).

Future Prospects Along with its use as ornamental palm, it has also medicinal value in preparation of some medicines supposedly to cure diseases. Therefore, it has great potential to be used in pharmaceutical and landscape industries. *Livistona chinensis* is being used as a medicinal herb in eastern Asia to treat certain types of tumors, which is a folk remedy to kill cancerous cells (Cheueng and Tai 2005).

*1.6.7 Bottle Palm (*Mascarena revaughanii*)*

Origin A species of flowering plant, its habitat is Mauritius island. One of the accent plant naturalized in many subtropical and tropical zones of world. They are cold sensitive and shed their leaves below 0 °C. The plant is also known as *Hyphorbe lagenicaulis*. Their commercial propagation is done in Asian countries like China, India, Pakistan, and USA.

Growth and Botany Bottle palm's trunk has a swollen base and height does not exceed than 2 m. The exact diameter of the trunk cannot be described because of the tapering habit from base towards head. It has maximum six and minimum four open leaves at a time. The pinnate, dark green colored, up to 1.5 m long leaves half roll around the trunk and make an aesthetically important canopy. Fruits are almost 2.5 cm long and orange to black in color. They contain a seed that is important for commercial propagation. Excessive heat from sunlight is crucial during first 3 years of growth. Well drained soil and frequent irrigation is the best recommendation for warm subtropical and tropical areas.

Propagation *Mascarena revaughanii* are propagated through seed. They do not produce suckers or offshoots. Seeds are sown in garden soil and seedlings become ready for transplanting after 150–180 days of sowing. The plants are ready for landscape purposes within 2 years. To enhance seed viability, a hydro priming technique and soak is applied to the costly seeds in water, for 5–7 days before sowing.

Economic Importance It is a highly expensive palm species, used for uniform design. It is well suited for the roadside plantation, which creates an avenue. Most of the time it is recommended for the tall buildings and artificial beach plantations. Fruit is non-edible but important for seed collection, while leaves are **toxic** to pets and children.

Future Prospects It is actually considered as one endangered palm species, which needs to be conserved in different parts of the world to safeguard its biodiversity.

*1.6.8 Canary Palm (***Phoenix canariensis***)*

Origin It is native to Canary Islands. It belongs to the same genus *Phoenix* that also include date palm, and shows more resemblance to the date plant when matures. It became an invasive palm species in many areas of world i.e. Bermuda, Florida, Hawaii, Australia, China, Japan and Indo-Pakistan region.

Growth and Botany *Phoenix canariensis* grows 15–20 m tall and has a straight single stem. Leaves are dark green and pinnate. They also contain spines on petiole while half roll along the tree canopy. They attain life for almost a century. They also produce purple bluish edible but tasteless fruits. A single seed is present in each fruit that is of prime importance in propagation. Well drained sandy loam soil with frequent irrigation is the best condition during early 5–6 years, while in later stages irrigation is applied only on demand. This palm is also slightly resistant to drought and salinity.

Propagation Canary palm produces a huge number of fruits every year, which contain seeds. Their propagation practice is done by seed as well as suckers. Canary palm produces its first sucker at the 8th year of life. Suckers are an easy way to propagate it and have high survival rates after transplant, but their removal from mother plant is a hectic and technical process. Seed priming with water is the best way to get high germination rates, otherwise sowing in hundred percent moist well drained media for 3 days also dissolve its hard endocarp. Seed takes 120–140 days to prepare seedlings for transplant.

Economic Importance It is the best choice for wide green belts of curly roads. Their plantation in group with base covered by annuals creates a look which shows bloom in autumn. Plantation in desert places does not affect their survival. Dried leaf petioles remain attached to main trunk, that makes a non-uniform but beautiful dry look.

Future Prospects Other than landscape and ornamental uses, pollens of *P. canariensis* are rich source of carbohydrates, proteins, amino acids, enzymes, fatty acids and minerals. Moreover, they are rich in steroids and saponins, with a potential in pharmaceutical industry to treat different types of tumors (Hifnawy et al. 2016). The pollen of *P. canariensis* is also beneficial and has prophylactic effect against prostatic hyperplasia (Hifnawy et al. 2018).

***Caryota mitis* (Fish tail palm)**

***Livistonia chinensis* (Chinese Fan palm)**

***Mascarena revaughanii* (Bottle palm)**

***Phoenix canariansis* (Canary palm)**

*1.6.9 Date Palm (***Phoenix dactylifera***)*

Origin *Phoenix dactylifera* is also a flowering palm species cultivated for dates. This species is naturalized over the world and acclimatized in a wide range of temperature zones, due to which there is a controversial discussion about its actual native area. However, signs of its origin are found in Mesopotamia (Middle East) and Arab peninsula. There is a strong evidence of cultivation of date for centuries, due to its edible, sweet fruit of highly commercial importance. There are more than 3000 varieties of date palms in various zones of world, although a selected list of almost 20 varieties is of commercial importance. Dates contain high amount of sugars when dried, being an historical staple food for thousand years in Middle East countries.

Growth and Botany Date palms have a single solitary stem with the bases of the leaf petioles attached to them. Moreover, it may happen sometimes that more than one stems grow on the same root system. *Phoenix dactylifera* generally reaches around 20–25 m in height. The stem is light brown to brown in color and produces suckers on its own root system. The roots also grow upright with the stem, and can be seen when suckers get removed. Leaves are light green on lower side and green on upper side. They contain spines attached to the petiole, with sides as sharp as a blade. It is dioecious (male and female plants are different) in nature and may be pollinated manually for commercial production. Male plants have small and wider inflorescences, while female plants have taller and thinner inflorescence. Male plants have more spines on petiole while female plants have a few. They are known for their strong resistance to drought and salt, in nature. Date palms produce almost 3–6.5 cm long oval edible fruit (size depends upon varieties), that contains one seed.

Propagation Dates are commercially propagated by suckers, produced by the plant itself. Although for ornamental purposes they are grown by seed. Undoubtedly, they have a low germination rate, but well drained aerated and nutritive soil media help the seed to grow well. Seedlings become ready after 8 months of sowing. These can also be propagated through tissue culture for mass propagation of disease free plants.

Economic Importance Excellent choice for landscape of desert areas whose irrigation depends upon only on rain water. Back plantation in parks, home and offices gives an aimed look. Fruits are of high commercial importance. Nowadays, bark is also being used as soil substrate of nursery production. People in developing countries made mats of dried date leaves. Dates are used for both dietary purposes as well as for phytomedicinal impacts against different diseases. Being a rich source of various phytochemicals with a strong antioxidant potential, they have great impact on human health. Dates are rich in carbohydrates, proteins, alkaloids, fatty acids (palmitic, linoleic, lauric and stearic), vitamins, polyphenolic compounds, carotenoids, flavonoids, and tannins along with nutrients such as potassium, magnesium, calcium, and phosphorus.

Future Prospects Date palm is a unique food, industrial and pharmaceutical product. Being one of the oldest palm tree, which has environmental, nutritional, ornamental and economic significance, it has huge potential to be used as ornamental tree as well as in preparation of various folk medicines. Its oil has potential to be used in cosmetic and pharmaceutical industries. Different parts of date fruit can be used in preparation of various food supplements and medicines. Moreover, it has anti-inflammatory, antimicrobial, gastro protective and immunostimulant properties (Qadir et al. 2019).

*1.6.10 Royal Palm (*Roystonea regia*)*

Origin Royal palm is also known as Cuban or Florida royal palm. This species of palms was originated from Florida, Mexico and Caribbean areas, and has now naturalized in subtropics and tropics all over the world, as formal landscape tree. Royal palms were also mentioned in official landscape of Great British rule in eighteenth and nineteenth centuries.

Growth and Botany Its straight, long and grey trunk has most aesthetic value. Trunk achieves about 15–20 m height, when the tree gets mature. Fronds are 2 m long while in structure they are pinnate. Bright green colored leaves make a graceful crown-like canopy which is of utmost aesthetic importance. This palm grows well in tropical zone, while in soils sandy loam is best. They are also drought resistant. *Roystonea regia* produces unisexual inflorescences, where pollination carriers are bees and bats. Bats also eat its fruit and disperse seed.

Propagation Royal palms are propagated through seeds. Seeds initially produce only a part of the embryo, and the seedlings start to produce the stem 2 years after germination. It is reported that the royal palm grows 51 cm every year, after a specific period of time.

Economic Importance Being an excellent plant for formal landscaping, it is often recommended with flowering shrubs. High roof formal buildings and lawns of villas must have a Royal Palm as accent plant. Fruits are eaten by bats and they disperse seed all around. Seeds are used to extract oil and mix in livestock feeds. It is used as stem beauty in landscapes. Its wood is also used for construction, while leaves for thatching.

Future Prospects Royal palm has great potential to be used in livestock feed preparation. Moreover, it has potential to be used in pharmaceutical industry to treat prostatic hyperplasia (Oyarzábal et al. 2017).

*1.6.11 Ravenala Palm (*Ravenala madagascariensis*)*

Origin *Ravenala madagascariensis* is a flowering plant, generally known as traveler's palm, which is a false palm, but its growth resembles to palms. It is native to Madagascar and belongs to the family Sterlitziaceae (Order: Zingiberales), a flowering monocotyledonous family. It is thought that sheaths of tree store rain water which later became useful in the past for travelers during journey, that's why it is known as travelers' palm. However, the water stored in sheaths of the palm is black and smelly, and should not be used before purification.

Growth and Botany Long petioles with paddle-shaped, banana-like leaves make a big fan, clearly visible in the landscape. Flowers are white in color and reminiscent of the bird of paradise plant (*Strelitzia reginae*), but considered less attractive. Lemurs and birds do pollination in ravenalas, resulting in the production of beautiful blue colored seeds. As the plant gets older, it sheds leaves and a dirty grey trunk appears with leaf scars. Generally, in landscape it reaches up to 7 m in height while in forests of Madagascar it attains about 20–30 m.

Propagation *Ravenala madgascariensis* produces seeds as well as suckers in the base. Both ways are suitable for commercial propagation, while offshoots are a quick way than seed. Seeds are placed in well drained nutritive soil media for 90–100 days for germination. After this period, the seedlings become ready to transplant 70–90 days after germination. Ravenalas need sunlight and humid conditions to grow smooth.

Economic Importance It is super accent choice for landscape and always a best recommended plant in parks and formal and informal landscapes. Its leaves are used for roofing, petioles for walls and bark as floor (Rakotoarivelo et al. 2014).

Future Prospects It is quite common in Madagascar and used as building materials. Moreover, using *Ravenala* in house construction reduces the use of slow growing trees and contributes to the sustainable use of natural forest resources.

*1.6.12 Desert Fan Palm (*Washingtonia filifera*)*

Origin Desert fan palm is also known as California palm, California fan palm, endemic to USA (California) and Mexico. It is another palm flowering species and a true example of plants which grow well in almost all parts of world. Desert, subtropical, tropical and lower hilly areas all are suitable for *Washingtonia filifera*.

Growth and Botany The fan palm has a massive, strapping, columnar long trunk up to 20 m. Its canopy also occupies up to 6 m. Leathery, wax type leaves show a dense green color. Older leaves remain attached to plants for several years and display like a skirt. A large range of soils (sandy loam, loam, clay and silt) and climatic zones (subtropical, tropical and low hilly areas) are suitable for its growth. However, well drained sandy loam with tropical zone is the best option for this species. They live for one to two and half centuries, depending on favorable climate. They farm edible but tasteless fruits. In the sixteenth century, these fruits were used during a famine period in Southern Paiute (now part of California) to feed people. Fruits are small and black in color like a black berry, and contains seed.

Propagation *Washingtonia filifera* are propagated through seeds, that are small but with a hard coat. Seeds need 70–90 days for germination when sown in well-drained soil. They become ready to transplant 6 months after sowing.

Economic Importance Prominent choice for boundaries of landscape parks and big lawns. Its super beauty lies in the stem skirt made by old dry leaves. Wide canopy and high surface area of leaves absorb pollution. It also has a different look during the fruiting season, when black small berry-type branches of fruits hang along the stem. It is also habitat for several bird species.

Future Prospects These palms may have economic value in urban landscapes in tropical regions and may be used for making huts on beaches and coastal areas.

***Phoenix dactylifera* (Date palm)**

***Roystonea regia* (Royal palm)**

Ravenala madagascariensis
(Ravenala palm)

Washingtonia filifera
(Desert fan palm)

1.6.13 *Mexican Fan Palm (*Washingtonia robusta*)*

Origin This palm tree species is also known as common ornamental palm or Mexican Washingtonia, and originated from USA (California, Florida, Texas, Hawaii), Europe (Spain, Italy) and Asia (Lebanon).

Growth and Botany Fast growing long heighted palm with non-straight grey trunk, it reaches up to 25–30 m in height. The leaves are almost 2 m long, where half-length is the petiole and next half is a fan like leaf. A long (about 10 m) inflorescence consists of large number of pinkish flowers. The black, spherical, drupe fruit formed is edible and contains a seed. It is also suitable in a wide range of soils (clay, loam, sandy loam, silt) and agro-climatic zones.

Propagation *Washingtonia robusta* is propagated through seeds, which are placed in humid, warm conditions. Germination takes place in 60–80 days after sowing, while seedlings are ready to transplant 6 months after sowing. The palm grows, after transplanting, more rapidly than other *Washingtonia* species.

Economic Importance This palm is one of best choice with flowering shrubs, when it is not much more taller as during its mature age. It is also used as indoor up to 3 years of age. Background and corner plantation is most recommended place for Mexican fan palm. Its leaves were used in making baskets, sandals and roofs, while the fiber is used for making cords.

Future Prospects *Washingtonia robusta* fruits have high fermentable sugars, which can be used for extraction of ethanol. Ethanol extraction is getting popularity nowadays for alternate fuel production and *W. robusta* may be used as alternate to food crops for extraction of ethanol (Mazmansi 2011). Studies are also being conducted to use its fruit as urban food.

1.6.14 *Foxtail Palm (*Wodyetia bifurcata*)*

Origin The genus *Wodyetia* contains only *W. bifurcata* as a single species. This is known as foxtail palm because of its leaf shape and length. It originated to Australia Cape Melville (an area in Australia popular for biodiversity).

Growth and Botany Its trunk is grey and dark brown, with rings left by leaf scars. It grows up to 10 m high. Leaves are fragmented from mid and wider about 30 cm on tip. Leaves are long about 2 m and half roll towards earth, this is why known as foxtail palm. It can tolerate a wide range of soils, with sandy loam as the best. It does not need frequent irrigation, while full sun is best for rapid growth. They are also placed in semi shade as house plants, but growth becomes very slow. When it is placed in a pot in which its roots occupy all the soil, it grows very quickly. White flowers develop and form a 5 cm long orange oval fruit.

Propagation Fox tail palms are propagated through seed. Seeds are sown in garden soil and germinate in almost 2 months. It has been seen that when seeds were treated with sulphuric acid, their germination took place in 1 week. Seedlings become ready within 90–100 days after germination.

Economic Importance Foxtail is best choice for semi-shade, full sun and as house plant. Group plantation creates focal points in parks. Plantation in central green belts of roads and lawns of high rise buildings creates a formal, path developing and aimful look. Maintaining foxtail palm is quite easy, since its trunk is self-cleaned and does not require pruning. It is also great for the pool area, patios, or even a Zen garden oasis.

Future Prospects Foxtail palms often suffer for deficiency of Fe, which leads to interveinal chlorosis and leaf spot, which can be controlled by soil application of the Fe chelate EDDHA (Broschat and Elliott 2005). It has potential to be used in urban landscapes and sometimes its seeds are even expansive than other crops. Foxtail palm also accounts for huge economic value.

*1.6.15 Ponytail Palm (***Beaucarnea recurvata***)*

Origin *Beaucarnea recurvata,* (another renowned name is Elephant's foot palm) belongs to the Aspargaceae family and is a false palm, however its growth resembles to palms. It is endemic to different states of Texas, America. They live for several centuries, even in Texas there are registered pony tail palms about 350 years old. Its leaves are of drooping nature around terminal portion that looks like banded pony of a girl, due to which known as Ponytail palm. Its base on soil is very wider and looks like the foot of an elephant, the reason behind the word elephant's foot.

Growth and Botany *Beaucarnea recurvata* is a perennial evergreen palm which grows up to 4.5 m in height. The light grey, uneven, but uniform surface of the trunk gives an old look to the plant. The trunk is swollen at base, almost 3 times the terminal portion. Leaves are long up to 2–3 m, while not wider than 15 mm. The leaves are smooth and bright green in color. A bunch of flowers appears after the tenth year of growth. Full sun to partial shade, with 20 °C average temperature is best for their fast growth. It has been seen that ponytails again develop from side nods even after crown death. Pink bloom of plants develop small round blackish seeds.

Propagation *Beaucarnea recurvata* is propagated through division. Spring is the best time to divide all Beaucarneas. Take a multistem plant, uproot from soil and remove all the media. Take a sharp knife to make their swollen stem separate, while segregate all the roots carefully, attached to each swollen stem base. Plant separately each one and irrigate well. A 18–22 °C temperature with moist conditions is best for root establishment. Seeds are also used to propagate ponytails. They require special care and are sensitive to too low/too high temperatures. The average temperature is 20 °C for best germination and seedling growth. Seeds need 2–3 months for germination and seedlings may be ready up to 3 months after germination.

Economic Importance A multitask plant in landscape which is used outdoors as well as indoors. As a specimen plant surrounded with annuals in a pot it provides an awesome look. It grows outdoor 2–3 times taller than indoors.

Future Prospects Beaucarnea is a common indoor plant, which has potential to purify indoor air and fill indoor landscape with fresh air. Its main use is only as ornamental.

*1.6.16 Bismarckia Palm (*Bismarckia nobilis*)*

Origin *Bismarckia* is a large graceful tree, endemic to Madagascar Island. The name derived from the German statesman Otto von Bismarck.

Growth and Botany Bismarckias when mature get heighted around 15 m in open grassland of Madagascar. Expanded older leave's petiole remain attached to the plant that shows a grey color look. Stem and leaves both have a light grey color and provide an entirely different look in landscape. Leaves are 2–3 m long where petioles are almost 1 m long. Leaves remain in tilt angle rather other horizontal. Petiole is about 5–7.5 cm in diameter as stem that ranges from 5 to 7.5 cm (depends upon growth stage). Bismarckias grow best in open land and are strong tolerants to high temperatures and drought when matured. In initial years, they need well drained soil and humid conditions. Bismarkias are grown under subtropical and tropical areas over the world. They are dioecious in nature, but inflorescences of male and female plants (small brown flowers) look the same. Fruits are ovoid, small brown drupes formed on female plants, each with a single seed.

Propagation *Bismarkia nobilis* is propagated by small brown seeds that have a hard endocarp, and need some priming before sowing. The hard Bismarkia seed coat does not allow the cotyledonary leaves to open, so a halo or hydro priming approach is the best way to break the seed coat. Seeds need a 18–22 °C temperature with moist conditions for best germination and frequent irrigation when seedlings become ready. Later stages are tolerant to heat, and drought.

Economic Importance A very good, decent choice for focal point in lawn, corners in landscape parks. Central planting in low heighted flowering shrubs makes Bismarckias more stunning. Its stems are used as planks or in partitioning walls, while leaves are used for making baskets and for roofing.

Future Prospects It is one of most widely used palm species in landscapes around the world. Therefore, its seed as well as nursery demand is rising all over the world for its grey foliage color, which contrasts well with green background. They are best tolerant to heat and drought stress.

Washingtonia Robusta **(Mexican fan palm)**

Wodyetia bifurcata **(Foxtail palm)**

Beaucarnea recurvata **(Ponytail palm)**

Bismarckia nobilis **(Bismarckia palm)**

*1.6.17 Cane Palm (*Dypsis lutescens*)*

Origin *Dypsis lutescens*, also known as *Chrysalidocarpus glaucescens*, has many common names in different areas i.e. Yellow Palm, Golden Cane Palm etc. It is native to Madagascar, Philippines and South India while it has been naturalized over all of subtropical and tropical areas of El Salvador, Florida, Dominican Republic and Cuba. This is also a flowering member of palmae (Arecaceae) family. Its leaves develop as an upward arch-like wings of a butterfly from multiple stems, that's why also known as butterfly palm.

Growth and Botany The yellowish stem has fallen leaf rings, and makes multiple stems in an upright growth. Stem grows up to 36 m in open subtropical and tropical areas, while in indoor conditions it does not exceeds 18–24 m. Every stem has terminal leaves which are structurally pinnate, lengthen up to 2–3 m with several pairs of leaflets. Average temperature for a cane palm is 16–24 °C. It is also sensitive to high humidity levels. Sudden fall in temperature may cause the leaves to get dry. It bears a variety of soils, even high in clay, but does not bear over watering. There should be a dry period between two irrigations, especially when it is planted indoors. Cane palms produce orange-red flowers which form a small round seed.

Propagation *Dypsis lutescens* are propagated through seed, and division of co-lateral growing stems. Seeds are the main source of commercial propagation, while divisions are made on availability. Seeds are sown in spring and seedlings become ready in autumn. Irrigations must be applied carefully, because cane palms are very sensitive to moisture.

Economic Importance Cane palms are a fair choice for indoor plants because they provide a long time green tropical touch in indoor landscapes. They are also best choice in outdoor landscapes, with low height colorful shrubs. Their fruits are a suitable food for several birds.

Future Prospects As cane palm is the second best indoor palm after arecas, a rapid growth rate is expected in its future use with the growth of houseplants. Moreover, its use will increase due to its capacity to clean indoor air by filtering different pollutants such as benzene (coming from kitchen burnings), formaldehyde (coming from paints, furniture and cigarettes) and toluene (coming from building material and greases).

Dypsis lutescens **(Cane palm)**

1.6.18 Alexandra palm (Archontophoenix alexandrae)

Origin

This member of Arecaceae family, endemic to northeast Australia also known as king alexandrae, king palm or palmier royal (French). Besides its origin, this species was first imported to Florida which later became one of the famous species in tropical, subtropical and lower northern spots of the globe.

Growth and Botany

Pure gray single trunk, 0.6–1.2 feet diameter with parallel rings drawn by leaf scars are key identification and beautification signs of Alexandrae palm. Compound pinnate leaves are evergreen with spiral arrangement and about 85 cm long leaf blade. Monoecious flowers bloom in summer which are light yellow in color with spike in arrangement. Flowers produce true, round, red berry in summer which is 1.6–3 cm long. Mature tree makes 2–4 feet round canopy. King palm grows well in full and partial sun, acidic and neutral soil.

Propagation
Seeds are the main source to propagate these palms. Seeds are sown in spring and seedlings are ready to transplant within 6–8 months. Low germination percentage is common problem in almost all species of palms especially when seeds have hairy covering on hard seed coat. Seed priming with bio membrane solvents is the best solution.

Economic Importance
Suitable for symmetric gardening, line plantation along pathway of hotels and parks are landscape uses. It is also feasible in indoor plantation when younger in age. Besides landscape, this palm is also recommended for coastal rainforests to reduce water and wind approach towards peri-urban areas.

Future Prospects
A high value palm plant for formal landscapes and for erosion control in peri-urban settings.

1.6.19 Queen Palm (Syagruss romanzoffiana)

Origin
Syagruss romanzoffiana is one most ordinary and common palm tree of southern as well as northern parts of California, which is now distributed over the world. In early 1800s Louis Choris named it as cocos romanzoffiana. Later on Bee F. Gunn (Geneticist) described that queen palm is not member of cocos genus, he added this plant in syagruss genus of Arecaceae family.

Growth and Botany
One of medium sized palm tree ranges from 9–13 m but maximum record height is 15 m. Pinnate leaves with 300 – 500 leaflets. One bunch of leaves develop every year. Leaves remain healthy for 3 years and older leaves fall every year leaving their petioles. Long biscuit color inflorescence produces fruits containing seeds. It produces small, yellow and edible fruits. Fruits taste is mixture of banana and plum. Seeds have brown hard seed coat covered with husky material. They remain alive for a year if stored dry at 15–20 °C temperature. Seeds have long dormancy and only source of propagation in in-vivo conditions. Sandy to sandy loam soils with good aeration are suitable for these palms. Queen palms are tolerant to high pH and EC. Queen palm is one of the few palms which can tolerate low temperature up to −5 °C. They are native to tropical regions but now distributed in all tropical, subtropical and lower temperate regions of the world.

Propagation
S. romanzoffiana is propagated through seed. Moreover, due to hard seed coat seeds take 150–180 days to germinate but germination percentage is < 20%. Hydro-priming technique is used to enhance germination and shorten the germination time by soaking seeds in water for 4–7 days.

Economic Importance
Accent plant in landscapes. Leaves and inflorescence are used as fodder for animals in endemic areas of queen palm. Best choice in rapid growing palms. It attains almost 2 m height within 2 years of growth.

Future Prospects
Highly valuable palm for landscape uses as well as fodder for livestock.

1.6.20 Ravenea Palm (Ravenea rivularis)

Origin
R. rivularis, also known as majesty palm, is originated from island of Indian Ocean known as Madagascar. This is also a descent member of family Arecaceae. Previously, it was in most endangered palm species of the world but later introduction as houseplants spread this plant over the world. Major commercial cultivated area is south California.

Growth and Botany
Generally, this is a slow growing species but attains up to 20 m height with the time. Single trunk is tapered towards neck, ringed by leaf scars and 0.3–0.4 m in diameter. Fronds are 2–3 m long with pinnate arrangement having arch like twist at end and small bare petiole at base. Male and female flowers are borne on separate plants but looks same in white color. Female inflorescence is more erect and long as compared to male. Fruits are red in color and 1–1.25 cm long in size. High humid areas with fertile land are best for this species.

Propagation
Majesty palm produces a plenty of seeds every year that is the only way to raise new plants. Seeds are placed in vermiculite or garden soil mixed with coco coir to get best germination percentage. Seedlings become ready for transplanting after 6 months of sowing.

Economic Importance
The shape and specific arrangements of fronds makes it a specimen as well as accent plant. Now it is a popular indoor houseplant up to 10 years of life. It is a highly water and salt tolerant species. This is also non-poisonous to pets and children.

Future Prospects
Highly suitable plant for focal points in landscape and most suited indoor palm during early growth stages.

1.6.21 Phoenix Palm (Phoenix robelenii)

Origin
Phoenix palm also known as pygmy date palm due to its growth behavior similarity to date, belongs to Arecaceae family while endemic to south Asia as well as northern parts including China, Vietnam and sub-continent. Very well adapted to wide range of climates from tropical and sub-tropical to northern areas.

Growth and Botany
Solitary stem with stubble surface towards leaf flush, light brown from base while dark from end grows straight. This species attains up to 3 m height while 6−12 inch diameter. Leaves are shiny and green in color while up to 1 m long with slight arch at end of every leaf. It bears up to −3 °C while in extremes up to 52 °C. Inflorescence produces small light yellow flowers that develop in minute date just 1 cm long fruit. Propagation These palms are commercially propagated by suckers, produced by plants itself. Although are also grown by seed. Undoubtedly, they are less in germination percentage but well drained, aerated and nutritive soil media helps seed to grow well. Seedlings become ready after 6 months of sowing.

Economic Importance
Best choice in focal points when base is surrounded with low heighted shrubs and ground covers. Shiny green leaves with dark brown stem makes it more attractive for viewers. On the other hand, adaptation to extreme high and low temperatures, water logging and salinity makes it more feasible for growers. This is also being used as houseplants.

Future Prospects
Best choice to be used in landscape as containerized plant or for patios and corners with groundcovers around base of the palm.

1.6.22 Mazari Palm/Peesh Palm (Nannorrhops ritchiana)

Origin
Nannorrhops ritchiana is an especially eye-catching palm due to its blue – green leaves and is one of the hardiest palm in the world. It is native to Middle East to Pakistan (It is found in Punjab specially in hilly areas of Dera Ghazi Khan (Fort munro hills and koh-e-suleman mountain ranges) and some places of Balochistian and KPK hilly areas). Its high altitude desert type origin in Iran, Afghanistan and Pakistan growing at altitudes up to 1600−1700 m gives an indication of its requirements. Nannorrhops ritichiana are successfully cultivated in such diverse places as California, Florida, Texas, France, Italy and Venezuela. It is successfully grown in pots and put it outside more than 10 years. In winters, its cold hardiness is −10 °C and if possible its roots keep dry, it may resist temperatures as low as −4 °C. During

summer heat it is comparatively fast growing and develop into a large shrub with many short erected trunks, thick blue – green and leathery fan shaped leaves.

Growth and Botany

Maari palm/Peesh palm has monotypic genus of palm. It is clumping, unarmed, fan shaped palm with subterranean trunk and reaches to 1–5 m height. Mazari Pal/Peesh Palm has slow growing habit and must have excellent drainage. Mazari/Peesh palm is dioecious with male and female flowers on separate plants. Its individual stem has monocarpic habit, dying back on the soil after flowering and the plants continue its growth from the basal sprouts. Flowering stalks are about 1 m with yellow flowers. Usually used as ornamental plant but due to its slow growth habit it is not widely cultivated all over the world.

Propagation

Mazari/Peesh Palm are propagated through fresh seed within 4 months and also propagated through clumps. Single plants are capable of producing fertile seed. Seed germination is very slow and fickle. Fruit colour of the palm is reddish brown and each fruit has a single seed.

Economic Importance

This palm is native to desert areas, so is best choice for landscape of desert areas, stony soils, rainfed areas and infertile places where irrigation depends on rain water. Due to its clumping and shrub like habit it is the best choice for outdoor landscaping in sunny areas of the subtropical and temperate regions with low height and foliage beauty of its bluish green leaves. People in developing countries specially in tribal areas of Pakistan where Mazari/Peesh palm naturally grows make prayer mat, sleeping mat, handmade shoe (Slippers), hotpot, storage of grains, hat, brooms, baskets, burden basket (for carrying loads on horses and donkeys mostly used in mountainous areas, Pot rope, Cordage, trays, bread pots, chair, hand fan, rosaries, face mask and thatch of dried Mazari Plam/Peesh Palm leaves (Ali et al. 2020).

Future Prospects

Nannorrhops ritchiana has great potential in handmade handicrafts and is an economically important plant to improve the low income families. Due to its charismatic and bluish evergreen crown, it is commonly planted for ornamental purposes in sub-tropical and dry regions. Fresh fruits are edible and are directly eaten as a purgative and a tonic. The leaves extract is used to treat diarrhoea and dysentery in traditional medicine (Ali et al. 2020).

1.6.23 Caranday Palm (Copernicia alba)

Origin

Copernicia alba is an attractive palm due to its phyllotaxy pattern on its stem. It belongs to south America and due to its stem beauty is successfully grown in tropical, subtropical and as well as in temperate regions.

Growth and Botany
An attractive palm with slender stem which reaches to height of 25 m tall and a rounded crown of stiff leaves and the inflorescence arises among the leaves and has bisexual flowers.

Propagation
Copernicia alba are propagated through seeds. Fresh seeds germinated promptly in 3–4 months. Seedling growth is slow and takes a lot of time to reach maturity.

Economic Importance
Copernicia palm is highly expensive palm species and is well suited for the road side plantation, which creates avenues.

Future Prospects
Copernicia palm has great demand in tropical and subtropical countries and is a high demanded palm in commercial nurseries for use in landscapes.

Alexandra palm (*Archontophoenix alexandrae*)

Queen palm (*Syagruss romanzoffiana)*

Ravenea Palm (*Ravenea rivularis*)

Phoenix palm (*Phoenix robelenii*)

Caranday Palm (*Copernicia alba*)

Mazari Palm/Peesh Palm (*Nannorrhops ritchiana*)

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Chapter 2
Ornamental Palms: Molecular Taxonomy, Ecology and Distribution

Siddra Ijaz and Maria Babar

Abstract Ornamental palms characterize landscape in tropical and sub-tropical regions around the globe. They are of great economic and ecological importance. Ornamental palms exhibit extraordinary complex spatio-temporal patterns of distributions and diversity, which is fundamental in the ecology, diversity and distribution of many species. Ornamental palms display an amazing geographic distinction in their life forms in terms of diverse species number and discrete phylogenetic composition, exhibiting varied species richness patterns, reflecting their taxonomic complexity. By considering their complex geographical ecology and empirical determinants such as distribution and diversity, we attempted in this chapter to articulate their taxonomical features, molecular taxonomy, ecology and distribution in an inclusive way.

Keyword Molecular taxonomy · Ecology · Ornamental palm · False palm · DNA barcoding

2.1 Introduction

The family Arecaceae is a group of perennials plants including shrubs, climbers and, most important, palm trees. Palmae family (Arecaceae) has a long evolutionary history as its members originated from single ancestor, which makes it a monophyletic group. The family is quite a gigantic and divergent group, including approximately 240 genera and 27,000 species (Lorenzi et al. 2010). Members of this family are distributed in tropical and sub-tropical regions of the world (Henderson et al. 1995). The fossil history of palms revealed its distribution in the Mesozoic

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_2

(geological time interval of about 250–65 Mya) and Cenozoic (most recent era, extending from 66 Mya till today). Moreover, palms are assumed to be originated in Australasia, presently including New Zealand and New Guinea (Bremer and Janssen 2005). During the Paleocene (time period which lasted from 66 to 56 Mya) to the Eocene (period from 56 to 33.9 Mya), palms experienced a crucial transition and suffered global warming for a longer period of time (Zachos et al. 2001; Dransfield et al. 2008). Recently, the Palmae family has been grouped in the commelinids cluster of monocots (Davis et al. 2006). Arecaceae is further divided into five sub families namely **Arecoideae** (107 genera and about 1300 species), **Ceroxyloideae** (8 genera), **Calamoideae** (21 genera and about 615 species), **Nypoideae** (*Nypa fruticans*, only member of genus *Nypa*) and **Coryphoideae** (44 genera and about 450 species) (Tomlinson et al. 2011; Dransfield et al. 2005; Asmussen et al. 2006). The sub-families were classified into tribes and sub-tribes. The tribes of **Arecoideae** include: Chamaedoreeae, Sclerospermeae, Areceae, Manicarieae, Iriarteeae, Reinhardtieae, Euterpeae, Podococceae, Pelagodoxeae, Oranieae, Geonomateae, Cocoseae, Leopoldinieae and Roystoneeae. **Calamoideae** include three tribes i.e. Lepidocaryeae, Calameae and Eugeissoneae. **Nypoideae** has no tribe, containing only one genus (*Nypa*). The tribes of **Ceroxyloideae** include Ceroxyleae, Cyclospatheae and Phytelepheae. **Coryphoideae** consists of Borasseae, Trachycarpeae, Crysophileae, Caryoteae, Corypheae, Sabaleae, Chuniophoeniceae and Phoeniceae.

2.2 Taxonomy and Molecular Taxonomy

Species identification and discrimination is a fundamental step in taxonomic studies. Morphological identification is performed through phenotypic characters such as shape, color, petiole pattern etc. However, since Carl Linnaeus developed the first species classification system, taxonomy became quite cumbersome due to the lack of information about certain species and ambiguity in the morphological characters of certain organisms. The ambiguity was overcome by the DNA barcode concept, laid down by Prof. Paul Hebert (Hebert et al. 2003a), after which CBOL (consortium for the barcode of life) was established to develop methods of species discrimination as well as identification. DNA barcode is quite an accurate and fast method allowing species identification using short fragments of DNA. It became a fascinating method in the world of bio-taxonomy (Sun et al. 2011). DNA barcoding has wide application and its importance has extended in various fields of science i.e. ecology, forensic sciences, evolutionary lineage studies, epidemiology and conservation biology. In case of animals, COI (mitochondrial cytochrome c oxidase subunit I) was anticipated as a barcode (Hebert et al. 2003b). Moreover, the COI gene has been used for fish, insects and animals discrimination (Kerr et al. 2007; Tavares and Baker 2008). The rate of evolution of the COI gene, in case of plants, is very slow so it is only used in barcoding of few algae (Evans et al. 2007). To overcome this issue, various scientists strived to search for plant barcodes from nuclear and chloroplast genomes (Cho et al. 2004; Chase et al. 2005). To resolve this issue, CBOL-PWG (CBOL Plant Working Group) proposed the gene combination, which might help in settling down the problem. The suggested genes include rpoC1, UPA, matK, trnH-psbA, psbK-psbI, rpoB, atpF-atpH, ITS and rbcL (Kress and Erickson 2007; Pennisi 2007). Among the suggested barcode genes, rbcL and matK have been recommended by CBOL-PWG as universal barcodes for plants (Hollingsworth et al. 2009), due their higher resolution and discrimination power.

In various molecular studies, the Arecaceae family is considered to be a monophyletic group (Asmussen and Chase 2001). During the last decades, significant work has been done to understand the intra-family relationships and various taxonomic and phylogenetic studies of palms have been published. However, the efforts for rearranging classification were greatly hindered due to different ambiguities. The subfamilies are sub divided with the aid of DNA molecular markers (matK and rbcL) which helped in their resolution into different clades with supportive bootstraps (Asmussen et al. 2006). In various phylogenies, Calamoideae (sub family) is grouped as monophyletic (Uhl et al. 1995; Asmussen and Chase 2001; Hahn 2002). Based on morphological as well molecular data a new classification was proposed by Baker et al. (2000) for Calamoideae, including three tribes and nine sub-tribes. Based upon parsimony analysis, Nypoideae and Calamoideae were classified as sisters to all the other palm members (Hahn 2002). This study is different from previous studies in which the phylogenetic analysis was based upon restriction fragment length polymorphisms. It revealed that *Nypa* (Nypoideae) is the sister of all palm members. However, Calamoideae was resolved as sister to all palms, except for *Nypa* (Uhl et al. 1995).Another study, in which non-palm outgroups were included as well, also resolved *Nypa* to be the sister of all palm members (Lewis and Doyle 2001). Unfortunately, not a single study of Calamoideae and *Nypa* was supported by bootstrap analysis, which made results quite ambiguous. For Coryphoideae (sub family), DNA sequence-based phylogenetic analysis did not classified it as a monophyletic lineage (Baker et al. 1999; Hahn 2002). However, DNA sequence phylogenetic analysis based on nuclear and plastid genes resolved this sub-family as a monophyletic group (Uhl et al. 1995). Many studies provided evidence that sub-family Ceroxyloideae is not a monophyletic group, however, Phytelephantoideae (recently downgraded as tribe, not a sub-family) and Arecoideae (sub-family) are classified into monophyletic groups (Uhl et al. 1995; Asmussen and Chase 2001; Hahn 2002).

Recently, we conducted a phylogenetic study of 15 ornamental palms commonly planted in Pakistan (*Archontophoenix* alexandrae, *Chamaedorea seifrizii*, *Bismarckia nobilis*, *Hyophorbe lagenicaulis*, *Chamaedorea costaricana*, *Caryota* mitis, *Wodyetia bifurcate*, *Dypsis lutescens*, *Rhapis excelsa*, *Syagrus romanzoffiana*, *Ravenea hildebrandtii, Roystonea* regia, *Cycas revolute*, *Dioon spinulosum*, *Washingtonia* robusta) using matK and rbcL DNA barcodes and their evolutionary lineage was assessed through phylogenetic topology. This study also supported these ornamental palms as a monophyletic group, though with varying degree of relatedness and divergence.

2.3 Morphology

The stem is the fundamental character for the identification of palm species. The five types of palm trunks are: clustering, climbing, solitary, subterranean and aerial branching. This identification feature is confusing in some cases, in which solitary and clustering branching habits are found in the same species. The solitary (single stemmed) branching habit is the common characteristics of most ornamental palms. However, clustering habit or multiple stems are also common in several popular palm species, that are used for aesthetic or economic purposes, such as date palm. These palm species produce suckers. Similarly, palm leaves also have distinguished characteristics and variable nature as concerns growth habits. Palm leaves are referred to as fronds. Four types of leaves are present: palmate, entire, pinnate and bipinnate as shown in Fig. 2.1 (Johnson 1983, 1998; Johns 1995).

The word "palm" is used for the members of family Palmae. However, it is being used for those plants, which do not belong to Palmae family but they just resemble to true palms in same way. Some plants have word "palm" with their common names, nevertheless in true scientific sense they are not palm. These "False Palms"

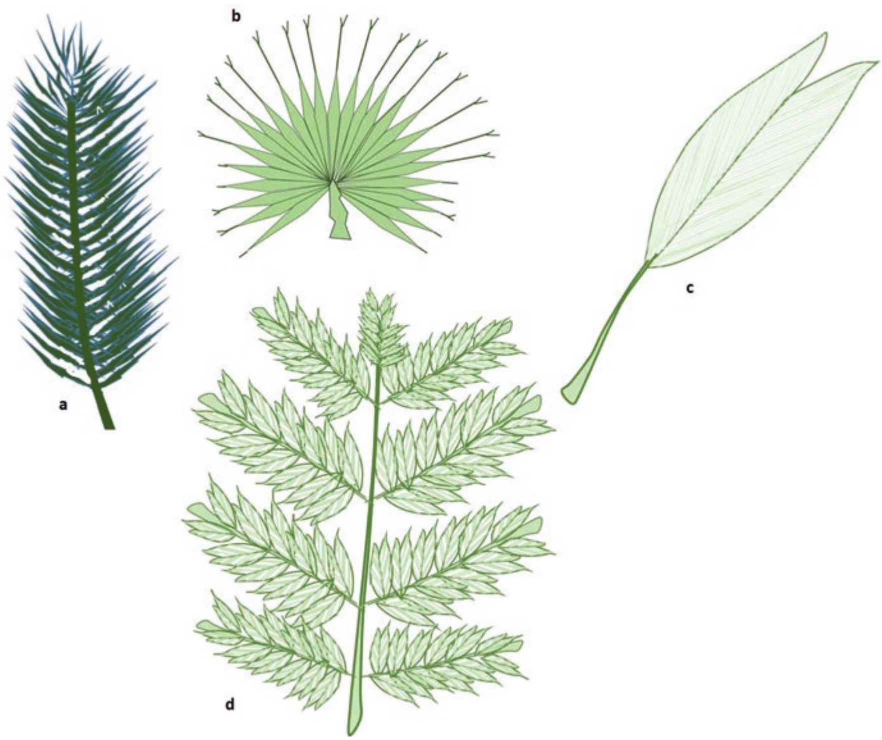

Fig. 2.1 Leaf types of palms: pinnate (**a**) palmate (**b**) entire leaf (**c**) and binate leaf (**d**). (Redrawn from Johnson 1998)

are Traveler's palm (*Ravenala* madagascariensis), sago palm (*Cycas revoluta*), palm grass, palm ferns, screw palm and Panama hat palm. Traveler's palm is a woody tree. It has palm like stem, though its leaves have resemblance to banana plant than palm. Similarly, stem and crown of pinnate leaves *Cycas revoluta* (sago palm) are similar to true palm but its leaves are stiff and born as rosette not as single as in true palm (Johnson 1998).

2.4 Biology, Ecology and Distribution of Ornamental Palms

North America is considered as the native land for palms, during different geological ages. The fossil evidence of palms reveals their abundance in the Tertiary period. However, most divergence appeared in the Cretaceous era. In present era, palms are mostly distributed between two main areas, i.e. the tropical regions of America and Asia. According to geological scales, palms are distributed between tropical latitudes (37° S and 38° N), with temperature ranges between 15 and 56 °C. Palm are unique for their endemism (property of being unique to a specific region), a characteristic that explains why most of palm genera consist of five or less species. Every region contains in fact specific palm species. For example, New Caledonia is a rich hub of endemism representing 17 genera with 30 species. In Old and New World, major divergence exists in palm flora with great variation in genera. Moreover, palms have been used as indicators of warm climate (Walther et al. 2007). Palms morphology is not suitable for mesothermal or temperate climates, being limited to mega thermal or tropical climates (Tomlinson 2006). For example, *Euterpe edulis* is absent in lower geological regions of Brazilian Atlantic forests due to cold freezing air which is detrimental for many palm species (Gatti et al. 2008). The growth of *Trachycarpus fortune* (Chinese windmill palm) is limited due to the combined adverse effects of cold temperatures and frost damage, which affect the species range (Walther et al. 2007). Fluctuations in temperature as well as precipitation also affect and restrict palm distribution to tropical regions of the world (Sesnie et al. 2009). In addition to temperature dynamics, any kind of extreme climatic or weather conditions adversely affect the palm distribution, as i.e. in the Puerto Rico forest, where the population of *Prestoea acuminata* is severely damaged by hurricanes (Frangi and Lugo 1998).

2.4.1 Archontophoenix alexandrae

Commonly known as Alexandra palm, Northern bungalow palm, Alexander palm, King Alexander palm and King palm (Brickell and Zuk 1997; Wagner et al. 1999), *Archontophoenix alexandrae* is endemic to rainforest of Australia, being distributed along the coastal regions of Cape York Peninsula to Baffle Creek near Gladstone, in Queensland. The genus took its name from Greek "archon" (ruler), while the species name was given after Princess Alexandra (Jones 1995). This species is distributed in tropical and sub-tropical regions and is widely appreciated as ornamental palm (Starr et al. 2003). It is an elegant palm with a thin greyish stem along with broad, feathery leaves. It is fast growing, monoecious, evergreen and grows up to 30 m in height. Its crown consists of a clump/cluster of 10–12 broad leaves, which are 3–5 m in length. The greyish colored stem is around 30 cm wide. About 60–80 leaflets, measuring ca. 80 cm in length and 3–5 cm in width, are arranged on each side of the leaf stalk. The upper surface of leaflets is dark green while the lower side is greyish-silver in color. The flowers, in the form of clusters, are usually white in color, borne on 15 cm long stalks. The flower emerge in the patterns of three, each trio group consisting of two male and one female flowers. The fruit is egg-shaped 8–15 mm in length and 6–11 mm wide. The color of fruit changes during maturation, from green to red.

Alexandra palms reproduce only by means of seeds, which are 1.2 cm in size. Their dispersion is most probably through birds, bats and water as well as rain splashes. The palm grows best in clay-loamy soil, with acidic pH. It requires high water amounts for growth and proliferation. It can thrive in full sun to partial shady conditions (Nagao and Sakai 1979). *Archontophoenix alexandrae* thrives best in partial shade as a young plant, but requires full sunlight as adult to attain its full height. It is generally a water loving plant, but can tolerate dry conditions although it grows best in moist and fertile soils (Turner and Wasson 1997). The young plants cannot bear frost conditions but mature, adult ones can tolerate temperatures as low as −2 °C (Brenzel 1995). The Alexandra palm is a widely grown garden tree and it is famous for its enchanting, graceful look, which make it a quite suitable ornamental plant.

2.4.2 *Chamaedorea seifrizii*

Chamaedorea is a large genus consisting of about 130 species distributed from Mexico to North and Central America. It is considered to be the largest genus palm in Mexico, comprising of about 50 species, out of which 14 are native to this country (Hodel 1992). *Chamaedorea seifrizii*, commonly known as Bamboo palm or reed palm, is endemic in Central America, Belize, Honduras and Mexico. It is widely cultivated in Florida, Hawaii and California. It is naturally found in the rainforests and spreads by forming clonal colonies through underground runners. It typically grows in tropical and sub-tropical areas but can also grow well in temperate habitats. It is a deciduous, elegant, indoor plant with feather like leaves and stem resembling a bamboo. The plant grows up to 2.2 m in height with a stem that is slender and thin, containing nodes, which gives its resemblance to a bamboo tree. The cane like stems of these palms measure around 1 cm in diameter and the leaves measure 60–90 inches in length. The leaflets, up to 38 cm in length, cluster at the top of the thin stem. The leaves are dark green to greyish in color with 12 pinnate patterned leaflets, which are darker green in color. The fruits are orange or dark red, 5–20 cm in diameter.

Bamboo palms grow best in moist, well-drained soil and require shady to partial shady conditions. They require good amount of water, not wet but thoroughly soaked as the roots widely spread over large soil volumes. The best watering time is either early morning or evening when the transpiration rate is quite low, as compared to the rest of the day. This palm can endure wider temperature ranges but it best grows at 18–24 °C, tolerating a minimum temperature of 13 °C. The best soil conditions are slightly acidic to slightly alkaline, and soil must be rich in humus. Moreover, for enhancing growth, applications of liquid fertilizers are highly recommended during the developmental stages.

The use of Chamaedorea palm as ornamental started in late nineteenth century, whereas the floricultural industry use of its leaves started in 1950s. The leaves and whole plant of approximately 20 species are used in the floricultural and horticultural industries. *Chamaedorea seifrizii* is an attractive indoor plant due to its aesthetic elegance as well as its growth capability in various environments. It is highly recommended in house indoors, office decors and recreational parks. The best time to grow outdoor palm is early summer. This palm is propagated through seeds, which take 6–9 months for germination. However, its propagation through offshoots and suckers are also a common practice. During germination, it requires high temperature of about 32 °C and high humid conditions, to avoid seed shrinkage and enhance its growth rate. After germination, a mildly decreasing temperature, with a lighter shade in moderately warm conditions should be ensured. This palm grows at normal rate and attain up to 3.6 m height and 1.8–2.4 m in width. During the early development, it requires full sun for shoot and stem growth as well as size attainment. For color attainment, it requires shady conditions. The yellowish, staminate flowers grow up to 15 cm in length, while pistillate flowers grow up to 10 cm. The fruits are spherical in shape, 6–8 mm in diameter, turning orange to black when ripened. It takes approximately 2–5 years to gain maximum size. *Chamaedorea seifrizii* is non-toxic as its stem, flowers and leaves are harmless to animals and human as well. However the fruits, berries are **highly toxic** and poisonous so their removal is recommended especially when grown indoors.[1]

The Chamaedorea tribe (Arecoideae sub-family) consists of genera *Chamaedorea*, *Synechanthus*, *Wendlandiella*, *Gaussia* and *Hyophorbe*. In the current palm classification, *Chamaedorea* is the largest genera in the tribe (Uhl and Dransfield 1987). In molecular phylogenetic studies, the Chamaedorea tribe is resolved as monophyletic (Uhl et al. 1995; Asmussen 1999; Hahn 2002; Thomas et al. 2006). *Chamaedorea* is highly distinct from all other genera, as characters of species under this genus do not match with the species of other genera regarding size and inflorescence. In Chamaedorea the species within genera exhibit quite variable morphological characters that is why it is quite cumbersome to distinguish intra-species characters i.e. flowers and inflorescence.

[1] See https://www.greenandvibrant.com/bamboo-palm

2.4.3 *Chamaedorea cataractarum*

Chamaedorea cataractarum, commonly known as Cat palms and cascade palm, is native to Central America and Mexico and is distributed from tropical to temperate climates of Florida and California. It is found in Oaxaca, Tabasco, in moist forests and on the Atlantic slope at 300–1000 m altitude. It is a rare rheophyte from the Arecaceae family, which grows in either running or stagnant waters. It grows up to 18 cm in height and 24 cm in width. The leaves are pinnately patterned and the leaflets grow up to 30 cm in length and 2.5 cm in width. Cat palm grows best at 2–27 °C and can tolerate temperatures of as less as 2 °C. It requires well drained moist, wet soil with pH 5.5–7.0. It normally grows in dense and clump pattern. The flexible leaflets along with trunkless, dense growing pattern make it suitable to withstand in running water. Due to its aesthetic beauty, it is mostly grown as fancy barriers along pools, garden oasis and streams. It is a slow growing clumping palm and a good choice as indoor plant. When grown indoor, it must be placed in an area with bright sunlight. It can bear harsh, cold climate so being a very tolerant and tough palm among other members of genus *Chamaedorea*. It is a deciduous palm with male and female on separate plants. It is a lavish, quite favorite palm for landscape decor due to its bright and attractive dark green leaves. Female plants contain interfoliar florets which become orange in color when fruits get ripened. The appearance of orange inflorescence with black ripened fruits gives a very lush attractive look for bird species (Wilson et al. 1990).

Cat palm is propagated through seeds but their rate of germination is very slow. The bright yellow-colored and fragrant flowers emerge in early spring. After pollination, as seeds become mature, female flowers turn bright orange. Fruits are ovoid in shape, dark green in color, which become black when ripened. The roots are delicate and can easily break during plantation so great care is required. It is highly sensitive to salts, which get accumulated in soil. Excess salt can damage foliage and roots, which ultimately damage the whole plant. It is an important palm as it purifies the air, cleaning the environment from pollutants such as carbon monoxide, benzene and formaldehyde.

2.4.4 *Ensete ventricosum*

Ensete ventricosum, (also called ensete or banana palm), is commonly known as Banana palm, Abyssinian banana and Ethiopian banana. It belongs to the monocot family Musaceae. It is not a true banana and mostly it is used as landscape. It is widely distributed in various regions of the world including Ethiopia, Uganda, Sudan, Kenya, Zambia, Zimbabwe, Mozambique, Tanzania and Malawi. In Ethiopian language, it is called “Enset” which means “provider of large amount of carbohydrate from trunk base”. It is generally a heighted, fast-growing, annual evergreen containing a basal, central trunk, which gives it a palm-like appearance.

Ethiopian banana is a source of food for inhabitants of southern as well as south-western Ethiopia. It has been cultivated in these areas for 8000 years and are source of food, fiber and medicine. Moreover, enset is widely used as ornamental plant as well as for shade purposes. The banana palm grows up to 2.4–3 m and does not produce suckers. It is naturally found in riverine forests or open mountain forests mostly near streams, at 1000–1600 m elevation. It grows best at 16–24 °C but can bear temperature ranges of 8–30 °C. It cannot however tolerate temperatures below −2 °C. The banana palm shows best growth with average rainfall of 1100–1500 mm (annual) but can also tolerate 900–1700 mm annual rainfall. It requires full sun for optimal growth but loves shade for some period of the day, when temperature rises. It prefers well drained, fertile soil with pH ranging between 5.6 and 7.3 and can bear pH fluctuation up to a range of 5–7.5. Mature, established Banana palms can resist drought conditions.

The enset is monocarpic, i.e. it flowers only once in its life time and dies once flowering occurs. The emergence of flower depends on soil fertility, cultivar and other climatic conditions. Generally, it takes approximately 2–10 years from germination to flowering and about 6 months for fruiting. Low temperatures and frost conditions slow down the plant growth and it may take a double time to reach an optimal growth stage. Leaves are about 6 m long, green with red margins while their lower surface are red, which gives an overall red appearance to the plant.

Ensete ventricosum is a monoecious plant, with male and female parts on the same plant. It shows best growth in moist soil and can survive in variety of soil types i.e. sandy, clay and loamy. For propagation, seeds must be soaked in warm water for 24 h and germination occurs in 3 months. The banana palm is harvested before flowering as this stage would utilize all starch so, when the plant is 3–4 years old, its basal corm is utilized for various purposes. The cooked corm, called “amicho”, is consumed like cassava and potato. Leaf sheath and corm pulp is fermented to make “kocho” flour, which is then used in bread making. Bread can be prepared either by 100% kocho or by mixing kocho with other cereals. Starchy liquid, obtained from squeezing the chopped pulp, is used to prepare “bulla”, which is utilized in preparing porridges or in dough, which is further baked and consumed. The yield depends upon the plant age, climatic conditions and soil fertility. The annual yield of kocho is about 12–25 tonnes per ha per year, while the yield of fiber is recorded as 500 g per plant. Seed endosperm is utilized in famine period when nothing else is available. Flower stalk is also edible while its fruit is consumed only in famine period. Apart from food, banana palm has many medicinal properties. The leaves and stem are used in liver treatment and curing miscarriage issues. Leaves and fruits infusions are helpful in treatment of liver ailments and hepatitis. For curing injuries, powder extracted from seeds are very effective. Banana palm has many additional uses: its leaves are exploited for shading purposes, the fiber of the trunk is widely used in sacking while that from leaves are widely used in rope, mats and basket making. Leaves are utilized in weaving while in a dried form they are used in construction of houses, fences as well as for wrapping and packing goods. Seeds of banana palm are used in making jewels such as in making necklaces, rattles and make children toys. A brown stain is obtained from the trunk, that can be used for coloring purposes.

2.4.5 *Bismarckia nobilis*

Bismarckia nobilis, commonly known as Bismarckia palm, is an attractive, silver blue fan palm, native to Madagascar. The only species of genus *Bismarckia, it took its name from* Otto von Bismarck, a German chancellor. Its popularity increased in last two decades, as previously it was used in landscape only in its native land, Madagascar. It grows well in sunlight, warm and dry climatic conditions. It is an elegant palm popular for its silver blue color, that can survive in a wide range of climates i.e. from tropical, humid to dry and desert areas. It can tolerate harsh environmental conditions and exist in plateaus, tolerating hot, humid and dry climates. It grows up to 18 m in height but may require 100 years to attain it. It is a single trunk palm, which is 45–60 cm in diameter. The trunk is smooth, brown in shade and scared with scratches of old leaves. It is a self-cleaning palm; its older leaves fall off leaving marks of leaf base on stem. Bismarckia palm lacks crown shaft. About 15–30 leaves of blue to silver in shade are present. There are two forms of this palm, i.e. blue and green. In the blue form, a silvery-blue waxy coat is present on leaves. The base and stems of leaves may be smooth or hairy. The absence of hair gives a smooth metallic aspect to the stem, making it blue in shade. The function behind the presence/absence of hairs on stem is unknown, still hairy and smooth polished stems are quite apparent in the case of this palm. Leaves are 20–25 cm in radius, with about 20–30 segments. The width of the crown is about 6 m. In mature palms, the petioles are 1.8–2.4 m long. It is dioecious in nature, with a dark brown inflorescence emerging on separate plants. Pollination occurs through insects and wind. The mature fruits are round in shape, brown to black in color and 3.8 cm in length.

Silver blue type of *Bismarckia nobilis* are more popular as compared to the green form, which is less tolerant to cold conditions and rarely seen as landscape palm. Due to the exposure of cold weather, red discoloration or purple shades appear on leaves usually on young palm of the blue type, which fade away with age. It grows well in sandy soil with good drainage. Its growth rate increases in full sun but decreases in cooler regions. Though, this palm can bear drought conditions but requires sufficient water during summer for fast growth. After its commercialization started, its splendid growth can be seen in tropical as well as sub-tropical climates of Hawaii and Florida. Moreover, it grows in various regions of California and in the Arizona desert. It can bear as low as −6 °C temperature and can bear hot temperature up to 43 °C. Bismarckia palm cannot tolerate poor drainage conditions, water logging, frost, freezing temperatures and roots damage. Regarding landscape, it is an ideal choice for gardens and recreational parks. It should be planted at a distance of about 4.5 m from the next palm. It should not be planted in shady areas and near to buildings. Its place of plantation must be selected very carefully as, once established, its displacement to some other destination is a very difficult task, as root damage can kill the whole palm. Its attractive blue color enhances its aesthetic beauty, which make tourist to stop by and admire its elegant look.

2.4.6 Hyophorbe lagenicaulis

Hyophorbe lagenicaulis, commonly known as the bottle palm, is a monoecious palm, present in Mauritius (Indian Ocean) and Round Island (Michigan, USA). It is becoming an endangered species as only 10 mature plants have been reported in its native Round Island. It got its common name from its physical appearance, which is similar to a large water bottle. The name was given by Harold Moore who was considered to be the pioneer of this palm, whose work was published in 1998 after his death. The first scientific name is the constituent of two words i.e. "hyo" means 'pig' while "phorbe" means 'fodder' which give indication that the fruit of the bottle palm was fodder for pigs. The second scientific name is the constituent of two Greek words i.e. "lagen" means 'flask' and "caulis" means 'stem' which gives hint about its appearance. Bottle palm is basically sun loving and attain height of approximately 3 m. Its leaves can grow up to 3.6 m in length with about 60 cm long leaflets. The stem is smooth, greyish-white in color, scared with scratches of old, fallen leaves.

It is semi-short, statured palm and gets attraction due to its unique physical appearance. It grows best in full sun light and cannot tolerate cold temperature, as it often dies in freezing conditions. It consists of a single trunk, swollen from its base. Above the base, the trunk and crown shaft are narrow which gives it a bottle-like look. The mature palm consists of 6–8 leaves, which are strongly attached with the trunk through the leaf bases. Mature leaves are of green color while in young plants a prominent red color can be seen at the leaf stems. In tropical regions with warm climate, the trunk is very much swollen and fat near the ground, measuring around 60–76 cm in width. The width decreases below the crown shaft, that is green to silver green in shade. A branched inflorescence emerges from the lower side of the crown shaft.

Although the bottle palm is endangered, its germplasm is not lost due to the development of well-established nurseries and botanical gardens, which propagate bottle palm through seeds. It is a monoecious plant (male and female flowers are present on the same plant) so that a single palm can produce many seeds for future propagation. The seeds are initially green in color, becoming blue silver to blackish when mature. The bottle palm grows well in sandy, well drained soil with an average water requirement and is drought tolerant. They represent a good choice for coastal regions being salt tolerant. For better palm growth, fertilizers with balanced nutrients ratio must be applied as sprinkled on soil near the base region, followed by deep watering, just after application. Bottle palms are fertilized four time per year i.e. spring, mid summer, early and late autumn. Regular pruning is required to remove older leaves. Bottle palm is mostly grown along street sides, road sides, recreational parks and in coastal areas.

2.4.7 *Phoenix dactylifera*

Date palm, *Phoenix dactylifera*, is a member of the Arecaceae family. It is a perennial monocot tree with an approx. 658-Mbp genome (Al-Dous et al. 2011). Date palm is an important fruit crop in dry areas, possessing great tolerance for water stress conditions (Johnson 2011). It is predominantly grown in Middle East, Africa and Arabic countries with annual production of 6–8 million metric tons. Approximately, 350 cvs are present in Saudi Arabia while about 2000 cvs are available in various countries of the world (Al-Mssallem 1996). Every cv is unique in its morphology, botanical characteristics and nutritional values (Fayadh and Al-Showiman 1990). Date palm was domesticated in Mesopotamia-Arabic Gulf area around 4000 B.C. (Tengberg 2012) and then distributed in other countries of the world. Various views are expressed in the literature regarding its origin. *Phoenix dactylifera* evolved from *Phoenix reclinata* (native to Tropical Africa) or *Phoenix sylvestris* (India) or may be a hybrid of the latter two species . *Phoenix sylvestris* (Indian sugar date palm) has been confirmed to be the closest sister of *Phoenix dactylifera* and probably an ancestor in its evolutionary lineage (Shah 2014). *Phoenix sylvestris* is still cultivated in Pakistan and India, suggesting that the Indus Valley was likely a hub of date palms, from where it spread to other regions i.e. Egypt, Mesopotamia, Eastern Arabia, through sea and land trade around the 6th millennium BC. Moreover, in ancient history, it had been recorded that date palm was extended from the Indus valley (actually Pakistan) to Mesopotamia (now Iraq), Eastern Mediterranean, Nile valley and Africa (Sanderson 2001).

Phoenix dactylifera is dioecious in nature i.e. its female and male parts are on separate plants. Among *Phoenix* species, date palm is the tallest with approximately 30 m in height. The leaves of date palm are large, approximately 4–5 m, growing in a circular pattern in clusters arranged around the central stem axis. Leaves terminals are pointed and sharp as a protection from grazing animals. The fruit is largest among other *Phoenix* species, with approximately 6 × 4 cm in size. Date palm is distributed in sub-tropical, tropical, temperate and arid regions of the world including Australia, USA, few regions of Spain, Eastern Africa and Asia (Sanderson 2001). Arabian countries are the largest producers of date palm. Its stone fruit has a single seed and is found in the form of clusters weighing approx. 10 kg. The sweet fruit has played a vital role in nomadic lives of desert areas and got a prominent status in Arabic societies. Approximately, 8 million tonnes are produced annually and the production rate is increasing every year due to increasing date palm cultivation . It is a quite important crop as all plant parts can be used including its trunk in constructions, or the leaves in basketry and other decor purposes (Tengberg 2012). Moreover, its fruit is a vital source of instant energy, vitamins and other elements such as Ca, K, P and Fe. In addition to this, high level of phenolic compounds are present, enhancing its antioxidant properties (Zineb et al. 2012).

For best cultivation and production of date palm, sandy loam soil is recommended, though it has no specificity regarding soil as it can tolerate salinity and drought stress conditions. Regarding flowering and fruit production, warm summer days with high temperature and quite mild winter (without frost) are required. Moreover, during the fruit setting period, substantial amounts of sunshine with low humidity level are of great importance. In 2011, India was the world largest importer while in 2012, Pakistan ranked as world 6th largest producer of date palm with a 600,000 million tons annual production. In Pakistan, Montgomery (Sahiwal), Lahore, Khushab and Multan are famous as best date palm producing cities (Shah 2014).

As in other plants, the genetic diversity has also been studied in date palm cvs. Diversity is thought to be due to the distribution of germplasm by human migration and selection (Chaludvadi et al. 2014). The commercial cvs are distributed by offshoots of the date palm as they are similar to each other, while non-commercial cultivars are propagated through seeds. In 2006, Rizk and Sharabsy suggested some parameters as date palm descriptors, which include ecogeographical data, ethnobotanical data, management and characterization data. Among these parameters, data included fruits, seeds, molecular markers as well as cytological parameters. The morphological markers are based upon the physical characteristics and, in case of date palm, they included leaves, offshoots, spines, trunk, fruits and seeds. Rivera et al. (2008) studied 37 quantitative and 45 qualitative traits of date palms from Western Europe. While Eissa et al. (2009) studied 77 morphological characteristics for distinction among Egypt date palm varieties. However, these markers are not sufficient for differentiation of closely related cvs. Morphological markers are not sufficient to study the genetic diversity as bias might exist in plant data recording, as all such markers are greatly influenced by the environment (Nybom et al. 2014). Various molecular markers were used in recent years to distinguish the closely related cultivars of date palm. Among many markers, CBOL plant working group has recommended maturase K and ribulose biphosphate carboxylase larger subunit (matK+rbcL), to distinguish among cvs due to their high discrimination power. The discrimination power of matK is much more as compared to trnH-psbA, atpF-atpH and rbcL (Burgess et al. 2011). Moreover, matK, in combination with other genes or alone has the ability to differentiate date palm cvs (Enan and Ahmad 2014). For the analysis of diversity among Pakistan date palm cultivars, Rps14 gene was used, which exhibited low evolutionary divergence and nucleotide diversity (Akhtar et al. 2014). In 2010, Hamweih et al. synthesized 1000 microsatellite markers through the genome of date palm and proposed their use in the genetic diversity studies. The markers were used to analyse diversity among date palm cultivars from various regions, including 45 cvs of Pakistan (Faqir et al. 2016), various regions of Qatar (Elmeer et al. 2011) and about 30 cvs from Iran (Khierallah et al. 2011). These markers-grouped date palm of various areas in clusters but individual discrimination was not possible. These microsatellite markers were quite crucial for taxonomy assessment up to the species level but for individual based variation, sequence-based phylogenetic evaluation was required (; Pintaud et al. 2010).

2.4.8 *Dioon spinulosum*

Dioon spinulosum, commonly known Dioon palm, Giant Dioon and Gum palm, native to Oaxaca and Veracruz (Mexico), belongs to the family Zamiaceae, and is a New World genus. It got its species name from Latin for 'spiny', due to the spiny pointed leaflets ends. The genus *Dioon* means "two eggs", referring to the female cones in which each scale contains two seeds. *Dioon spinulosum* is a cycad which can survive for many centuries and possess a long fossil history. It is known to be the tallest cycad in the world. Due to its palm-like characteristics it is mostly used as a replacement of palms. It's an evergreen, fast growing with a large crown, pinnate patterned light green leaves which give it an exotic look. This species is mostly found in rocky hills of tropical rainforests at 90–460 m elevations. It grows well in temperate as well as subtropical climatic conditions. It is a single trunk palm, growing up to 12 m in height in its natural habitat. In botanic gardens, its height does not exceed 3–5 m, with a 30 cm wide trunk. Dioon is known to be one of the oldest plants, with its history traced back to the flora of Mesozoic era, approximately 170 Mya. It shows a thin, slender, greyish to brown colored trunk covered with leaf scars. Growth rings are quite apparent on the trunk, which have no link to season but emerge in a period of 20–30 years or more. The leaves are bright green, pinnate patterned, 1.5–2.1 m long, radiating outwards from the stem. Leaflets are small, glossy, sea greenish in color, consisting of tiny thorns and narrower towards the sharp end. It is a dioecious species, with male and female parts present on separate individuals. Female plants produce cones of 50–80 cm in length and 20–30 cm wide. The cone weight reaches up to 15 kg, carrying 300 or more seeds. On maturation, the cone opens up with a loud noisy sound and seeds get scattered. Dioon seeds are oval in shape, white in color, measuring 3.8–5.1 cm in length and 2.8–3.3 cm in width.

Dioon spinulosum is a slow to medium fast-growing plant. It is adaptive to various climatic conditions and can tolerate heat, frost and sun. Though, it shows its best growth in partial shady conditions. It thrives best in well drained soil and requires abundant water during dry weather, but it is drought resistant as well. Traditionally, it is propagated either through seeds or by divisions. The offshoots from the truck base can be replanted for propagation. The seeds are as large as a grapes and hard, but germinate quite easily. The leaves of *Dioon spinulosum* are widely used in décor purposes even in religious events. In future, it can prove to be an ideal landscape for temperate and desert areas. It is not only an outdoor plant but also an ideal indoor choice, due to its elegant fronds pattern. While dealing with this plant, care must be taken as its leaflets have quite sharp points which can cause severe injuries.

2.4.9 Caryota urens

Fish tail palm, scientifically known as *Caryota urens*, is a monoecious flowering palm native to Sri Lanka and India. It is mainly distributed in South Asian countries including Malaysia, Indonesia, Nepal, Pakistan, Thailand and Philippines. It is also found in USA, Zimbabwe and Vietnam. It is naturally found in humid tropical forests of Asia and its distribution in rainforests of Sri Lanka was recorded as less as two trees per hectare, which indicated its rareness in nature (Ranasinghe et al. 2012). The fishtail name was given due to the shape of leaves, which resemble fins of fish, while “urens” is in Latin means “stinging”, referring to the presence of oxalic acid in its fruit. Oxalic acid crystals cause skin and eyes irritation (Tanuja and Rajyalakshmi 2004). Naturally, Fish tail palms grow best in humid climates along with shady and cool environments. It is basically a slow growing and shade loving palm growing best with 6–7.5 soil pH. These are naturally found in regions of humid tropical environment where temperatures never become lower than 10 °C, with annual rainfalls around 1500 mm. They can also thrive in temperate regions with minimum rainfall of 250 mm. Temperatures lower than 5 °C are detrimental for mature palms. The seeds of *C. urens* geminate in 2–4 months and their viability depends on the storage conditions. If stored at room temperature their viability extends up to 30–90 days. The fish tail palm is monocarpic with an ability to live without flowering, but once flowering occurs and the last fruit on the floret gets mature, the plant dies. It is propagated as ornamental and is widely cultivated in landscape decors in botanic gardens, parks and indoors in tropical as well as subtropical regions.

Fish tail palm has many popular names i.e. *jiggery palm*, *toddy palm* and *wine palm* in India, or *kithul* in Sri Lanka. Fish tail palm is quite attractive possessing a cylindrical truck, which grows up to 20–25 m in height. The leaves are broad i.e. 5–6 m in length and wide up to 2–3 m. The development of inflorescence is downwards toward to lower side of the palm. After the emergence of the terminal floret, the growth of the axillary floret is downward (Tanuja and Rajyalakshmi 2004). The mature seeds are round in shape and each fruit (fleshy part) contain a single seed. Traditionally, this palm is used for the preparation of *toddy* which is an alcoholic sap extracted from a young inflorescence. The leaves of *Caryota urens* are mostly used to feed animals in Sri Lanka while the tree, as whole, is famous for its good quality *kittul* fiber (Rajyalakshmi and Kumai 2000). The seeds are a rich source of starch, glucose and other simple sugars, but are poor of proteins and fats. The trunk is of great nutritive value as it contains starch known as *sago* consumed by local people in days of famine. The fluid extracted from the young inflorescence is processed to produce an alcoholic beverage through fermentation, consumed as *toddy* or palm wine. This alcoholic beverage can further be processed into *jaggery* by boiling it to make a syrup (Ranasinghe et al. 2012).

The products of *Caryota urens* possess medicinal qualities and are traditionally used to cure many diseases. The products of palm hold anti-aging, anti-oxidant and anti-inflammatory characteristics. The sap shows a glucosidase inhibition property which makes it effective in curing diabetes. Moreover, the sap is used to cure urinary disorders, flowers are used in ulcer or migraine treatments, whereas the root bark is used to cure snake bites and rheumatic inflammations. The antioxidant properties of *C. urens* was examined by the activity of free radicals (Ranasinghe et al. 2012). The phytochemical investigation of *C. urens* showed the presence of alkaloids, phenols, carbohydrate and flavonoids (Vaishnavi and Suneetha 2013). The palm has many other uses as well: the leaf bases are famous for a soft and delicate fiber, which is used in making baskets, ropes, stuffing pillows and cushions. The leaves are also used for shelter purposes. The mature wood is quite strong thus suitable to be used as timber for construction, fencing and partitioning purposes.

2.4.10 Wodyetia bifurcata

Commonly known as foxtail palm, *Wodyetia bifurcata* is native to Australia. The name "foxtail" is given due to a resemblance of fluffy leaves with the fox tail. It is intrinsic to Cape Melville, which is located in North of Port Douglas in Queensland, Australia. *Wodyetia bifurcata* took its name from two different sources. The name "*Wodyetia*" came from the aboriginal Australian people Wodyeti, while "bifurcate" in Latin means "twice forked", referring to the shape of fruits and leaflets. Foxtail palm was discovered in 1978 by Australian aboriginal bushman, and until then palm specialist had no idea about the existence of this elegant palm in nature. In 1983, general information about the foxtail palm was published and the news about the discovery of this palm circulated quite rapidly around the globe. It is an elegant, attractive thin trunk palm, which may gain maximum height of 8–10 m. In tropical regions, it might get taller due to environmental conditions. It requires full sunlight for its best growth and thrives in sandy soil. The native region of this palm has long dry and warm climatic conditions. Naturally, it is found at the height of 300 m. The foxtail palm is a monotypic species and is the only species of the genus *Wodyetia*. It is a medium statured, thin trunked palm, with a quite attractive appearance due to its bushy, fluffy leaves. The leaves are lush green with emerging leaflets giving it a bushy and fluffy appearance. The crown shaft of palm is silver to green in shade. About 8–10 leaves of approximately 1.8–2.7 m are present on a mature tree. The leaflets are thin, about 30 cm in length, emerging at any angle of the leaf. The crown of a mature palm is about 3–4.5 m in width. The presence of a crown shaft is quite attractive and it indicates its "self cleaning" ability i.e. it does not need any kind of pruning. The crown shaft, slightly swollen from base, gives a smooth look to the palm, which increases its beauty. The flowers emerge from the very lower side of crown shaft. It is a monecious species. The flowers are branched and white in color. Pollen dispersion is usually through wind or insects. The fruits are red orange in shade when ripened. The seeds are green when immature and change to brown black when matured. They have a eye-catching look due to apparent fibrous groves.

Foxtail palms grow best in full, bright sun and prefer this condition over shady or partly shady climates. This species grows well in warm climate, tolerating up to

43 °C. Its optimum temperature for better growth ranges between 20 and 35 °C. It can tolerate as less as −5 °C. It does not grow well in soil with high salt concentrations and grows best in sandy loam soil. Soluble fertilizers with heavy nitrogen amount are preferred as they give rise to a lush green foliage. Foxtail palms are planted in outdoor gardens and recreational parks under bright sun. They grow better in open areas as compared to indoors.

2.4.11 Dypsis lutescens

The golden palm, *Dypsis lutescens*, is a dioecious, perennial flowering plant native to Madagascar and South India and distributed in various tropical and sub- tropical regions of Cuba, Southern Florida, Jamaica and Venezuelan Antilles. It is known by many other names i.e. areca palm, golden cane palm and yellow palm, referring to the yellow color of its petiole and other parts. The species got its name "*lutescens*" from Latin meaning "growing yellow" which refers to its yellow stem. This palm best grows in low temperatures in tropical regions. It grows up to approximately 6–12 m in height with 3–6 m of crown expansion. The leaves are greenish yellow to dark green in color, pinnately arranged and 1.8–2 m in length. Multiple stem, each of 5–7 cm wide, develop from the base of plant with 40–60 leaflets in pairs. The leaflets are arranged in a way forming a "V" shape, which grows in opposite direction from each other along the center of the greenish stem. The yellow colored flowers develop from the lower side of leaves and droop in descending direction. The fruits are about 2.5 cm in length and change color from yellow to purple and ultimately black, when fully matured (Riffle and Craft 2003). This species grows best in soils with a good drainage capacity and can thrive in full sun as well as in partial shady conditions (Rushing 2005).

The golden palm has been widely used in indoor as well as outdoor decor. Due to its aesthetic beauty, it is also used as landscape in botanic gardens and recreation parks. This palm has some similarities with bamboo palm, as both have capability to grow upright rapidly in a pattern of clumps. Golden or areca palm is widely planted as fence around pool and garden oasis areas. The fruit is a good source of food for various birds including *Thraupis sayaca* (commonly known as Sayaca tanager) and *Pitangus sulphuratus* (commonly known as The great kiskadee) in Brazil (Ribeiro and Silva 2005). According to B. C. Wolverton and NASA Clean Air Study, Golden palm has special property of purifying air from toluene and xylene. Moreover, it acts as humidifier as it transpires one liter water per day, when reaching a height of 12–28 cm. It purifies air by eliminating trichloroethylene, formaldehyde and other pollutants and hazardous compounds from the environment.

2.4.12 Cycas revoluta

Commonly known as kangi palm, Japanese sago palm, king sago palm or simply sago palm, *Cycas revoluta* originated from Southern Japan. It belongs to the family Cycadaceae. It naturally exists on sea shores of Southern Japan and in Eastern China at 100–500 m elevations. It is grown in various regions of the world including New York, Missouri and St. Louis. In temperate climatic regions the leaves fell off in winter and the plant flourishes again in summer. The cycads are not true palms . They are seed plants with a long fossil history from a much diverse botanic group. *Cycas revoluta* is a slow growing plant with a thick, single trunk 20 cm or more wide. It can grow up to 6 m in height but being quite slow growing it can take 50–100 years to attain this height. The trunk produces many leaf heads on multiple branches. It produces bright dark green crown of leaves with 5–150 cm length. Leaves of Kangi palm are dark green and shiny, turning into branched feather-like pattern at the time of reproduction. The leaflets are 8–18 cm in length and the basal part shows a spiny look. The plant produces several offshoots, which are usually cleaned and are used for propagation. It is a hardy cycad, and can bear frosts up to some extents. It can bear temperatures as low as −10 °C. *Cycas revoluta* can grow in tropical and temperate climate zones, performing well in sunlight areas. It requires a sandy loam soil along with good drainage, but also thrives well in dry soils. It is dioecious, with male and female parts on separate plants, and does not produce any flowers but cones. Nitrogen in roots is produced in a symbiotic relationship with cyanobacteria. Pollination occurs with the aid of insects and wind. Propagation can be done through seeds or division. Before planting, seeds are soaked in water for 24 h and germination occur in 1–3 months at 25 °C temperature. It is widely grown in botanic gardens, in landscapes for its elegant appearance of feather like leaves in rosette pattern.

Cycas revoluta is known to containing alkaloids that are **carcinogenic** in nature and some amino acids which are responsible for various nervous disorders. Its consumption can cause chronic health ailments and ultimately results in death. The toxins can cause prostate cancer and Parkinson’s disease. If toxic components are removed, its seeds and trunk heart can be consumed. The seed of *Cycas revoluta* are dried, ground, mixed with rice and finally fermented to make “date miso”. Starch from the trunk is extracted and used in dumplings. Moreover, the heart itself is consumed either in baked form or in powered form. The consumption of this cycad is still not recommended, even after toxic removal as its heavy consumption mainly kills the plant, which is becoming rare in nature. Apart from edible uses, *Cycas revolut*a has many medicinal properties. The leaves are used in treating cancer, seeds are used in curing rheumatism while extracts of seeds are used in prevention of malignant tumor growth.

2.4.13 *Rhapis excelsa*

Rhapis excelsa, commonly known as lady palm, is a dioecious species native to China. Rhapis is a Greek word meaning “needle”, which refers to the pointy shape of leaves. Japan imported this palm somewhere in seventeenth century and then it was carried to Europe in 1770s and to America in 1850s. Lady palm possesses dark green fan-shaped leaves. It is also known as fan palm, finger palm and parlor palm. It is widely distributed in tropical and sub-tropical regions and can bear temperature of −5−37 °C. It may grow up to 4.2 m in height and 30 mm in width, and can easily flourish in humid and dry environments. The palmate leaves are quite broad, thick and pointed, divided in various segments, with a stem/stalk covered with brown fibers. The leaves show a bright green color. In young palms, number of leaf segments are less and increase as the plant gets mature. The leaves are pointed at tips with a length of 20–60 cm. In the young leaves a fibrous cover emerges which falls off as the plant gets older, exposing the trunk. The inflorescence emerges in a spiral pattern at the top, containing flowers whose petals get merged at the base. The ripened fruits are fleshy and white in color. Lady palm produces enormous offshoot rhizomes which are used for its division and propagation, though the plant can be propagated through seeds, although it is a rare method. Lady palms grow in to two types, open and butterball. The open style palms are straighter and more upright, ranging in 15–35 cm in height, while butterball types are grown from seeds and appear full of leaves.

Rhapis excelsa grows best in sub-tropical temperatures and can grow in full light to shade. However the sunlight should not be direct, and more the plant is kept in shade, more will its leaves be green. If it is exposed to full sunlight, the leaves turn yellow in color and ultimately get burned. This species can grow in a variety of soil types i.e. loamy, clay or sandy but the soil pH should be slightly acidic. The roots should be soaked in water for best growth and its soil must be moderately moist as excessive moisture can cause roots rot, while, while dry soil can burn the leaf tips and turning the color from green to grey. Fertilizer can be added to enhance growth but excess application can cause injury. Generally, lady palm is a slow growing species that’s why it is much expensive as compared to other ornamental palms, requiring approx. 4–7 years in nursery to achieve full growth.

Approximately, 100 or more cvs of lady palm exist, i.e. Zuikonishiki possessing green leaflets along with white stripes, Koban with dark green leaves, Gyokuho and Kodaruma which are dwarf and small statured. Due to broad leaves, lady palm is sometimes termed as “broadleaf lady palm”, which are of various types but can be grouped into two classes i.e. variegated and green. The famous variegated type of *Rhapis excelsa* is Zuikonishiki, which produces many sprouts. Out of all sprouts, only 40% are of the type to be used in propagation. Remaining sprouts either become too green or too white in color. When the leaves become too white, the effect is known as “golden chlorophyll”. These types must be grown in less temperate areas. Lady palm are generally indoor plants as they grow best in shady areas. It can be used outdoor in landscape but it must be planted in shades. As an outdoor plant, it attracts various butterflies and birds, and is home for birds.

2.4.14 Syagrus romanzoffiana

Syagrus species are important components of the flora in Brazilian woodlands, with 39 species altogether (Noblick 2017). *Syagrus romanzoffiana*, commonly known as queen palm, Jeriva or Coqueiro, belong to order Arecales, subfamily Arecoideae (Asmussen et al. 2006), Cocoseae tribe and subtribe Attaleinae. It natively belongs to South America and is an important landscape plant of Brazil, Argentina and Bolivia (Lorenzi et al. 2010). *Syagrus romanzoffiana* is distributed in a vast area of the Rio Grande do Sul state, spreading in various habitats including Atlantic and Pampa Forest. Most commonly, the presence of this palm has been observed along streams and water canals (Soares et al. 2014). *Syagrus romanzoffiana* was incorrectly known as *Cocos plumosa* for many years but Adelbert von Chamisso named it as *Cocos romanzoffiana* in 1823. Odoardo Becarri, an Italian naturalist, divided the Cocos genus into seven groups in 1916. During this period, the species was named *Arecastrum romanzoffiana*. After few years, the species was grouped into the genus *Syagrus* so up to the date, it is known as *Syagrus romanzoffiana*.

The morphology of *S. romanzoffiana* is categorized by its height, which is approximately 15–18 m with a trunk diameter ranging between 20 and 40 cm. The leaves are characterized by a pinnate shape with approximately 25 cm long leaflets, randomly arranged on branches. The arrangements of dark green leaflets give them an eye catching feathery look. The inflorescence of this species is unisexual (Noblick 2017) with includes bright yellow staminate flowers, arranged in pyramidal clusters. Insects like bees, flies and beetles have a vital role in pollination (Henderson 1986). The optimum temperature for seed germination is 32–35 °C. The low seed germination rate of *S. romanzoffiana* in laboratory conditions induced the idea of seed dormancy (Broschat and Donselman 1987; Goudel et al. 2013). Dormancy is an approach adopted by plants to overcome unfavorable conditions for their survival (Long et al. 2015). The fruiting of this species occurs from October to March i.e. winter to spring season. The mature fruits appear to be orange to yellow colored with oval shapes. This palm can resist cold environment and can survive at −9 °C, which makes it quite suitable as ornamental landscape palm in temperate regions (Sobral 2006; Curcio et al. 2007; Lorenzi et al. 2010).

Various paleontological studies revealed the use of *S. romanzoffiana* as food, medicinal source, fuel, handicrafts and landscape decors (Lorenzi et al. 2010; Bonomo and Capeletti 2014). It is not only a food source for mammals but also for various birds and insects due to its nutritional importance. The berries of queen palm are edible for human and can be used in jellies and different cooking sauces. *Syagrus romanzoffiana* plays a crucial role in maintaining the natural ecosystem with the aid of its pollinators and their interactions (Carvalho 2006; Galetti et al. 2013; Giombini et al. 2016).

2.4.15 *Ravenea rivularis*

Ravenea rivularis, commonly known as Ravenea palm or majesty palm, is native to south-central Madagascar and Onilahy river. It grows well in standing water along riverbanks and in deciduous forests at 350–370 m elevation. Morphologically, majestic palm is famous for its mildly swollen base and symmetrical green leaves. It grows best in range of 7–29 °C temperature but must be prevented from harsh climates, neither cold breezes nor heat waves. It can tolerate as low as −3 °C temperature. It grows up to 22 m in height and 36–50 cm in width. *Ravenea rivularis* possesses a light greyish stem on which leaf marks are quite prominent at a spacing of 4–10 cm. The leaves are green, pinnate, 2–2.5 m in length with rachis twist at tip, but lacking spines. The leaflets are green in color with a visible midrib and secondary veins. It is a dioecious palm with male and female parts on separate individuals. Male and female flowers are white in color. The female inflorescence is 1–1.5 m in length while male inflorescence is 90 cm in length. The fruits are attractive, bright red in color measuring 1–1.3 cm in length. For best growth of majesty palm indoor, it must be watered twice a day. Change in leaves tip indicates the soil condition i.e. brown tips shows that it requires more water. It can be grown in sunlight or shady areas, requiring high humidity and growing best in clay soil. *Ravenea rivularis* is non-toxic palm that can be grown as indoor or outdoor plant. It is wildly cultivated in landscape decors in botanic gardens and recreational parks.

2.4.16 *Roystonea regia*

Commonly known as royal palm, *Roystonea regia* is a monoecious, gigantic majesty tree, found in Cuba and South Florida. It is a national tree of Cuba. It was originally known as *Oreodoxa regia* and got its new name from Roy Stone who gave his services as army engineer in Caribbean land. In 1791, William Bartram, an American naturalist, recorded the existence of this palm in the vicinity of Lake Dexter, Florida. The genus Roystonea consist of 11 species, which are distributed to various regions of America and Caribbean Islands. Royal palm is known to tolerate cold temperature as low as −2 °C. It attains maximum height of 15–20 m and width of approximately 6–7 m. The trunk of Royal palm is smooth and greyish, with diameter of 60 cm, on which the scars of old leaves are quite apparent. Leaves of dark green color develop from crown shaft, which are about 1.8–3 m in length. The crown shaft is present at the height of 1.5 m from the trunk. The growth rate is 30 cm per year. These are "self-cleaning" in nature, older leaves fall off naturally at the rate of 1 leaf/month. The self-cleaning property eliminates the need of regular pruning and trimming of older leaves. The leaves of royal palm are heavy in weight so their falling can cause injuries to property or people on which they fall. Flowers of royal palm are cream in color, which become dark red to black fruits in late summer season. The fruits are eaten by birds which is also a source of seed dispersion. The pulp of fruits contains calcium oxalate crystals, which may cause skin irritation (Broschat and Latham 1994).

Royal palm grows best in wet soils, slightly tolerant to salt but cannot bear high concentration of salts in their roots. They are drought tolerant once they are matured and well established. It grows well in full sun to partial shady areas. It can grow in a wide range of soils, yet grows well in well drained and mildly acidic to alkaline soil. Excessive alkaline soil can make the leaves frizzled. The required growing conditions make it suitable for tropical areas. It cannot bear temperature drop off below −2 °C so wit ill not survive in frost areas. Due to its height, Royal palm is considered to be more suitable for outdoor landscapes, fencing along pools and for enhancing beauty of gardens and parks. Royal palm is a national tree of Cuba and it can be seen on the national seal of the country. It also holds religious importance in Santeria and Christianity of Caribbean. In addition to its aesthetic beauty, the whole plant and many of its parts are utilized. The seeds are used as animal fodder, leaves and trunks are used in various constructions and palm hearts are consumed in salads and soups.

2.4.17 Livistona rotundifolia

Livistona rotundifolia (*Saribus rotundifolia*) is commonly known as Table palm, Fan palm, Umbrella palm, Footstool palm and Round leaf fan palm. It originates from South-East Asian countries including Indonesia, Philippines, Malaysia, Java and Lesser Sunda Islands. It is recognized as “Anahaw” meaning “National leaf of Philippines”. This palm is widely distributed in tropical as well as sub-tropical rainforests of Australia and Africa. It usually grows at lower or medium elevation in rainforests. It got its name from the Baron of Livingston, who developed and established botanical garden in 1670 in Edinburgh, Scotland. The single smooth trunk is brown in color and consists of rings of marks/scars of leaves petioles, covered with greyish fiber near the top below the crown of palm. It grows up to 24 m in the wild but in gardens it remains short heighted. It is a single trunk, short statured palm as compared to others. The leaves are round and evergreen. The juvenile palm bears slightly lobed fronds while the mature tree possesses leaves with deep division and segments which radiate like umbrella spokes. The leaves are palmate, broad, slightly lobed and shiny green in color. They become more segmented but less beautiful at the adult stage. At the juvenile stage the leaves are small, round and are about 1.5 m in width with petiole length of 2 m along with spines at the lower surface of base. In mature palm, the leaves are costa-palmate patterned, spineless and short in length as compared to petioles. *Livistona rotundifolia* is a monoecious species, with an inflorescence about 2 m long, segmented into three axis, bearing tiny, yellowish flowers which bloom during spring. The flowers do not appear in potted plants, rather emerge as bunches in mature and old plants. Tiny, spherical shaped fruits about 1.5–2 cm in diameter appear, which turn red to black when ripened.

Livistona rotundifolia grows well at 18–24 °C and cannot tolerate temperature below 8–10 °C. It prefers high humid conditions and requires partial shade to bright light, but not direct exposure to sunlight. It does not grow in dark conditions so it is not suitable for rooms where sunlight is not available. It grows best in sandy-loamy soil. It should be watered in morning and avoid water logging as well as drought conditions. It is a slow growing palm and quite suitable for indoors. It needs pruning of lower leaves, which turn to brown color as the plant grows. Table palm is quite famous in western countries as air purifier and to remove hazardous components such as benzene, carbon monoxide and formaldehyde from the air. As it is a purifier, it is helpful in prevention of eyes irritation due to various harmful components in air. Table palm is a very elegant and ideal houseplant as it is easy to grow and get well adapted to the domestic environment. Its fan shaped leaves are graceful, elegant, full of aesthetic beauty and give royal exotic look.

2.4.18 *Ravenala madagascariensis*

As its name indicates, *Ravenala madagascariensis*, commonly known as traveler's palm, is native to Madagascar. This attractive, beautiful plant is actually not a palm but is closely related to the bird of paradise groups of plants from the Strelitziaceae and banana families. It is the only plant of genus *Ravenala*. The name "traveler's palm" is likely based on two alternative hypotheses. The first one is related to the arrangement of the gigantic fan-shaped leaves, oriented in east-west direction, which served as a compass for travelers and passengers. The second hypothesis involves the water collection in its small parts, especially in hollow leaf bases, which got space to hold rain water. This plant is widely grown in tropical and subtropical regions and is famous for its unique elegant leaves style, which make it an exotic landscape plant. The collected water might serve as thirst quencher for travelers, though its taste is not palatable. *Ravenala madagascariensis* usually grows in hot, humid areas in vicinity to coastal regions and is found at the elevations of 450–1000 m. It is an evergreen plant with fan like crown and grows up to 20 m in height. Some plants have been recorded to attain the height of 30 m as well. The trunk can be single or branched with banana-like leaves of 2.5–4 m in length and 80–150 cm in width. The petiole, bearing leaves, are 3–6 m in length. These are arranged in fan shape pattern consisting of around 20 leaves. It can survive in sandy or clay soil but prefers soils wet and moist but not water logged. It grows best in sunny areas but can tolerate partial shades. Wind storms can tear and damage the fan-shaped, large leaves.

In wild habitat, four types of *Ravenala madagascariensis* have been observed: *malama*, *hiranirana*, *bemavo* and *horonorona*. *Malama* is a rare form of traveler's palm and grows in rainforest. The young stage of this form includes leaves arranged in a spiral pattern, lack of petiole while the mature adult stage shows a fan-shaped crown. *Hiranirana* is present abundantly in various forest gaps. Its young stage is quite similar to a fan-like pattern, consisting of petioles and broad leaves, that are arranged in an alternate form in the adult stage. *Bemavo* is the most common type. It grows on deforested areas at 300–600 m elevations, resulting in Ravenala forests. All of its stages show fan-like crown, moreover, this type is often used in constructions. *Horonorona* grows in deforested areas but not on elevations, rather on lowlands. It can survive on well drained as well as poorly drained soil types. It is unique from the other three types as it does not get heighted and produces multiple suckers. It is commonly used as ornamental.

One of the unique characteristics of *Ravenala madagascariensis* is given by its flowers which emerge in between the leaf axils. It is a monoecious plant. The flowers are small, creamy white in color, odorless but full of nectar and emerge annually. They are strongly closed even at maturity, which raises questions about the way they get pollinated. The pollination starts with another Madagascar species namely Lemurs (mammals belonging to the Primates order), which are known to be the primary pollinators of traveler's palm. Lemurs, with the aid of their muzzles, forcefully opens the closed blossoms to access of sucrose containing nectar. The flowers are oriented in such a way that when lemurs opens-up the petals, anthers spring in the forward direction resulting in dusting the pollens on lemur's muzzles. In order to get nectar sip, lemurs use both its hands and feet, while doing so, it certainly comes in contact with stigma and the pollination process occurs. After pollination, the plant produces attractive edible seeds, which are covered in elegant blue arillus. The germination rate of seeds is slow. Seeds show best growth in moist, sandy soil, at temperature of 20 °C. After germination, 2–6 months older seedlings are planted in loamy soil and allowed to grow in full sun light.

The seeds have mealy texture and its oil is used in cooking. Seeds and arils contain 4% and 68% oil content, respectively. The fatty acid composition of its oil lies in between cocoa butter and palm oil. The sterol fraction analysis of seed oil showed seven sterols, out of which beta-sitosterol was abundant, about 65%. Aril oil sterol fraction analysis revealed 12 sterols of which stigmasterol was the main. Regarding medicine, seed oil is reported to have an antiseptic property. Apart from oil, trunk sap is a source of sugar, which can be extracted. The leaves of traveler's palm are mostly used in packing purposes and roofing of houses, its petioles are used in wall construction, bark is usually used to make floors while its trunk is used in construction of houses. It is planted in gardens as landscape, as an anchorage in garden beds, and for its aesthetic beauty in tall buildings and houses.

2.4.19 *Washingtonia robusta*

Washingtonia robusta, commonly known as Washington fan palm or Mexican fan palm, is endemic in North Mexico, Arizona, California and Florida. It is distributed in various regions of Mediterranean Europe, Texas and Hawaii. It is also called sky duster due to its epic height. It is a single trunk palm, which grows up to 22 m in height and 80 cm in width. Older leaves fell off leaving leaf marks on smooth greyish stem in the form of rings. Leaves are of bright green color in a costa-palmate pattern, forming a fan shape, which are about 1–1.5 m in width with 1.2–1.8 m long sharp petioles. The bases of leaves are reddish brown in color and sharp spines are present on the trunk. Canopy of a health palm consist of approximately 30 leaves and it produces 50 leaves per annum (Broschat and Donselman 1990). The older leaves of this palm fall around the stem and give appearance of a hula skirt. *Washingtonia robusta* tolerates hurricanes much better as compared to other broadleaf trees, but it is more susceptible of uprooting as compared to other palm species of the Arecaceae family. It is a monoecious palm with white colored flowers. Flowers bloom in spring season, from a stalk about 2.7 m long, on which white colored blossoms appear. Inflorescence is branched and emerges from the crown. Fruits are edible, round to pear shaped, delicate skin, with approximately 1 cm in width, become brownish black to dark black on ripening. It is a fast-growing palm, tolerating high level of drought stress, and cold as well. In the summer season its growth is surprisingly fast. It can grow up to 1.2 m in a year, in optimal conditions. It continues its growth at moderate levels in colder climates, and can tolerate wide ranges of temperature i.e. as high as 40 °C and as low as −6.5 °C. It can grow in clay, sand or loamy soils but cannot bear water logging conditions. It can bear various pH ranges, though cannot tolerate highly acidic soil but can grow in high alkaline soil. This palm possesses high salt tolerance so it is an ideal landscape choice for coastal regions.

Washingtonia robusta is a fast-growing palm, so it is a good choice for indoor and outdoor growth. As it can be grown in wide climatic conditions, palm specialists and botanicals keep keen interest in this palm. However planting care must be taken and there should be at least a 1.8 m distance between plants if grown in a row pattern. These are mostly grown as fence, as architectural beauty in heighted buildings and in coastal areas. They are widely grown in nurseries, as their transplanting is easy.

2.5 Germination and Propagation of Ornamental Palms

Among woody plants, palms are hardiest to nurture as, besides few exceptions, they can only be propagated through seeds with average germination rates about 20% (Tomlinson 1990). Low rate of germination is due to the presence of immature embryos in seeds. The rate of seed germination varies enormously from species to species. For example, the seeds of *Washingtonia robusta* initiate in more 2 weeks, for *Dypsis lutescens*, the germination time is 3–4 weeks while for *Chamaedorea elegans* germination can halt for many months to start again and continue for more than a year (Wagner 1982). Seeds of palms differ greatly in size, with mostly 0.6 cm in diameter. However, the largest seed among flowering plants belongs to the palm *Lodoicea maldivica* (also known as *coco de mer*, a protected and endangered species). As for the shape, the seeds are mostly round or elongated whereas their small sized embryos are cylindrical. Two types of germination occur in palm, i.e. remote germination and adjacent germination. In former type, the emergence of seedling is away from the actual seed. Primarily, a cotyledonary petiole develop from the seed, which is misunderstood by many people as first seedling roots. The petiole swells at its base from which radicle and plumule appear. Lateral roots emerge from radicle after some time. The palms with this type of germination include *Washingtonia robusta*, *Chamaerops humilis*, *Livistona chinensis*, and *Phoenix* spp. In adjacent germination type, the cotyledon appears from the seed as a small portion known as "button" from which radicle and plumule appear. The first radicle is short lived and rapidly replaced by roots. The type of germination is quite common in *Cocos nucifera*, *Dypsis lutescens* and *Archontophoenix alexandrae*. The viability rate of seeds varies greatly among different palms and is greatly affected by the seeds age and storage methods (Broschat and Donselman 1987). For example, the viable seed time of *Latania* spp. is only 2–3 weeks but for *Dypsis lutescens* the viability extends to a year or more (Broschat and Donselman 1986).

Palms grow best in high temperature so the best time for their growth is the warmer season. Soil temperature can be amplified by covering the germinating containers with polythene sheets. The optimum temperature for best yield of palms is in the range 30–35 °C. For example, the optimum temperature for *Acoelorraphe wrightii* was recorded as 33–40 °C while for *Leucothrinax morrisii* and *Cocothrinax argentata*, the optimum germination temperature is 32–36 °C (Carpenter and Gilman 1988). Many palm species grow best in the forest canopy e.g. *Licuala* spp. that grow best under shades, however a few grow in full sun as well e.g. *Roystonea* spp. However, although leave bleaching may occur due to full sun exposure, it is a guarantee of enhanced root and seedling growth as well. . It is recommended to adjust the depth of seed planting to optimize the level of seeds, which is to be exposed to the sun. Uniform moisture requirements are critical in primary stages of petiole and button emergence. Water logging, over watering and alternate day rainfall is quite lethal for palm development and growth.

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Chapter 3
Cultivation and Growth Constraints of Ornamental Palms

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Abstract Palms are a diverse group growing in tropical to subtropical climates, with more than 2300 species. Palm species are widely used for landscaping, indoor and outdoor decoration. Although palms have great significance in our environment, there are many limitations for a proper palm industry development. There is lack of infrastructure facilities, germination requirements, propagation knowledge, soil type, season of planting, irrigation scheduling and care for young and old trees, nutrional deficiencies and corrective action, control of insect pest and disease management, abiotic and biotic factors and lack of reliable database information. These factors individually or collectively affect palm growth and development. In this chapter we mainly discuss the cultivation and growth constrains of palm species. This information might be useful to overcome major problems of cultivation and beneficial for successful development of palm industry.

Keywords Palms · Cultivation · Propagation · Growth · Management · Nutritional problems

3.1 Introduction

Palms trees (monocotyledonous, family Arecaceae) grow in all climatic zones of the world. This family contains different species of tropical shrubs, trees and climbers. Palms are considered native to tropical regions but some species have their prolific performance in subtropical areas as well (Hazir and Buyukozturk 2013). Palm trees

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consist of several indoor and outdoor species. The most important commercially ones are nut, date, coconut and ornamental palms. Palm trees are considered as the symbol of victory, peace and productivity, tropics and tourism. Mostly they are used as ornamentals, and are thought to impart a “tropical” appearance to a landscape. A wide variety of species are available with a range of characteristics that make them fitting for most landscapes.

Ornamental palms are mostly grown in parks, squares and public gardens, or along streets, roads, avenues and houses. They are cultivated along the coastal belt of any country to increase the economic value of tourism. Ornamental palms are mostly used as indoor plants as they are evergreen, beautiful and very attractive in appearance. Most palms have large fan-shaped leaves which are shiny with green glossy colors when young. However, as they gets older, the leaves become larger and divided. Palms generally do not blossom large flowers, especially when potted indoor as house plants. At old stages, they show a blossom which appears in the form of bunches when grown outdoor. Ornamental palms are very important house plants as they cleans and purify different pollutants produced in house during cooking, filtrating carbon monoxide, formaldehyde and benzene originating from the surrounding environment.

3.2 Botanic Traits

Palm trees are different from conifers, evergreen, deciduous and shady trees. They differ from others trees for their shapes and growing habit as they have tall heights, large big leaves, distinguished foliage and large seeds. Further, they differ in their care and cultural practices. Palm trees have only one apical growing meristem which is located at the top of the trunk. This is the main point of growth. All growth starts from this point that, with the surrounding tissues around originates the terminal bud. In any case, during growth or after maturation of the palm, if this terminal portion is injured the whole palms dies. The inflorescence of palms blooms between, above or below the foliage, either solitary or in multiples depending upon the species. Palms root are not as thick and hard like in other trees. Palms may live from a few months to many years. New roots develop from the root initiation zone and sometimes they become visible at the base of trunk (Basu et al. 2014).

3.3 Constraints in Ornamental Palms Production

3.3.1 Lack of Propagation Practices

Like other fruit trees, palms are cultivated sexually and asexually. The sexual reproduction is not preferred as there are several growth constraints in propagation. If palms are grown through seeds, the offspring obtained will not be uniform. There will be no symmetry among the offsprings as a high level of cross pollination often occurs. The seed shell is often very hard, and special treatments may be required to break the seed coat. The other problem related to sexual reproduction is that the gender of plants cannot be identified, which sometimes may be necessary to know.

The asexual reproduction is mostly preferred as plants can grow easily and their rate of survival is higher. Furthermore, the plant gender is also known. However, the constraint of asexual reproduction is that it is laborious. The suckers or offshoots are required for propagation. Sometimes, during separation of suckers or offshoots, the mother plantroots may be damaged, which can cause the death of the whole plant. A different way of asexual reproduction is through tissue culture. For this method, a proper lab equipment is required. Furthermore, it is an expensive technique and is not always adopted as more experienced staff is required. In developing countries there may be a shortage of resources including electricity, which is of great concern.

3.3.2 Unavailability of Quality Planting Materials

The availability of plant material is a fundamental requirement. Being Arecaceae a very diverse family including several species, there is the huge problem of palms identification. There is no proper attention of private and public sectors towards the palm industry, especially in developing countries. The fluctuation of growth conditions is also a key aspect, as unadequate growth rooms can destroy the whole plant populations. Furthermore, there is a shortage of good quality planting materials. Hence acclimatization of imported palm species is often necessary.

3.3.3 Lack of Proper Knowledge of Plantation

Palms tree require full sunshine and water to keep their green look throughout the year. Often, palm plantation under shade shows stunted growth and poor health conditions. Due to shade conditions, palm trees remain under mature and unproductive for longer periods of time. Palms planted in open area with full sun light mature earlier and may yield flowering and seed production few years after plantation. When planted close to building structures they may remain unproductive for many years. *Brahea armata* (one of the Mexican fan palms) and *Bismarckia nobilis* (originating from Madagascar) are similar, however there are many differences regarding their growth habitats. *Bismarckia* is a monotypic species with only one species in the genus, and having large leaves, growing faster and finally gaining much height. *Bismarckia* seeds are larger in size, less cold tolerant than *B. armata* seeds. For seed germination, proper knowledge should be required to growers about plantation time and germination requirements. Growers have limited information about the production technology and cultural practices of palms. Even they don't know about the planting season which affects their productivity. Further, there is also lack of information about the seed rate, amount of irrigation required, proper nutrition management, plant to plant distance and the general management (Liebenberg and Zaid 2002).

3.3.4 Lack of Management Practices

Management practices plays an important role for the successful cultivation of palms. Lack of proper practices may affect growth, cultivation and propagation of major palm species. Most palm species are imported from Thailand, China and Sri Lanka. These palm are native to the desert mountain valleys, canyons and washes where underground water is continuously available. They are then naturalized in disturbed areas with moderate rainfall. *Washingtonia* robusta is found in California, Florida, Hawaii, Mexico Northwest, La Réunion Island, and Mediterranean countries. This palm is native to the desert mountain valleys and canyons of Sonora and Baja Mexico. It is a popular landscape plant in Florida, California and Arizona and hardy areas throughout the world.

Palm importers have lack of proper technical knowledge of planting and caring of these palms in nurseries. In this way major losses have been occurred to importers. After import, there is need of special care in greenhouses used for proper seedling establishment and growth, which can facilitate a subsequent successful cultivation. Palms need well drained soil for growth, however some of them can grow well on poor soil or even on sand, such as Washington palm. Proper amount of irrigation during the first year of plantation is a very important factor. Too much irrigation may cause different diseases and even the of palm death. Adequate moisture improves a faster growth and plants look better and healthier. In addition, all other crops have proper fertilization programme for good health and early maturity, while there is lack of proper studies for the nutrional requirement in different soils. Trees that are pruned this way again and again can lose vigor and the upper trunk can become spindly such that the crown dies or breaks off in a high wind. Therefore, at least 50% of the green fronds should remain intact with the plant. In most cases, dead fronds should be removed from trees.

3.3.5 Nutritional Problems

Proper nutrition plays a significant role for the growth, health and early maturation of palms. It also helps trees to mitigate adverse environmental conditions. Improper application or non-availability of certain major and minor elements cause drastic effects on growth. As most palms are imported from other countries, proper fertilizer programmes are missed mostly due to importers' negligence. There is also a lack of proper studies on nutritional requirements of different species. No proper documentation is available regarding nutronal deficiencies in palm trees. However, relatively few nutrional problems have been reported such as potassium (K) deficiency in Mexican fan palms. Potassium deficiency is virtually ubiquitous in this species, inducing necrosis of the leaflet tip, leaf discoloration and death of premature and oldest leaves. Palms tree need proper combinations of nitrogen, phosphorous, potassium and microelements to attain a good health. There are fertilization programmes with a controlled release (such as 8-2-12-4) with micronutrient applications to enhance palms growth. These applications will increase the number of leaves in the canopy. Higher K deficiency required higher application of fertilizers for 2–3 years. In addition, boron deficiency encountered in palms produce small, crumpled new leaves. Foliar application of boron has been used for the recovery of plants. Some palm species shows discoloration of leaves such as purple or smaller juvenile plants. Long time exposure of cold weather also produces a discoloration in leaves which disappears with age and increasing plant size.

3.3.6 Lack of Seed Production in Palm Species

Palm have a slow growth as compared to other fruit trees. Some species are also dioecious in nature, in which male and female individuals are separated. For many species, it takes almost 8–10 years for proper growth, development and maturity. However, most of palms have no seed production in Pakistan (e.g. spider palm) except a few that produce seeds e.g. coconut palm. Due to improper information, seeds are not properly harvested and correct sowing techniques are also neglected by many local nurseries. Seeds should be picked after fruit maturation or when fallen off the trees, before germination. They should be washed thoroughly to remove fruit or other material debris and, for germination, must be planted in good quality soil with a good drainage capacity. Proper amount of watering schedules should be followed for germination (normally 2–3 times in a week). On the large scale seed may be sown on the bed in the field, whereas on the small scale a deep container may be used for germination, provided it allows enough space for the root system.

3.3.7 Irregular Irrigation During Plant Growth and Development

It is observed that orchards where palms are cultivated are watered irregularly due to farmers lack of knowledge. Most palm species require plenty of water but there are certain species, such as date palm, which require sandy soils with a low water holding capacity. Irrigation in hot climates can also cause problems and less irrigation during summer may be responsible for deaths (Hussen 2010). The irregular irrigation promotes several stem fungal diseases, especially stem rot and damping off, in early stages. Further flood irrigation practices applied in palm cultivation also have harmful effects by spreading diseases and insects. Moreover, the quality of flood water is not good in palm production areas, and flood irrigation represents a wastage of water as well.

3.3.8 Climate Vulnerabilities

Actually, climate changes are of great concern, the production technology of any crop varying with the changing environment. Climate changes greatly affect the commercial production of palms as well, in particular due to changes in cool and warm weathers. Furthermore unpredicted rainfalls, fog and even storms greatly affect the palm cultivation and their production. Drought, poor or excessive rainfalls, and losses in soil fertility also represent great problems in ornamental palm cultivation.

3.3.9 Lack of Interest for Conservation of Palm Species

Some palm species populations perform well in their native habitats, while remaining unable to vigorously propagate in other environments. *Bismarckia nobilis* propagated on a large scale in its native environment domestically successfully present fruiting and viable seeds. There is need of time for the conservation of available sources of endangered palm species on a large scale, reducing the stress due to the collection of seeds and plants in their original habitats. The developing countries are only limited to specific palms which mostly are grown as food sources, i.e. date and coconut palms. There is no attention towards the ornamental palms, explaining why the industry of these ornamental species is very limited in the developing countries. Furthermore, there is lack of interest shown by growers and government towards this industry.

3.3.10 High Density Plantation and Intercropping

It is observed in palm growing orchards that farmers mostly plant palms at very close distances, so that sunlight cannot reach the stems. Consequently, the microclimate between palm trees becomes favorable for insects and pests, becoming conducive to several fungal diseases. Furthermore, intercropping is also applied by growers at early stages, to get an early profit, but the intercropped plants may become host to insects which also affect the palms foliage.

3.3.11 Non-availability of Resistant Ornamental Palms

In the past, there was a lack of interest in people for landscape and floriculture. So unfortunately, very little research was done on ornamental palms. Until now, we don't have enough palm species which resistant to insect pests or that have tolerance against fungal diseases.

3.3.12 Lack of Reliable Database

There is no available database regarding the palm distribution, cultivation and production technology. As mentioned earlier, due to palm diversity, the research effort is mostly paying attention to fruit trees, including some palm fruits species. But there is no attention toward the ornamental palms. However, nursery men have several palms in their nurseries but their source is unknown and the data base of ornamental species is far from being complete. Furthermore, in developing countries most nursery owners are illiterate, and even do not know the names of their palms. Hence, for accurate identification and promotion of the palm industry, the Government sector should play an active role, inducing nursery producers to strictly follow quarantine measures.

3.3.13 Non-availability of Skill and Infrastructure Facilities

Skill and expertise of workers is still of great concern, as palm cultivation differs from other fruit trees, which receive more attention than other crops. Hence special tools and skilled labor are required for the proper cultivation of palms. Lack of technical labor is still a major issue of many tropical, palm growing areas. To develop type palms cultivation on a large scale, micro-propagation and tissue culture techniques are required. But these techniques are costly and are very less adapted on a commercial scale. Moreover, there is a lack of greenhouses and infrastructures where proper cultivation of ornamental palms should be conducted. The nurseries also need modern tools and handling equipment. Moreover, cold storage and greenhouses are more demanding, due to high maintenance costs.

3.3.14 Insect Pests and Diseases Management

The palm trees grown in oasis environments are often severely attacked by insects and diseases (Al-Yahyai and Manickavasagan 2012). But this problem can be managed and varies with the palm species, climatic conditions and the cultural practices adopted by the farmers (Zaid et al. 2002). Borers, mealy bugs and weevils are the major insects of ornamental palms. While phytoplasms, Fusarium wilt and lethal yellow disease are the major palm diseases. Therefore, huge attention is required to manage insects and pests by providing training to growers, through sessions and extensions services to avoid these major constraints (*Salah* 2015).

3.3.15 Lack of Coordination

There is also a lack of coordination among Government sector, growers, exporters for the floriculture industry. This sector, especially palm industry floriculture, is unorganized, paying poor attention for the palm industry development. This is one of the major constraints in development of the palm industry in developing countries.

3.4 Conclusion

In spite of the great potential of the palm floriculture industry, the performance of this sector is not encouraging. The constraints in palm cultivation include lack of reliable basic quality material, basic inputs and skilled manpower for cultivation. Moreover, there is a lack of infrastructures such as greenhouses and screenhouses. There is no proper control of insects and diseases related to palms. Moreover, there is still need to select varieties tolerant to insects, pests and diseases which can perform better with a changing environment. The Government should play a role to develop this industry, as there is a huge need of cooperation between growers and public sectors. The Government action should support farmers through subsidies for palm cultivation and adoption of modern techniques, sustaining greenhouse infrastructure development and maintenance costs.

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Part II
Economically Important Fungal Diseases of Ornamental Palms: Etiology and Management

Chapter 4
Fungi: Cynosure of Ornamental Palms Diseases

Imran Ul Haq, Siddra Ijaz, Qaiser Shakeel, Guoqing Li, Long Yang, and Ifrah Rashid

Abstract Kingdom fungi is a wide-ranging group of living organisms with rapidly varying and evolving genetic fashion which makes this group more diverse and complex domain of life. Fungi effect and interact other domains of life in different modes and tiers. For plants, they may be a good friends or even worst enemies. They make relation in symbiosis and interact in worsen way as pathogen. It has been established that among diseases, fungal diseases are the cynosure coercions to ornamental palms. Keeping in view this perspective, fungal disease of ornamental palms have tried to be spotlighted in this chapter. A touch base of fungal diseases, which hit majorly ornamental palms has provided in this chapter. Besides integrated management, their molecular diagnosis has tried to be insighted briefly. The chapter provides a brief and comprehensive insight about fungal diseases on the palm in general.

Keywords Ornamental palm · Pathogenesis · Etiology

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_4

4.1 Introduction

In horticultural industry ornamental palms account for $404 million, that is 10% of total output. In California, ornamental palms achieved $70 million sales annually (Hodges et al. 2011). Palm cultivation increasing day to day in developed and developing countries by provision of food, shelter and aesthetic value. These plants decrease the environmental pollution and have a positive effect on the atmosphere (El-Juhany 2010).

Mostly palms are used for aesthetic purposes but some species are used also for food, in tropical and subtropical regions (Howard 2001; Neal 1965). Different genera of subfamily Arecoideae (*Butia*, *Chamaedorea*, *Howea*, *Ptychosperma*, *Archontophoenix*, *Roystonea*, *Syagrus*, *Cocos*, *Dypsis*, *Roystonea*, *Syagrus*, *Veitchia* and *Wodyetia*) and Coryphoideae (*Rhapis*, *Sabal*, *Trachycarpus*, *Brahea*, *Bismarckia*, *Washingtonia*, *Phoenix*, *Pritchardia*, *Caryota*, *Chamaerops* and *Livistona*) are commonly grown in different wet tropic areas of world such as Madagascar, Southeast Asia, Australia, USA, Central and South America, Indonesia and Malaysia (Dransfield et al. 2005; Govaerts 2013).

4.2 Problems Associated with Ornamental Palms

Ornamental palms are affected by many biotic factors including insect and diseases, and abiotic factors such as temperature, nutrition and soil composition (Schmidhuber and Tubiello 2007). Different pathogens fungi, bacteria, viruses and nematodes reduced the aesthetic value of palms at different stages in nurseries. Fungal diseases include wilt, blight, spots, smut, root rot, stem and petiole rots, diamond scale or leaf sheath diseases, *Ganoderma* butt rot etc. (Broschat et al. 2014).

4.3 Fusarium Wilt of Palm

Palms species are threatened by Fusarium wilt. A first infection site was reported as plants started to die in the early decades of 1980s at the Centennial Park of Sydney in Australia (Priest and Letham 1996). This disease was also appeared in different countries of world USA, France, Canary Islands and Japan (Priest and Letham 1996; Simone and Cashion 1996; Arai and Yamagoto 1977). Disease symptoms appeared on leaves of canary island palm *Phoenix canariensis* on different locations of Sydney, Australia. Characteristics symptoms were leaf yellowing, with a chlorotic and brown color starting from one side of the frond towards the center and lower parts of infected trees. Vascular bundles of plants showed discoloration as the pathogen obstructed the xylem tissues of vascular bundles. *Phoenix canariensis* plants, widely used Australia, were severely affected by this disease, which is caused by different strains of *Fusarium oxysporum*. Some strains may be not pathogenic and occur in the soil. It is difficult to identify the pathogenic strains of this soil borne pathogen based on morphology, in laboratory conditions. To diagnose this pathogen at a molecular level a technique has been developed in USA.

Among different fungal diseases, Fusarium wilt is a major hindering factor to different palm species used for ornamental and food purposes. Different species of *Fusarium* cause wilt on different palms, i.e. *F. oxysporum*, *F. solani* or *F. prolifera-yum*. *Syagrus romanzoffiana* and *Washingtonia robusta* are primary hosts of *F. oxysporum* f. sp. *palmarum*. This fungus blocks the vascular bundles, especially the water conducting xylem tissues of palms, ultimately inducing a leaf discoloration and death of rachis. Rachis of the queen palm becomes chlorotic, shaded brown in color on one side of leaves. Cross section cuttings of diseased fronds show a dark brown to reddish color of xylem tissues, a typical symptom of Fusarium wilt. In the case of the Mexican fan palm, half leaf becomes chlorotic, yellow and dried while the other half remains healthy and green. In both palm species the lower oldest leaves become diseased first, then progressively death of upper younger leaves occurrs, and ultimately the spear leaf dies. Palm species die very quickly three to six month after initial symptoms appearance.

Fusarium wilt is spread by contaminating soil, pruning tools, birds, seeds and insects. Seventy different isolates of *F. oxysporum* f. sp. *canariensis* were collected from different parts of the same palm, as well as from different plants, and examined as vegetative compatibility groups (VCGs). Two different groups of strains from one site were found in the Sydney region. One group, from the same region, was based on the frond whereas the other group included non-frond isolates proceeding from roots, soil and fruit. Both groups were not compatible with each other, but seed isolates showed compatibility which indicates the transmission of disease from one location to another. PCR analysis and VCGs results confirmed that the *Phoenix canariensis* wilt epidemic observed in Sydney was caused by *F. oxysporum* f. sp. *canariensis* (Gunn and Summerell 1999).

During 2005 to 2010 a new Fusarium wilt disease appeared on *Syagrus romanzoffiana* and *Washingtonia robusta* in southern Florida. Chlorosis to necrosis on one side of older leaves, with reddish brown stripes on petioles and internal discoloration of rachis tissues appeared on diseased palms. Canopy of plants became desiccated and died within 2–3 months, but dead leaves hang around the trunk. Pathogenicity, morpho-cultural and molecular characterization proved that the causal agent of this disease ws a new forma specialis, *F. oxysporum* f. sp. *palmarum*. Molecular analysis of EF-1α gene from 27 different isolates placed them in two groups with differences in two transition mutations. These two groups were pathogens of both palm species. Phylogenetic analysis of a genetically diverse group of *F. oxysporum* isolates based on EF-1α sequences including three forma specialis (f.sp. *canariensis* pathogenic to *Phoenix canariensis*, f. sp. *albedinis* and f. sp. *elaeidis*) revealed that f. sp. *palmarum* and f. sp. *albedinis* are closely related to each other than the other two pathogenic f. sp. (Elliot et al. 2010).

Fusarium proliferatum caused wilt and dieback on different genera of palms including *Phoenix*, *Washingtonia*, *Trachycarpus* and *Chamaerops*. Different toxins and fertility profiles of strains from 36 different locations have been studied on palms. All of these are infertile except two that belong to mating papulation D. MATD-1 and MATD-2 had high genetic recombination potential in field and isolates of same host species. Among these strains eight were fertile and crossed once as female. Different toxins i.e. fumonisin B1, moniliformin, beauvericin, fusaric acid and fusaproliferin are produced from seventeen strains of *Fusarium proliferatum*. Eight-month post inoculation, plants of *P. canariensis* showed lesions at the base of leaves, followed by wilt symptoms. This proved to be a first report of *F. proliferatum* causing wilt or dieback on *Phoenix dactylifera, C. humilis*, *P. canariensis*, *P. reclinata*, T. *fortunei*, W. *filifera* and W. *robusta* in Spain (Armengol et al. 2005).

For confirmation of the pathogenicity of *F. oxysporum* f. sp. *canariensis* and *F. oxysporum* f. sp. *palmarum* (causing wilt and die back in ornamental palms) some assays have to be performed. A established protocol is based on inoculation of two to three leaves, with 25 ml of a 10^6 spore suspension per ml, pipetted on the base of leaves allowing the excess to run down to the roots in the plant container. After three days, the inoculated plants are transferred to a pine bark/ sedge peat/sand potting mixture. For *F. oxysporum* f. sp. *canariensis* the lower 20% roots are cut and then inoculated for six months as compared to the *F.oxysporum* f. sp. *palmarum* assay. These methods are used for multiple isolates of each pathogenic strains and susceptibility of different palms to become host of these strains. *Washingtonia filifera*, *Butia odoraat*, *Phoenix dactylifera* and *P. reclinata* are susceptible to *Fusarium oxysporum* f. sp. *palmarum* at a juvenile stage. These inoculation methods are helpful to diagnose the plants susceptibility and in management strategies of the Fusarium wilt.

4.3.1 Management of Fusarium Wilt

Ornamental palms should be disease-free for their commercialization. Once the *Fusraium* wilt is established on plants their cure is difficult but integrative approaches can be used for management. Among them, varietal selection, biological control (based on microorganisms and botanicals) and chemical control are most applied management strategies.

4.3.1.1 Chemical Control

Fusarium solani causes the sudden decline disease in palm orchards, with severe losses observed in Khairpur district of Sindh province in Pakistan. This is a soil borne pathogen. For its management six fungicides has been evaluated in laboratory and natural conditions. Among these studies the fungicide Bavistin® DF. at different concentration showed maximum disease reduction. This fungicide controlled the pathogen when applied on diseased plants, that became recovered and healthy (Maitlo et al. 2013).

4.3.1.2 Biological Control

Biological methods include use of microorganisms and botanicals vs Fusarium wilt of ornamental palms. However, once the microorganisms or botanicals proved effective vs Fusarium wilt, their production at commercial level is laborious. Production of various bio-products depends upon their mode of action, survival and dose. Twenty-six different bioproducts are commercially available worldwide, used alone or combination, against *F. oxuysporum*. They can be used also in combination with other control methods to develop a good management of Fusarium wilt (Lecomte et al. 2016).

*4.3.2 Calonectria (*Cylindrocladium*) Leaf Spot of Palms*

Calonectria is a known pathogen occurring worldwide, causal agent of many diseases including damping-off, shoot blight, cutting rot, leaf spot and root rot, on a broad range of host plants i.e. horticultural, timber, ornamental and other agricultural crops. It is well known as causing damping-off in palm seedlings. Initially, the fungus causes a leaf spot disease in palms, that later leads to damping-off. Generally, palms are susceptible hosts for this pathogen particularly in those locations where they are grown at high densities i.e. in nursery fields or containers. Immature palms (in which the trunk is not yet developed) are considered the most susceptible phase to leaf spot.

4.3.2.1 Pathogen and Hosts

Calonectria is the sexual stage (teleomorph) of this pathogen while the asexual stage (anamorph) of this genus is *Cylindrocladium.* Anamorph is the most observed stage of this pathogen. The pathogens include species such as *Cy. pteridis* (also known as *Ca. pteridis*), *Cy. colhounii* (i.e., *Ca. colhounii*), *Cy. theae* (i.e., *Ca. indusiata*), *Cy. parasiticum* (i.e., *Ca. ilicicola*) that have been reported as causing blights and leaf spot diseases of palms in Virginia, Louisiana, Hawaii, Oregon, Tennessee, Florida, North Carolina and South Carolina. Regardless of producing indistinguishable symptoms of the disease, all the four species can be identified easily based on morphology of both the conidia (asexual spores) and conidiophores (stalk-like structures bearing the conidia), as their appearance or structure may be used to differentiate them from one another. The conidiophore has an elongated axis having vesicles at its end point. The size and shape of the vesicle play a chief role in species identification. The palm species that are often affected by this pathogen in the USA include Areca palm or Golden cane palm (*Dypsis lutescens*), Cat palm (*C. cataractarum*), Kentia palm (*Howeae forsteriana*), Belmore sentry palm (*H. belmoreana*), Princess palm (*Dictyosperma album*), Chinese fan palm (*Livistona chinensis*), Parlor palm (*Chamaedorea elegans*), Majesty palm (*Ravenea rivularis*), Atherton palm (*Laccospadix australasica*), Queen palm (*Syagrus romanzoffiana*), Maxican fan palm (*Washingtonia robusta*), Desert or California fan palm (*W. filifera*) and Coconut palm (*Cocos nucifera*). Apart of these mentioned species some other palm species may likely show susceptibility to these pathogens, although not been reported yet. The alternative hosts of *Calonectria* pathogens include many ornamental plants.

4.3.2.2 Symptoms and Disease Development

Small specks and water soaked lesions of varying colours i.e., greyish yellow, reddish brown, dark brown or black appear on the infected plant. Small, circular, brown leaf spots having less than 1 mm diameter are initially developed on infected plants. The old leaf spots are found to be spherical to oval, with a 3–5 mm diameter size range. When lesions enlarge, they show a tan or greyish colour in the center which is bordered by a brownish or halo appearance. With the progression of the disease, the lesions extend and become more irregular. Similar symptoms of specks can also be observed on the rachis. Hence, due to the expansion of lesions the entire leaves, or their leaflets, shrink. Leaf spots can be observed at all the leaf stages, but the fully mature or older leaves are more suceptible.

Leaf spots are the spots which are separated individually from each other by a green tissue of the leaves, while a leaf blight indicates spots which enlarge and merge each other, without any separation between them.

Usually, the asexual or anamorph stage of pathogen (that produces conidia) is responsible for causing the disease, furthermore, the sexual or teleomorph stage producing ascospores may also infect some plants. The conidia can be dispersed by air, insects, rain, handling, irrigation water or pruning. On the other hand, in the perithecia of the teleomorph release the ascospores, which are dispersed by airflows. High relative humidity and moisture on the surface of the host tissue favour the germination of ascospores and/or conidia. Perithecia generally develop on the surface of infected tissues, and later on release the ascospores. Initially the conidiophores are produced by the fungus on the surface of the infected host tissues, and then the conidia are formed for the local dispersion of the pathogen.

4.3.2.3 Diagnosis

Leaf spots have similar patterns as compared to symptoms of K deficiency, visible on mature leaves as blackish spots or of Mn deficiency, visible on young leaves as nectrotic strips.

Some pathogens other than *Calonectria* spp., are also responsible for causing a leaf spot disease on palms i.e., *Pseudocerospora, Colletotrichum, Pestalotiopsis, Pestalotia, Phyllachora, Phaeotrichoconis, Gliocladium, Exserohilum, Cerospora, Bipolaris, Annellophora* and *Stigmina.* All fungi causing leaf spot produce similar symptoms, and hence the diagnosis of a particular fungus (responsible for causing the leaf spot) becomes difficult. So, the determination of *Calonectria* (*Cylindrocladium*) disease on palms can be determined by observing the fungal spores, either directly from the infected leaf or by isolating the fungus from infected leaf and then observing its spore morphology, once in culture.

4.3.2.4 Control

Usually, leaf diseases of palms appear at the seedling stage in nurseries where hundreds of palms are grown in close vicinity with each other. The little space separating plants increases the humidity and dispersal of the pathogen, from infected towards healthy leaves, as the spores can easily travel this little distance towards new plants. Hence, it may be concluded that disease infection can be minimized and plants health improved by growing the plants at a higher distance from each other.

High moisture levels and humidity provide a suitable environment for the germination and dispersion of the fungal spores. Therefore, to avoid leaf spot disease, moisture control is necessary. Disease can also be prevented by increasing the air circulation to minimize moisture or to keep the leaves dry. High moisture content and humidity can also be restricted by irrigating the plants before dawn in the early morning, because wet leaves dry swiftly during a sunny day. Irrigation at night should be avoided, preferring the palms growth under a covered greenhouse or excluding any overhead irrigation. Planting also should be made in such a way that larger plants are unable to restrict the air circulation towards the smaller ones. Regular inspection for leaf diseases is also a key factor because the infection progresses swiftly. To restrict its dispersal to healthy plants it is important to observe the first development of the disease symptoms as soon as possible. In case of palms grown in containers, the infected plants should be eliminated or discarded as soon as possible, to reduce or suppress the further dispersal of infection. Similarly, the symptomatic leaves should be eliminated from the plant when palms are grown in nursery fields or landscape. Infected leaves should not remain on the palm or in the growing area. Various fungicides are available in the market to control *Cylindrocladium* and *Calonectria* pathogens, but their use is not enough to manage the disease, as they become more effective when applied alongwith the implementation of the above mentioned cultural control practices. The fungicides should be applied after removing and discarding the infected leaves and plants. Systemic fungicides should be applied evenly to the leaf tissues by following the instructions on the label, in acquiescence with national rules and regulations.

4.3.3 Candidatus *Phytoplasma Palmae (Lethal Yellowing of Coconut)*

4.3.3.1 Taxonomy and Nomenclature

The phytoplasmas (wall deprived bacteria, earlier known as MLOs which stands for mycoplasma-like organisms) are members of the prokaryotic monophyletic clade Mollicutes. This group has been associated with genus *Acholeplasma* on the basis of phylogenetic analyses of 16S rRNA ribosomal gene sequence (Sears and Kirkpatrick 1994; Gundersen et al. 1994; Seemüller et al. 1994, 1998). Phylogenetic analyses distinguished various groups or subclades, with different species characterized within the subclades according to the phytoplasmas taxonomy (ICSB Subcommittee on the Taxonomy of Mollicutes; ICSB Subcommittee on the Taxonomy of Mollicutes). The "*Candidatus*" name is given on the basis of a taxonomic status to an unculturable strain within each primary subclade (White et al. 1998; Murray and Schleifer 1994; Davis et al. 1997; Zreik et al. 1995; Harrison et al. 2011). Phytoplasmas are transmitted to host plants by insect vectors, mostly planthoppers and leafhoppers (see Sect. 4.3.3.7.1).

Among the 11 subclades of phytoplasmas initially determined by Gundersen et al. (1994), the phytoplasma responsible for the palm lethal yellowing (LY) and coconut lethal decline (CLD), (Yucatan, Mexico) (Harrison and Oropeza 1997) showed a distinctive, merely close association with subclade VII. Phytoplasmas related to coconut lethal yellowing-like disease found in Eastern (lethal disease, Tanzania) and Western (Awka disease, Nigeria; Cape St. Paul wilt, Ghana) Africa are distinguished from those associated with CLD and LY. According to latest phylogenetic classification, these phytoplasmas were placed in new subclades XIV and XII, respectively (Tymon et al. 1998; Liefting et al. 1996). RFLP (restriction fragment length polymorphism) analysis through PCR amplification of 16S rDNA sequences was made to derive the coefficients of resemblance or similarity that resulted in a demarcation of phytoplasmas into 14 groups (16Sr groups) and 40 subgroups (Lee et al. 1993, 1998a, b). Based on less conserved ribosomal protein genes derived from RFLP analysis data, total subgroups of 45 strains were completely resolved. Phytoplasmas variation and classification has been amplified through computer imitation of RFLP analysis of 16S rDNA sequences for 800 phytoplasma lines (Zhao et al. 2009). On the basis of distinct simulated RFLP configurations and calculations of the coefficients of similarity, the strains of phytoplasma were classified recently into 28 total groups (Wei et al. 2007). Considering the RFLP-based classification system, the phytoplasma causing LY has been allocated to the 16SrIV (coconut lethal yellows) group of RFLP subgroup A (16SrIV-A).

4.3.3.2 Description

The size of phytoplasmas is too small so that they cannot be resolved usefully and effectively under a light microscope. Being pleomorphic[1], when examined with transmission electron microscopy (TEM) of ultra-thin sections, the phytoplasmas seem to comprise of spherical to filamentous bodies, surrounded by a tri-laminar membrane unit. Ribosomal granules and DNA strands are often deceptively lost during the specimen preparation (Thomas and Norris 1980; Thomas 1979).

In coconut palms, the phloem vessels contain LY phytoplasma cells varying in diameter and lengths, ranging from 142 to 295 nm and 1 to 16 μm, respectively (Waters and Hunt 1980).

4.3.3.3 Distribution

Currently, the disease is more prevalent in the Caribbean, particularly in Saint Kitts and Nevis islands and can also be found in Antigua (IPPC 2012; Myrie et al. 2012). Since 2005, the disease was reported in Nevis. Currently, the northern and eastern regions of Saint Kitts are affected by this disease (IPPC 2012).

4.3.3.4 Risk of Introduction

LY and related diseases impose a substantial threat to the worldwide production of coconut (Harries 1978b). To depress involuntary dispersion of LY in the tropical regions, the movement or transfer of incarnate palms and palm seeds from infected to uninfected fields is generally prohibited. Moreover, the requirement of quarantine measures vary considerably, involving particular geographic regions.

Mechanical guidelines for the innocuous transfer of coconut germplasm from LY disease affected areas have been established under sponsorships of the International Board for Plant Genetic Resources (IBPGR) for research purpose, while for commercial scale purpose no guidelines have been developed yet (Frison et al. 1993).

4.3.3.5 Hosts/Species Affected

LY phytoplasma (16SrIV-A) has a wide host range including Kutze seashore palm (*Allagoptera arenaria*), Ruffle palm (*Aiphanes lindeniana*), Giant fishtail palm (*Caryota rumphiana*), Clustering or Burmese fishtail palm (*C. mitis*), Coconut palm, (*Cocos Nucifera*), Buri palm (*Corypha taliera*), Round leaf palm (*Chelyocarpus chuco*), Lifou palm (*Cyphophoenix nucele*), Caranday palm (*Copernicia alba*), Rootspine palm (*Crysophila warsecewiczii*), Triangle palm

[1] Showing different shapes and dimensions

(*Dypsis decaryi*), Cabada palm (*D. cabadae*), Puerto Rican Gaussia palm (*Gaussia attenuata*), Kentia or Sentry palm (*Howea forsteriana*), Belmore Sentry palm (*H. belmoreana*), Spindle palm (*Hyophorbe verschaffeltii*), Footstool palm (*Livistona rotundifolia*), Chinese fan palm (*L. chinensis*), Latan palm (*Latania lontaroides*), Mazari palm (*Nannorrhops ritchieana*), Date palm (*Phoenix dactylifera*), Silver date palm (*P. sylvestris*), Canary Island date palm (*P. canariensis*), Cliff date palm (*P. rupicola*), Senegal date palm (*P. reclinata*), Thurston palm (*Pritchardia thurstonii*), Kona palm (*P. maideniana*), Remota loulu palm (*P. remota*), Fiji Island fan palm (*P. pacifica*), Hildebrants palm (*Ravenea hildebrantii*), Arikury palm (*Syagrus schizophylla*), Chinese windmill palm or chusan palm (*Trachycarpus fortunei*), Christmas palm (*Veitchia merrillii*) and Montgomerys palm (*V. arecina*) (Harrison and Oropeza 2008; Eden-Green 1997; McCoy et al. 1983; Harrison and Jones 2004).

LY phytoplasma has been inoculated to various palm species viz Christmas palm, Canary Island date palm, Fiji Island fan palm, Thurston palm, coconut palm, Chinese windmill palm or chusan palm (*T. fortunei*), for experimental purposes. A plant hopper (*Haplaxius crudus*) was used as a vector, collected from Florida diseased palm fields, used for the replication of LY phytoplasmas (Howard et al. 1983, 1984; Howard and Thomas 1980). Florida thatch palm (*Thrinax radiata*) and Mexican silver palm (*Coccothrinax readii*) are considered as symptomless palm hosts (Narvaez et al. 2006). Nevertheless, the host range of LY phytoplasma mostly belongs to members of the family Arecaceae, but at least one non host palm, i.e. arborescent monocot screwpine (*Pandanus utilis*) is also involved (Harrison and Oropeza 1997).

The host range of CLY phytoplasmas (16rIV) from various subgroups is mentioned below:

Subgroup 16SrIV-B: Coyol palm (*Acrocomia aculeata*) and Coconut palm (*C. nucifera*) (Roca et al. 2006).

Subgroup 16SrIV-C: Coconut palm (*C. nucifera*) (Lee et al. 1998a, b).

Subgroup 16SrIV-D: Jiggery palm (*Caryota urens*), Date palm (*Phoenix dactylifera*), Pygmy data palm (*P. roebelenii*), Silver date palm (*P. sylvestris*), Senegal date palm (*P. reclinata*), Canary Island date palm (*P. canariensis*), Buccaneer palm (*Pseudophoenix sargentii*), Queen palm (*Syagrus romanzoffiana*), Mexican palmetto (*Sabal mexicana* and *Roystonea* sp.,), Mule palm (*Butia capitata*), Sabal or cabbage palm (*Sabal palmetto*), Mexican fan palm (*Washingtonia robusta*) (Vázquez-Euán et al. 2011).

4.3.3.6 Growth Stages and Symptoms

Growth stages involved in phytoplasma disease are floral, fruit bearing and vegetative growth stages. A prolonged quiescent (incubation), symptomless stage of infection is the characteristic feature of LY. It takes about 112 to 262 days from the initial infection to development of obvious visible symptoms on young, coconut palm seedlings (Dabek 1975). The length of diseased palms is enhanced about 80 days earlier to symptoms development which is followed by a gradual decline period resulting into complete inhibition of growth, one month prior the the termination of the incubation stage.

The primary phases of LY of coconut palms are accomplished by various physiological and biochemical deviations in roots, that involve clear variations in respiration rate, total and reducing sugars (Maust et al. 2003; Islas-Flores et al. 1999; Oropeza et al. 1995; Martínez et al. 2000). Before development of visible symptoms on aboveground palm parts, reduction in respiration and increment in necrosis of root systems can be noticed (Eden-Green 1976, 1982).

Moreover, the initial symptoms overlap with modifications in phloem fluidity rates (Eden-Green and Waters 1982) and alterations in water circulation (Eskafi et al. 1986; McDonough and Zimmerman 1979) due to suppression of leaf stomatal conducting tissues (León et al. 1996; Oropeza et al. 1991). Due to reduction in growth regulators, photosynthetic pigments and carbon reduction cycle, the lower enzymatic activity reduces the photosynthetic ability of the palm (León et al. 1996; Dabek and Hunt 1976). The Jamaica tall (also known as Atlantic tall) coconut ecospecies, a highly susceptible palm, shows visible symptoms that involve flaking of premature fruit (nutfall) irrespective of their developing phase. A brownish to blackish calyx end rot, that reduces the seed viability, is developed on aborted nuts. Floral necrosis is accompanied by the premature falling of nuts. Emergence of recently mature inflorescences from ensheathing spathe is the characteristic symptom usually observed. Generally, light yellow to off-white coloured inflorescences show partial necrosis or blackening at the tips of floral spikes. With the disease progression, total discolouration as well as more severe necrosis on newly emerged or nonemerged flowers, is the prominent symptom. Escalation of such symptoms leads to the destruction of male flowers together with with lack of fruit set. After the development of necrosis on two or more floral parts, leaves starts discolouration by giving yellow colour and losing their original colour more swiftly, as compared to senescence in normal leaves (Arellano and Oropeza 1995). Yellowing starts from the most mature (older) leaves that extended upward, towards young leaves and reaches the entire crown. The yellow leaves turn brown, wither and then ultimately die. In certain circumstances, the arrival of disease symptom is obvious on the flag leaf, i.e. a single yellow leaf in the middle of the crown. Drooping of effected leaves can be observed developing a skirt-like structure surrounding the trunk some days prior their falling. A rotten basal soft rot of the freshly emerged lance i.e., the youngest leaf, occurs with the progression of foliar yellowing. Toppling of spear leaves and rotting of apical meristem leads towards the death of the palm, consistently and to the collapsing of crown, resulting in the bare trunk of the tree. Within three to six months after the development of initial symptom, the effected palms generally die (McCoy et al. 1983).

LY disease may be also revealed by many other factors. For instance, non-bearing palms are unable to develop flower and fruit symptoms. Among all the varieties and hybrid types of coconut, the discolouration of leaves fluctuates significantly. The coconut palms of the most tall type show golden yellowing of effected leaves before their death, while the small or dwarf varieties usually turn greyish brown to red. Falling of nuts and necrosis of florescence are the basic symptoms at early stage found in all palm species affected by the LY disease. Variation among symptoms can be noticed in that stage at which necrosis of spear leaf developed. Death of spear leaf are followed by discolouration of foliage in edible Date palm (*P. dactylifera*). On the other hand, in Montgomery palm (*Veitchia arecina*) and Manila palm (*Adonidia merrillii*), the spear mainly remains unaffected or healthy until death of all the affected leaves. Leaf discoloration shows two pattern types. Before dying, the leaves turn yellow in colour in species such as gebang palm (*Chelyocarpus elata*), round leaf palm (*C. chuco*), fishtail palm (*Caryota* sp.), princess palm (*Dictyosperma album*), fan palms (*Livistona* and *Pritchardia* sp.) and windmill palm (*Trachycarpus fortunei*). Other susceptible palm species show browning of leaves instead of yellowing. Regardless of species, though, discoloration of foliage usually progresses in the downward to upward direction i.e., from the most mature towards the most fresh or youngest leaf, reaching the crown (McCoy et al. 1983).

4.3.3.7 Biology and Ecology

Transmission

Insects belonging to the families Fulgoroidea and Cicadelloidea (Homoptera: planthoppers and leafhoppers, respectively) are vectors of phytoplasmas, that are transmitted in a persistent manner (D'Arcy and Nault 1982). In Florida, the cixiid *Haplaxius* (syn. *Myndus*) *crudus* is the main vector of LY (Eziashi and Omamor 2010; Howard et al. 1984). North, South and Central Americas and the Caribbean regions are the geographic zones where the respective diseases are common (Howard 1983), where various species of planthoppers are well distributed. Due to this association these insects play a key role in the transmission of LY in these areas (Eden-Green 1995).

Spread and Incidence

Initial occurrence of LY is characterized by two types of dispersion.

One includes the symptoms development either on one or two palms initially, followed by further local dissemination in a random pattern about a vigorous focus of disease, ultimately demanding the most vulnerable palms within the vicinity. This initial focus leads to a second type of dispersion occurring as a chain of spots ranging from a few to 100 km or more, with repetition of local patterns of dissemination (McCoy 1976). In Dade region (Florida), the assessment of local dissemination from palm to palm (McCoy et al. 1983), showed that affected coconut palms served as infection source for 4.6 new palms during of eight months, resulting in the establishment of initial disease foci. The logarithmic dissemination phase proceeded for 2 years, each diseased plant acting as an inoculum reservoir for infection of 9.3

new palms. In south-eastern Florida, the ostensible amount of dissemination of LY infection was normally minor at restricted sites, i.e. palms that are located at the seashore, compared to palms at interior sites under high cultural areas. Variation has also been observed in the amount of infection dispersal among various geographic localities.

Several studies have been conducted based on amplification of phytoplasma DNA through PCR analysis from tissued proceeding from infected coconut palm seeds (Córdova et al. 2003; Harrison and Oropeza 1997; Harrison et al. 1996). Oropeza et al. (2011) showed that presence of DNA of LY phytoplasma in embryos at various developmental phases. The occurrence of phytoplasma DNA in embryo of coconut suggested a possible disease spread through seeds, as there was no previous confirmation for seed transmission of LY (Romney 1983; Córdova et al. 2003).

Impact

The highly vulnerable ecotype of coconut palm is the tall Atlantic, which is the most dominant type all around the Atlantic coast of the Americas and Caribbean regions (Harries 1978a). Throughout previous decades, the estimation numbers of coconut palms eliminated due to LY disease ws about 50% of one million palms in Florida and about 80% of five million coconut palms in Jamaica (McCoy et al. 1983). Congruently, coconut palm were lost due to LY epidemic along the Atlantic coasts of southern Mexico and Honduras (Oropeza and Zizumbo 1997). However, also the palms less than 5 years old occasionally get infected, and the disease inhibits the re-planting of extremely susceptible coconut palms in regions where LY is endemic, including Florida and Jamaica.

Diagnosis

Phytoplasmas cannot be cultured or grown on artificial media as they are obligate parasites in nature. The techniques adopted for their identification have generally been dependent on visual observation of symptoms, electron transmission and fluorescent microscopy. Currently, molecular analysis through hybridization of DNA probes as well as specific and generic PCR primers are used with RFLP analysis or PCR products sequencing.

Transmission Electron and Fluorescent Microscopy

Earlier, the confirmation of field analyses was usually dependent on detecting the phytoplasma in palms through TEM (Thomas and Norris 1980; Plavsic-Banjac et al. 1972; Beakbane et al. 1972). Phytoplasmas that are present in phloem vessels of coconut palms have been termed as non-filamentous and filamentous. The former average diameter range is 295 nm in diameter, whereas the latter measure around 142 nm, with about 16 μm in length (Waters and Hunt 1980). The pathogen is usually found in symptomatic palms in the basal young leaves around the apical meristem, that are rich in phloem (Thomas and Norris 1980). Rarely it may be found in partially necrotic inflorescences and tertiary roots (Waters and Hunt 1980). The mature tissues of infected palms have very low concentration of phytoplasmas that cannot be noticed or detected through this diagnostic technique. Phytoplasma disease is characterized by a concomitant DNA accretion within the phloem which can be confirmed through the treatment of either fresh or chemically preserved plant tissues (Seemüller 1976; Sinclair et al. 1992) using the DNA-binding fluorochrome DAPI. Fluorescence of blue and white patches can be seen in the phloem vessels during exposure of tissues to UV light, through epifluorescence microscopy, while in the vessels of unaffected plants the fluorescent signal is generally absent (Cardeña et al. 1991). However, this method can be applied for analysis at large scale (Andrade and Arismendi 2013). However, due to comparatively high levels of false negatives in palms many problems may arise. The samples in which the phytoplasma concentration is very low or the cells have accrued in an irregular pattern all over the plant are referred as false negatives. Within the plant sample, the presence or absence of phytoplasma is allowed only by both the DAPI and TEM detection schemes, but both these detection procedures are unable to determine the particular pathogenic strain (Harrison et al. 1999).

Molecular Analyses

Non-specific microscopic methods have been extensively substituted by molecular assays through hybridization of DNA probe or PCR analysis, as preferred techniques for disease identification. DNA fragments cloned by LY infected Windmill palm or Manila palm have been used as DNA probes in dot hybridization analyses (Harrison and Oropeza 2008; Harrison et al. 1994a; Harrison et al. 1992) for the identification and detection of the LY phytoplasma and closely associated strains, from extracts of apical meristems (Tymon et al. 1997; Harrison and Oropeza 1997; Harrison et al. 1994b, 1994c). However, variations in specificity and sensitivity for these DNA probes have been observed (Harrison et al. 2008). For the analysis of phytoplasmic DNA restriction profile, Southern blot hybridization has been used, that provides a degree of genetic variation among closely associated phytoplasma strains (Harrison et al. 1992, 2008). Detection of phytoplasma improved considerably after the construction of universal primers for PCR analysis through amplification of the 16S rRNA ribosomal gene (Lee et al. 1993; Martinez-Soriano et al. 1994; Gundersen and Lee 1996). Cleavage of the PCR products with particular restriction endonucleases for RFLP analysis relies on DNA fragment patterns to resolve the phytoplasma identity, by separating the sample fragments through agarose gel or polyacrylamide gel electrophoresis (PAGE) (Harrison et al. 1999).

The sensitive recognition of LY phytoplasma in inflorescence, spear leaf and trunk tissues and the safe or non-damaging sample collection to diagnose LY disease is now possible through PCR analyses. The PCR products digested through restriction endonucleases (including HinfI, Tru9I, AluI or TaqI) are resolved by PAGE. Their profiles are suitable to identify the phytoplasma of the 16SrIV group

(Harrison et al. 1999). They can also be used to differentiate this pathogen from phytoplasma related to lethal decline diseases of African coconut (Harrison et al. 1994a), as well as from other members of the LY phytoplasma group (Cordova et al. 2000).

Ribosomal gene sequences of '*Ca*. Phytoplasma palmae' and associated strains are selectively amplified by PCR primers based on regions of the 16S rRNA gene or the 16–23S intergenic spacer region (SR), allowing a specific recognition of groups or subgroups. Products of 928 bp from strains of LY phytoplasma causing infection in coconut and Pandanu, s and from LY phytoplasma of Yucatan coconut lethal decline (YLD) and Carludovica palmata yellows (CPY) are amplified using forward and reverse primers 503f and LY16Sr, respectively, which amplify the 16S rRNA gene (Cordova et al. 2000; Harrison et al. 1999). Digestion of the resulting amplified product through AluI endonuclease is then performed to further distinguish the strains. 16S rRNA gene sequences of the LY causal organism are selectively amplified by LY16Sf and LY16Sr from mixtures including DNA of the host palm (Harrison and Oropeza 2008). The product obtained by using the LY16Sf/LY16Sr primer pair may be then used for re-amplification by using the universal primer set P1 and P7 (Harrison et al. 2002).

Phytoplasmas infecting coconut in Jamaica are distinguished from those found in Florida, Honduras and Mexico through the cleavage of rDNA products, showing a polymorphism due to the HinfI endonuclease restriction site (Harrison et al. 2002). Specific strains of '*Ca*. Phytoplasma palmae' of subgroup 16SrIV-A may be identified in screwpine palm (*Pandanus utilis*), and in the insect vector (*Haplaxius crudus*), by PCR analyses with non-ribosomal primer set LYF1/LYR1 (Harrison et al. 1994a, b, c; Llauger et al. 2002). Various groups and subgroups of phytoplasmas have also been differentiated by analysing less conserved gene sequences (secA) (Hodgetts et al. 2008).

Detection and Inspection

The status of LY diseased palms cannot be determined successfully through visual observation of symptoms due to the disease prolonged development in the host palm (Dabek 1975). For recognition of LY neither biological nor serological tests have been developed yet. Currently, PCR is only the most sensitive test available for the recognition of phytoplasma, however, due to the low pathogen concentration in palm tissues, this diagnostic technique is complicated. For evaluation of non-symptomatic, pre-bearing coconut palms for natural LY disease development, monthly collections of spear leaf samples wer performed, for disease assessment followed by PCR analyses. Data showed that in these palms, the phytoplasma was detectable 47 to 57 days before the development of visible symptoms on foliage (Harrison et al. 1994c).

Similarities to Other Species/Conditions

Some diagnostic symptom for LY palm disease may be similar to other stress or disease conditions. Abiotic factors including deficiency of essential nutrients may also cause similar symptoms i.e., deficiency of boron may also cause premature nutfall and deficiency of potassium may cause discoloration of foliage. The advanced symptoms produced by ganoderma butt rot (*Ganoderma zonatum*) closely resemble those of LY, including a basal stem rot progressing towards the canopy and resulting in wilting, decline of mature leaves and dying of the spear leaf (Broschat et al. 2010). Coconut palms may also die off because of Phytophthora bud rot, hart rot and red ring (Parthasarathy and Van Slobbe 1978; Bennett et al. 1986; McCoy and Martinez-Lopez 1982; Uchida et al. 1992; Joseph and Radha 1975; Griffith 1987). All these diseases show numerous symptoms that resemble those of LY. The geographic range of these diseases overlay with LY zones in certain areas of the western Caribbean region and, as a consequence, they may induce confusion during field diagnosis. The development and sequential advancement of symptoms (syndrome occurance) are helpful to define a precise identification of LY disease.

In other regions such as Togo (kaïncopé disease) (Dabek et al. 1976), Nigeria (Awka wilt), (Ekpo and Ojomo 1990), Cameroon (kribi disease) (Dollet et al. 1977), Ghana (Cape St. Paul wilt), Tanzania and Kenya (Nienhaus et al. 1982), coconut diseases due to phytoplasmas that resemble LY have been documented. In the past, the unavailability of methods for the comparison of associated aetiological agents resulted in inaccurate assumptions about the origin and association of these diseases (Howard 1983; Maramorosch 1996). Currently, comparisons through molecular assays showed that LY was phylogenetically dissimilar from the phytoplasmas of the African coconuts. Correspondingly, in West Africa, phytoplasma strains of group 16SrXXII infecting coconut palms (Wei et al. 2007) were also found to be different from strains causing a coconut lethal disease in Tanzania and Kenya, closely related or analogous to phytoplasmas infecting coconut in Mozambique (Bonnot et al. 2010). A number of phylogenetically different phytoplasmas related with coconut diseases have been found in other areas, involving diseases such as coconut root wilt (Manimekalai et al. 2010), Kalimantan wilt in Indonesia (Warokka et al. 2006), Bogia coconut syndrome in Papua New Guinea (Kelly et al. 2011), yellow leaf disease of *Areca catechu* (Ramaswamy et al. 2012) in India, coconut yellow decline in Malaysia (Nejat et al. 2009a, b, 2012), and Weligma coconut leaf wilt in Sri Lanka (Perera et al. 2012).

Prevention and Control

For the application of chemical control, the pesticides registration, list of nationally registered products and significant authority should be considered to determine legally permitted pesticides products in one's country. Pesticides should be applied or utilized legally, relying on labelled products and available informations. The only way to practically control LY disease of coconut for long periods is the use of genetically resistant host palm varieties, types and hybrids. In the past, Malayan dwarf and the Maypan (Malayan dwarf × Panama tall) were found to be resistant coconut hybrids against LY disease, and widely used for re-cultivation in Jamaica and other countries where the disease was present. However, current data from cultivations of these hybrids in LY infected areas showed high death or decline rates, as these cultivars cannot be considered resistant, any more (Broschat et al. 2002; Lebrun et al. 2008). In other countries, including Ghana, other hybrids showed no resistance to LY disease, although there was extensive cultivation of the hybrid Malayan Yellow Dwarf × Vanatu Tall (MYD x VTT). This hybrid were used to substitute those palms that surrendered to the Cape Saint Paul Wilt disease of coconuts (Danyo and Dery 2011; Danyo 2011). Moreover, resistance levels have been recognised in other palm ecotypes including Fiji dwarf, Red spicata dwarf, Chowghat green dwarf, Cuban dwarf, Sri Lanka yellow dwarf and King, but this resistance has yet to be utilized commercially (Harries 1995; Ashburner and Been 1997).

Apart of coconut, no resistance against LY has been developed in other palms, i.e. date palm (*Phoenix dactylifera*) in spite of its significant commercial value (Howard 1992). Excluding *Pritchardia* species (Howard and Barrant 1989), other palm hosts show susceptibility to LY disease, although their suceptibilty is variable and usually less as compared to coconut palm (McCoy et al. 1983; Meerow 1992). Various important species of ornamental palms are ostensibly non-hosts of LY disease and may be suggested for landscape and amenity cultivation in infected areas (Chase and Broschat 1991; Meerow 1992). Elimination of affected palms is not sufficient to suppress LY disease dissemination among extremely susceptible coconut ecotypes, in recently infected regions. Suppression of disease dispersion has been noted through the use of insecticides, by reducing the population of the vector *Haplaxius crudus* (Howard and McCoy 1980). The tropical fodder grasses, including *Hemarthria altissima*, *Brachiara brizantha* and *Chloris gayana,* are considered as poor hosts for the vector *H. crudus*. Using theses grasses as groundcover in the palm growing areas is considered as a suitable method to reduce the vector population (Howard 1989, 1990).

Treatment through systemic antibiotics i.e., oxytetracycline-HCl (OTC), by quarterly trunk injection, can be successful but are not suitable on a commercial scale or in large coconut cultivated areas (McCoy et al. 1976). Meanwhile, in landscape and amenity cultivated palms this control method can be used for disease management at early stage of symptoms development, as well as to avoid the disease as a preventive measures, in healthy palms (Hunt et al. 1974; McCoy et al. 1982).

4.3.4 Ganoderma Rot Disease

Ganoderma butt rot is caused by *Ganoderma zonatum*, which is one of the major pathogens that causes a specific disease in palms, termed as butt rot disease. This fungus attacks the plant bottom 1.2–1.5 m along with root rots, both in natural and planted conditions. The genus *Ganoderma* owns wood-decaying fungal members distributed worldwide on all wood types i.e. palms, gymnosperms and woody dicots. *Ganoderma zonatum* belongs to Phylum Basidiomycota, Class: Agaricomycetes, Order: Polyporales and Family: Ganodermataceae.

4.3.4.1 Symptoms

The first visible primary symptom of Ganoderma rot is a mild to severe wilting or withering and drooping of the lowest fronds in the plant canopy. The older leaves die prematurely and the infected tree shows a general growth decline with a slower growth and foliage discoloration in newly formed fronds. These symptoms may be observed even if the plant has a proper nutrition. Furthermore, the head dropping off and development of conk (a spongy, white mushroom-like outgrowth) are also distinct symptoms. Tapping the outer solid looking trunk produces a hollow sound, and the palm roots are severely damaged.

Initially the symptoms produced by Ganoderma butt rot-like wilt or premature death of the lowest leaves in the canopy can be confused with symptoms produced by phytoplasma, Texas Phoenix palm decline or LY. Moeover they differ from the Thielaviopsis trunk rot that normally causes a rot in the upper trunk half, starting from the outside to the inside at a precise and definite infection point.

4.3.4.2 Host Range, Source and Dispersal

Ganoderma *zonatum* infects all palm species. The spores produced in the basidiocarp act as a primary source of infection among plants. They fall in soil and germinate producing hyphae that then grow over the roots, leading up into the woody trunk. The area of palm trunk that is closest to the soil gets damaged first and then the infection is expanded in diameter, moving towards the central area of the trunk, making the infected trunk cone shaped.

4.3.4.3 Management

Literature data show no association of Ganoderma butt rot with environmental conditions or landscape management. Even highly maintained, well drained, nutritionally strong, transplanted and natural (never transplanted) landscapes have shown occurrence of the disease. Moreover, no positive correlation has been found between soil type and the disease incidence, whether the palms were grown in deep sands, muck (peat), or limestone rock.

Although no specific management strategy is available for control of *G. zonatum*, keeping low moisture levels in the palm tree vicinity and practicing a strict field quarantine may help in managing the disease. The chipping or mulching of the lower trunk portion is not recommended as the fungus affects lower parts, up to 1.2–1.5 m. If possible, the section that is diseased is recommended to be destroyed or to be placed in a landfill, chipping and mulching the remaining uninfected part of the palm trunk. The dead or removed palms must be separated from the growing areas to avoid basidiospores perpetuation from conks (basidiocarps) that are the source of primary inoculum. The conk must be incinerated. Monitoring the palms every six months is recommended.

4.3.5 Bud Rot Disease

Phytophthora palmivora globally affects crops, infecting more than 170 diverse host plants species that include dicots and monocots, vegetables and trees, resulting in catastrophic yield losses (Drenth and Guest 2013). The pathogen is capable to infect roots, shoots, stems, leaves, flowers and fruit of numerous plant species, proving itself troublesome as a tropical plant pathogen. In palms, it attacks the apical meristem (the growing point of the palm or bud or heart) making the whole plant stressed. As the agriculture in tropics is getting intensified, the damage caused by *P. palmivora* is increasing due to the pantropical distribution of this pathogen.

4.3.5.1 Pathogens and Hosts

The palm bud rot is caused by either one of these two pathogens viz. the oomycete *Phytophthora palmivora* or the ascomycete *Thielaviopsis paradoxa*. Both of these pathogens produce similar symptoms. Thus, for identification of the exact casual agent, a laboratory diagnosis is required. However, its quite uneasy to isolate these pathogens.

4.3.5.2 Symptoms of Bud Rot

The typical symptom produced by *P. palmivora* is the formation of water-soaked tiny lesions in the soft leaflets tissues at the spear leaf base, that gradually increase in number and size. The careful dissection of diseased palms heart tissues reveals lesions extending to developing leaflets. Drying of lesions makes middle lamella to falls out, as a result a shot-hole that appears in the middle of the leaflet. Also the interveinal tissue is destroyed, with a bite-like symptoms that occurs in lesions at the edge of the leaflet (Sarria et al. 2013). Numerous growers call these symptoms as spear rot, when they become visible at an early stage of bud rot.

With high rainfall and/or humidity, the lesions become larger and affect more leaflets near the heart of the palm. At later stages, when the disease is fully developed, a totally dried part of the emerged leaf spear is observed, while a complete destruction occurs in the white central not yet emerged tissue and above the meristem (Sarria et al. 2013). Despite the extensive variations in bud rot symptoms, the young developing tissues and the meristem are always destroyed, giving the name to the disease. Destruction of the meristem by *P. palmivora* results in the development of no younger leaves and the subsequent invasion of saprotrophic microbes and insects completes the bud deterioration.

Factors such as a broad host range and the invasion of multiple tissues on a single host plant, i.e. fruit, leaves, flowers, stems and roots, contribute to a complex life-cycle of *P. palmivora* in the tropics (Waterhouse 1974). The production of spore variants such as zoospores, oospores, chlamydospores and sporangiospores, promote host invasin and disease transmission to new hosts, as the propagules spread by air, soil, water and different vectors (Konam and Guest 2004).

4.3.6 Phytophthora

Phytophthora palmivora is the most common fungus considered as causal agent of bud rots in palms and other plants in warm temperate, subtropical and tropical climates. The Phytophthora bud rot infects palms in landscape, containers and field nurseries at all developmental stages. The fungus is characterized by the production of three spore types i.e. sporangia (moved by wind or water), zoospores (motile in water) and chlamydospores (very long lived in the soil). Availability of excessive amounts of water is very crucial in the life-cycle of this fungus and disease development.

4.3.6.1 Symptoms

Chlorosis and wilting of youngest, unopened spear leaf are the first symptoms of Phytophthora bud rot. The upcoming new leaves are also wilted and discolored (lighter green) or yellow (chlorotic). Ultimately, they turn brown, become desiccated and collapse. Most often blighted areas on the blade are observed if leaves are closely examined. Distinct necrotic or brown areas also develop at the leaf base. At disease progressin, the leaf base becomes rotted with a foul odor and the spear leaf can be easily pulled out from the bud. The pathogen infects youngest leaves, progressing down the leaves to the bud.

The symptoms of wilting and discoloration of youngest leaves are most common when infected palm plants are in a container or in the field, with a size less than 1.75 m. However, if plants are larger, then lack of new leaves in general, and specifically of spear leaves with an open-topped crown, are the first symptoms of bud rot infection to be observed. No new leaves emerge any more from the already dead buds. However, the already present leaves remain green, healthy and attached to the trunk for many months, finally turning into several shades of green, brown and yellow as they naturally senesce.

During rainy season, bud rot is more likely to occur in landscape conditions and more frequently after a hurricane or a tropical storm. However, in field production or in container nurseries the disease can occur at any time, particularly if the palms are given an overhead irrigation.

4.3.7 Thielaviopsis

Thielaviopsis paradoxa has a broad host range within the palm family. The fungus produces two diverse kinds of asexual spores, endoconidia and chlamydospores, the latter surviving for very long periods in the soil.

4.3.7.1 Symptoms

It is reported that *Thielaviopsis* bud rot produces identical symptoms as in the case of Phytophthora bud rot, although this similarity is not well documented. However, the possible difference is that *Thielaviopsis* invades the trunk after passing through the bud tissues, as it can degrade woody tissues, whereas *Phytophthora* does not.

4.3.7.2 Diagnosis

The causal agent of bud rot is usually identified in the laboratory. The proper identification of these pathogens is very crucial as each of them requires as different fungicide for management. Generally, a combination of both healthy and diseased tissues is considered as the best sample for disease diagnosis. The diagnosis becomes more difficult if a sample contains completely rotted tissues, as secondary saprotrophic organisms are likely to be present. The information related to environmental conditions prevailing during and prior the symptoms development are also helpful in diagnosis.

4.3.7.3 Management

Cultural Control

Water management and proper sanitation conditions are important for pathogen control in field and/or container nurseries. The spores are likely to be spread by rain or irrigation splash as excessive water favors their germination and subsequent infection. Moreover, spores also move from one to another place in a flooded field. The movement of air among plants is helpful, and increased by increasing distances. Also, early morning irrigation may reduces leaf wetness and infection rates. Overhead irrigation should be avoided or, if possible, plants must be grown under a rain shelters. The plants should be trimmed carefully with disinfected tools and damage to the bud or young leaves should be avoided. Immediate removal or destruction of severely diseased plants is also effective to limit the spread of the pathogens. The potting mix of containers with diseased palms should be removed from the nursery. The diseased palms must be removed, destroying the canopy region (including the bud). The lower trunk of mature palms can be recycled in the landscape, if it results pathogen-free.

Chemical Control

The products with active ingredients such as phosphite, propamocarb mefenoxam, or fosetyl-Al are usually recommended for bud rot caused by *Phytophthora* spp. The product containing propamocarb may be used in container nurseries only. Products containing thiophanate-methyl active ingredients are recommended for bud rot caused by *Thielaviopsis*.

The mixture of these products can also be used if the actual cause of bud rot remains unknown, even after a laboratory analysis. A similar product named Banrot® (a mixture of active ingredients etridiazole and thiophanate-methyl) is available in market for nursery crops. It should be applied only as a bud drench with other fungicides. All fungicides should be used following the instructions provided by the manufacturers on their labels.

The actual reason for applying a fungicide in nursery conditions is to avoid infection as the palm usually dies unless bud rot is detected in a juvenile stage. Frequent monitoring the nursery stocks for bud rots is recommended all the time in general, and in specific in prolonged periods of rainy weather or after a tropical storm.

In the case of mature palms, it is more difficult to manage the disease as in the nursery, because in field or landscape conditions the palms have tall trunks and the bud and emerging leaves are difficult to reach. The palms with missing spear leaves and without new emerging leaves, or with easily removable spear leaves upon pulling, should be immediately removed as they will only act as a source of fungal spores for neighboring plants. Applying fungicides to such plants is not recommend since their bud is already dead.

However, it can be helpful to apply fungicides on palms neighbouring a bud rot infected one. In the case of bud rot caused by *Phytophthora* spp. it is recommended to apply the products containing mefenoxam or fosetyl-Al as bud drench. Injecting phosphite in the trunk of palms can also be effective.

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Chapter 5
Fungal Diseases of Foxtail Palm (*Wodyetia bifurcata*)

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Abstract The foxtail palm, *Wodyetia bifurcata,* is an ornamental perennial member of family *Arecaceae*. It is native to Queensland (Australia) and a sole member of genus *Wodyetia*. This palm is adaptable to various climates and is host of only a few fungal pathogens. However, it is frequently infected by leaf spot disease that badly damages its ornamental value. This chapter will describe the basic growing conditions of the foxtail palm, the associated fungal pathogens and their management.

Keywords Palm · Foxtail · *Wodyetia* · Pathogen · Fungi

5.1 Introduction

Being classified as monoecious and being the sole specie within its genus, the foxtail palm (*Wodyetia bifurcata*) has become a popular landscape focal specimen and desired indoor container plant, because of its charismatic fronds which are naturally arched as it grows. The foliage also gives a feather-looking appeal because of its fishtail leaflets that are arranged in a slender stem, creating a design such that of a ‘fox tail’ hence it became its popular name (Perez et al. 2009). Foxtail palms inhabit tropical regions such as Australia and South Florida because it naturally loves exposure to sun. It can also withstand moderate drought and is salt-tolerant, making it desirable to plant near coast areas such as Miami, Honolulu and Los Angeles. Historically, this plant was accidentally discovered by ‘Wodyeti’, an Australian aboriginal sometime before 1978. It was in 1983 that he brought his newly discovered specimen to a plant grower thus naming the plant after him. *Bifurcata*, however, was derived from a Latin word which means “*twice-divided*” or divided into two, as the crown shaft of the palm does, emerging from the center dividing the foliage not only into two but as many as eight parts (Perez et al. 2009). This palm is

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_5

solitary in nature when fully grown. It can reach as high as 10 meters and makes a canopy of at least eight or ten leaves per trunk, making it a favorite among palm growers and commercially produced for ornamental purposes. When the foxtail palm blooms, it can be a good focal point for a garden landscape, especially when planted in a cluster of three or five trunks. Most architects chose Foxtail palm, using it as lining for a walkway or driveways. Some people uses it for additional impact to a beautiful background/view. Foxtail palms can also be grown for household ornament in large, decorative containers. Provided it receives an appropriate care, the palm can be placed indoor or to partly shaded areas in a room. In case of hotels and other big buildings, it can be used as focal accent as long as lights can be mounted above the foliage at least 8 m away from it. It is also suitable for indoor landscaping if the plant receives partial to slight sunshine, proceeding from a window or any open access in the building such as a roof top, balcony or patio (Perez et al. 2009).

Palms like coconut and African oil palm are highly valued in the market because of their many uses. Foxtail palm is considered of economically importance as it is regarded highly as a landscaping specimen because of its charismatic appearance. When relying on foxtail palm for any environmental purposes, we should be aware that *Wodyetia* is easy to manage whether at home, in hotels or upon open areas. The plant needs minimal care as it matures. It only needs moderate amount of water and fertilizer. The moist coming from the coast is favourable for the plant, particularly among its frond. Trimming is not necessary as the palm is self-cleaning, meaning when old leaves die, they simply fall to the ground to give room to the new leaves. The cycle of growth continues until the palm reaches its maturity height up to 3 m (Perez et al. 2009).

5.1.1 Growing Conditions

Wodyetia bifurcata is native of Australia and Oceania but it can also adapt the weather temperatures of Auckland (New Zealand), or Cape Town (South Africa). It prefers well-drained, acidic-free soil and a location with good sunlight exposure. Foxtail palms can tolerate humidity and wind of seashore , making it suited to be planted along ocean fronts and areas which are salt-prone. To maintain a moist environment, waterfalls, fountains or swimming pools could be improvised. This will be favorable not only for the foliage of the palm but is beneficial for growers and palm enthusiasts who enjoy the plant, as it will also accentuate the immediate background (Perez et al. 2009).

5.1.2 Propagation

Propagating foxtail palms begins from seeds, that have to be separated from their fruits and scarred by splintering their coat using any pointed tool, or by rubbing the seed coat with sandpaper. Too much pressure in scraping should be avoided. The seeds are planted in a large container filled with organic peat or humus, possibly in a large pot to give room for the future roots system.

The seeds of *Wodyetia* can be sown horizontally as long as the medium used can be easily drained. A mixture of 2:1 or 3:1 perlite should be added in the medium to provide aeration and to improve water drainage. Seeds can be then covered with soil (Perez et al. 2009).

5.1.3 Germination and Transplant

Foxtail palm seeds can be germinated in tight-sealed plastic containers filled with the above mentioned peat. A nursery or greenhouse with mist can be set up to maintain moisture. The best time to transplant *Wodyetia* is during spring and summer. However, care should be taken when transplanting a foxtail palm. The planting site must be free from pests and diseases, without nutrient deficiencies and capable to accommodate the spread of fronds as the palm grows. The crown can spread up to 4.6–6.1 m across its canopy so the palm should be transplanted considerably 2.4 m away from any premise, or even farther to give way to its multiple trunks. Likewise, space in planting allows the head of the palm to flourish out without fronds being damaged. If planting in a row, they must be placed at least 1.8 m apart. If a close structure is desired, 1 m distance is acceptable. In the first year from transplanting *Wodyetia* top-growth is usually less than expected. In fact, the care given should be monitored because during the early year of its maturation, foxtail palm dedicates its energy for the growth of new roots (Perez et al. 2009).

5.1.4 Management

Mulching lessens the weed growth, favouring water retention beneath the canopy area. However, mulch should not hug the trunk because it might encourage disease infestation. As mulching help retaining moisture, it is advised to be done quarterly. Aside from the cited benefits, mulching also discourages ornamental growers or maintenance staff from wounding the trunk with mowers and trimmers (Perez et al. 2009).

5.1.4.1 Watering

Foxtail palms appreciate well-drained sandy soil and are not suitable to areas that have stagnant water for extended periods. Raised mounds are necessary if the soil condition is a bit clayey or if water tends to stand for quite a time. When a transplanted plant is established, it would not require much water to survive. Foxtail can withstand dryness provided moisture is available throughout the year. Nonetheless, regular watering is required during the first two years (Perez et al. 2009).

5.1.4.2 Fertilizers

A moderate application of slow-release fertilizer above the root ball area provides effective results 3–4 months after transplant. Whenever the juvenile leaves emerge, the palm needs a regular supply of nutrients. Fertilizers should be balanced, must contain micronutrients and trace elements. Rapid release fertilizers easily seep through soil, which is not beneficial to the deep and spreading root system. Therefore, a controlled release is favored. Nitrogen encourages lush green foliage growth thus foxtail needs heavy nitrogen fertilizer for foliar growth. Manganese and nitrogen help boost deep-greening of the fronds. However, in case of manganese toxicity, it can be corrected by applying limestone. It is desirable that nitrogen, and especially potassium and magnesium, be in slow-release forms such as resin- or sulfur-coated products, to prevent leaching of the nutrients away from the rhizosphere.

As most palm desire, fertilizers in a pellet form are suggested to be distributed around the area. Fertilizers should not be dumped in large amounts on newly forming roots because they may severely affected. It should also be avoided to broadcast fertilizers close to the trunk. There are formulations which are appropriate for foxtail palms such as 13-5-8. In addition to the major nutrients, micronutrients may also be added to the palm to boost up its immunity and reproductive traits (i.e. flowering). There are different variants of the fertilizer formulations that can release nutrients over different time periods. This fact should be considered and discussed with the manufacturers before applying special garden fertilizers. Application of fertilizers every month is recommended if water soluble fertilizers will be used to equilibrate the potential of rapid leaching of nutrients. As for controlled-release fertilizers, even broadcasting is recommended over foliar. Emerging aerial roots at the stem base should be protected from direct contact with fertilizers, to prevent them from being damaged. For foxtail palms growing in containers, a controlled-release fertilizer with NPK ratio of approximately 3:1:2 is recommended. At all times, following the manufacturer's application rate remains advisable. Applications could be done on spring, summer and autumn (Perez et al. 2009).

5.2 Fungal Diseases of the Foxtail Palm

Generally, foxtail palm is easy to manage and not much of a problem when it comes to maintenance. If a foxtail palm is observed to be "sick", there is only one factor to check. It is either failure in care and maintenance practices or a climatic condition is not fair. Being problem-free it doesn't exclude susceptibility to diseases because fungi can attack even the healthiest tree. Common symptoms of "foxtail palm sickness" generally include yellowing or browning of foliage. Drooping leaves and slow growth are observed above the palm tree while below the soil, roots tend to be soft and pulpy. Experiencing rot in palm could be a result of poor cultural practices, mainly due to poor drainage, stagnant water and overwatering. Here are some of the common fungal diseases found in Foxtail palm.

5.2.1 Ganoderma Butt Rot

Ganoderma but rot was first observed on *Wodyetia bifurcata* in Malaysia in 2016, but reported in literature during 2018 (Farid et al. 2018). In 2018 *Ganoderma zonatum* was also discovered infecting foxtail palms in Florida, USA (Elliott et al. 2018).

The disease is primarily caused by the fungal pathogen *Ganoderma boninense* (Farid et al. 2018) as well as by *G. zonatum* (Elliott et al. 2018). The genus belongs to the phylum Basidiomycota, order Polyporales, family *Ganodermataceae*.

5.2.1.1 Symptoms

In the field, the foxtail palms show pale green leaflets often wilted. Fronds show only a single spear leaf remaining, and white fungal primordia emerge at the base of infected plants. This white fungus (differing in color from the creamy-white healthy tissues) makes the infested tissues succulent, brown and rotten on the later stages. Outer bark indicates clear depressions and necrotic lesions particularly around the basal stem portion. The rotten stem emits a mushroom-like odor and looks brownish, dry, and friable particularly at the center (Farid et al. 2018).

When infested with these pathogens , foxtail palms may live only for 3–4 years at maximum.

5.2.1.2 Pathogen Biology

The pathogen generative hyphae are hyaline, septate, and thin-walled with clamps. The binding hyphae are hyaline in color, branched and thick-walled without septa. Shape of the cuticular cells is spherical to irregular with a golden-brown and encrusted thick wall. The fruiting bodies of the pathogen are light to dark brown, with undulating and laccate upper surface. Spores are golden-brown in color with thick wall and rough surface, ellipsoid in shape measuring 11.8 to 13.8 × 7.7 to 9.7 μm (Farid et al. 2018).

5.2.1.3 Disease Management

Care should be considered in choosing the field where planting or transplanting of palm trees should be done, because *Ganoderma* spp. thrive in any type of soil once it comes in contact with them. The fruiting body (conks) do not visibly appear on the trunk so growers never know exactly when a palm is infested or not (Elliott and Broschat 2018).

Ganoderma spp. are wood-decaying fungi that thrive in almost any kind of wood such as softer hard wood of palms. These fungi develop a palm disease that attacks the trunks of the closer trees. When the new leaf turns brown to yellowish in color it should be remove before it gets unrolled. It is typical for the fungus to attack the new leaf first, known as bud, developing a bud rot. This process just duplicates on the adjacent frond, moving to the newest ones, with further discoloring and eventual rotting (Elliott and Broschat 2018).

Through basidiospores, which are formed from basidiocarps, *Ganoderma* infections spread rapidly throughout the palm. Therefore, the first step to prevent the fungus from multiplying is to monitor its growth closely. Since basidiospores scatter easily with the aid of wind and water, it is highly recommended that all dead palm tree parts should be removed from the trunk and incinerated or thrown to a dumpsite. Placing the cut trunks in a trash would not help eliminate the conks. It might just spread along the way as the trash will be thrown in time to a nearby garbage area in the backyard. If the conk is removed soon, the less it would spread basidiospores in the surroundings. It is adequate to monitor the palm tree semi-annually. A fungicide can be used to treat the initial growth of the pathogen. It might take some applications before killing the fungus (Elliott and Broschat 2018).

Ganoderma butt rot occurs naturally and is difficult to eliminate. It may be favored by many conditions even in highly maintained landscapes or nutrient rich-soils. The disease even occurs in swamps or in properly drained environments, and in different types of soil. Also, it is not known why some palms are infected by *Ganoderma* while other trees appear to be resistant (Elliott and Broschat 2018).

Ebbinghaus et al. (2015) filed a patent (No. US 9049865 B2) on a method for the control of this disease on several palms, including Foxtail. Several fungicide groups were used to determine their efficacy over *Ganoderma* ssp. Best results were shown by triazoles, such as tebuconazole and prothioconazole, strobilurins as trifloxystrobin and succinate dehydrogenase inhibitors such as penflufen.

5.2.2 Leaf Spots

Palms are often affected by many leaf spot fungi, that induce cosmetic and economic losses in the ornamental plant industry. Leaf spots can be round to elongated, brown, and maybe oily in appearance. It is difficult to distinguish leaf spot fungi by visual symptoms alone, as they are the result of infections caused by many fungal pathogens, with almost the same symptoms.

5.2.2.1 Causal Agents

Potential causes of fungal leaf spots include species from genera *Bipolaris*, *Annelophora*, *Colletotrichum*, *Cercospora*, *Calonectria* (*Cylindrocladium*), *Gliocladium*, *Exererohilum*, *Pestalotiopsis*, *Phoeotrichoconis*, *Phyllachora*, *Pestalotia*, *Stigmina*, and *Pseudocercospora*. Diseases caused by these pathogens are transmitted through spores, which are easily spread by wind and water (rainfall or frequent irrigation) (Elliott 2005).

A research on foxtail palm indicated that leaf spot disease in this plant is mostly caused by *Exererohilum rostratum*, a member of the phylum Ascomycota, order Pleosporales, family *Pleosporaceae* (Broschat and Elliott 2005).

5.2.2.2 Host

Almost all palm species, including foxtail palm, are infected by fungal leaf spot disease. The host range for the pathogens mentioned above is considered to be vast within palms, and each species may be vulnerable to at least one of these pathogens.

5.2.2.3 Symptoms

Mature leaves are most susceptible to infection, showing fully expanded leaf spots, typically isolated by green tissue. Many pathogens cause leaf spots, with very similar initial symptoms. At this critical moment, leaf spots that would eventually produce easily recognizable signs of disease may be identified, including diamond scaling, glial atrophy, scalp ringworm spots, and tar spots (Elliott 2005).

The initial stage of leaf spots is usually round to oval varyin in color from yellow to brown or black. At the initial disease stage the spot is just the size of a point. Some leaf spots at their initial stage occur as water soaked lesions. During the development of the disease at different points the leaf spot will have opposite edges or haloes, for example, a brown spot with a yellow halo, a tan center with a tan edge, or a halo with a black edge and a gray center. All combinations of colors are possible. As leaf spots expand, the shape and color may change. As the disease progresses, leaf spots often merge together to form large areas of blighted tissue (Elliott 2005).

Leaves of any age can be affected by leaf spots and usually have no noticeable streaks. It can occur at any stage of the palm life-cycle. This is a more serious problem for seedlings and young palms because they have fewer leaves than mature ones. Leaf spot diseases in which the spore structure becomes darker on the leaves, and the host tissue becomes darker, is collectively called “tar spots”. For tar spots, the pathogen is always part of the “spot“. However, the initial symptoms are usually smaller and the water soaked lesions are similar to those observed in other leaf spot diseases. The initial focus is the appearance of a point spot. When the spots enlarge, the center becomes gray and the edges are saturated as water soaked. As the lesion continues to expand, a yellow halo may be observed. Enlarged lesions were observed to merge until large areas of blighted tissue appeared. If the disease is severe enough, as the lesion expands and fuses, the entire leaflet or palm leaf may dry out and die, causing leaf wilt (Elliott 2005).

Leaf spot disease can also be confused with Potassium (K) deficiency. Inadequate nutrition may also induce leaf spots that look similar to those caused by plant pathogens. Leaf spots caused by K deficiency are usually limited to the oldest leaves, and are more severe at the tip of the leaf rather than at its base. However, if the deficiency is severe, the oldest leaves may be necrotic or near-necrotic (and may have been removed), and leaf spots due to the K-deficiency will appear on the next youngest leaf. In addition, chlorotic and necrotic tissues caused by K deficiency are often colonized by leaf spot pathogens as saprotrophic or opportunistic pathogens. Once these fungi induce necrotic tissues, they form spores under appropriate environmental conditions and then spread to other healthy palm leaf tissues (Broschat 2005).

5.2.2.4 Disease Management

Developing an appropriate management strategy is essential to ensure a proper growth of pathogens-free palms. The best strategy to deal with these diseases is a comprehensive approach that combines prevention, exclusion, hygiene, proper species selection and proper care. Good palm nutrition and preventing injuries is part of an overall management strategy, followed by sanitation and water management.

Seedlings in the nursery are more susceptible to leaf disease, and hundreds of palm trees in the nursery are closely aligned. This condition increases the humidity among plants and also favor the transfer of pathogens from infected plants to healthy ones, by reducing the distance required for spores transmission. Therefore, increasing the distance within plants will improve their health by reducing infections. Regularly, monitoring of diseases is also valuable because they spread rapidly. It is important to notice early symptoms as soon as possible to limit a disease spreading to other plants. Other methods of limiting humidity and moisture are irrigation in the early morning, avoiding overhead irrigation, avoiding wet leaves at night and growing palms in covered greenhouses (Elliott 2005).

Infected leaves should not be placed on the ground under the palm. If palms are mixed with other plants, attention should also be given to potential alternative hosts. Although fungal spores are usually transmitted to healthy plants by splashing water or wind, nursery workers can also bring spores by treating infested plants. Insects and animals also spread pathogens. The population of insects must be monitored and snails must be eliminated.

Fungicides are not the principal solution for this problem, however, they could be used as a part of an Integrated disease management plan. After removing the diseased palm or leaf tissues, a fungicide should be applied. Even if a systemic fungicide is used, the product should be spread evenly on the leaf tissue.

Direct use of mancozeb (Dithane M45®) has been reported to suppress the onset of the leaf spots. But it should be applied in a reasonable amount so as to cover the whole foliage for direct inhibition of spore germination and mycelial growth (Elliott 2005).

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Chapter 6
Fungal Diseases of Cat Palm (*Chamaedorea cataractarum*), Bamboo Palm (*Chamaedorea seifrizii*) and Cluster Palm (*Chamaedorea costaricana*)

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Abstract Palms numerous fungal pathogens show symptoms that are similar and common to many diseases, such as leaf spots and blights. The most susceptible stages of *Chamaedorea cataractarum, C. seifrizii* and *C. costaricana* palms are seedlings and juvenile plants. In addition to these problem, soil borne *Fusarium solani* is also an important threat to these palms, together with many other soil and air borne fungi. It is very important to understand the etiology of these diseases, in order to properly plan suitable management strategies. This chapter summarizes updated information about fungal diseases of palms species in the *Chamaedorea* genus.

Keywords Diseases · Fungi · Palms · *Chamaedorea* spp

6.1 Introduction

Palms are known and famous for their aesthetic values both as indoor or outdoor plants (Tomlinson 1990). The noblality of palm lies in their large leaves and seeds compared to other species. They can reach up to 25 m in height (*Raphia regalis*) with seed weight up to 50 pounds (*Lodoicea maldivica*) (Uhl and Dransfield 1987; Neal 1965). Members of the Palmae family are found in Mediterranean, tropical and

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_6

subtropical climatic regions which makes them very diverse both ecologically and morphologically. Exploitation of palms include fibre for rope, mats, hats, coir, baskets and cord; source of oil, tannin, food and lumber; production of furniture and roofing material (Howard et al. 2001; Ploetz and Mitchell 1989). The use of palm for landscape adds to their value. Palms are very widely used for interior decorations and landscapes. Palms enthusiasts distributed the palms to new locations in the world with different climates compared to their native ones. As a result of this, palms are now distributed to both sides of the equator. Breeding programs has helped to develop date palm cultivars that are adapted to new locations and very widely used as food. There is, however, a minor focus on ornamental palms to develop new cultivars, as they are mostly transported to new locations where they might not adopt to new climatic conditions. This situation poses great challenges to growers who are interested in production of ornamental palms (Uhl and Dransfield 1987; Howard et al. 2001; Ploetz and Mitchell 1989; Tomlinson 1990).

Parlour Palms (*Chamaedorea* spp.) is very popular as indoor plant because of its low level light requirements. It is an evergreen with a dense foliage which makes it even more desirable. *Chamaedorea* spp. were originally grown in tropical and subtropical areas (Huxley 1992a, b). The genus includes many small palms with large foliage, thin stem and many leaflets, which make them very attractive (Quattrocchi 2000). The genus includes 107 species with Cat palm (*Chamaedorea cataractarum*), Bamboo palm (*Chamaedorea seifrizii*) and Cluster palm (*Chamaedorea costaricana*) being the well-known species.

Cat Palm (*Chamaedorea cataractarum*) also known as cascade and cataract palm, originated from jungles of Central America (Balslev, pers. comm; Groth, pers. comm.). It is very easy to grow, and has a very high light requirement. It will grow up to 2 m height in pot and 3 m infield. Initially it will grow like stemless clumps with leaves showing leaflets 2.5 cm wide and 30 cm in length. The new plants will grow from the base of old plants reproducing both sexually and asexually (Huxley 1992a, b; Moore 1963). With continuous growth, it form dense clumps. Features such as trunkless habit, thin leaflets and flexible nature confer resistance to different conditions. The cat palm needs more water as compared to others, so ample water provision to keep the soil moist prevent it from damages (Standley 1920).

Bamboo palm (*Chamaedorea seifrizii*), is characterized by dense clusters, long canes and bamboo-like appearance, with grey to dark green leaves. It grows up to 2.1 m in height. Each stem has nodes and is slender and long (this ensures its similarity to bamboo). Similar to bamboo, this palm grow by offshoots and suckers too. A good plant health and hygiene must be maintained by removing old leaves. The leaf bases and sheath are allowed to dry. These trimming will maintain the shape of the bamboo palm, exposing its attractive stems.

Cluster palm (*Chamaedorea costaricana*) is mostly found in wet and moist forests of Costa Rica, at elevation from 600 m to 2300 m. Apparently, *C. costaricana* has a very close resemblance to *C. seifrizii* as both form thin clusters of green bamboo-like stems. However, its 6 m height makes a difference compared to the bamboo palm (Christenhusz and Byng 2016; Zona 2000). Due to its high aesthetic value, minor problems such as leaf spot, can cause considerable losses to the landscape and ornamental palm industry. These palms can be very expensive, and during landscape operations the loss of a single palm tree may lead to considerable losses. However, losses are not only due to palm death or leaf spots diseases, including also disorders due to nutritional deficiencies (Broschat and Meerow 2000). Palms are monocotyledons like i.e. corn plants, and understanding their anatomy is very important to manage their health (Uhl and Dransfield 1987). Once the single, apical meristem is damaged, (irrespective of its origin, i.e. mechanical, herbicidal, environmental, nutritional deficiency or pathogens), the death of the palm is likely to happen. The absence of a vascular cambium makes the situation even worse for palms because no secondary growth occurs. Therefore, once the injury or damage occurs, the palms cannot repair their stem. A diligent effort to maintain a good care of palms is required to prevent injuries, which are the source or entry point for pathogens, especially fungi that can thus penetrate into the trunk.

In the following portion of this chapter we discuss about most important fungal diseases of *Chamaedorea* spp. (Broschat and Meerow 2000; Uhl and Dransfield 1987).

6.2 Leaf Blight

This disease is also known as leaf spot. The difference between leaf spot and leaf blight diseases is related to the symptoms appearance. If the spots appear on the leaf blade and are scattered and separated by green leaf area, they are referred as leaf spot. Otherwise, if the spots appearance occurs suddenly and they merge to form large diseased areas, the symptom is called leaf blight of palm (Broschat and Elliott 2005; Chase 1993; Elliott et al. 2004). Numerous pathogen are known as causing either leaf spot or blight disease, with similar symptoms. Seedlings and juvenile stages of *Chamaedorea* spp. (*Chamaedorea cataractarum*, *C. seifrizii, C. costaricana*) are the most susceptible for the leaf spot and leaf blight diseases. Initially, the lesions are water-soaked and small, subsequently the color of the spots turn to reddish, brownish, blackish, gray or yellow. Most of time a shade or a circular tissue surrounds these spot, with a color of the circle that is different from the spot. As the symptoms develop, the spots increase in size and number and ultimately cover a large leaf blade area. Avoidance of injury, sanitation, nutritional management, proper irrigation and fungicides should be applied as part of an integrated management, because there is no single, available solution (Chase 1993; Elliott et al. 2004).

6.2.1 Etiology

Leaf spot and blight are caused by fungi. There is a wide range of fungal pathogens that are reported to cause these diseases, including Cercospora, Pseudocercospora, Colletotrichum, Exserohilum, Annellophora, Calonectria (Cylindrocladium), Stigmina, Bipolaris, Phyllachora, Pestalotia, Gliocladium, Phaeotrichoconis,, Botrytis, Phytophthora and Pestalotiopsis. Other pathogens include bacteria such as

Acidovorax spp. or *Phytophthora* spp., which belong to Stramenopila, Phylum Oomycota (Broschat and Elliott 2005; Chase 1993; Elliott et al. 2004).

No matter which fungi are causing a damage, symptoms appear similar for many species. It is considered that all palm species are susceptible to one or two of the above listed pathogens. Most susceptible stage of palm is the seedling and juvenile plant which show a disease impact usually more severe. Other than palms, many other plants are also susceptible to these pathogens. Grass-like leaves at a palm seedling stage can easily be invaded by pathogens. There is no trunk at the juvenile stage but tissue differentiation occurs. At this stage the leaves and the apical meristem are near the soil surface, a condition that makes the plant more susceptible (Broschat and Elliott 2005; Chase 1993; Elliott et al. 2004).

6.2.2 Vectors

Wind, water, insects and human activities are considered to spread many diseases. All leaf spot fungal pathogens produce sexual or asexual spores that are spread by wind, along with rainfall or irrigation, that will carry them from one host to an other. Insects and rodents can also spread fungal spores from one host to an other. Human activities such as pruning and movements through a nursery etc. can also contaminate new hosts, by spreading the fungal spores (Broschat and Elliott 2005; Chase 1993; Elliott et al. 2004).

6.2.3 Symptoms

- Small water soaked lesions are produced at the initial stage of leaf spot.
- This lesion will turn into different shades within days. Shades of the lesions might be reddish-brown, blackish, yellowish or gray.
- A ring or hole surrounds lesions that are differentiated by their color. If the development of spot is black, the ring or hole will be chlorotic (yellow). On the contrary, a yellowish spot is surrounded by a black or reddish-brown ring.
- The colored spot spread across the leaf blade and appear oblong or round in shape, and of variable size.
- Eventually, the affected tissue will die.
- Depending on environmental conditions, size and number of spots will increase. Under optimal environmental conditions the spot size and number will definitely increase covering a large area of the leaf blade or leaflet.
- As the size increases, the spots will coalesce, causing the leaf or leaflet desiccation or death. This condition is called leaf blight.
- Usually this disease appears at all ages of leaves. If the palm growth is at an early stages (juvenile), the spots will appear on all leaves.
- Most of pathogens will produce spore directly on the leaf tissue.

- Instead of spore dispersal, water is also very essential for germination and invasion of new leaf tissue.
- Manganese and potassium deficiencies symptoms could be confused with leaf spot or blight disease of palm (Chase 1993; Elliott et al. 2004).

6.2.4 Diagnosis

The best possible way to diagnose this disease is through isolation of the pathogen. Once the fungal pathogen is identified, the exact cause can easily be devised. For fungal identification we need to examine some structures such as spores. If these are directly produced on the leaves we can observe them (Broschat and Elliott 2005; Chase 1993; Elliott et al. 2004). Otherwise, the infected tissue should be placed in a moist chamber to induce sporulation. Eventually the spores can be transferred to artificial media for germination that will ultimately produce the mycelium *in vitro*. It is unusual that more than one fungal pathogen is isolated from a leaf spot. If this happens, the primary pathogen of the palm can easily be identified as it will invade the fresh tissues of the leaf blade, while the secondary pathogen moves in after infection, as a saprotroph. Plant disease diagnostic manuals will be helpful for morphological identification, while molecular identification will provide the identity of the pathogen (Broschat and Elliott 2005; Chase 1993; Elliott et al. 2004).

6.2.5 Disease Management

There are two reasons why leaf diseases are most prevalent at juvenile stages either grown in a container or in a field nursery. First reason is that leaf or blight diseases are more severe on juvenile palms because at this stage the trunk is not developed. The invasion is favoured by soft tissues and if it occurs, the diseases will be more devastating in juvenile than in mature palms. The second, and important, reason is that in nursery many juvenile palms of the same age and species are available. They are closely spaced so spore dispersal is very easy. There are hundreds and thousands of tissues that can be easily invaded compared to a palm in the landscape. Mature palms are not closely spaced and, most important of all, different species are planted. For this reason most of the discussion will target the management at nursery level. Leaf spot disease can be batter managed through an integrated way rather than focusing on a single tactic (Broschat and Elliott 2005; Chase 1993; Elliott et al. 2004).

1. *Irrigation*: this is the first line of defence against the disease, through the sanitation and management of water. It is a very critical factor not only to control its spread but also for spore germination and tissue invasion. Removal of extra water and protection against rain water is highly recommended. Dry conditions minimize the disease risks. If it is not possible to keep the leaves dry, then the

palm should be irrigated at such time and way so that leaves should remain wet for a minimum time. For example, irrigating palms about one hour before dawn.

2. *Air circulation*: in nurseries the palms are placed very close to each other. To avoid leaf spot or blight diseases, the plant to plant space should be increased, so that the air circulation will be higher, a condition that helps in maintaining the palms dry. Make sure that larger palms are not blocking the air circulation to smaller palms.
3. *Sunshine*: leaf spot disease is severe when palms are grown in high sunshine time. So palms should be placed under a shade with enough air circulation and penetration of light. Direct irradiation should be avoided.
4. *Pruning*: removing and properly destroying the already infected plant parts or leaves is very important to eliminate the source of inoculum. For this purpose, the nurseries should be monitored properly. Regular pruning of the infected parts in necessary. Proper disposal is equally important to decrease the inoculum source. If mature palms are planted in the vicinity of the nurseries, they should also be monitored regularly. Leaf spot disease has minimal devastating effects on mature palms, but they can serve as source of inoculum. Pruning of infected parts of mature palms is also necessary.
5. *Destruction of alternative hosts*: Sometimes other plants in the nursery are ignored but they can also be host of leaf spot causing fungi. If a variety of ornamental plants are available in the nursery then they have to be checked as potential hosts. Weeds are important alternative hosts with less consideration, as they serve as a reservoir for fungi to survive and cause the disease. Removal of weeds from the nursery must be followed regularly.
6. *Prevention from injury*: during working in the nurseries care must be taken to avoid any palm damaging. Once a palm is damaged, the resulting injury will serve as opening for pathogens. Fungi will invade the injured tissue and produce spores that will act as inoculum for the attack on health tissues. It is very crucial to avoid any injuries in the nurseries, as well in mature palms.
7. *Monitoring of pests*: many insect and rodent pests cause damage to the leaves and produce injuries providing opening to fungi. Proper monitoring of insect pests is hence important to avoid leaf spots disease.
8. *Nutritional stress*: leaf spot severity is also linked to the nutritional stress. For example, palms deficient of iron are more prone to attacks by leaf spot pathogens. Similarly, potassium deficiencies may favor the establishment of leaf pathogens. It is of prime importance that nutritional deficiencies in palms should be eliminated to manage leaf spot and leaf blight disease.
9. *Side effect of treatments*: to maintain the health of the palm sunburn, herbicidal toxicity, fertilizer burn and cold temperature injuries should be avoided.
10. *Application of fungicides*: it must be kept in mind that fungicides alone will not cure the problem, if a palm is already infected by a leaf pathogen. Fungicides will not cure the plant, the problem will remain as long as the leaf ages. Fungicides are only applied to avoid the further spread of pathogens. They merely work as supplements to nutrition and water management, injury prevention and sanitation. Pruning of severely infected parts before application of

fungicides is recommended in nursery situations. This results in the reduction of fungicidal dose which will ultimately reduce any unwanted toxic effect. But in case of landscape pruning this is not recommended. In landscape anything that need to be managed is nutrition deficiencies, as they are far more harmful for mature palms than leaf spot problems. Application of fungicides, especially contact ones, must be properly done, so that they will cover the whole leaf blade. Recommended or labelled doses must be applied (Broschat and Elliott 2005; Chase 1993; Elliott et al. 2004).

6.3 Basal Stem Rot

6.3.1 Etiology

Ganoderma spp.
Ganoderma boninense, *G. orbiforme*

Ganoderma butt rot, also known as basal stem rot of palm, is a lethal disease which has a huge potential to spread. Presently it is limited to the USA, more specifically to the South-Eastern regions (Elliott and Broschat 2001), while in tropical areas it is known as basal stem rot (Flood et al. 2000). It also gained importance in other parts of the world, especially in Thailand, Malaysia, Papua New Guinea and Indonesia (Miller et al. 1999).

Chaotic efforts were made to identify and classify the *Ganoderma* spp. associated with basal stem rot. However, advances in science and especially in molecular systematic practices made it possible to clarify the disease etiology, showing that *G. zonatum* and *G. boninense* are associated with palms in the South-Eastern Asia (Moncalvo 2000).

6.3.2 Symptoms

- Mild to severe wilting of foliar parts as primary symptoms of butt rot.
- Pale green discoloration of foliar growth as compared to normal (not chlorotic, just discoloration).
- Loss of vigour, which results in reduced growth.
- If the disease persists, whole palm will show off-color.
- As the disease progresses, necrotic or chlorotic areas will appear on old fronds.
- Drooping of older fronds is common.
- Appearance of these symptoms is accompanied by death of the internal stem, at the basal portion.
- The dead stem shows a distinct color as compared to healthy tissues, as observed in stem cross section.

- The disease progresses from base towards top in a cone-shaped pattern. The exact infection point may remain unknown.
- The upward progression of the disease is usually limited within 1.5 m.

6.3.3 Pathogen

In case of severe attacks, basidiocarps produced externally on the stem will release basidiospores. Initial growth of basidiocarps appears as a white flat mass, irregular to circular in shape. Further growth will expand the white soft basidiocarps visible on the outer surface of the growing trunk, protruding as shelf-like with swollen margins. The top surface of mature basidiocarps is reddish-brownish in color, hard and glazed. The under surface will appear as white. In case of *G. zonatum,* the species name is given after the characteristic growth zones in the basidiocarp attached to the trunk. The basidiospores are formed in the lower side of the basidiocarp, in tubes or microscopic pores, and then released, as indicated by the brownish color on the basidiocarp underside.

6.3.4 Disease Incidence

Basal stem rot is a threat to all the palms with woody stem. In Florida, several palms were destroyed by *G. zonatum,* All planted for ornamental purposes in the landscape (Elliott and Broschat 2001).

6.3.5 Disease Spread

The information about the spread of Ganoderma butt rot is limited. According to available data, considering the disease isolation, its prevalence and occurrence location, support the idea that the primary source of spread is given by the basidiospores. The spread of *G. boninense* also implicates the role of basidiospores in disease spread (Miller et al. 1999).

6.3.6 Disease Diagnosis

The best and easiest way to diagnose Ganoderma butt rot is the formation of basidiocarps on the standing palm. In case the basidiocarps cannot be seen, then conformation should be made by cutting down the tree trunk as the characteristic trunk rotting should be visible. Still there is not an exact diagnostic method for the disease (Elliott and Broschat 2001).

6.3.7 Disease Epidemiology

Currently, there is no conformation about the environmental conditions that support the disease development. Also no information are available about cultural practices or soil types supporting the development of Ganoderma butt rot (Moncalvo 2000; Elliott and Broschat 2001).

6.3.8 Disease Management

No effective management strategy has been devised for the Ganoderma butt rot. However, the disease is normally observed in palms before being transplanted. The transplanted and highly maintained palms are usually free of the disease (Elliott and Broschat 2001; Moncalvo 2000).

6.4 Phytophthora Bud Rot or Heart Rot of Palm

6.4.1 Etiology

Phytophthora spp. (*Phytophthora palmivora*)

Throughout the world *Phytophthora* spp. are the primary invaders of palms, causing devastating diseases. *Phytophthora palmivora* is most common pathogen more specifically related to the disease named lethal bud rot of palms (Parris 1942; Uchida et al. 1992a, b; Ko 1971, 1987).

6.4.2 Symptoms

- Discoloration is the early symptom of bud rot disease.
- It starts from the youngest palm leaf.
- Large dark brown fronds are produced upon leaf unfolding, with a progression towards its base. As this problem progresses, bud killing is quite common.
- When the youngest leaf dies, bud rot is already advanced.
- Young leaves are lost progressively, with older remains attached to trunk.
- With support of vascular bundles, the older leaves remain green.

- With the disease progress, falling of leaves takes place. Eventually killing all the leaves occurs, and the plant is left with only a bare trunk.
- Secondary infection by *Thielaviopsis paradoxa* has also been reported (Butler 2017; Freeman 2007; Huang et al. 1976; Hunter and Buddenhagen 1969; Hunter and Kunimoto 1974; Ko 1987) .

6.4.3 The Pathogen and Its Incidence

Destruction of young plant and bud rot of California fan palm (*Washingtonia* robusta) and Mexican fan palm (*W. filifera*) are reported to be caused by *palmivora*. *Phytophthora palmivora* belongs to the Oomycetes and is considered among the most serious disease causing agents. It occurs almost in every palm growing areas of the world, i.e. India, Africa and South America, year after year. In 1917, Edwin John Butler identified the causative organism as *P. palmivora* (Ko 1971). For years, many ornamental plants were found as hosts of *P. palmivora* and also *P. nicotianae*, both being more persistent in greenhouse environments (Atilano 1982; Ko 1987). Other hosts include mango, cacao, black pepper, olive, coconut and papaya plants. The estimated annual yield losses due to *Phytophthora* spp. account for 10–20% . If suitable moist conditions are prevailing the losses may increase by 75%. In coconut more specifically, annual losses may range up to 2.5%. The pathogen has an utmost dependence on moisture. During 1970, in Brazil the attack by *P. palmivora* to black pepper was so severe that this crop was no longer grown commercially, indicating that this pathogen is of significant importance (Huang et al. 1976; Hunter and Buddenhagen 1969; Trujillo and Hine 1965).

6.4.4 Disease Epidemiology

The two most important epidemiological conditions for *Phytophthora* spp. are rain and wind. The pathogen produces sporangia and rain splashes are required to liberate them from the infected tissue portion. Rain splashes are also required for projection of the inoculum from soil into air. The further dispersal is dependent on wind. As with the help of rain splashes, sporangia reach the air and strong winds may disperse them from one tissue portion to the other, or even from one plant to an other one. The primary infection is initiated by a strong wind blown rain. Activation temperature is 18–20 °C with high humidity (Butler 2017; Freeman 2007: Huang et al. 1976; Hunter and Kunimoto 1974; Ko 1971, 1987; Turner 1965).

6.4.5 Disease Management

- *Field moisture management*: soil moisture management can be done by the following strategies:
  - irrigation monitoring,
  - increase in airflow by pruning,
  - decrease in humidity.
  - Host plants should not be planted in an area prone to flooding.
  - Palms should be planted in incline areas.
- *Cultural control*: mulching can avoid release of sporangia due to rain splashes.
  - Other cultural control practice include the removal of infected hosts from the field.
  - Avoidance: the disease incidence can be reduced also by planting a companion crop that will divert some of the pathogen inoculum.
- *Chemical control*: Bordeaux mixture, dithiocarbamates (mancozeb and phenylamides) control the spread of pathogen, phophonates may be applied to controls the mycelial growth of the pathogen.
- *Resistant plants*: this is the best method to manage the disease (Uchida et al. 1992a, b; Butler 2017; Freeman 2007: Huang et al. 1976; Hunter and Buddenhagen 1969; Hunter and Kunimoto 1974).

6.5 Fusarium Wilt

6.5.1 Etiology

Fusarium solani (Mart.) Sacc. (Haq et al. 2019; Leslie and Summerell 2008).

6.5.2 Symptoms

- The primary symptoms of this disease is chlorosis on rachis.
- Chlorosis is followed by wilting of plants. Partial to complete wilting has been observed as result of Fusarium wilt.
- Premature leaf drop.
- The vascular system is destroyed and browning of vascular system occurs.
- If the palm is attacked at an early stage of growth, damping off is very common.
- Late infection will result in stunting of palm.
- Necrosis of young leaves has also been observed.

The Fusarium wilt starts with clearing of leaf veins, followed by drooping of leaves (Elliott 2012; Elliott et al. 2010, 2017).

6.5.3 Pathogen

Fusarium spp. (phylum Ascomycota) have been divided into about 100 *formae specialis*, each reported with one or two host species, due to their host specificity. The complex of *F. solani* consists of at least 26 closely related filamentous species . They are predominantly found in soil and survive by invading plant debris. *Fusarium* solani is not only a plant pathogen, as reports of human diseases are also available (Haq et al. 2019; Leslie and Summerell 2008; O'Donnell et al. 2015). Formation of conidia and chlamydospores are the means of asexual reproduction. The conidia are of two types, microconidia and macroconidia. Macroconidia producing phialides are shorter than phialides of microconidia. The conidia are broad, hyaline and slightly curved, while chlamydospores are brown and round. They may be produced individually or in pairs. As soil fungi, *F. solani* is generally found associated with host roots and at 80 cm depth in the soil (O'Donnell et al. 2015; Leslie and Summerell 2008; Giesbrecht et al. 2013).

6.5.4 Disease Cycle

The entry point for *Fusarium* spp. is the developing roots. After establishment they produce both macro and microconidia. After infection, conidia are further dispersed by water and air. The conidia can survive in soil for decades. *Fusarium* can also survive on plant and seed surface. It overwinters by producing chlamydospores. If left unchecked, *Fusarium* spp. can cause huge losses (O'Donnell et al. 2015; Leslie and Summerell 2008).

6.5.5 Disease Ecology

Generally, *Fusarium* spp. are soil-borne pathogens, occurring worldwide. However, when studying the ecology of species infecting palms, *F. solani* may not have a worldwide spread (O'Donnell et al. 2015; Leslie and Summerell 2008; Smith et al. 2003).

6.5.6 Disease Epidemiology

These are generally found in temperate, tropical and subtropical regions and very less frequently in alpine climates. Soil pH has not a marked effect on *F. solani* development while it is has been reported that fumigation may increase its occurrence. The pathogen has also been found in rivers, ponds and water pipes. It is typically sensitive to some fungicides. This fungus has also been found in symbiotic relationship with *Ambrosia* sp. beetle. It is considered as a serious threat in North and South America.

6.5.7 Disease Management

1. *Soil Solarization*: soil must be solarized before planting palms in the field. Once palms are planted its not economic to change the soil. Similarly if palms have to be used for indoor, the pot soil must be properly sterilized to avoid the *Fusarium* infection.
2. *Sterilization of cultural substrate*: it is quite common to reuse of cultural substrate for soilless culture. In this case remaining from previous plants, especially roots, contaminate the substrate and surve as source of infection for the next plant. A proper sterilization of cultural substrate is hence equally important for the proper healthy growth of palms.
3. *Biosolarization*: the combination of soil solarization and bio-fumigation is collectively called as biosolarization. The decomposition of organic matter in soil, such as manure and agricultural by-products, also helps in reducing the incidence soil borne pathogens. The volatile substances released by decomposition of organic matter may also have a negative impact on soil borne pathogens.
4. *Biological control agents*: several biocontrol agents such as *Trichoderma*, *Streptomyces* and *Pseudomonas* spp. are also very effective against *Fusarium*. This aspect still needs further studies to check the efficacy of these microorganisms and also to understand the mechanism of biocontrol.
5. *Application of fungicides*: several fungicides such as fosetyl-Al, mancozeb, carbendazim, benomyl and metalxyl can also be used for management of *F. solani*.
6. *Genetic resistance*: development of genetic resistance is the best possible solution for Fusarium wilt of palm (Simone 1998; Elliott 2012; Elliott et al. 2010, 2017; O'Donnell et al. 2015; Leslie and Summerell 2008; Giesbrecht et al. 2013).

6.6 Helminothosporium Leaf Spot

6.6.1 Etiology

Drechslera setariae, *Exerohilum rostratum*, *Phaeotrichoconis crotalariae*

6.6.2 Symptoms

Reddish-brown to black oval spots less than 6 mm inch in diameter merge to become irregular in shape.

6.6.3 Management

1. Avoid overhead watering.
2. Apply fungicide to protect plants.

6.7 Fungal Spot of Bamboo Palm

The older leaves are infected by rust-like fungal spots. Their damage is mostly cosmetic while they are round in shape. The disease spreads very quickly in humid climates. As this disease appears on older leaving, culling helps in reducing its incidence, and also promotes a vigorous growth. Fungicides can also be applied to reduce the disease occurrence.

6.8 Sooty Mold of Bamboo Palm

Many sucking insects such as scales, aphids, mealybugs etc. are considered to cause sooty mold. After feeding, these insects excrete substances which are sticky in nature, called honeydew. Soon after excretion, the honeydew is infested by sooty mold fungi. It is very easy to manage the sooty mold by washing, as the main problem is the insect infestation. As long as the insect infestation is present, sooty mold returns very rapidly. The only way for its management is to get rid of the insect infestation, by repeated applications of suitable insecticides or other management practice.

6.9 Root and Heart Rot of Bamboo Palm

Root and heart rot are also devastating problems for bamboo palms. Heart rot disease is caused by fungi which live inside the stem and can be found in any part of it. While root rot affects the roots and also the loser parts of the stem. Mushrooms can be found growing on bamboo palm stem or in the soil near the tree. This makes the situation very severe and the problem difficult to solve, as these disease cannot be cured. The only possible solution is to remove the infected palm. While removing the palm care should be taken to remove all roots, in order to limit the spread of the disease to other close palms.

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Chapter 7
Fungal Diseases of Washingtonia Palm (*Washingtonia robusta*)

Iqra, Nabeeha Aslam Khan, Muhammad Zunair Latif, and Yasir Iftikhar

Abstract Among ornamental palms, Washington (*Washingtonia robusta*) or Mexican fan Palm is one of the most important and regularly cultivated tree, throughout the world. It is fast growing, with thick reddish stem and large, shiny leaves. It is an ecologically and economically important plant, that can be used as profited farm business as well source of wood, thatch and other byproducts such as oils, phenolic compounds and terpenoids. There are different constrains in palm cultivation including pathogens that significantly diminish its production. Many fungal diseases such as wilt, bud rot, crown and rot rots, leaf spots, blights, seedling blight and damping off have been recorded, caused by different pathogens. Among several pathogens *Phytophthora* and *Fusarium* spp. are the leading cause of death of *W. robusta*. Various conventional and modern management strategies have been successfully exploited for sustainable palm production.

Keywords Washingtonia · Etiology · Mexican palm · *Phytophthora nicotianae*

7.1 Introduction

Palms trees are extensively employed in landscapes and interiorscapes. Various national and international gardens have impressive collections of palms, accommodated in greenhouse with a temperate weather (e.g. Kew Gardens of England, The Palm house of Royal Botanical Garden). Palm has been known as one of the most used families utilized by humans following Fabeaceae and Poaceae (Tregear 2011). These plants are greatly diversified ecologically and morphologically and are common in Mediterranean, tropical and subtropical climatic areas of the world. Most

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_7

palm species diversity is, however, confined to humid tropical, although many groups occur in desert oases and savannas (Klimova et al. 2017).

Washingtonia is an important genus of palms belonging to subfamily Coryphoideade, tribe Trachycarpeae and sub tribe livistoninae (Guevara et al. 2014). It includes two native species of northwest Mexico, e.g. *Washingtonia filifera* found in Baja California and *Washingtonia robusta*, distributed in Baja California and Sonora (Nehdi 2011). Both species are grown as ornamental plants around the world, mainly in California, and southern Europe, northwest Mexico, Mediterranean basin as well as some regions of Australia (Coşkuner and Gökbudak 2016). *Washingtonia robusta*, also known as Mexican washingtonian palm, is one of the most common species throughout the world, cultivated as ornamental palm tree. It is a desert palm that is present in areas having constant surface or sub surface water (Broschat 2018).

Death of many 4–5 years old *W. roubsta* plants occurred at Al Qassim area of Saudi Arabia and was brought to consideration in March 2015 (El Meleigi et al. 2019). Among several problems associated with low cultivation of *W. robusta* is fungal plant pathogens. Several fungal pathogens including Fusarium, Phytophthora, Colletotrichum, Chalara and Botryodiplodia have been found associated with different diseases such as trunk and leaf spot, blights, damping off, seedling blights, root and crown rots, petiole rots; bud, apical or heart rot; nut drop; wilting and dieback, leading the palm trees from a deteriorated growth to a complete death (Garofalo and McMillan 1999).

7.2 Phytophthora Bud Rot of Washingtonia Palm

Diseases of different plant parts such as leaves, roots, stem, fruits, crown of a large number of agricultural host plant have been reported to be caused by ca. 59 species of *Phytophthora* (Erwin and Ribeiro 1996). Phytophthora bud rot is a common disease recorded in wet tropical regions (Garofalo and McMillan 1999). One of the species of *Phytophthora* i.e. *P. nicotianae* has been detected to infect more than 301 ornamental and host plants such as poinsettia, *Euphorbia pulcherrima*, carnation (*Dianthus caryophillus*), onion (*Allium cepa*), tomato (*Lycopersicum esculentum*) in Italy and Iran (Nazerian and Mirabolfathi 2013; Faedda et al. 2011). It is a oil born fungus-like organism that belongs to the group of water molds (Ho 2018). *Phytophthora palmivora* was also recoded to cause bud rot of *W. filifera* and *W. robusta* (El Meleigi et al. 2019).

7.2.1 Symptoms

In this disease, the first trait is given by the young leaves that start to wilt. The leaf colour is a paler green changing to green brown and later light brown, and at the end the leaf is desiccated and wilted. If the cross section of an infected palm tree is made at the base, brown to dark brown colored soft tissues having a foul smell can be easily observed at the base of petiole. Further segregation of petiole base exposes tan necrotic lesions having brown edges. The surface of some lesions is covered with a white growth of mycelium. At the later stage of infection, pale leaves are completely dried up, buds are rotted, and disintegration of leaf petioles result in black cavities at the base of the dead palm. Transverse section of petiole of infected tree exhibits rot and brown colored discoloration at terminal buds and base (El Meleigi et al. 2019).

Many species of *Phytophthora* have been found associated with bud rot of palm trees in the world. *Phytophthora nicotianae* is reported to cause basal leaf rot in Mediterranean fan palm (*Chamaerops humilis* var. *argenta*) in Iran (Nazerian and Mirabolfathi 2013), Italy (Faedda et al. 2011) and North America (Bomberger et al. 2016). Therefore, reed palm (*Chamaedorea seifrizii*), bamboo palm (*C. erumpens*), red sealing wax palm (*Cyrtosta chysrenda*), Mexican fan palm (*W. robusta*), thatch palm (*Thrinax* sp.) Macarthur palm, (*Ptychosperma macarthurii*) have been reported with leaf, stem and root rots caused by infection of *P. nicotianae* (Elliott et al. 2004). Seedling blight in golden palm, and collar and trunk rots of California fan palm is also caused by *P. nicotianae*. The disease begins to appear in form of wounds as a result of leaf removal near the base line. The disease symptoms can be reproduced by inoculation at lower trunk causing bud and rot of the entire stem (El Meleigi et al. 2019).

7.2.2 Morpho-Taxonomic Characters

Phytophthora nicotianae has a branched and thick hyphal growth (5–7.1 μm wide). Zoosporangia ranging from 30 to 43 μm are formed after 3–4 days on mycelium, with incubation at 28 °C. Extensive thick walled sporangiospores 59–68 μm wide can be observed in 7–15 days old cultures. Sporangia are formed after 3–4 days of incubation at 28 °C and chlamydospores are also extensively formed in 7–15 days old cultures (Stamps et al. 1990; Faedda et al. 2011).

7.2.3 Management

The potential of biocontrol agents has been effectively used for management of plant diseases. *Lysobacter* species have recently been exploited for different fungal diseases (Sullivan et al. 2003; Folman et al. 2003). *Lysobacter enzymogenes* of strain C3 exhibited strong antagonistic activity against many fungal pathogens (Li et al. 2008). It has also been found effective for suppressing activity of other soil borne pathogens such as *Rhizoctonia solani*, causing brown patch in truf grases (Giesler and Yuen 1998). The use of *L. enzymogenes* has also been explored for management of foliar diseases i.e. *Bipolaris sorokiniana* causing leaf spot disease of tall fescue (Zhang and Yuen 1999), *Uromyces* appendiculatus responsible for rust of bean (Yuen et al. 2001) and *Fusarium* spp. causing head blight of wheat (Jochum et al. 2006). *Lysobacter enzymogenes* BB14 showed high chitin hydrolysis of

P. nicotianae (El Meleigi et al. 2019). Different extracellular enzymes like chitinase and β-1, 3-glucanases play significant role in to biocontrol activity (Palumbo et al. 2005; Zhang et al. 2001). Many other *Lysobacter* spp. like *L. capsici* and *L. antibioticus* have also been known as potential biocontrol agents (Hayward et al. 2010). OH11 and 3.1 T8 strains of *L. enzymogenes* have been found very effective, suppressing mycelial growth of *Phytophthora capsici*, *Pythium* aphanidermatum, *Py. ultimum*, *Fusarium graminearum*, S*clerotinia sclerotiorum*, *Ralstonia solanacearum* (Christensen and Cook 1978; Jiang et al. 2005; Folman et al. 2003; Qian et al. 2009).

7.3 Fusarium Wilt of Mexican Palm

Wilt of palm is a disease caused worldwide by different *Fusarium oxysporum* ff. spp. i.e. *F. oxysporum* f. sp. *canariensis*, *F. oxysporum* f. sp. *elaeidis* and *F. oxysporum* f. sp. *albedinis*. Before 2010 only *F. oxysporum* f. sp. *canariensis* was known to infect the palm species in the USA. In Florida, isolates of *F. oxysporum* were investigated to cause death of Washingtonia *robusta*. The molecular and morphological studies along with infection to unique host plants by fungal pathogen revealed a new *forma specialis* of *F. oxysporum* named f. sp. *palmarum*. The fungal pathogen infects to the foliar tissues, resulting in complete necrosis of crown leaves and progressively causes the death of the palm tree within 2–3 months (Giesbrecht et al. 2013).

In 2012 dying samples of *W. robusta* palm were carried to the Texas Plant Disease Diagnostic Laboratory (TPDDL) from palm trees cultivated in landscape of Harris County, Texas. Petioles of leaves had reddish-brown stripes along with necrotic and cholorotic symptoms. Fungal isolates were obtained from diseased foliar tissues and characterized as *F. oxysporum* on morphological basis. The shape of microconidia was oval to reniform with 1–2 septations and ranging 5 to 18 × 2.5 to 5 μm. Short phailides were observed with microconidia formed on false heads. Macroconida were slender and curved having foot-shaped basal cell with three septations, measuring 22 to 37 × 2.5 to 5 μm. Roundish chlamydospores ranged 7–13 μm in diameter. Colony color was white to purple on potato dextrose agar medium (PDA). Pathogenicity was confirmed on *W. robusta* and *W. filifera* (Giesbrecht et al. 2013)

7.4 Diamond Scale of *Washingtonia robusta*

Diamond scale is a fungal disease caused by *Sphaerodothis neowashingtoniae*, originally described from California fan palms (*Washingtonia* filifera) with severe incidence near the coast. The host range of the fungus is restricted to Washingtonian fan palms and *W. filifera* is the most affected species. Palms grown along the coastline were more susceptible to this fungus than those grown in Irvine, CA. The disease is less common on young palms cultivated along riverside. Previously *W. robusta* were considered completely resistant to this disease. At present the disease is also found on cultivated and wild palms in California and Mexico respectively. Hybrids Washingtonian palms are somewhat susceptible to this disease (Hodel 2009).

7.4.1 Symptoms and Disease Progression

The “Diamond scale” is not a “scale” insect incited disease, but it was actually named as such due to the fruiting body or “ascus” bearing structure, that are formed on infected leaf surfaces. Sexual spores are formed within these fruiting bodies. Anamorph or asexual stage of this fungus are unknown. Due to lack of knowledge on spore formation stages, it is not yet possible to have an accurate life history of the pathogen. The fungus, initially restricted to California, was also reported from Arizona and Nevada. Data on complete history of pathogen occurrence, time of infection, optimum temperature requirements and other events are essential to determine disease starting conditions and successful infections. A little is known about the pathogen and associated disease in fan palms. The fungus infects petioles, leaf blades and rachis, and infection starts from oldest (lower leaves) moving upward to the canopy causing infection of the 4th or 5th newest leaf. Infection starts with circular, water soaked lesions (1–3 mm diameter) that appear on fronds of infected plants. At disease progress, hard, black fruiting bodies (stroma) develop and continue to enlarge over periods of weeks-months. Leaf tissues encircling the stroma turns yellow, and elongated yellow streaks are visible along the midrib of fronds. On mature leaves lesions coalesce and severely infected leaves collapse downward turning yellow or completely brown. Newly emerged leaves remain unaffected, probably because they do not stay in an upright position for longer period, as required for disease development. Uninfected palms look two times greener than palms infected by this disease. As a consequence of diamond scale disease, host plants also lose their vigor.

7.4.2 Management

Pruning has little effect in disease management especially when inoculum source is nearby. The fungus remains active around the whole year by infecting younger leaves and producing fruiting bodies (stroma) in less than three months. Thiophanate-methyl is being used by practitioners to enhance plant vigor and to retain older palms with diamond scale infections.

7.5 Pink Rot of *Washingtonia robusta*

The disease has many names as pink rot, pink bud rot and Gliocladium blight. It is caused by *Nalanthamala vermoeseni*. The fungus was initially reported as *Penicillium vermoesi* and later as *G. vermoeseni*, to be finally placed in the genus *Nalanthamala*. The fungus has a worldwide distribution, grows in culture media, on palm surfaces and produces long chains of salmon color conidia. It grows well in cool, wet weather, the optimum temperature for growth being 24 °C with inactivation occurring above 33 °C. In date palm pink rot may simultaneously occur with *Phoenix canariensis* wilt disease. It is a common problem of *Archontophoenix*, bamboo palms, *Dypsis* and *Trachycarpus* spp., Queen and Washingtonia palms.

7.5.1 Symptoms and Diagnosis

Symptoms include leaf spots, petiole and rachis blights, sheath, bud and trunk rots and decay of susceptible palms, usually characterized by trunk and bud rot. Symptoms of the disease also include formation of light brown spots on the leaves and rachis, chlorosis and necrosis of leaf tips, rot on rachis, sheath and trunk leading towards palms death. Pinkish to orange fungal growth appears on the surface of the infected tissues. The fungus may kill the apical meristem or stunting and twisting of spear leaves. It causes trunk rot in bamboo and king palms and stem rots in queen palm, but the fungus does not seems to sporulate in stem cankers. Necrotic lesions encircled by water soaked margins will be formed on the green healthy trunk tissues. Salmon pink colored spores are produced on advanced cankers. Presence of pink spore masses is a diagnostic sign of pink rot infections. In *P. canariensis* the fungus causes dark brown vascular streaking and one sided necrosis (Downer et al. 2009; Ligoxigakis et al. 2013).

7.5.2 Management

Exclusion, avoidance of wounding and injuries, plant health, sanitations and water management are crucial in disease prevention. Use of healthy, vigorous seed and seedlings is essential to avoid disease. Wounding is essentially required for successful penetration and infection in many palms such as bamboo and king palms. Susceptibility to the disease is greatly influenced when older leaves are removed and a tear arises from the point of attachment. In many palm species, including fan, date and windmill palms, infection was higher when the trees were injured with extreme abiotic stresses. Extreme pruning will also enhance the vulnerability to the disease. Hence, good agro-technical practices are extremely useful for disease prevention. Keeping plants at proper distance, increasing the air circulation and irrigating plants early morning are helpful practices. Plants should always be pruned during sunshine hours when temperature exceeds 30 °C, trying to keep the plant surfaces dry as moisture is helpful in disease development (Uchida 2004; Downer et al. 2009).

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Chapter 8
Fungal Diseases of Golden Palm (*Dypsis lutescens*)

Muhammad Taimoor Shakeel, N. I. Katis, Muhammad Mohsin Alam, Rashida Atiq, and Qaiser Shakeel

Abstract Palm tree species are one of the most common, well established and expensive ornamental plants. A number of palm tree species have their importance for specific attributes. They are important as ornamentals, air cleaners, source of medicinal and industrial uses. Palm trees are affected by several fungal pathogens which cause leaf spots, blights, butt rots, bud rots and wilts. Leaf spots of varying colors are developed on leaves which might be of several shapes. Blights are also usually developed on leaves which are more devastating than the leafspots. Butt rots and bud rots are also important diseases which affect leaves and stem. The palm trees that are affected by wilts are attacked by different species of *Fusarium*. These pathogens gain entry in the plant from the roots and get established in the vascular bundle which are late on clogged by the physical presence or the exudates released by the pathogen. Fungicides are mostly helpful in protecting the plants from fungal diseases, however, they are not much effective after the plant is infected. All these diseases are well controlled only by good management practices.

Keywords Fusarium · *Dypsis lutescens* · Golden cane palm

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_8

8.1 Introduction

In several ancient civilizations palms were a symbol for notions as win, harmony, and fertility. *Dypsis lutescens* is recognized by many names among which the most common are butterfly palm (as the leaves bear a resemblance to butterflies), areca palm, golden cane palm (as the lower canes have a gold / yellow color) and yellow palm. The plant was inherited to Philippines, Madagascar and South India and adapted in the southern Florida, Réunion, El Salvador, Canary Islands, Puerto Rico, Cuba, Andaman Islands, Jamaica, the Dominican Republic, Haiti, Venezuelan Antilles and Leeward Islands (Beentje and Dransf 1995). The plant has the potential to grow up to 2.4 m in a well-drained aerated potted soil mix including peat, pine bark and coarse sand (Chiduruppa et al. 2018).

The plant is highly adaptive to its surrounding environment, and is ranked among the most endangered ornamental plant species. Seed propagation of *D. lutescens* is a very time consuming and laborious job, which requires optimum temperature of 26 °C while the growth is drastically affected when the temperature drops below 12.7 °C. Sudden drop in temperature, especially during winter, can produce brown spot on the leaves. *Dypsis lutescens* is considered an effective air cleansing ornamental plant. It thrives to grow almost everywhere like office décor, corridors, hallways, reception areas and even at balconies but only if it is provided with sufficient light, enough temperature and desired moisture. Overwatering can cause water to stagnate near the root zone making it almost impossible for the plant to uptake nutrients and oxygen from the pot mix soil. *Dypsis lutescens* has been known by many names i.e. Golden Cane, Butterfly, Yellow or Areca Palm.

8.2 Description and Importance of *Dypsis lutescens*

Dypsis lutescens normally gains a height of 6 to 12 m in height. Numerous shoots arise from its base and give rise to curved leaves, 2–3 m in length. The pinnate has 40-60 pairs of leaflets and bear panicles of yellow flowers during the summer season. As a propagation method, offsets are cut off when they become mature. It is grown as a perfect ornamental plant in gardens in subtropical and tropical areas, and elsewhere indoors as a household plant. *Dypsis lutescens* was awarded with the Garden Merit of the Royal Horticultural Society (Chiduruppa et al. 2018). All over America, the Areca palm is utilized widely as a landscape plant that endures best where the normal annual minimum temperature arrays from 1.6 to 4.4 °C (35 to 40 °F).

Apart from the utilization of *Dypsis lutescens* as an ornamental plant, it has been known as a perfect air sanitizer or cleaner as well as a plant of medicinal importance.

8.3 Fungal Diseases of Golden Cane Palm

The fungal diseases affecting golden cane palm include:

1. Leaf spot and blight
2. Ganoderma butt rot
3. Bud rot
4. Fusarium wilt

8.3.1 Leaf Spot and Blight

Leaf spots and blights are induced by several fungal pathogens but the symptoms exhibited by their infection are quite similar to those caused by a number of other fungal agents. All species of palms are susceptible hosts for leaf spots and blight, particularly during seedling and juvenile stages. The variance concerning leaf spot and blight is related to the gradation of damage caused to the leaf blade. For understanding the difference between the two diseases: if the spots are individually parted from one another by green tissue then the disease is stated as leaf spot. When these spots arise rapidly to fuse together to make a larger area damaged by the pathogen the disease is stated to be a leaf blight.

8.3.1.1 Etiology

The spots and blights that appear on the surface of the leaves are produced by several plant pathogenic fungi. The symptoms of all fungal species are similar to each other regardless of the fungus which is causing the spot or blight. Possibe causes of leaf spots and blights in palms are *Annellophora*, *Exserohilum*, *Phaeotrichoconis, Stigmina, Bipolaris, Cercospora*, *Gliocladium, Pestalotiopsis, Pestalotia, Phyllachora, Colletotrichum*, *Pseudocercospora* and *Calonectria (Cylindrocladium*). All palm species are infected by at least one of above-mentioned fungal pathogens, exclusively in the early stages. Also, most of these pathogens are also reported to cause diseases on plants other than palms trees (Elliot and Broschat 2018).

8.3.1.2 Symptoms

- The primary symptom for leaf spot is given by numerous tiny water-soaked lesions. Within 24 hours, these lesions turn to different shades of yellowish gray, reddish-brown, brown to black in appearance.
- Lesions developing as a result of disease are of multiple and varying colors and are sometimes surrounded by a colorless ring or by a tissue that is of any color

other than that of the spot. For example, black spots surrounded by yellow (pale) ring; pale spots surrounded by reddish-brown halos or black rings; gray spots surrounded by a black halo surrounded by a pale halo. There is change in the usually undeviating color of the healthy leaf blade with a disruption circular or oblong in shape.
- Every pathogen causes spots of different sizes ultimately results in killing of the diseased tissues.
- Leaves of all ages are susceptible to leaf spots.
- Juvenile palms only have few leaves and their pathogen has the potential to produce symptoms on all those leaves at the same time.
- Sometimes potassium deficiency can be confused with the symptoms of leaf spots because it appears in the form of yellow to orange translucent spots or black spots.
- Similarly, manganese shortage produces symptoms on the youngest leaves that could be considered as leaf spot or blight as well. These symptoms appear in the form of interveinal dead necrotic streaks(Elliot and Broschat 2018).

8.3.1.3 Dispersal

Spot and blight are caused by many different fungi which are propagated through many kinds of spores which are dispersed by environmental factors like wind, water and rain splashes. These spores are also disseminated through different insects, rodents and also during managemental practices such as pruning by humans. The tools which are used can also transport the spores from diseased plant to healthy ones. Water has great importance not only in dissemination of spores, but also for these spores to germinate and penetrate in the host through its wet surface.

8.3.1.4 Disease Management

- Sanitation of pots to retain aeration in the mixed soil.
- Efficient use of water is critical for the management of leaf spot. For this purpose, it is recommended the removal of excessive water, and conservation of rainfall is of utmost importance.
- Leaf spots are negligible if the surface of the leaves is kept dry. Higher air circulation can be utilized to keep plants drier.
- It has been observed in juvenile palms that the severity of leaf spots increases when the palms are grown under direct sun, somewhat more than in those grown under shade.
- The nursery must be checked consecutively. Infected leaves should be pruned, or eradication of the palm must be utilized to prevent the spread of the disease. Pruned leaves and eradicated plants must be destroyed away from the nursery or buried in the soil away from palm as these infected plants or parts can be a source of inoculum for healthy palms.

- Mature palms must be kept under observation as these plants can be a source of inoculum against healthy plants.
- Leaf spot pathogens do not depend only on palms and have other alternate hosts on which they can survive. Therefore, if there is a nursery that produces other ornamental plants, these plants must be kept under regular check. Some weeds are also alternate hosts for these disease-causing organisms, which can be managed through herbicides.
- Fungicides may provide a protective control, but alone they cannot solve a problematic situation. Fungicides are not effective in treating the leaf spots that are already present on palm leaves, which means that if a spot has developed, it will never be cured through-out the the infected plant life. Application of fungicides can only provide best protective control but cannot be curative once the spots appear on leaves(Elliot and Broschat 2018).

8.3.2 Ganoderma Butt Rot

Ganoderma butt rot is a fungal disease which has the potential to attack every existing species of palm. Its most destructive feature is that the plant will look healthy until its death. This disease is recognized by a spongy growth which is whitish in color occurring at or near the base of the palm, often known as the butt of the palm. This growth is just the foundation of the Ganoderma butt rot. The pathogen takes its nutrition from the wood inside the palm, killing it from the inside out. It causes wood rot and convert it into a spongy texture. The fully mature growth resembles a seashell with prominent stripes, brown in color. The outgrowth is known as basidiocarp or conk, which after maturity breaks open to disperse the spores by wind or water (Elliot and Broschat 2018).

8.3.2.1 Symptoms

- The initial symptom of the disease is a mild to severe wilting mostly on the lower leaves, but it can be found on all leaves of the palm canopy. This causes premature death of older leaves and retarded growth of palm, despite of balanced application of fertilizer.
- The basidiocarp or conk is the utmost prominent structure that can be identified in a first look. The basidiocarp originates from the growth of the fungi inside the palm trunk. As it matures, a small shelf will begin to produce basidiocarp which initiate its extension further from the trunk. This extension is white in color on both upper and lower surfaces. Ultimately, the fungus will develop this structure which has a very hard surface which is glazed with reddish-brown color on the top.
- Fully developed basidiocarps have different zones, that is why the fungus was given the name of *Ganoderma zonatum.*

- Stalk or stem is not attached with the basidiocarp to the trunk.
- Rust-colored spores are released after the maturity of basidiocarp which cover the basidiocarp and the surrounding area after sometime (Elliott and Broschat 2018).

8.3.2.2 Etiology

Ganoderma zonatum is a plant pathogenic fungus that has the potential to infect all palm species. It is classified in the order Polyporales. This fungus causes devastating effects up to 1.2 – 1.5 m of the plant from the bottom, which causes rotting of roots. It is found in both natural as well as planted environments.

Members of *Ganoderma* are wood-decaying fungi which can be found all around the globe on every kind of woody plant or tree. Although there are many different species, *Ganoderma zonatum* is only pathogenic to palms and is not reported to cause any disease to plant species from any other family.

8.3.2.3 Spread

The disease is dispersed mainly by the spores which are produced by the conk. *Ganoderma zonatum* is present in soil and from there it penetrates the woody trunk tissue at or below the soil line. The pathogen may not show symptoms on the infected tree as soon as it established in its wood. It may keep itself hidden in the plant for months without showing any symptoms, until the environmental conditions are favorable for its growth.

8.3.2.4 Disease and Fungus Life Cycle

The fungus multiplies itself through spores with the help of wind or water. The spores are mixed into the soil, germinate, and develop hyphae that grow over the palm roots. It does not produce any kind of damage on the palm root system. It only utilizes roots tissues for its spread towards the woody trunk tissue. As soon as a palm is infected with *G. zonatum*, the fungus will also be transmitted to the area where it is transplanted. It is also possible that soil is conducive that means it is abundant with the pathogens propagules (Elliot and Broschat 2018).

Disease Management

- As the disease initiates from soil therefore there is no effective fungicide suitable for its management.
- Palms should be monitored closely. Community patrols can be an effective way to identify the conk and demolishing it before it reaches maturity.
- If the conk appears on the palm, then that palm should be removed from the field.

- Bring in new soil in the palm nursery and fumigate it time to time (Elliot and Broschat 2018).

8.3.3 Bud Rot

8.3.3.1 Etiology

Phytophthora palmivora is a pathogen known to be the cause of bud rot. It is an oomycete that causes fruit-rot of coconut or bud-rot of palms and areca nut, considered as among the most destructive diseases caused by a fungus. Its incidence is frequent, at least once in a year, in areas like Malnad, Mysore, North and South Kanara, Malabar and other areas. The pathogen develops intercellularly, with a hyaline and coenocytic mycelium. Sporangiophores, which may be single or branched,are transparent and thin walled, pear shaped with a well-defined papilla. Sporangia releases reniform zoospores with two flagella (biflagellate). It also may form thick walled, spherical oospores and, for surviving harsh conditions, it can also produce yellowish to brown chlamydospores, with a thick wall. High rainfall, high atmospheric humidity (>90%), temperature that range from 18 to 20 °C and injury caused by Rhinoceros beetles, may increase the disease incidence.

8.3.3.2 Survival and Disease Transmission

Survival mainly relies on chlamydospores and oospores in tough environmental conditions, in crop residue whereas mycelium remains dormant in infected tissues. Sporangia and zoospores transmit the disease through air and rain. Few insects play their role in dispersal of inoculum from diseased trees.

8.3.3.3 Symptoms

- Younger palms between the age of 5-20 years are more prone to infection.
- Initial symptoms appear on the spindle, which is the central shoot of the tree. The heart leaf develops a clear decolorization and turns brown rather than yellowish brown.
- Subsequent to decolorization the defoliation of heart leaf occurs.
- As the disease progresses the number of leaves get affected with loss of shine, becoming pale yellow.
- The base of crown is usually rotten producing a foul smell.
- Main central shoot can be detached on minor pulling.
- The leaf falling and shedding starts from the top of the crown and continues to defoliate until a few outer leaves are left healthy. In few months, the disease

continuous to spread and all the leaves are shed, resulting in the eventual death of the entire tree.

8.3.3.4 Management

- Cold outdoor temperature results in greater chance for a palm to get infected, therefore it is adviced to cultivate palms at low temperature, i.e. indoor.
- If the palm is to be planted indoor then it must be planted in areas where it can get maximum sunlight and good protection from cold and drying winds in winter.
- Irrigate palms at the base of the plant to avoid getting water on leaves and crown. Ensure that outdoor palms get morning sun to quickly dry any dew from the leaves.
- To plant a palm a soil which has well-draining capacity is preferred, because the bud rot pathogens thrive in moist soil. If growing palm in a container, ensure that it has drainage holes.
- If a palm is already infected with bud rot, then chemical treatment is not effective to manage the disease. Therefore, if new leaves separate because of infection then the best management is to dispose the infected trees to prevent further spread of the disease.
- For younger plants, protective fungicide can manage the disease. For this purpose, only use recommended fungicides, which can be applied on all plants at same dose without causing any sort of phytotoxicity.

8.3.4 Fusarium Wilt of Golden Palm

Fusarium wilt is another very common disease problem of trees and shrubs belonging to ornamental group. Palm tree Fusarium wilt appears in several forms, but produces similar symptoms on different plant species. It is a fungal species involved in the etiology of wilt in palm trees, host specific with no effective control measure, which results in the death of the diseased palm.

8.3.4.1 Etiology

The causal organism of the Fusarium wilt is *Fusarium oxysporum.* Two important strains causing this disease are *F. oxysporum* f. sp. *canariensis*, which effects Canary palms, and *Fusarium oxysporum* f. sp. *palmarum*, causing a disease to several ornamental palms in nature (Bonnie 2018).

8.3.4.2 Symptoms

- Wilting problem arises with the presence of the mycelium and spores in the vascular bundle of the tree, which results in the interruption of water uptake. As soon as the disease develops, fronds and leaves are the first organs to exhibit the symptoms. Just as any other plant start lose the green color and integrity of leaves because of loss of water, the fronds will become yellow and eventually brown, crinkled at the ends of leaflets and eventually will die.
- The symptoms start developing at older fronds and move up to the younger part of the palm.
- An accompanying disease, called pink rot, add up to the dying process in many cases. This disease attacks the old, injured and weak plants as an opportunistic fungus. Fusarium wilt of palms may be treated with thiophenate-methyl fungicide application to stem (Bonnie 2018).

8.3.4.3 Disease Cycle

The *Fusarium* spp. causing wilt in palm trees can survive in soil for years. Spores penetrate the plants through the roots and move into the vascular system. Fusarium get established in the xylem, reducing water uptake and interfering with the upward movement of nutrients. With the passage of time it clogs the water transporting tissue with a gummy substance. Over the passage of time the infected tree start showing signs of stress, due to insufficient supply of water.

8.3.4.4 Dispersal

The pathogen can also be transmitted by mechanical means. Purchase of infected or contaminated plants and poorly managed trees are the most common mode of disease spread. Tools contaminated with the pathogens are also a common way to introduce it during pruning and cutting. Therefore, it is extremely essential to sanitize tools before using them on another plant.

8.3.4.5 Management

- Careful management of palms is the only way to control the disease spread because there is no effective control strategy available. In case of poor management and disease outbreak, there is no other option than removing the affected palm tree.
- Irrigate the plants with supplemental water and remove the infected debris without delay.
- If the debris is suspected to be contaminated with fungal spores, this must be removed and never be considered for preparation of compost.

- Hygiene and proper management are the primary facets of Fusarium wilt treatment for the palms trees. Always use disinfected tools for pruning of healthy plants, and especially for the disease fronds. Never use a chainsaw and trim the palms only on a windless day to avoid the drifting of sawdust from diseased to healthy trees. Apart from management, application of clean and good quality water along with appropriate supply of nutrients can increase the lifespan of the trees for years.

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Useful Links

Https://www.ourhouseplants.com/plants/areca-palm

Http://www.secrets-of-longevity-in-humans.com/oxygen-producing-plants.html

Https://www.houseplantsexpert.com/areca-palm.html

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Chapter 9
Fungal Diseases of Bismarckia Palm (*Bismarckia nobilis*)

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Abstract Bismarckia palm (*Bismarckia nobilis*) is a popular ornamental plant used for landscapes, green belts and home gardens due to its marvelous aesthetic look. This tree is native to Madagascar that hosts a long cool and wet seasons in most parts of the country. Bismarckia palm adapts well to the changing environments, hence no major disease epidemics have been reported for it. However, due to its increasing demand and popularity for the landscapes, it may become exposed to some associated fungal pathogens. This chapter will discuss the important fungal diseases of Bismarckia palm and their integrated management.

Keywords Palm · Bismarckia · Pathogen · Fungi

9.1 Introduction

The Bismarck palm, *Bismarckia nobilis,* is native of Madagascar. It can grow as tall as 9 to 18 meters and spreads 3.6 to 4.8 meters wide. The costa-palmate fronds that characterize this species are approximately 1.2 meters wide, showing a silvery-green color, with some varieties displaying light olive-green leaves. This palm usually has split leaf bases, which create an exquisite pattern on its trunk, around 38–45 cm in diameter. On separate male and female trees dark brown flowers are developed, producing a fruit that have an olive to brown color, with a diameter of about 4 cm. This arrangement became a famous focal attractions in landscaping, particularly in small residential areas. Bismarck palm have made a strong marketing potential based particularly on its color, bold texture and outstanding height (Broschat 2017).

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9.1.1 Taxonomy

Family: Arecaceae, Subfamily: Coryphoideae, Tribe: Borasseae, Genus: *Bismarckia*, Species: *B. nobilis* (CABI 2019).

9.2 Management

Most of the palm species are resistant to windstorm damage but Bismarck palms, mainly because of its widely spread fronds which may tend to break against exposure to strong winds. Nonetheless, this palm tree species is highly tolerant to drought and can moderately tolerate salt stress.

9.2.1 Nutritional Management

Bismarckia palms can adapt to a wide range of soils except to those deficient in potassium. This deficiency causes necrotic spotting on leaves, eventually turning them to yellow-orange translucency or worse, with death of the leaflet tip of eldest leaves. Potassium deficiency causes death of immature leaves, thus reducing the spread of fronds supported by the palm (Broschat 2017).

However, magnesium deficiency in soil where the Bismarck species are planted manifest silvery leaves which give an unusual light yellowish tint. Other symptoms of magnesium-deficient *Bismarckia* include chlorosis (insufficiency in chlorophyll), occurrence of necrotic streaking, and leaf spot symptoms, particularly on new leaves. Boron deficiency is considered one of the nutritional problem of Bismarck palms. In temporary mild cases, one or more necrotic cells became evident around young leaves. This happens nearly five months before leaf emergence. Chronic boron deficiency, which are reasonably common in Bismarck, results in improper opening of its meristem. Sometimes, a specialized region of the leaf tends to shut thus showing no leaves for a certain period of time. In cases of severe boron deficiency, stunted and distorted leaves, particularly for new ones, can be found on the palm (Broschat 2017).

Nutrient deficiency in *Bismarckia* must be prevented early rather than correcting it later, for it will take 2 or 3 years for some species to achieve a balanced nutrition. A regular use of fertilizers is suggested, choosing a fertilizer with NPK composition of 8-2-12, with addition of 4 Mg and micronutrients. This analysis can correct mild to moderate deficiencies on magnesium, potassium and boron. It can also prevent their recurrence, although it cannot be implied that all fertilizers having a similar composition are effective. If they are formulated improperly, it may be harmful to the palm, rather than representing a preventive measure (Broschat 2017).

9.2.2 Propagation

Bismarck palms can only be propagated by seeds. Its germination period took six to twelve months at high temperatures (32–37 °C). Tomlinson (1990) estimated that over 25% of all palm species require more than a hundred days to germinate, with only 20% germination rate. Growth moderately occurs once the trunk is visible and developed. If guidelines for germinating palm seeds are followed strictly, palm growers can achieve a maximum germination.

Since palm seeds often have a slow and uneven germination, pre-plant treatments are greatly considered to yield higher germination rates. People who commercially grow palm trees should consider the value of seed pre-treatments as a part of their labor cost. Eventually, if they get positive results from this method, they may gain more success and guarantee more profitability.

After germination, once leaves appear, the palm seedlings are ready for transplanting. It is best to transfer seedlings in a big container before roots begin to spread and become entangled. This method lessens the degree of root disturbance to the seedlings. There are two possible ways to transfer seedlings. They can be transferred to a bigger container to have a larger access for root development. Alternatively, they can be transferred to a larger pot than itself to give room for growth before transplanting them to the ground (Meerow and Broschat 2015). Palm growers should consider that when seedlings grow maturely inside the fields, transplanting may become very difficult. Stress on the roots will surely cause a damage, eventually leading to the plant death.

It is advisable to prune the roots few months before moving the seedlings to achieved successful transplanting. Digging larger root balls or removing most of the leaves are recommended during this activity. Root grows rapidly during warmer months thus it is advisable to transplant the Bismarckia palm in summers (Broschat 2017).

9.2.3 Cultural Practices

Pruning of the Bismarck palms can be considered during any time of the year. It is done by removing dead leaves from their petioles or cutting petioles very close from the trunk. Partially dead leaves should not be cut immediately for they serve as a supplemental source of potassium to the palms. However, when living leaves are wounded, a volatile chemical is released attracting palmetto weevils (*Rhynchophorus cruentatus*). This palm weevil tend to lay their eggs in the base of the leaves, thus paving its way to hole into the trunks, particularly near the meristem or bud. When this happens, infested palms slowly die. Unfortunately, Bismarck palms are highly sensitive to this pest, especially when they are stressed due to cold temperatures, improper transplanting, or other factors caused by its immediate surroundings (Broschat 2017).

9.3 Fungal Diseases

9.3.1 Ganoderma Butt Rot

Ganoderma butt rot is one of the fungal diseases known to attack palm trees including Bismarck palms. *Ganoderma butt rot*, a fungal disease, caused by *Ganoderma zonatum,* starts to decay the lower part of the trunk affecting the palm stability, which leads to its death. Mostly infected by the fungus is the lower lignin of the trunk, about 1.2 to 1.5 m above the ground. The trunk deceivingly looks hard because the fungus does not cause the trunk to look soft inside out. This fungus is spread by spores, which are produced and released from the basidiocarp (conk, see previous Chapters).

Although the disease is said to prevail in Southern USA, where palms grow abundantly, but it is not confined there. Most part of Florida is affected by this disease and distributed throughout Key West to Pensacola, and in part of South Carolina and Georgia, as well.

9.3.1.1 Etiology

Ganoderma is a genus of pathogenic fungi that can infect almost all types of tree wood including woody dicots, gymnosperms and palms. A sole pathogen of palm tree, *Ganoderma zonatum*, is found in Florida but it does not create diseases in any other member of the plant family. It commonly thrives on the stout palm trunk of the tree in a form of basidiocarp (or conk). *Ganoderma* spp. are often observed on oak trees since they have hardwood. Saprobes, fungi that live off dead plant material, appears visibly on dead trunks and stumps. This disease attacks the inside of the tree thus making the palm rotten inside out. The wood looks spongy in texture when rot. All palms are acknowledged to be susceptible to *Ganoderma* species. About 65 species of palms in Florida are documented to acquire Ganoderma butt rot.

The enzymes produced from *G. zonatum* bruise, rot and eventually kill the woody tissues of the palm. It attacks the lignin of the palm wood first followed by its cellulose. As the wood deterioration occurs internally, the water-conducting xylem tissue is affected, resulting in a mild wilting that could develop severely on the fronds, except the leaf spear. Discoloration of the leaf could also be observed and slow growth is expected. However, these symptoms cannot be attributed to *G. zonatum* only, as other diseases could also show the same effects.

The most distinctive makeup associated with the fungus is the presence of its basidiocarp. It develops inside the trunk in a form of solid white mass that is soft, irregular in shape and thrives flatly on the stump or trunk. As it matures, a small ledge starts to form as the conk set about to grow from the trunk. It will remain white in color upside down, forming a very defined, hard, reddish-brown shelf-like structure on top and white beneath. Distinct zones will be formed form mature conks hence the name *G. zonatum*. The basidiocarp creates a crescent-shape with a "straight" side attached directly to the trunk.

Cross-cutting the sections of the trunk is the safest way to determine the presence of the *Ganoderma* butt rot. However, a bare eye should not be deceived for conks commonly appear before the palm tree is almost dying and slow growth is manifesting. The sign that the trunk is infected with *G. zonatum* is through the darkening of woods caused by fungal infection.

Conks of *G. zonatum* grow to 20 cm in width and 5 cm in thickness. However, conks will eventually follow the size and shape of the area in which they grow. Microscopic basidiospores are produced on the underside of the conk. They look brownish-red when conks are dropped in large amount on a white, clear surface. If there are objects around the basidiocarp, a rust-color dust will be visible to the naked eyed. Each conk produces at least 3 cups of spores making the disease spreading fast.

Spores are major source of the fungal inoculum. When they move into the soil, they sprout or germinate, and the fungal hyphae grow on the palm roots. This fungus uses the roots as a way to reach the palm woody trunk tissues. It may be observed that, once the trunk is infected, it is characterized by a distinct dark section.

Ganoderma zonatum transfers to the soil where the infected palm tree is transplanted thus giving the fungus an easy access to multiply itself. It could also be possible that the soil where the palm is transplanted is already infested with *G. zonatum.*

It is difficult to assess when a palm is initially infested or not with *G. zonatum* until the conk is formed. There is no exact evidence yet as to how many months or years does the initial infection occur, until it develops into conks. A detection protocol has not yet been determined.

The fungus colonization and xylem deterioration in the palm trunk occurs initially nearest to the soil line. It then spreads out first in diameter at the base up to the center or near-center of the trunk. Thus, the internal progression pattern of the disease in the trunk takes a conical shape, with the widest part at the soil line and narrowing towards a central pinpoint.

It is said that where the fungus emerges, it developes into the conks. This cycle internally occurs from the lower center of the palm first, then moving towards the outside. Consequently, a wound outside the trunk could not manifest the rotting and cannot likely be associated to the initial disease. Some external factors such as striking the trunk during irrigation, mulching around the trunk, grown flowers or shrubs that are too close to the trunk and painting the wounded or unwounded trunk, could not be also associated to the fungus in the palm.

9.3.1.2 Management

Nevertheless, care should be taken in choosing the field where planting or transplanting of Bismarkia palm trees, because the fungus thrives in any type of soil once it gets in contact with them. As conks do not visibly appear on the trunk, growers never know exactly when the palm is infested or not.

Ganoderma is a wood-decaying fungal genus that thrives in almost any kind of wood such as soft wood and, hard wood palms. When the new leaf turns brown to yellowish in color it should be removed before it infect new leaves. It is typical of the fungus to attack the new leaf first, known as bud, making it rot. The process just duplicates on the adjacent frond, it will move to the newest ones, discoloring and eventually rotting them.

Through basidiospores, which are formed in the basidiocarps, the fungus spreads rapidly throughout the palm. Therefore, the first step to prevent the fungus from multiplying is to monitor its growth closely. Since basidiospores scatter easily with the aid of wind and water, it is highly recommended to remove and incinerate dead treesor any part of the palm removed from the infected trunk, . Placing the cut trunks in a trash would not help eliminate the conks. It might just spread the spores along the way as the trash will be thrown in time to a nearby garbage area in the backyard. If the conks are removed soon, the less they would cause basidiospores to scatter in the surroundings. It is adequate to monitor the palm tree semi-annually. A fungicide can be used to treat the initial growth of *G. zonatum*, but it will take some applications before the fungus is killed.

There is no management practice established yet culture the fungus,. It occurs naturally making it difficult to eliminate. It is favored by many conditions, even on highly maintained landscapes or nutritionally rich-soil. *Ganoderma zonatum* even occurs in swamps or in a properly drained environment. A clue has not been found even to understand why some palms became infected by *G. zonatum* while others are resistant to it (Elliott and Broschat 2018). See Chap. 5 for fungicide applications.

9.3.2 Pestalotiopsis Leaf Spots

The fungus *Pestalotiopsis* causes leaf spots and petiole/rachis blights. Unlike other leaf spot pathogens, it can attack all parts of the leaf, from base to tip. This disease has been reported on *Bismarckia nobilis in 1984 in USA (Alfieri et al.* 1984). It is reported that mechanical injuries and pest damages are required for entry in the host.

9.3.2.1 Etiology

Leaf spot of *Bismarckia nobilis is caused by* Pestalotiopsis palmarum (Ascomycota, Xylariales).

9.3.2.2 Symptoms

- Disease symptoms can appear on the leaf blade (leaflets or leaf segments) as well as petiole and rachis.
- Infection starts as small yellow spots that later turn brown-black.
- If the infection does not proliferate systemically, the spots size usually is restricted to 0.6 cm (1/4 inch) in size.
- Under conducive conditions, the spots increase in size and number, later they merge (coalesce) to form a leaf blight or rachis blight.
- Sometimes the spots turn into grayish color outlined in black.
- The same type of lesions may even be seen on leaf spines (in spiny species).
- Young plants are most affected as compared to older ones.
- Rachis and petiole blight due to *Pestalotiopsis palmarum* are more injurious, as they can invade the vascular system, usually leading to the death of young plants.

9.3.2.3 Management

- *Pestalotiopsis palmarum* produces abundant spores that can be dispersed easily through wind and rain. Hence sanitation is the foremost protection advise for growers.
- As mentioned earlier, mechanical injuries favor the pathogen infestation, hence care should be taken while performing the field operations. Pruning may be followed by a spray of a broad spectrum, protective fungicide.
- Water management is also required to limit the higher humidity, particularly during the winter seasons. Adequate plant spacing will decrease the leaf wetness by increasing the air circulation.
- Diseased leaves should be pruned and rouged well. Young plants with few leaves may be completely destroyed.
- It is critical to understand that fungicides do not cure a leaf spot or petiole blight already present. Once a leaf spot or petiole lesion occurs, it will remain during its entire life. Fungicides may prevent further spread of the disease, by protecting leaf tissue that has not yet been infected by the pathogen (Elliott 2018a, b).

9.3.3 Fusarium Wilt of Bismarckia Nobilis

9.3.3.1 Etiology

Fusarium solani has been primarily reported to cause the Fusarium wilt in Bismarckia palms (Miller 1993). However, recent reports have indicated that *Fusarium oxysporum* f. sp. *palmarum* is also associated with *Bismarckia nobilis* (Elliott 2018a, b), although this association does not confirm a pathogenicity of *F. oxysporum* towards *B. nobilis*.

9.3.3.2 Symptoms

There have been little details about symptomology of Fusarium wilts, particularly over Bismarckia palm. However, general symptoms have been found as below.

- The fungus blocks the vascular system of the host plant.
- Vascular clogging affects the water transport in the plant.
- Affected plants show the yellowing of younger leaves and dead leaflets, which start on one side of the leaf blade.
- The disease normally progresses upward, starting from the lower leaves, eventually moving upwards and killing all leaves.
- The internal stem tissue turns reddish-brown when viewed in cross section (Lester 2015).

9.3.3.3 Management

Management of *F. solani* has been proposed in various literature. However, control of this pathogen has been reported as successful for palms under greenhouse conditions. It was also indicated that most *in vitro* methods may not show the same results as in controlled conditions. Initially, the fungicide Cidely® Top (difenoconazole and cyflufenamid) successfully provided *in vitro* inhibition of *F. solani* at 250 ppm up to 79.5–96.3%. Later these results were also confirmed in pot experiments, as it caused septal malformations and cytoplasmic coagulation in the hyphae and conidial deformation (Alwahshi et al. 2019). Moreover, Propizol© was also released in the USA as a broad spectrum fungicide for the control of wilt diseases in ornamental palms.

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Chapter 10
Fungal Diseases of Date Palm (*Phoenix dactylifera*): Etiology and Management

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Abstract The Date palm (*Phoenix dactylifera* L.), is one of the oldest and ancient crops in Southwest Asia and North Africa. The Food and Agriculture Organization (FAO) estimated that more than 100 million date palm trees are scattered over the area of 1.3 million hectares world over. Although Date palm is mostly cultivated for fruit, it is also grown in many countries as an ornamental plant or as a landscape tree. This palm is subjected to the attack of many fungal diseases, which not only reduce the date fruit yield but also deteriorate their quality, and the plantation as well. In some cases the diseases are more destructive, which may lead to the death of the plant. In this chapter we discuss briefly major fungal diseases of Date palm, their etiology, symptoms and management.

Keywords Date palm (*Phoenix dactylifera* L.) · Fungal plant pathogens · Etiology · Integrated management

10.1 Introduction

Date palm is the oldest known cultivated plant among the fruit crops (Zohary and Hopf 2000). It is important crop of the arid region, cultivated in almost thirty five countries of the world (Biglari et al. 2008). Its cultivation has been widely distributed to new areas including India, Pakistan, Australia, South America, Mexico, North Africa and USA since the last three centuries. This species has great nutritional, medicinal, ornamental as well as cultural and religious importance. It is grown as an ornamental plant in many countries worldwide, due to its beautiful

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_10

foliage and attractive growth habit. Its leaves are used for the celebration of "Palm Sunday" among Christians and celebration of "Sukkoth" among Jews. Historically, it has been represented extensively, as on coins and monuments.

Date palm (*Phoenix dactylifera*, family Palmaceae) is a perennial, diploid, monocotyledonous, dioecious, tall and evergreen palm (Barrow 1998). The name is the combination of two Greek words: "phoenix" purple (fruit), "dactylifera"that means finger-like fruit bunch (Sudhersan and Abo El-Nil 1999). Fruit bearing on trees start at the age of 4 to 6 years, completely maturing at 12 years (Zohary and Hopf 1993), with full production achieved at15–20 years of age (Nixon and Carpenter 1978).

10.2 Propagation and Pollination

Date palm is propagated using three methods i.e. through seeds, by a vegetative method or through tissue culture (Zaid and de Wet 2002; Nixon and Carpenter 1978). Use of seeds for propagation is just for breeding purposes, while offshoots are used to obtain true to type variety (Tisserat 1984; Omar et al. 1992; Benbadis 1992). Three to five years old offshoots can be detached from mother plants and used for plantation. Through tissue culture (organogenesis) genetically similar palms can be obtained. Somaclonal variation is the major problem in tissue cultured date palms, which is high in some cases (Gurevich et al. 2005).

Pollination is accomplished by different methods i.e. manually and mechanically (Goor 1967). Manual pollination is laborious and not cost effective (Brown and Perkins 1969). While mechanical pollination has many advantages over manual pollination, reducing by 50% the cost compared to hand pollination (Perkins and Burkner 1973). Date palm takes five to seven months from pollination to maturity, with harvesting completed during August to October. Rainfall can cause damage at the time of fruit maturation (Barreveld 1993).

10.3 Date Palm Ecology

This palm is best adapted to the tropical and subtropical climate. It needs temperature higher than 35 °C (95 °F) during May to October for proper maturing of fruit. It requires high sunshine, less rainfall and can tolerate extreme climatic conditions (cold, heat, dryness, salt and wet conditions (Saudi Aramco World 1962). No harm to the palm occurs even at 50 °C (Barreveld 1993). The temperature requirements for flowering and fruit formation are more than 18 °C and 25 °C, respectively (Zaid and de Wet 2002).

10.4 Products

A variety of products are prepared from different parts of the date palm tree with varying extent of economic value. Trunk furnishes timber used for construction working and fuel, leaves midribs are used for crates and furniture, leaves for basketry, fronds used as roof covering, fruit stalks for rope, fiber is used for packing material and grinded seeds are used as livestock feed (Tengberg 2012).

10.5 Nutritional and Medicinal Importance

Dates provide highly energetic food (El-Juhany 2010). Date palm fruit contains 44–88% carbohydrates, 2.3–5.6% proteins, 0.2–0.5% fats, 6.4–11.5% of dietary fibers, salts, minerals complex of vitamins (vitamin A, B1, B2, C and nicotinic acid), 0.2–0.5% oil and 25% water. Dates are also used in preparation of syrup, alcohol, vinegar and liquor. Tender terminal bud of date palm is used as a salad (Al-Hooti et al. 1995; Al-Shahib and Marshal 2003; Al-Shahib and Marshal 2003; Sawaya et al. 1982).

10.6 Growth Constraints

The average economic or commercial life of Date palm is approximately up to 60 years (Chao and Krueger 2007; Erskine et al. 2005). Production is facing severe problems, the main reasons for decline of growth and productivity are the lack of applied research, constraints of marketing, poor marketing services, manual labor increases as cost of production, lack of high yielding varieties, extensive use of low quality undesirable varieties for cultivation, overage trees, insufficient quantity of offshoots for new orchards and high price of offshoots with good qualities (Bashah 1999; Al-Sakran and Muneer 2006). These add to less attention of farmers towards postharvest processes and packing, no proper infrastructure for storage of fruit, lack of industrial added value of date products, poor handling practices, pests and diseases that greatly damage quality and yields, lack of proper transporting facilities causing fruit deterioration, poor water management (El-Juhany 2010). Approximately 40 kg per tree is an average yield but 100 kg fruit per palm can be obtained from a well maintained and properly managed field (plantation of offshoots, propagation, pollination, fertilization, irrigation, integrated disease management, horticultural practices, harvesting, proper handling and management of post-harvest diseases).

Among diseases, fungi are the most devastating pathogens. Some important fungal diseases of Date palm are shown in Table 10.1.

Table 10.1 Most important fungal diseases of date palm and causal organisms

Disease	Causal organisms
Bayoud disease	*Fusarium oxysporum* f. sp. *albedinis*
Black scorch	*Thielaviopsis paradoxa*, *T. punctulata*
Inflorescence rot	*Mauginiella scaettae*
Date palm decline	*Fusarium oxysporium, F. proliferatum,F. solani.*
Botryodiplodia theobromae rot	*Botryodiplodia theobromae*
Pestalotia leaf spot	*Pestalotia* spp.
Bending head disease	*Ceratocystis paradoxa, Thielaviopsis paradoxa*
Heart and trunk Rot disease	*Botryodiplodia theobromae, Fusarium* spp., *Gliocladium* spp., *Thielaviopsis paradoxa*
Belaat disease	*Phytophtora* spp.
Drying of apical leaves	*Alternaria* sp., *F. solani*, *Phoma* sp.,
Graphiola spot	*Graphiola phoenicis*
Omphalia root rot	*Omphalia pigmentata, O. tralucida*
Fruit rot	*Alternaria* alternata, *Aspergillus flavus, A. fumigatus, A. japonicus, A. niger, A. ochraceus, Botryodiplodia* sp., *Fusarium* spp., *Ceratostomella* sp., *Cladosporium* sp., *Penicillium* sp., *Thielaviopsis paradoxa,*

10.7 Economically Important Fungal Diseases of Date Palm and Integrated Management

10.7.1 Bayoud

This is one of the most destructive fungal diseases of Date palm. Its name is derived from the Arabic word, "abiadh". It is a vascular wilt caused by *Fusarium oxysporum* f. sp. *albedinis*, causing heavy yield losses (up to 75%) as well as death of the whole tree (Killian and Mayor 1930; Toutain 1965, 1972; Toutain and Louvet 1972). This disease was first recorded long ago, approximately in 1870, in the Draa Valley, in Southern Morocco. This devastating disease, historically, destroyed approximately more than ten million palm trees in one century in Morocco and three million in Algeria, among which the world most popular cultivars with high production potential and good fruit quality (Toutain and Louvet 1974; Mercier and Louvet (1973). The disease is continually spreading and continued to spread in Date palm plantations, covering almost 70 to 80% of its cultivated area. If the situation remains unsolved, thedisease will continue to produce serious problems to growers, affecting their social and economic status, worldwide (Meloncon 1947; Dubost et al. 1970).

10.7.1.1 Symptoms

The Bayoud is the major growth limiting and yield reducing factor in Date palm, world over. This is well described by the pathologists in terms of types of symptoms produced, disease progression and management strategies. As far as symptoms of Bayoud are concerned, mature as well as young palms and offshoots are affected by the disease (Saaidi 1979). Firstly the sign of the disease appeares as an ash gray discoloration on affected palm fronds of the middle crown, and fronds then wither. The withering symptoms progresses from base to apex and approached to leafstalk. Complete whitening or dying process of the pinnae may complete in a few weeks or may take up to several weeks. Once the complete side of frond is affected, withering spreads to other fronds of the opposite direction and ultimately destroys the whole leaf. If we split open the Date palm plant tissues, the parts infected with Bayoud, the sign of the fungus can be observed throughout the infected tissues. Externally the palm fronds exhibit reddish brown color. Due to systemic infection, the symptoms may be observed in the vascular system of the whole plant, from the roots to the tips. After getting infected the plant may die at any growth stage and period of time, which may range from several weeks to several months, depending on the environmental conditions prevailing and verities cultivated. Disease symptoms also appear on the roots, that become reddish in color and reduced in number.

10.7.1.2 Pathogens

Fusarium oxysporum f. sp. *albedinis* (Killian and Mayor 1930; Malençon 1934) causing Bayoud is a soil borne fungus. It was described by Malençon (1950a, b). Later on many scientists (Pereau-Leroy 1958; Bulit et al. 1967; Louvet et al. 1970) also confirmed the same fungus as causing the Bayoud disease.

10.7.1.3 Morpho-Cultural Characteristics

The pathogen can be easily isolated from symptomatic plant tissues of rachis and palm leaves. As the isolates are wild types, having great instability in their morphocultural characteristics, they produce mutants rapidly. Therefore it's challenging to preserve them in their original form. As far as morphocultural characteristics of *F. oxysporum* f. sp. *albedinis* are concerned, it produces curly but clear mycelium with small sporodochia having orange-pink in colour. Sclerotia are produced either in scattered forms or in groups, blue to black in color.

10.7.1.4 Microscopic Characteristics

F. oxysporum f. sp. *albedinis* produces normally fine, uniform septate and hyaline mycelium in fresh cultures, while in mature cultures hypertrophic cells are produced in form of chains, having close resemblance with chlamydospores. Asexual reproduction occurs through microphalides, which are swollen at their base having pointed tips, arising perpendicularly from the mycelium. The hyaline (normally unicellular, rarely bicellular) microconidia form at the apical tip of phialides. These are varying in shape and size. They are globulous when the culture is fresh but more elongated in mature cultures. Macrophialides are larger than microphialides and they cluster together forming sporodochia. The fungus also produces a few macroconidia. The sclerotia produced are dark blue-black, and form rarely (Sedra and Djerbi 1985).

10.7.1.5 Physiology

Although little literature is available on the physiology of *F. oxysporum* f. sp. *albedinis*, Malençon (1947) studied the physiological characteristics and find out the temperature range for optimal growth of the fungus. Normally the fungus starts to grow at 7 °C, but at a slower rate which remain as such up to 12 °C. The highest growth rate was recorded between 21 °C and 27.5 °C and checked at 37 °C. The optimal growth was recorded at 28 °C (Bounaga 1975; Shabani and Kumar 2013; Shabani et al. 2014). This fungus can exploit complex carbon sources and carbonic gas or penta-chloro-nitro-benzene, at high concentrations and can also metabolize organic nitrogenous sources for growth (Louvet and Bulit 1978). The fungus also has the capability to withstand up to 40 g/l concentration of sodium chloride during its growth (Toutain and Louvet 1972).

10.7.1.6 Disease Cycle and Epidemiology

F. oxysporum f. sp. *albedinis* overwinters as chlamydospores on diseased plants debris, especially on the dead infected roots, as well as in soil. The fungus invades the vascular tissues through roots and invasion rate depends upon the availability of sufficient quantity of food (De La Perrière and Benkhalifa 1991). After the invasion of vascular tissues, the pathogen starts to grow rapidly and advances towards the stem of the plant (Ghaemi et al. 2011; Laurence et al. 2012). It disseminates regularly from infected palms to the healthy ones. Irrigation water plays a vital role in its dispersal. Transporting and planting infected offshoots or suckers with the associated fungal pathogen is one the major factors of disease dispersal over long distances. Cultural practices, such as intercropping of fodders, e.g. alfalfa, henna and vegetables (Djerbi et al. 1985) may act as host in harboring, inoculum buildup and dissemination of the pathogen, and as symptomless carriers, without developing any symptoms (De La Perrière and Benkhalifa 1991).

10.7.1.7 Infection Cycle

The microconidia produced in the vessels, carried upwards, penetrate the cell walls through germ tubes, resuming the formation of microconidia to the next transverse wall. The same process continues, which leads to the ultimate death of the infected plant (Sedra and Djerbi 1986). During the infection process, the fungal mycelium breaks the xylem and colonizes the plant, giving reddish brown color, a characteristic symptom of Bayoud disease. The mycelium continues its development and forms chlamydospores in sclerenchyma cells, after the death of the diseased Date palm (Sutherland et al. 2013).

10.7.1.8 Disease Dispersal in Date Palm Groves

Few studies have been conducted to determine the rate of dispersal of Bayoud disease in Date palm plantation. However, we have few reliable examples, like the experimental palm grove of Nebch established at Zagora, Morocco, where 125 palm trees of “Bou Feggous” (susceptible) variety were planted in a plot and over a period of about 14 years, (6% per year). The whole plantation was destroyed by the fungus (Toutain 1970). The second example is from “In Salah” palm grove in Algeria, with similar outcomes (Kada and Dubost 1975).

10.7.1.9 Integrated Management of Bayoud Disease

Genetic Control The selection as well as development of genetically resistant clones is the most effective strategy to protect Date Palm plantations from Bayoud (Saaidi 1992). Many scientists have reported and emphasized that resistance varieties are the most effective and reliable control method against Bayoud disease in Date palm (El-Modafar 2010;Saleh et al. 2015). The same strategy was adopted in Morocco where many resistant cultivars have been developed by selecting high-quality, resistant clones from natural population (Djerbi et al. 1986). Recently in Najda, a new line of date palm resistant to Bayoud disease was reported that also produces high-quality dates (Boumedjout 2010). Several scientists consider that genetic control might be the only solution to this problem (Megateli and Berdja 2015).

Prophylactic Measures As discussed earlier in this chapter the disease is disseminated through plant debris contaminated with the pathogen, infected offshoots and infested soils. A regulatory control (to restrict the transportation of infected propagation material from country to country, or from region to region) could also be an effective management strategy to prevent dispersal of Bayoud. Such kind of legislation has already been passed by different Date palm growing countries, including Algeria, Iraq, Egypt, Mauritania, Saudi Arabia, Tunisia, and USA.

Cultural Control It is evident from the literature data that the disease spreads through root grafting between healthy and infected plants,. By avoiding this root contact, through digging a trench, palm trees can be protected from the disease for more than 10 years (Djerbi 1983). Although adequate irrigation is an important factor to get optimum yield and growth of Date palm, this factor also favors the growth of the pathogen. By reducing the rate of irrigation it is possible to reduce the infection spread, especially during the hot season (Pereau-Leroy 1958; Dubost and Kellou 1974).

Biological Control Proved to be a promising alternative for disease control, this approach relies on microorganisms to suppress plant diseases (Chérif et al. 2002; El Hadrami et al. 2011). So far, several biocontrol agents have been evaluated and selected including plant extracts, bacterial and fungal antagonists, which can protect plants from a variety of pathogens (Arfaoui et al. 2007; El Hassni et al. 2004). These antagonists may adopt one or more modes of action such as direct parasitism, competition, antibiosis, induced resistance, etc. (Compant et al. 2005). Use of suppressive soils is also a kind of biological control for several soil borne pathogens. The amendment of palm plantation soils by certain species of bacteria, including *Pseudomonas* (Maslouhy 1989), *Bacillus* (Chakroune et al. 2008), Actinomycetes (Sabaou et al. 1980; Amir and Sabaou 1983), and fungi including *Aspergillus*, *Penicillium* (Chakroune et al. 2008), saprotrophic species of *Fusarium* (Oihabi et al. 1992) proved as effective methods of disease biological suppression (Ouhdouch et al. 1996). Mycorrhizal fungi also proved to play an effective role in biological management of soil borne pathogens. It is reported that mycorrhization of Date palm seedlings, in particular by *Glomus* species, reduced disease severity (Oihabi 1991; Jaiti et al. 2007). The effect of endomycorrhization by *Glomus intraradices* has been studied extensively on Date palm growth improvement, as well as enhancing resistance to the attack of *F. oxysporum* f. sp. *albedinis*. It is proved that mycorrhization improved not only the growth of seedlings (by approximately 26%) but also reduced the tree mortality rate to 55%, which might reach 100% with a 82.5% biomass decline, due to pathogen attack (Souna et al. 2010).

10.7.2 Date Palm Decline

This disease is very similar to the Bayoud of Date palm in terms of symptoms, pathogens involved and other important aspects. It is reported that Fusarium species are associated with the decline of Date palm due to attacks on leaves, roots and trunks. Most of symptoms are similar to wilt and dieback caused by *Fusarium oxysporum*, *F. proliferatum* and *F. solani.* Date palm decline is caused by a complex of Fusarium species, including *F. proliferatum* that has been reported as pathogenic through pathogenicity test (Abdalla et al. 2000). *Fusarium. solani* has a lower impact as compared to *F. proliferatum*, with *F. oxysporum* considered as less virulent (Abdalla et al. 2000). It is reported that Date palm plantation infected by

F. solani showed symptoms to similar those of *F. proliferatum* (Al Yaseri et al. 2006). Also, *F. moniliforme* and *F. solani* have been reported to cause decline in Date palm (Rashed and El Hafez 2001).

10.7.2.1 Symptoms

Yellow colored streaks on the rachis of leaves are produced which gradually become dry and malformed. Necrotic brown areas develop on the stalk of fruit and new stalks become stunted (Sarhan 2001). Other symptoms are similar to Bayoud disease as discussed earlier.

10.7.2.2 Dissemination of Pathogen and Management

Pathogen disseminates from infested to healthy fields by movement of humans, animals, flood irrigation, soil, parts of plants, wind (Kommedahl et al. 1970; Stover 1970; Ooka 1975). Almost the same management strategies are recommended in case of Date palm decline, as in the case of Bayoud.

10.7.3 Black Scorch Disease of Date Palm

Black scorch disease can cause a serious damage and has an association with Date palm Decline disease (Laville 1966). It is caused by *Thielaviopsis paradoxa* or *T. punctulata* (de Beer et al. 2014). Both fungi are soil borne pathogenic microorganisms. All parts of the tree are affected by these pathogens, at all ages. Black scorch causes less than 50% losses in young offshoots (Gariani et al. 1994; Abdelmonem and Rasmy 2007). The fungal pathogens causing this disease have a wide host range and affect various plant hosts, such as sugarcane, pineapple, coconut and other palms (Sanchez et al. 2007; Elliott 2006; Singleton et al. 1992). Different reports proved that *T. punctulata* is the causative agent of black scorch disease in Date palms (Al-Sadi et al. 2012; Al-Naemi et al. 2014).

10.7.3.1 Symptoms

These pathogens cause infestation in Date trees at all ages, penetrating all parts of the Date tree i.e. trunk, leaves and inflorescence. Characteristic symptoms include rotting of trunk, inflorescence and black scorches on leaves (Abbas and Abdulla 2003; Al-Raisi et al. 2011; Suleman et al. 2001). Such fungal infection cause black and hard necrotic lesions. Rotted internal portions of the tree disintegrate with a bad smell. Nursery plants and young transplanted trees commonly show foliar symptoms. The pathogens enter through wounds (mostly due to pruning) the stem, causing a canker. In some cases infected trees rapidly die when infested by fly maggots. Infected trees become weak and topple over by winds (Suleman et al. 2001). Susceptibility to the fungus varies with varieties (Klotz and Fawcett 1932).

10.7.3.2 Pathogens Morphology

Short branched hyphae produce light to dark brown aleuroconidia having a thick wall. Hyaline to pale brown phialoconidia form in chains. The phialoconidia and aleuroconidia spores are approximately 11 and 16 μm in length, respectively. Aleuroconidia are oval to round in shape (Suleman et al. 2001).

10.7.3.3 Integrated Management

It is recommended, in order to manage this disease, to avoid woundings during cultural practices to inhibit entry of the pathogen (Chase and Broschat 1991). Proper sanitation practices should apply to avoid more damage. Benomyl application proved effective in controlling the disease in Date palms with mild infection. Similarly, difenoconazole appeared also effective for inhibition of mycelial growth. It is obvious that in case of foliar diseases caused by soil borne pathogens, chemical control is less effective and also may have hazardous effects (Yourman and Jeffers 1999; Mercier and Manker 2005). Therefore, use of alternative methods such as resistant varieties and biological control using antagonists (*Chaetomium* spp., *Tricoderma* spp., *Clonostachys* spp.) proved to be effective control methods for pathogenic fungi (Weindling 1932; Harman 2000, 2006; Schroers et al. 1999; Harman 2000, 2006; Dev and Dawande 2010; Schroers 2001; Whipps and Lumsden 2001; Sanchez et al. 2007; Chakrabarty et al. 2013; Soytong et al. 2005; Benítez et al. 2004; Rojo et al. 2007).

10.7.4 Inflorescence Rot

Inflorescence rot in Date palm is also known as Khamedj. *Mauginiella scaettae* is the reported causal agent of this disease, first recorded in Libya (Abdullah et al. 2005). Later on the disease was reported from many other Date palm growing countries, worldwide (Munier 1955; Michael and Sabet 1970; Calcat 1959a, b; Djerbi 1982; Abu Yaman and Abu Blam 1971; Al-Sharidi and Al-Shahwan 2003; Abdullah et al. 2006; Hussain 1958; Al-Ani et al. 1971; Abdullah et al. 2005). It is considered as second most harmful disease after Bayoud in Date palm. Due to this pathogen, 70 to 80% annual losses have been reported (Zaid et al. 2002). Some other fungi are associated with inflorescence rot with minor importance such as *Fusarium* spp., *Trichothecium roseum, Thielaviopsis paradoxa, Botrytis aclada*, and *Acremonium* *strictum* (Brown and Butler 1938; Rattan and Al-Dboon 1980; El-Behadili et al. 1977; Al-Sharidi and Al-Shahwan 2003; Al-Roubaie et al. 1987).

10.7.4.1 Symptoms

Brown lesions are produced on the outer surface of unopened spathes. At the beginning of spathes emergence, they show rotting symptoms. Splitting of infected spathes, destruction of flowers and whole strands are the symptoms that appearas disease progresses. In case of severe infection at early stages, the spathes remain unopened and then become dry (Al-Ani et al. 1971; Djerbi 1983).

10.7.4.2 Morpho Cultural Characteristics and Epidemiology

Hyaline branched hyphae form white mycelia on artificial media. After sporulation, the mycelium shows a powdery appearance. Arthroconidia form by segmentation of hyphae (Abdullah et al. 2005; Cavara 1925). Primary infection occurrs at the time of formation of floral buds, and before the development of spathes (Al-Roubaie et al. 1987). Heavy rains, humid and hot climates are more favorable for the disease development. High relative humidity (95%) is required for germination of conidia (Abdullah et al. 2006), and no germination of conidia occurs below 80% relative humidity (Abdullah et al. 2006). Conidia of *M. scaettae* can also survive as saprotrophic for twelve months, and then contribute to new infections (Al Saadoon et al. 2004).

10.7.4.3 Integrated Management

A plan based on various appropriate control methods has been proposed by many scientists. Among the important management practices there are: 1) cultural control, use of uninfected inflorescences and pollens, uncontaminated spathes; 2) use of disease resistant verities; 3) use of fungicides as preventive after harvest, followed by a treatment at emergence of spathes in the next season (Sedra 1999, 2012, 2015). A range of fungicides including Bordeaux mixture (0.5%), copper oxychloride (0.4%), methyl-thiophanate (0.2%) and thiram (0.2%), are recommended for aerial application, one month before the emergence of spathes (Sedra 2013, 2012, 2015).

10.7.5 Botryodiplodia theobromae *Rot*

Botryodiplodia theobromae is reported from Date palm in different countries of the world. This fungus is widespread in tropical and subtropical regions. It causes many diseases on different hosts such as fruit rot, dieback, blights, leaf spot, gummosis, witches' broom disease, stem necrosis and root rot (Punithalingam 1980). It has a wide host range such as avocado (Darvas and Kotze 1987), grapevine (Ammar 1998; Aly et al. 2004), Date palm (Abdel-Megid and Gafar 1966), mango (Al-Adawi et al. 2003; Aly et al. 2004), apple (Latham and Dozier 1989), guava (Baiuomy et al. 2003), cocoa (Mbenoun et al. 2008), coconut (Correia and Costa 2005), citrus (Adisa and Obinyereokwu 1998), stone fruits (Barakat et al. 1990), papaya (Wang et al. 2007).

10.7.5.1 Symptoms

Brown lesions along the rachis and infection of terminal buds are characteristic symptoms of this disease, with wilting and drying of the young leaves, showing a yellow color. The youngest leaves become soft and dead. Fungal growth covers the surface of leaves while mature leaves are less susceptible to this fungus. Infected Date palms have necrotic patches on terminal buds and crown (Brun and Laville 1965). Offshoots also become infected.

10.7.5.2 Disease Cycle

The *B. theobromae* over-winters in the form of pycnidia on infected wood. Pycnidia produce bi-celled conidia which are dark brown in color. Dissemination of conidia mainly occurs through rain splashes and wind. Disease starts at the time of attachment of conidia to the wood. Then the germination of conidia and damaging of vascular bundles start. Necrotic regions appear on the wood, then dieback of tree can be observed.

10.7.5.3 Epidemiology

Growth rate of B. theobromae and disease severity mainly depend upon environmental conditions including relative humidity and temperature (Arafat 2011). The optimum temperature for growth and infection is 30–35 and 30 °C, respectively (El-Morsi 2004). While optimum relative humidity was recorded as 70% (Arafat 2011). No fungal growth was observed at 40 °C (Saha et al. 2008).

10.7.5.4 Integrated Management

The pathogen can be managed rapidly by using chemicals. Thiabendazole, mancozeb (individual application) and both in combination evaluated *in vitro* against the fungus showed significant results (Da Silva et al. 2012; Bester et al. 2007). Some fungicides such as triazoles, dicarboximides, mancozeb, phthalamides, oximinoacetates are effective against this pathogen. Reduction in inoculum can be achieved by washing the infected portion and treating with thiabendazole. Eradication of the pathogen by using hot water treatments also proved as an effective method for controlling this disease (Edwards et al. 2004; Halleen et al. Halleen et al. 2007).

10.7.6 Pestalotia Leaf Spots of Date Palm

Pestalotia causes leaf spots, blights and bud rot in Date palms. This fungus attacks all parts of the leaves (tip to base). It is an opportunistic pathogen and can be isolated from healthy tissues. It requires wounds for penetration into the plant tissues for the establishment of infection. Usually it is isolated along with other pathogens from the same plant tissues. The fungus can attack Date palm, avocado, guava, mango, apple and pomegranate (Kamhawy et al. 2011).

10.7.6.1 Symptoms

Development of disease is restricted to leaflets or only to the rachis and petiole, or may develop on both tissues at the same time. At the beginning of disease development, spots are very small in size, and brownish black in color. Under unfavorable conditions, spots become restricted, while they may expend and convert into blight under favorable conditions. Later on, the spots turn gray in color with black outline. The spots then collapse and form lesions on the petiole. The fungus destroys the plant tissue in the petiole, then it affects the vascular tissues. The pathogen spreads to the apical meristem region, affecting in this way the growing point. The disease has been observed on both juvenile and mature palms.

10.7.7 Bending Head Disease

Most frequent pathogen associated with Bending head disease is *Thielaviopsis paradoxa* (Sedra 2001, 2003a, b, 2012). *Thielaviopsis punctulata* is also reported to cause rot of apical meristem, and produces very similar symptoms of bending head. *Thielaviopsis paradoxa* is favored by warm climates and distributed worldwide, while *T. punctulata* is limited to a few regions (Kuwait, Mexico, South Africa, California) (Sedra 2012). *Thielaviopsis paradoxa* is also frequently isolated in association with *Fusarium* moniliforme. Although this disease is limited to certain areas so far, if it spreads to other major Date palm growing countries it may become very dangerous (Sedra 1995). The pathogen may attack a variety of palms including Date palm, African oil palm, Coconut palm, Canary Island palm, Washingtonia and others. The disease incidence and intensity mainly depend on the level of maintenance of the palm trees. The pathogens mostly attack weak palms. In case of negligence in controlling the disease, it may spread and kill other trees. For example, in Morocco hundreds of infected palms were killed in a short period of time (Sedra 2002, 2006a, b).

10.7.7.1 Symptoms

The fungus *T. paradoxa* degrades non-lignified tissues under the apical meristem and causes rot. The disease is more prevalent in adult palms. Palms having shorter trunks, less lignified tissues may be attacked at any part of the trunk and rot may occur. No sign of fungal attack are visible until the trunk collapses. Normally the wilting and necrosis of leaves, weak heart with crispiness, and drying of fronds are the characteristic symptoms of the disease. The rotten areas of the trunk are darkened and become soft. Ultimately, the head hangs and bends on the trunk and may even break and fall.

10.7.7.2 Disease Cycle

Injured fronds are attacked by the pathogen at their base, as well as the apical bud degrades with its non-lignified tissues. Dry rot systems appear on the fronds, which become white. As disease progresses, it reaches the apical tissue and ultimately causes rot. If no control measures are adopted, the disease can cause the palm death. As the symptoms appear partially, control strategies must be applied to rescue a diseased palm tree.

10.7.7.3 Integrated Management

Various control methods are advised by scientists for proper management. Proper sanitation practices (disinfection of tools and equipment), proper horticultural practices by avoiding injuries to the plants, destruction of infected plant debris by burning or burying them, are effective in reducing the inoculum level and dispersal of the pathogen. Use of resistant varieties, fungicides (maneb, methylthiophanate, Bordeaux mixture) at the onset of early symptoms (injecting fungicides, such as methylthiophanate and thiram in the diseased part of the apical area, in case of an advanced attack) proved to be effective in controlling this disease.

10.7.8 Heart and Trunk Rot

A number of pathogenic fungi, including *Fusarium* spp., *Botryodiplodia theobromae*, *Chalara paradoxa* (syn. *Thielaviopsis paradoxa*) have been reported to cause heart and trunk rots (Sedra 2002, 2006b). This disease has a wide host range and damages Date palm, Canary Island date palm and many other cultivated palm species (Nelson 2005). It causes heavy losses in all kind of Date palm farming systems, either tin raditional and modern farms. Under favorable conditions, disease incidence and severity vary from region to region or country. Date palm farm management practices have direct influence on the prevalence of the disease which has worldwide distribution and was found in major Date palm growing countries including North Africa, Arab countries, Iran, etc. It is widely distributed in Mauritania and Yemen and in some oases of the Sultanate of Oman (Sedra 2008a, b).

10.7.8.1 Symptoms

This disease attacks at any point of the stipe or at the heart of the tree. Symptoms begin with death from the top and then heading to the base. Infected leaves turn brown or black and, under favorable conditions, the disease progresses and leads to the palm death. Dead leaves can be easily detached. In some cases infection starts from the apical bud, producing symptoms of heart rot and ultimately death of the palm. In some cases part of the trunk gets rotten. Further investigations showed the association of certain bacteria and fungi with the disease (Sedra 2002, 2003a, b, 2008b). The latter included *Ceratocystis paradoxa* and *Botryodiplodia theobromae*. In Morocco, pink colonies of fungal growth were observed on the heart rot of affected Canary Island date palm trees, but such type of symptoms are rarely found on Date palm (Sedra 2003a). This disease of Canary Island date palm has been also reported in Europe and USA.

10.7.8.2 Disease Cycle

In case of trunk rot, the pathogen overwinters as mycelium, spores, and chlamydospores depending upon the pathogenic species involved. The fungus attacks the offshoots and tree trunk. Under favorable conditions the pathogen develops and causes rot, and as the disease progresses the trunk may break and fall. While in the case of heart rot, the pathogen attacks the apical buds through wounds or injuries produced, due to poor horticultural operations. The symptoms of the disease vary from partial heart rot to the plant death. The pycnidia, spores, and mycelium (depending upon the fungal species involved) are released from the dead plant parts into the soil.

10.7.8.3 Management

Preventive measures are highly recommended in case of heart and trunk rot disease of Date palm. In fact, once the pathogen invades and starts the rot in the trunk or heart then it is very difficult to control the disease. Integrated management is recommended based on cultural, chemical and host resistance. Under cultural practices, disposing of infected plant parts, proper horticultural practices to avoid injuries, sanitation practices, wounds treatments, proper agronomic practices (offshoots planting at soil surface rather than deep planting, application of organic fertilizers), are recommended. So far no resistant variety is reported against this disease. As far as chemical control is concerned, fungicidal sprays (both systemic and by contact) are recommended. The range of fungicides as recommended earlier in case of Black scorch disease are also effective against this disease.

10.7.9 Belaat Disease of Date Palm

This disease is of minor importance, recorded on Date palm and Canary Island date palm, first in North African countries (Maire 1935; Monciero 1947; Calcat 1959a, b; Toutain 1967; Djerbi 1988; Sedra 2003a, 2015). The disease is caused by *Phytophtora* spp. (Djerbi 1983). Symptoms appear at the crown region and are characterized by the destruction of the heart of the palm. Initially, young fronds turn white and die quickly, followed by terminal bud death. As the infection progresses downwards, it causes wet heart rot symptoms, releasing an odor of acetic and butyric fermentation.

10.7.9.1 Disease Cycle

The fungus overwinters in the form of resting propagules, and under favorable conditions the oospores germinate and produce the sporangia. The zoospores are then released from sporangia to infect the young leaves at their base and the terminal buds. The symptoms also appear on the infected young fronds.

10.7.9.2 Management

Cultural (field sanitation, proper horticultural practices to avoid injuries) as well as chemical management both preventive and curative is recommended. Bordeaux mixture is recommended for preventive, while metalaxyl or fosetyl aluminum may be recommended for curative treatments.

10.7.10 Drying of Apical Leaves

Apical dying of leaves is caused by *Phoma* sp., *Alternaria* sp. and *Fusarium* solani (Abul-Soad 2011; Mansoori and Kord 2006; Sedra 2001, 2003b; Al Yaseri et al. 2006). This disease is found in many countries including Morocco, Mauritania, Algeria, Libya, Egypt, Yemen and Saudi Arabia. It is more common where palm orchards are not well maintained and irrigation water is not sufficient. It has minor economic importance. It may cause reduction of production and in severe infection plant mortality may occur.

10.7.10.1 Symptoms

This disease causes the drying of apical leaves, rachis and pinnae, and then apical leaflets become wilted. Dryness starts from the terminal portion afterwards covering the entire frond. Symptoms initiate from older to younger leaves and are more or less similar to the Bayoud disease. Under favorable conditions (less irrigation water), disease spreads to all leaves. Similar symptoms rwere eported from Pakistan where the disease is named wilt disease of Date palm (Abul-Soad et al. 2011). Color of infected fronds turns yellow, and infected trees gradually die. *Fusarium* solani is also reported as causal agent of this severe disease of Date palm that is found, associated with yellowing and death of the fronds, also in Iran and Iraq (Mansoori and Kord 2006; Al Yaseri et al. 2006). Spores of the fungus may be disseminated by wind and rain splashes, and then attack the leaf causing wilt/dryness, which comes down along rachis, base and then the apical portion of the meristem.

10.7.10.2 Management

In order to manage this pathogen all infected parts of the palm have to be removed and burnt, maintaining the orchard properly. If available, resistant hosts should be cultivated. Fungicides such as thiram and methylthiophanate may be applied.

10.7.11 Graphiola Spot

This disease is also called false smut. It is caused by *Graphiola phoenicis*, known as smut causing fungus. The disease is widely spread among the Date palm growing countries i.e. Niger, Mali, Mauritania, Senegal, Morocco, Algeria, Vietnam, USA, Qatar, Argentina, Egypt and Libya (El Gariani et al. 2007; El Deeb et al. 2007; Sedra 2003a, 2012). This disease is more common in humid regions. The fungus can attack *Phoenix dactylefera*, *P. canariensis* and *P. sylvestris*. In case of severe infections, reduction in tree growth and its production can be observed. Its incidence and severity depend on favourable environmental conditions.

10.7.11.1 Symptoms

The fungus attacks older leaves. In severe infections the pathogen invades younger leaves. It may cause necrotic lesions on the leaflets of young plants. Spots appear on both sides of the leaf with small sori (fruiting structures). The pustules are cylindrical, yellowish, later on becoming black in color.

10.7.11.2 Disease Cycle

The fungus attacks the leaves of palm and small sized spots appear on both sides of them. The fruiting structures emerge from infected parts as small black sori. The mature pustules rupture and release the spores to originate more infection. The spores are spherical with a hyaline wall. The dissemination of spores occurs by means of birds, wind and insects.

10.7.11.3 Management

Proper spacing between the palm trees is needed, together with a proper pruning and burning of the infected leaves. Resistant host varieties should be used (Barhee, Gizaz and Abdal Rahman). Genetic tolerant varieties can be cultivated, i.e. Khastawi, Tadala, Iteema and Jouzi, whereas Khisab, Zahdi, Ashrasi and Maktoom are highly susceptible (Nixon 1954; Sinha et al. 1970). Fungicides may be applied in field after pruning i.e. Bordeaux mixture and maneb (after sporulation four to five applications, on a 15-days interval).

10.7.12 Omphalia Root Rot

Omphalia root rot is caused by the two species of *Omphalia* (*O. pigmentata* and *O. tralucida*). This disease is common in the Date palm growing regions (Sedra 2002, 2006b).

10.7.12.1 Symptoms

The characteristic symptoms are the reduction in tree growth, weakness, with palms remaining non productive that usually tend to die. The symptoms include necrotic patches, rotting and destruction of roots. It is associated with stunting and premature death of leaves.

10.7.12.2 Disease Cycle

The fungi *O. tralucida* and *O. pigmentata* attack roots causing necrosis of tissues and rotting. The highly favorable condition for the disease is an inadequate supply of irrigation water. The spores are released from the rotted roots. They can be disseminated by irrigation water and working equipments.

10.7.12.3 Management

In order to manage the disease, the soil must be properly aerated by cultural practices. Disinfect the equipment. Use tissue cultured plants for new plantation. Drip irrigation can also reduce the spread of the pathogen. Avoid cultivation of susceptible varieties. The use of chemical such as brestan - (fentin acetate, one spray at a two weeks interval, for eight weeks). Carbon disulphide can be used as disinfectant for soil.

10.7.13 Fruit Rot

Fruit rot in Date palm is caused by several fungi and some bacteria e.g. *Acetobacter* sp. Fungi responsible for fruit rot are *Alternaria alternata, Aspergillus niger, A. flavus, A. japonicas, A. fumigatus, Botryodiplodia* sp., *Ceratostomella* sp., *Cladosporium* sp., *Fusarium* spp., *Penicillium* sp., *Thielaviopsis paradoxa*Fruit rots in dates occurs worldwide. Rots cause significant damage under rainy seasons,during storage. Losses depend upon rain and high humidity during the stages of maturation and khalal (Carpenter and Elmer 1978). Losses are estimated around 10% – 50% of dates (Darley and Wilbur 1955; Djerbi et al. 1986; Calcat 1959a, b).

10.7.13.1 Disease Symptoms

At the start of disease development, fruits may rot at Khalal stage, with cracks appearing on fruits. The spots are brown in center. The symptomsare cracked brown spots at two stages (Khalal and Rutab), caused by *Cladosporium* sp. and *Thielaviopsis paradoxa*. Rot is due to a high concentrations of sugars. The disease is facilitated by a high relative humidity and poor post-harvest handling. The fungal spores may be disseminated by rain and wind.

10.7.13.2 Disease Management

Preventive measures should be adopted in the field, if necessary to improve the conditions of ventilation, which reduce the moisture levels. Covering the fruit bunches with paper bags at the Khalal stage may help to avoid wetting of fruit, as well as fruit injuries and attacks by insects and birds. Dusting with 50% sulphur, 5% ferbam and 5% malathion may be also applied (Djerbi 1983).

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Chapter 11
Fungal Diseases of Alexandra Palm (*Archontophoenix alexandrae*) and Queen Palm (*Syagrus romanzoffiana*)

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Abstract The Alexandra and queen palms are globally grown plants with high ornamental and economic value. They are arious attacked by various fungal and bacterial diseases, including different kinds of leaf blight and leaf spots (caused by *Pestalotia palmarum* and *Pestalotia palmicola*). For management of these pathogens, the following practices can be helpful: proper sanitation, avoiding overhead irrigation, maintaining proper plant distance, with extensive care in pruning, use of disinfected tools, avoiding plan damage, removal of infected plant parts or whole plants, use of proper recommended fungicides as recommended by manufacturers on label.

Keywords Alexandra palm · Queen palm · *Pestalotiopsis palmarum*

11.1 Introduction

The Alexandra palm (*Archontophoenix alexandrae*) is a splendid, towering, attractive and popular palm with a slendery grey trunk swollen at base, and large, dark green, feather-like leaves in a spreading crown, which lends a tropical look to the landscape. The name *Archontophoenix alexandrae* is derived from two Greek words: 'Archontos' meaning chieftain, and 'Phoenix' which is used for date palm. Therefore,

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_11

Archontophoenix means the ruler of palm while "*alexandrae*" memorializes Princess Alexandra of Denmark. It is also named as 'King Palm'. *Archontophoenix alexandrae* is a tracheophyte angiosperm monocot, native to North Eastern Australia and widely used as an ornamental plant in tropical and subtropical regions over the world (i.e. Africa, Central and South America and Malay Peninsula) (Starr et al. 2003).

The plants may achieve about 25 m in height with single or multiple trunks, bearing a rarely branched two meter round crown. It has about 15–20 evergreen fronds (leaves) which emerge from the crown shaft. The leaves are bright green and are 1.8–3.0 m long. There may be 100–150 leaflets which measure 15–30 cm in length. The petioles may have spines. In summer the palm produces pink flowers held by a 60–90 cm long inflorescence. The inflorescence is unbranched or branched into a large panicle and commonly arises from the base of the leaf. Protecting woody bracts that overlap each other are formed and remain until the development of flowers.

The small flowers are formed singly or in a cluster of 2–3. These flowers are monoecious or dioecious and their perianth is in 2 whorls. The female flowers contain imbricate sepals and petals that are three in number with equal number of stamens. While in male flowers the number of petals and sepals are sometimes 4. The wind and insects such as flies, ants, beetles and bees are involved in flowers pollination.

The spherical fruits that hang in clusters usually own a single seed turning red at maturation. The fruit is a drupe or berry and its smooth surface is hairy, prickly, woody, fibrous with a dry or fleshy mesocarp, with seldom 2–10 seeds. The Alexandra palm is propagated only by seeds. The stem of the palm is greyish brown, smooth and with scars. Its base is noticeably swollen. It is a fast growing and both outdoor and indoor planting palm, although generally not suitable for indoor plantation. The ideal weather condition for its growth is a warm and humid weather. The Alexandra palm grows best in nutrient rich, well drained and somewhat acidic soils that have pH ranging from 6.0 to 7.5. Amending the soil with organic matter can be very beneficial. It may tolerate clay soils if not over irrigated. It needs moderate water provisions and grows best in moist, well drained soils. This palm is not a good choice for planting as houseplant, but is suitable for plantation in low altitude mountains, alongside river banks and coastal areas.

*11.1.1 Queen Palm (***Syagrus romanzoffiana***)*

Syagrus romanzoffiana, commonly known as queen palm, belongs to subfamily Arecoideae (family Palmae or Arecaceae) and is native to South America. It has a gray color stem or trunk, from which graceful feathered leaves appear. A large inflorescence of cream color appeares during spring and summer seasons, with 2.5 cm round to elongated orange fruits produced. The fruit of this palm is not edible, and seeds are used as propagation material. They are soaked in water for two days and then sown in moist soil with a temperature range of 30–35 °C for maximum germination. It is not a self-cleaning palm, and pruning of fully dead leaves is necessary for this palm, otherwise its beautification is affected. The leaves not fully dried should not be removed because they provide supplementary nutrition.

11.2 Fungal Diseases

Various diseases attack Alexandra and Queen palms. Among them leaf blight and leaf spot are economically important fungal diseases.

11.2.1 Leaf Spot and Leaf Blight

Leaf blight and spot are the most common diseases of Alexandara palm. The fungi *Pestalotia palmarum* and *Pestalotia palmicola* are considered as their major cause. Besides, other fungal pathogens such as *Botryodiplodia palmarum*, *Melanconium* sp. and *Glomerella cingulata* have been reported to cause anthracnose of palms in Africa, while *Curvularia eragrostidis* and *Pestalotiopsis* spp. have been reported to cause leaf blights in Asian countries (Aderungboye 1977) causing huge economic losses.

Leaf spot disease is considered as a minor issue for palm trees in India, Thailand, Sri Lanka and Papua New Guinea. However there is a risk of its rapid spread leading to epidemics in these regions (Aderungboye 1977). In West Africa, nursery seedlings and young plam trees are affected by *Cercospora elaeidis* causing *Cercospora* leaf spot, the most widespread foliar disease (Rajagopalan 1973). Surprisingly, leaf spot disease is not restricted to ornamental palm trees, as it was also reported on other plants such as coconut (caused by *Pestalotiopsis palmarum*) (Ohler 1999). The yam trees are affected by *Curvularia eragrostidis* causing a serious yam leaf spot disease in northeast Brazilian growing areas whereas petal blight of dendrobium is a problem in the northern Territory (Duff and Daly 2002).

11.2.1.1 Pathogens and Host Range

Archontophoenix alexandrae and *S. romanzoffianum* are attacked by *Pestalotia palmarum*, while *Pestalotia palmicola* has been reported to attack *Syagrus* species. *Pestalotia* spp. are the causal agents of numerous fungal diseases characterized by leaf spots or blights of rachis/petiole. These fungi can attack all foliar parts from the base to the tip. The foliar blight spots also occur on a wide range of plants that include trees, shrubs and vegetables as well.

11.2.1.2 Symptoms

Both diseases produce symptoms that are hard to distinguish (Elliott 2005) and are difficult to differentiate by symptom alone. Usually, newly transplanted young seedlings that are up to the age of 3 months may be affected (Turner 1981). *Pestalotia palmarum* penetrates into the leaflet axil to exhibit light to dark greyish brown spots with black spore masses on the leaf blades that fuse to result in withered and dried dead leaves, falling prematurely and leading to a stem dieback. The infected tree becomes sparsely foliaged. The fungus develops spots of greyish brown color on the leaf blades. In case of *P. palmicola* infection the leaf tips are infected first and the disease progresses downwards throughout the whole frond, making it brown in color.

11.2.1.3 Source, Dispersal and Favored Conditions

The spores are produced on infected fronds and wind carries them towards new trees or nursery stocks. This spread is rapid and extensive. However, some tree species show tolerance to infection. Likewise, most *Pestalotia* spp. also like warm and still humid conditions, that's why these diseases are a problem in particular in tropical areas.

11.2.2 Management

The spores of *Pestalotia palmarum* are more likely to be dispersed by winds and water, so the disease spread can be prevented by efficient irrigation and sanitation management. Human and insect activities most often cause wounds or physical damage to the plants that facilitate an easy fungal infection, hence limiting their activities can help in disease prevention. As the pathogens prefer high humidity levels, avoiding overhead irrigation like sprinkling can be helpful to reduce the frond infection by reducing the risk of inoculation.

Nutrient management can avoid foliar chlorosis and necrosis that favor *P. palmarum* inoculation. Pruning of infected leaves may also be helpful in treating the disease. However, this practice should be performed by keeping in view the growth stage of plants. In case of nurseries the infected stocks should be destroyed. Also, perennial and annual weeds can be discarded.

The fallen infected leaves around the plant base contain the fruiting bodies of pathogens, hence they should be cleaned from there. Although, fungicides are an easy way to manage the disease, their use will not address the problem all alone. Spraying the infected plants with a broad spectrum fungicide at a five days interval can be helpful in this regard. The new infection to healthy leaves will be prevented, but the infection will stay in the infected leaves until leaf fall. An integrated approach by using combination of numerous techniques will be also effective for managing *P. palmarum*.

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Chapter 12
Fungal Diseases of Ravenea Palm (*Ravenea rivularis*); Etiology and Management

Muhammad Zunair Latif

Abstract The genus *Ravenea* belongs to a group of solitary, dioecious palms. Among its numerous species, *R. rivularis* is the most diversified and attractive palm species, widely grown for interiorscape and outdoor beautification. Foliage diseases, which became more severe in recent years, represent significant limiting factors causing economic losses and decreasing the high aesthetic value of plants. The frequency and nature of foliage diseases largely depend on local conditions. Accurate detection, identification and quantification of etiological agents, thorough the knowledge of pathosystems, pathogens biology, ecology and epidemiology, are of paramount significance in disease prevention and control. In this chapter, we focus on *R. rivularis* leaf spots and leaf blight, important fungal diseases related to diverse etiologies providing comprehensive details about each. This chapter reviews detailed pathogens description, procedures for diagnosis and comprehensive disease management strategies including agronomic practices, cultural, biological and chemical control measures.

Keywords Majesty palm · Pestalotiopsis leaf spots · Botrytis blight · Fusarium blight · Fungal dispersal · Plant nutrition · Disease management

12.1 Introduction

The genus *Ravenea* includes solitary, dioecious palms in the subfamily Ceroxyloideae and tribe Ceroxyleae. It was named after Louis Raven (a horticulturist) and is comprised of about twenty diversified and attractive palm species, native to Madagascar and Comoros Islands. The species are widely grown either indoor as house plants or

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_12

outdoors, as ornamentals. Significant height variations are found among different species of the genus, from smaller to larger, i.e. *R. hildebrandtii* being the smallest with height of less than one m, while *R. robustior* can achieve 25 min height. The crown has a bulbous base with leaves pointing upwards, shuttlecock-like. Sheath(s) may be either bulbous or contiguous; the petiole shows channels adaxially, with sharp edges. The rachis has proximal abundant leaflets, that are regularly arranged and always in one plane, on one side of the rachis. Solitary and multiple inflorescences are found within the genus and are always inter-foliar. The flowers are open from the earliest distinguishable stage, long before the inflorescence opens. Fruit color, fruit and seed sizes vary greatly among species. In addition to their high aesthetic values many species in this genus have a significant role in local-level economy. Hardwood from *R. robustior* and *R. sambiranensis* is resistant to termites, that's why it is widely practiced for floorboard, tables and furniture making. The palm heart of some species is edible and source of food and feed for local people and birds. Leaflets of some species are well known for making high quality hats, winnowing trays. Yet hollowed out trunks of a few species are commonly practiced as irrigation pipes. *Ravenea* rivularis is a species of great economic seed trade and horticultural significance (Beentje 1994; Bergman 2015). Important fungal diseases are:

1. Botrytis Leaf spot and Leaf Blight (Polizzi 2002),
2. Fusarium blight (Polizzi and Vitale 2003a, 2003b),
3. Pestalotiopsis leaf spots (Latif 2017).

12.2 Botrytis Leaf Spots and Leaf Blight

The fungal genus *Botrytis* is comprised of economically important plant pathogens that are responsible for severe losses in a wide range of plant species. It consists of 28 defined species (Beever and Weeds 2007). In recent years new species were discovered and added to this genus (Zhang et al. 2010; Li et al. 2012; Grant-Downton et al. 2014). *Botrytis* spp. are important necrotrophic pathogens of horticultural, floral and agricultural crops that have the ability to infect all plant parts at preharvest and post-harvest stages (Choquer et al. 2007; Mirzaei et al. 2007). *Botrytis* spp. have potential to infect seeds, seedlings, planting materials, stems, leaves, flowers and fruits. *Botrytis cinerea* is the most studied necrotrophic plant pathogen, infecting over 500 plant species with global economic losses of 10 to 100 billion USD (Boddy 2016; Hua et al. 2018). Botrytis infections are common problems of open fields, orchards, nurseries and greenhouses (Elad et al. 2007). Canary Island date palm, Sago palm, date palm and Pygmy date palm, Howea palm (*Howea* forsteriana, *H. carnosa*) and *Chamaedorea elegans* are important hosts vulnerable to attack by *B. cinerea* (Polizzi 2002; Polizzi and Vitale 2003a, 2003b; Elad et al. 2007).

12.2.1 Disease Diagnosis

Botrytis cinerea infects about 586 genera of vascular plants (Fillinger and Elad 2016). The fungus is capable to induce leaf spots and leaf blights on juvenile palms grown in greenhouse or plastic covered houses, and in nurseries situated in an open filed (Polizzi 2002). In open fields, greenhouses and nurseries the disease can be easily identified by observing any of the above mentioned symptoms. However, it is very difficult to identify the disease at its initial stages. Late stage infections can be identified in infected tissues by the presence of conidial clusters on infected plant parts (Khazaeli et al. 2010). Accurate identification of the casual fungus relies on fungal morphology in culture media and conidial morphology, and varies from species to species (Chilvers and du Toit 2006).

12.2.2 Symptoms

Botrytis cinerea produces a wide range of symptoms ranging from damping off, spots, blights, rots, wilts and cankers on different host plants. On *R. rivularis* it produces brown necrotic spots with thick grey mycelia and conidia that can be visible on surface of spots or lesions of infected leaves. The leaf becomes blighted within 5–12 days after initial formation of lesions, under optimal environmental conditions. During humid conditions a grey mold appears on infected tissues. Smokey-grey clouds can be easily seen with conidiophores emerging after periods of high humidity.Black sclerotia may also be visible on dead plant tissues. Small, chlorotic spots appear on leaf blades and edges of pygmy date palm leaflets. With disease progress, these spots become enlarged with yellow or reddish brown margins and grey or brown sunken centers. Sometimes these spots or lesions merge, giving a blighted appearance to young expanding leaves or killing apical buds. Leaf colonization by the fungus and leaf dieback may occur as the result of increased leaf age, high temperature and prolonged leaf wetness (Alderman and Lacy 1983; Polizzi 2002; Polizzi and Vitale 2003a, 2003b; Zhang et al. 2009; Chen et al. 2019).

12.2.3 Morphology and Physiology

Botrytis spp. produces a septate, branched and hyaline to brown mycelium. Conidiophores arising from mycelia or sclerotia are tall, slender and irregularly branched. Clusters of asexual conidia are produced at the tips of conidiophores. Conidia are egg-shaped, smooth hyaline or grey with mean size of 10 × 5 μm (Barnett and Hunter 1998), variable, however, from species to species (Beever and Weeds 2007). Moisture, temperature, microbial activity and exposure to sunlight determine the survival ability and duration of conidia that are mostly short lived

(Carisse et al. 2012; Nassr and Barakat 2013). Fungus overwinters as sclerotia under adverse environmental conditions (Williamson et al. 2007).

12.2.4 Ecology

It is believed that *B. cinerea* inoculum is always present in field and propagule production, as conidia liberation and dispersal is an ongoing process. However, in most cases there are factors, including propagule viability, inoculum source, favorable conditions for spore production and dispersal, that sustain a high concentration of inoculum in the air (Jarvis 1980). Studies have shown a close correlation between spore dispersal and environmental conditions conducive for sporulation. Additionally, fluctuation in wetness period and temperature vary greatly within a growing season and affects the propagule production (Rotem et al. 1978). Thus, a complex relationship exists in the field between weather conditions and inoculum production and dispersal. Transmission of conidia by means of air currents is a common dispersal mode for nearly all *Botrytis* species. However, agricultural machinery, pruning tools, wind, leaf vibration, insects, water and rain splashes are also important means of conidia dispersal (Fermaud and Le Menn 1992; Blanco et al. 2006). In greenhouses conidia can travel up to 1.8 m (Kerssies et al. 1995), but outdoors in fields they may certainly travel for much larger distances,especially with wind speeds higher than 2.8 km/h (Carisse et al. 2011). Each part of the mycelium can serve as a survival and dispersal unit, and may be disseminated by insects, wind or rain (Holz et al. 2007). Presence of nutrients (simple sugars and pollens) boost up conidial germination on plant surfaces (Chou and Preece 1968).

12.2.5 Epidemiology

Sporulation of *B. cinerea* occurs in cool and moist conditions. Relative humidity plays a vital role in germination of conidia. Conidia germinate in the presence of free moisture. Optimum temperature range is 18–23 °C for spore germination and release, and a high relative humidity (93–100%) and 4 h light period are required for lesion development. However, disease is significantly reduced below 15 °C or above 25 °C (Elmer and Michailides 2007; Carisse 2016).

12.2.6 Disease Cycle

Botrytis epidemics involve inoculation, penetration, infection, incubation, reproduction, conidia dispersal and survival. Each stage is facilitated by surrounding environment (temperature, wind, rain, humidity), cultural practices and host factors (tolerance and phenology). Survival of propagules between different cropping seasons and their dispersal to healthy plants are crucial for the disease cycle. In case of either phase is missing disease will either be delayed or not occur. First phase of disease cycle involves production and dispersal of initial inoculum followed by primary infection, and subsequent production and dispersal of secondary inoculum, ending with the production of survival propagules. Berry moth (*Lobesia botrana*) were found to transmit *B. cinerea* from infected to healthy grape berries (Fermaud and Le Menn 1992). The fungus overwinters in soil as sclerotia in plant debris or decayed material (Carisse 2016). Survival of sclerotia varies from several weeks to several months. *Botrytis cinerea* overwinters as sclerotia for 5–9 months as well as mycelium in plant debris and other plant parts such as leaves and petioles. The sclerotia are produced in wet seasons (Thomas et al. 1983; Entwistle 1987). Conidia produced from overwintering mycelium and sclerotia act as primary source of inoculum (Braun and Sutton 1988; Yunis and Elad 1989). Primary inoculum produced from mycelium and sclerotia results in new epidemics. As a result of first[t] infection cycle, completion of secondary inoculum is produced and blighted leaves provide main sites for the production of secondary inoculum.

12.2.7 Disease Management

12.2.7.1 Cultural Control

Botrytis epidemics are common problems of ornamental and horticultural crops in field, greenhouses and orchards, which vary in different agro-systems (Elad et al. 2007). Such infections are greatly influenced by availability of excessive moisture contents such as dew and relative humidity on plant leaf surfaces. Cultural practices include air ventilation and circulation, canopy management and plants spacing, crop nutrient management. Reduction of leaf wetness or humidity and soil mulching can be good choices either to prevent infections or managing the disease caused by this pathogen (Elmer and Michailides 2007). Botrytis inocula can originate either inside or outside greenhouses (Korolev et al. 2006). Removal of source of primary inoculum is hence an important component of disease prevention. Nutrients imbalance can enhance hosts susceptibility to *Botrytis* infections as reduced application of N fertilizers and increased amount of Ca and K reduced infection (Yermiyahu et al. 2006, 2015; Elad 2016). Heating of greenhouses can be an effective tool in controlling the amount of dew and high humidity, ultimately reducing infections (Legard et al. 2000; Dik and Wubben 2007). Leaf wetness sensors can be effective tools to monitor the conditions favoring infection. Use of mulching sheets to cover soil to protect lower leaves, and removal of infected plant tissues can result in reduced infections by *B. cinerea* (Michailides and Elmer 2000).

12.2.7.2 Biological Control

Several plant and microbe groups have been tested against *B. cinerea* to control infections in filed and greenhouse trials. However, only a few showed consistent field efficacy and very few have gained commercial importance (Nicot et al. 2016). Botector® (extracted from strains of *Aureobasidium pullulans*), Timorex Gold® (tea tree extract), R-egalia® (giant knotweed extract), JMS Stylet-Oil® (paraffinic oil), Trilogy® (Neem oil) are commercially available for effective control of ornamentals diseases incited by *B. cinerea* (Schilder 2013; Nguyen et al. 2013; Segarra et al. 2013). Mixing compost with soil and other plant growing substrates proved helpful in controlling foliar diseases (Vallad et al. 2003). Compost of olive origin was helpful to induce resistance against *B. cinerea* in *Arabidopsis* thaliana (Segarra et al. 2007, 2013). *Serratia plymuthica* and various species of *Pseudomonas* produced Pyrrolnitrin (an antibiotic), were effective in suppressing mycelial growth of *B. cinerea* (Ajouz et al. 2011).

12.2.7.3 Chemical Control

This is considered as the easiest and principal way to reduce *Botrytis* incited epidemics in different crops, achieved by applying fungicides from several groups. For initial and mid-level infections cultural and biological control(s) are recommended. However, chemical fungicides are only recommended when an outbreak of the disease is expected. When permitted, aerial spraying at varying doses of fungicides such as maneb, carbendazim, folpet, dicloran, thiram, tolylfluanid, pyrimethanil and chlorothalonil may be effective against *Botrytis* spp. (Leroux 2007; Fillinger and Walker 2016). Anilinopyrimidines has protective and curative effects against mycelial growth and germ tube elongation of *B. cinerea*. Foliar application of Fludioxonil (a protective fungicide) is effective in suppression of foliar diseases induced by *B. cinerea* by inhibiting mycelium, spore germination and germ tube elongation. Fenhexamid showed excellent potential against *B. cinerea* by inhibiting conidial germination, germ tube elongation and mycelial growth (Rosslenbroich and Stuebler 2000).

12.3 Fusarium Blight

Fusarium spp. commonly occurr as saprophytes, endophytes as well as human and plant pathogens. They are commonly found in soil, water, organic substrates, air, insects and plants (Al-Hatmi et al. 2016). *Fusarium* plant diseases have a great socio-economic impact (Palmore et al. 2010). Diseases incited by *Fusarium* spp. include leaf and flower spots, leaf blights, damping off wilts, rots (seed, fruit, stem and root) and cankers (Leslie and Summerell 2008). *Fusarium proliferatum* is a well known pathogen of several plants, ornamentals, trees and palms causing wilt and dieback diseases (Windels 2000; Abdalla et al. 2000; Leslie and Summerell 2008; Hernandez et al., 2010). This pathogen is reported to cause date palm decline, crown and root rot of maize, root rot of pine seedlings, Fusarium blight of *R. rivularis* and has been isolated from rhizosphere of *Livistona* palms, and several grass species. Others hosts of *F. proliferatum* are wheat, barley, sorghum, *Aloe vera*, rice, citrus fruits, banana and orchard crops (Abdalla et al. 2000; Polizzi and Vitale 2003a, 2003b; Leslie et al. 2004; Neumann et al. 2004; Jurado et al. 2010; Avasthi et al. 2018).

12.3.1 Disease Diagnosis

In open fields, greenhouses and nurseries the disease can be easily identified by observing any of the above mentioned symptoms. However, it is very difficult to identify the disease at its initial stages. During wet seasons and high humid conditions, a white mycelium may develop on surfaces of infected tissues (Salvalaggio and Ridao 2013). Accurate identification of the causal fungus is subjected to observations on its morphology in culture media, as conidial morphology varies from species to species. For the pathogen accurate identification, laboratory diagnosis of the infected plant tissues followed by isolation and identification of *F. proliferatum* are essential.

12.3.2 Symptoms

Fusarium proliferatum induces symptoms on various plant parts, that may vary from host to host. On *R. rivularis* the symptoms appear on the unopened, expanded, youngest, spear leaves as small, reddish-brown necrotic lesions having a 2–4 mm spot size, with a yellow halo. In presence of high humiditythe lesions begin to increase in number and size, coalescing into large, irregular dead areas. Later on these symptoms turn into blights of unopened youngest leaves. As a result, infected leaves usually dieback as only a few plants may recover from these infections. Remaining plants may develop reddish brown necrotic lesions on the rachis (Polizzi and Vitale 2003a, 2003b). In orchard crops, *F. proliferatum* causes damping off and rots of young plants. On *Dendrobium* orchids, new shoots get blackened and rots develop at the leaf tips. The fungus produces small circular to oval spots that may expand slowly. Some spots develop sunken centres and black edges. Leaf tissues surrounding the spots become slightly chlorotic. Production of spots in a row across the leaf width may be considers as a characteristic symptom of the disease. Infected leaf sheaths develop black-brown rots that expands slowly and after few months the centre of sheath blights. Circular to elongate spots may also appear on flowers.

12.3.3 Pathogen Biology, Ecology and Host Range

Fusarium proliferatum is the anamorph (or asexual state) of the fungus. Its teleomorph (sexual state) is *Gibberella intermedia*, that belongs to the *G. fujikuroi* complex (Nelson et al. 1983). Being a toxigenic species, *F. proliferatum* produces a wide range of mycotoxins (Seefelder et al. 2002; Stankovic et al. 2007). The fungus has a worldwide distribution and has been recovered from many environments. It produces a white mycelium, which turns purple-violet with age. Tan to pale orange sporodochia may be present. Its macroconidia are usually 3–5 septate and slender, thin walled and relatively straight. The abundant microconidia are aseptate and club shaped, with a fattened base. Pyriform microconidia are rarely present. Conidiophores are branched or un-branched, cylindrical, often proliferated, with mono and polyphialides. Chlamydospores are absent. Many isolates may develop blue-black sclerotia (Leslie and Summerell 2008; Salvalaggio and Ridao 2013; Kim et al. 2016; Alberti et al. 2018). The fungus has a broad host range such as barley, wheat, sorghum, maize, cereals, pea, fig, pineapple, citrus, mango, orchids, asparagus and palms (Elmer 1990; Bottalico and Perrone 2002; Logrieco et al. 2002; Armengol et al. 2005; Zhan et al. 2010; Waśkiewicz et al. 2013; Lei et al. 2019).

12.3.4 Epidemiology

This disease may spread to healthy plants by over irrigation. The inoculum may also spread by wind, water splashes, and insects and by mechanical means. The fungus can survive for months in potting media and diseased plant materials. Optimum growth of the fungus occurs at 23–25 °C, and is favored by high moisture contents (Elshahawy et al. 2017).

12.3.5 Disease Cycle

Disease cycleinvolves inoculation, penetration, infection, incubation, reproduction, conidia dispersal and survival. Each stage is affected by environment (temperature, wind, rain, humidity), cultural practices and host factors (tolerance and phenology). The genus *Fusarium* is a well-distributed soil inhabitant and most of its members survive in plant debris near the soil surface (Onyike and Nelson 1993). *Fusarium* spp. can survive in peat land ecosystems which act as a reservoir for pathogenic species (Thormann and Rice 2007; Latiffah et al. 2010). The species of Fusarium can survive as chlamydospores, thick walled hyphae in soils, organic residues or plant debris. The survival propagules may form and provide primary inoculum for new infections by germinating in prolonged wet weather on crop residues (Nyvall and Kommedahl 1970). The ascospores are usually wind blown or water splashed.

The secondary infection is favored by high humidity and prolonged moist weather (Munkvold and Desjardins 1997).

12.3.6 Disease Management

12.3.6.1 Cultural Control

All infected plant parts must be removed from the nursery or palm growing area, avoiding surface contact of infected plant parts with the ground, to prevent infesting the area for a longer period of time. As most fungal spores germinate when they find sufficient moisture, avoiding humidity will definitely helpto reduce the inoculum (Cowger et al. 2009). Irrigation must be done during sunshine hours and avoided during dark hours. Application of N fertilizers in relatively high doses and low level of K fertilizer, proved helpful to control Fusarium ear rot of maize (Pusztahelyi et al. 2017).

12.3.6.2 Biological Control

Recent plant disease management trends encouraged use and focused on biological control agents for effective and ecofriendly disease management. Essential oils extracted from different plants have inhibitory effect on different isolates of *Fusarium* spp. (Naeini et al. 2010). Application of essential oils (*Cinnamomum zeylanicum*, *Melissa officinalis, Coriandrum sativum*, *Salvia officinalis*, *Thymus vulgaris*, *Mentha piperita*) at 2000 ppm showed strong antifungal potential against *F. proliferatum* (Sumalan et al. 2013). *Streptomyces misionensis* (strain PMS101) and *Geobacillus thermoglucosidasius* (strain PMB207) are efficient biocontrol agents controlling seedling blight of lily caused by *F. proliferatum* in laboratory and field conditions as well (Chung et al. 2011). *Bacillus subtilis* can be used as biological control agent against garlic clove rot caused by Fusarium spp., including *F. proliferatum* (Bjelić et al. 2018).

12.3.6.3 Chemical Control

Use of synthetic chemicals may be considered to manage fungal pathogens diseases. A wide range of fungicides including metconazole, propiconazole, tebuconazole, difenoconazole, dithane M45, thiophanate-methyl and folpet proved as effective against *F. proliferatum* (Masiello et al. 2019). Carbendazim, thiophanate-methyl and metalaxyl 8%+mancozeb 64% also showed a strong inhibition against *F. proliferatum* (Elshahawy et al. 2017).

12.4 Pestalotiopsis Leaf Spots

Species of *Pestalotiopsis* occur commonly as plant pathogens, producing a wide range of chemically novel, diverse metabolites (Maharachchikumbura et al. 2012, 2014; Debbab et al. 2013). *Pestalotiopsis* spp. cause post-harvest diseases, severe chlorosis, leaf spots, leaf blights, leaf blotch, needle, tip, and gray blight, shoot dieback, fruit rot, canker and scab on different economically important host plants (Pirone 1978; Espinoza et al. 2008; Crous et al. 2011; Suwannarach et al. 2013; Maharachchikumbura et al. 2014).

12.4.1 Symptoms

Members of *Pestalotiopsis* induce a variety of symptoms depending on the host plants and disease. The spots may be initially small, brown and oval to irregular, turning larger, grey brown and surrounded by a dark brown margin, on later stages. Black or greenish-black acervuli may appear as tiny black or brown spots on infected tissues or leaf lesions. On palms, the disease development may be restricted to only petiole and rachis or leaf blade. Initial spots color may vary from yellow, brown to black, surrounded with yellow haloes restricted to either side of the midrib that turns brown as necrosis spreads over the leaf parenchyma. The size of the leaf spot may vary from 0.4 to 0.8 cm or more. When the disease is restricted and if favorable environmental conditions prevail for a longer period the spots may coalesce giving blighted symptoms on leaves and rachis. Necrotic lesions having slightly raised margins may also be seen on leaf spine as well. These lesions may also cause shoot blight (Kokalis-Burelle et al. 1997; Vitale and Polizzi 2005; Ko et al. 2007; Luan et al. 2008; Elliott 2009; Shen et al. 2014).

12.4.2 Pathogen Biology, Ecology and Host Range

Pestalotiopsis is a monophyletic genus, characterized by fusiform conidia and acervuli. The conidia up to 5-celled and fusiform, with 3 brown median cells and hyaline end cells and two or more appendages arising from apical cells. *Pestalotiopsis* spp. are ubiquitous in distribution and occur on wide range of substrates. Many species have been recovered from human and animal infections, wood, paper, soil, polluted stream water, wool and extreme environments (Guba 1961; Strobel et al. 1996; Sutton 1999; Tejesvi et al. 2007; Monden et al. 2013). The fungus usually requires injuries or wounds for successful penetration into the host tissues (Elliott 2009). In general, *Pestalotiopsis* spp. have a broad host range. Almost all palm species host this disease. However, pygmy date palm, oil palm, doum palm, mango, apple, loquats, blueberry, pines, grape vines, hazelnut, peach, chestnut, tea, coconut, papaya, wax apple, guava, peanut, ginger, *Syzygium* samarangense, orchid, lychee, rambutan, *Camellia* spp. and ornamental plant are common host plants of *Pestalotiopsis* spp. (Kokalis-Burelle et al. 1997; Keith et al. 2006, Elliott 2009; Chen et al. 2011; Evidente et al. 2012; Ismail et al. 2013; Maharachchikumbura et al. 2013; Ren et al. 2013).

12.4.3 Epidemiology

The fungi can grow in a temperature range from 10–40 °C, with optimal growth at 20–30 °C. The fungal growth increases as relative humidity increases from 35 to 100% (El-Gali 2017). Disease progress is more likely inhibited or slowed down at low or high temperatures (McQuilken and Hopkins 2004).

12.4.4 Disease Cycle

Pestalotiopsis spp. overwinter on infected stock plants, cuttings, deposits of dry growing medium, soil, dust and floor coverings for a long period. The overwintering fungus is considered as the primary source of inoculum for new infections. The pathogen may also spread with workers' shoes, air currents and water splashes. Spores of *Pestalotiopsis* sp. may cover a distance of up to 1 m (McQuilken and Hopkins 2004). During wet periods, the conidia produced outside sporodochia are specially adapted for dispersal by insects. These spores smear on insects and are then dispersed to healthy plants (Agrios 2005).

12.4.5 Disease Management

12.4.5.1 Cultural Control

Use of disinfectant (hydrogen peroxide) for floor and pot disinfection and disinfectant foot dips may be helpful to prevent spread of the disease in the greenhouse. Sanitation of nursery and potting materials is helpful in disease prevention. Contact of nursery materials with pathogen-infested dust and soils must be avoided. Overhead irrigation facilitates new infections and increases disease severity. Simple hygiene, with good crop-management practices, are effective for pathogen prevention (McQuilken and Hopkins 2004).

12.4.5.2 Biocontrol

Bacillus subtilis NCIB 3610 had significant suppression effects on the growth of *Pestalotiopsis* sp. in culture media. In field experiments, *B. subtilis* significantly suppressed the disease symptoms (Okigbo and Osuinde 2003). Plant extract of *Azadirachta indica*, *Bougainvillea spectabilis*, *Lantana camara*, *Lucas aspera* and *Eupatorium odoratum* inhibited growth of the fungus (Ray et al. 2016).

12.4.5.3 Chemical Control

Fungicides such as frowncide, benomyl + thiram, carboxim and captan could be effective in the management of diseases incited by *Pestalotiopsis* spp. (Lisboa-Padulla et al. 2009; Teixeira et al. 2015). Bavistin and topsin-M followed by mancozeb showed significant pathogen inhibition in artificial media. However, Cu oxychloride proved effective in controlling diseases caused by *Pestalotiopsis* sp. (Ray et al. 2016). Dithane M-45, Score 250 EC, Diesomil Platinum 72 WP, Dolomite 580 WP gave significant colony growth reduction of *Pestalotia psydii* (Younis and Mehmood 2004). Bavistin showed excellent inhibition of *Pestalotiopsis* sp. in artificial media and reduce disease incidence of crown rot of strawberries (Ara et al. 2017).

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Chapter 13
Fungal Diseases of Royal Palm (*Roystonea regia*)

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Abstract Royal palm (*Roystonea regia*) belongs to family Roystoneae. It is an attractive ornamental plant present all around the tropical and sub-tropical regions. Where it provides nutrition and shelter to several birds, bats, and frogs. Its seed is consumed by livestock for oil and feed purpose, and the trunk is used in construction of huts, simple shelters, bridges. The palm is susceptible to several diseases that can be avoided or minimized by adopting various cultural practices. Fusarium wilt is one of the most severe disease of this palm. Necrosis from one side of the pinnae followed by brown striping around the rachis and dieback from leaf tip is the characteristic symptom of this disease. Application of bio-fungicides at seedling stage may help in preventing the disease. Premature dropping of fruit following foliar necrosis is the initial symptom of lethal yellowing caused by phytoplasmas. Injection of OTC antibiotic in the palm tree trunk reduces the disease severity. *Helmintosporium*, *Pestalotiopsis*, *Cylindrocladium* or *Cercospora* may cause leaf spot disease in palms that can be managed by avoiding overhead irrigation and several other cultural practices. False smuts (Graphiola leaf spots, due to *Graphiola* spp.) appear as sorus initially turn black producing yellowish spores and small emerging fibres. Cultural practices help to reduce the disease as no fungicide is yet recommended for its management. Ganoderma rot due to the fungus *Ganoderma zonatum* shows severe wilting and logging of lower leaves. Discarding the conk may be required to supress the

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_13

disease dissemination. *Phytophtora* spp., *Pythium* spp. or *Thielaviopsis* spp. maybe involved in bud rot disease of the palm and can be managed by avoiding overhead irrigation and applying copper-based fungicides.

Keyword *Roystonea regia* · Disease · Management · Florida royal palm

13.1 Introduction

The Cuban royal palm *Roystonea regia (also known as Florida royal palm* and previously named as *R. elata*), is a species native to Caribbean, Central America, Mexico, and Southern Florida. The Cuban Royal Palm is the national tree of Cuba, and is also utilized as timber in construction and roofing. It is a tall (15–30 m or up to 34.5 m) (Zona 1996) and eye-catching ornamental is distributed all over tropical and subtropical areas. The diameter of its trunk is around 47 cm with maximum diameter of 61 cm (Connor 2002). The stem color is greyish-white and texture is smooth. The stem bears a swelling underneath a green crownshaft. The leaves are four meters long and about 15 in number. Its flower nectar and fruit is food for bats and birds, and the tree serves as resting site for birds and animals. The color of flowers is white with anthers of pink color. The immature fruit is green, changing to red with time, and the mature fruit is purplish-black. The fruit shape is spheroid to ellipsoid, 8.9–15 mm in length and 7–10.9 mm in width (Zona 1996). In India the *R. regia* palm roots were found with nodules formation due to a mutual association with *Rhizobium* bacteria, representing a first case of N fixation in a monocotyledonous tree (Basu et al. 1997).

13.2 Taxonomy

Roystonea regia belongs to subfamily Arecoideae and family Roystoneae (Roncal et al. 2008). However, its position inside subfamily Arecoideae is unclear because plastid DNA-based phylogeny did not support this placement (Asmussen et al. 2006). These trees are also known as palma criolla or palma real in Cuba (Zona 1996) whereas in India, these plants are named as *vakka* (Rao and Mohana 2007).

13.3 Fusarium Wilt

Fusarium wilt is one of the most devastating diseases of various palm trees species. Various ornamental and a wide range of significant crops are effected by Fusarium wilt disease (Garibaldi 1978; Elmer et al. 1996; Wang and Jeffers 2002). *Fusarium* spp. affects ornamental plants at all the stages but seedling or nursery stages are generally destroyed by these pathogens. *Fusarium* spp. are major soil borne pathogens present all over the world. In Pakistan 50% losses can be incurred in field harvests of vegetables, fruits, horticulture or ornamental crops due to diseases caused by soil borne plant pathogens. Among them, *Fusarium* spp. exhibit great importance as they cause wilting diseases (Akhtar 2000) by blocking the xylem vessels, causing disturbance of water translocation in the plant. A overall crop loss range from 50 to 100% can be experienced, due to severe *Fusarium* spp. attacks (Otadoh et al. 2011).

13.3.1 Etiology and Ecology

The causal organisms, Fusarium spp., are soil borne, filamentous fungi (Ascomycota, Class: Sordariomycetes, Order: Hypocreales, Family: Nectriaceae). These pathogens are present all over the world and greatly affect the economy by damaging a wide range of crops. They are the most prominent soil borne pathogens, having ability to survive in a variety of soil types, and generally found in the rhizosphere of plants (Burgess 1981; Gordon and Martyn 1997). *Fusarium* spp. can survive and grow in soil with pH range 4.2 to less than 7. Below or above this range the pathogens are unable to grow but can remain in soil by producing chlamydospores (thick walled, resting hyphal cells). Under unfavourable climatic conditions or in response to the ooze out of material from roots of adjacent plants, Fusarium may produce chlamydospores and undergo a stage of dormancy or remain inactive, until the conditions become suitable again. The chlamydospores are capable of persisting in the soil, among debris and other dead matters for about 10–20 years. Some Fusarium are saprotropic in nature so nutrition is obtained by means of soil having trash, debris, litters etc. (Wilson 1946; Garrett 1970). Most of *Fusarium* spp. infect plants by penetrating in roots and then progressing upward in the vascular system. Some species are restricted only to the root system and do not move upward, so the vascular system can remain partially unoccupied (Olivain and Alabouvette 1997). The variability in *Fusarium* spp. results from variations in evolutionary and genetic makeups, capable of altering the physiology and morphology of this fungal lineage (Nelson et al. 1981, 1983). Some auxiliary metabolites (with low atomic weight) and optional metabolites are produced by these pathogens. Auxiliary metabolites have ability to sustain plant invasion, whereas others play a role of the plant infection. Other metabolites may include enniatins and trichothecenes enhancing the fungi pathogenicity (Bai et al. 2002; Herrmann et al. 1996; Maier et al. 2006). Steinberg et al. (1999) described that the *Fusarium* spp. form hyphae surrounding host plants at their base and then penetrate the plants through the roots. The germination of chlamydospores in soil promotes production of hyphe that connect with the host plant. Formation of appressoria facilitates fungal penetration (Kraft 1994).

13.3.2 Dissemination

The disease disseminates from plant to plant and field to field through field stakes, seeds (the pathogen also inhabits seed), wind, airborne transmission, irrigation water, rain splashes, movement of soil particles. The disease can also be dispersed by pruning equipment formerly used for pruning infected plants, by insects feeding on infected and then on healthy plants, and by human activities (Kraft 1994; Lester 2015).

13.3.3 Symptoms

Symptoms can be observed mostly late in the growing season and start arising from older leaves extending upwards towards young leaves and ultimately leading to wilting of all leaves or just their growing tips. Yellowing or necrosis of leaflets initiating from one portion of the leaf blade can be observed. The whole plant eventually becomes dark yellow in color, leading to wither aspect. Development of vascular clusters appearing as dark yellow to reddish can be noticed. On cutting the infected stem in cross section, a reddish to brownish color can be observed internally. Typical symptoms including necrosis on one portion of the pinnae with brown streakings alongside the rachis of the palm and dieback of leaves from their tips. Vascular discoloration can be found in a cross section area of the stems and trunk. After many months of symptoms development the death of palm tissues and whole plants may occur.

Signs of Fusarium wilt disease include wilting of leaves, branches, discoloration from green to yellowish and ultimate death of infected plants. The most important characteristic symptom of Fusarium wilt is considered as one side wilting or drying of the palm plant (Kraft 1994; Lester 2015).

13.3.4 Diagnosis

The disease can be diagnosed initially on the basis of the above mentioned symptoms. The characteristic symptom is that no fungi other than Fusarium are capable of killing the whole canopy of the palm tree so swiftly. On fast disease development, just one leaf showing characteristic symptoms may remain, as the leaves start dying quickly. In case of wilt disease due to Fusarium the spear leaf wilts or dies at the end, as the disease progresses from older to younger leaves. In wilt diseases other than Fusarium the spear leaves instead dry at early stages of symptom development. Moreover, early developed symptoms due to Fusarium wilt show many similarities with the rachis blight of palm trees. However, the palms affected by rachis blight disease occasionally die. It is hence important to diagnose the real cause of the disease through laboratory diagnosis. This includes isolation of the pathogen from symptomatic leaves on artificial media, observing the pattern of fungal colony, spores and hyphal structure and comparing observations with literature data. Finally for species identification molecular analysis is necessary.

13.3.5 Management

No cure or control of this disease is available and infected palm trees must be discarded. Various cultural and sanitation strategies should be adopted as best preventive measures. Pruning equipment or blades must be disinfected before use by applying 25% of Na hypochloride or rubbing with 50% alcohol. The equipment must be cleaned before dipping in the sanitizing solution, to remove dust particles or debris. The sanitizer must be replaced after pruning ten trees. After disinfection, the equipment should be rinsed with clean water. Trimming should be limited only to the exclusion of wilted or dead leaves, as a heavy pruning or trimming of infected palms branches can enhance disease spread. Susceptibility to the disease enhances due to the availability of heavy amount of nitrogen in the soil. Before plantation of palms the soil should hence be analysed.

Weeds must be removed by pulling manually, mechanically or by using herbicide, as they may be the alternative host for this pathogen. Use of biological fungicides i.e., mycostop either by applying as soil sprays or drenching at seedling stage can efficiently prevent the crops from Fusarium wilt disease. Adequate amount of water should be applied to allow movement of the fungicide to the root zone.

The infected plants should be removed and soil should be solarized before replanting. For soil solarization, the soil surface must be covered with a transparent plastic sheet during 4 to 6 weeks in summer. Population of many soil persisting organisms, including fungi, insects, nematodes etc., can be suppressed by soil solarization. The most efficient approach to manage the disease spread is the use of clean seeds and the removal of affected portions of infected palms. The use of resistant varieties if available can significantly contribute to manage the disease. Due to long time survival of the pathogen in soil, crop rotation are usually unsuccessful. Fusarium wilt might take one and a half year for symptoms development and the pruning of infected plants before the appearance of symptoms can favor the disease dissemination. Trimming of plants during wind-free days can considerably protect the healthy palms from being infected by prohibiting the movement of infected sawdust. Sterilization of the manual garden equipment and gloves i.e. by dipping in a pine oil and water solution (1:3) effectively kills the pathogen. Cultivation of disease-free nursery seedlings is important to avoid the *Fusarium* entry and field dissemination.

13.4 Lethal Yellowing

About a century ago, lethal yellowing (LY) disease was initially observed in the Caribbean region of North America. Until 1950s, its etiology was unknown and the disease caused severe economic losses in Jamaica and Florida. In 2007 the lethal yellowing (LY) disease of palm was found in Manatee, Sarasota and on the west coast regions of Florida for the first time. In 2012 LY was initially found in the Indian River country on the eastern coast of Florida. Currently, It is not as predominant as it was earlier, and it may occur sporadically at different times in Florida. The main reason for the reduction in LY aggression or disease rate is not known but a combination of various key factors like aggressive Oxytetracycline HCl (OTC) techniques, serious or regular monitoring and ultimate death of extremely susceptible host palms due to LY, might explain its reduction. About thirty seven species of palm have been recognized as affected with LY disease.

13.4.1 Etiology and Ecology

The LY disease is caused by phytoplasmas (wall-less prokaryotes) that are strictly obligate in nature and unable to be cultured on artificial media in the laboratory. The pathogen is systemic in nature and restricted only to the phloem vessels and disturbs the transportation of photosynthates in the plant. Phytoplasmas cannot persist on the outer surface of the hosts, including plants and insects (Martinez et al. 2000).

13.4.2 Disease Dissemination

Insect vectors such as *Haplaxius crudus* (plant hopper) and leaf hoppers disseminate the diseases, by piercing and sucking from plant to plant as they feed on the vascular bundles (including xylem and phloem vessels). The vectors transmit the disease in a persistant manner from infected palm to healthy ones, due to their movements and throughout their feeding cycles (D'Arcy and Nault 1982).

13.4.3 Symptoms

Initial characteristic symptom in mature palm trees is the premature falling of fruits, followed by floral necrosis i.e., the normal color of inflorescence turns black. Younger leaves show a brownish to reddish discoloration. Sometimes yellowing of one leaf, i.e. the flag leaf in the middle of the effected palm canopy, can be observed. On advancement of foliar discoloration in infected palms, the youngest leaves collapse and drop down the canopy, showing death of the apical meristem. Ultimately, the whole canopy of affected palms wilts and collapses, resulting in a bare trunk (McCoy et al. 1983; McCoy 1976).

13.4.4 Diagnosis

For initial diagnosis the above mentioned symptoms and transmission electron and flurescent microscopy observations are helpful. However, as the phytoplasms are obligate in nature and cannot be cultured on artificial growth media, molecular analysis using particular DNA probes and PCR primers is necessary for accurate identification of the pathogen. For molecular analysis the pathogen can be acquired by drilling the trunk of the infected palm.

13.4.5 Disease Management

When permitted, chemical control performed by injecting OTC antibiotic solutions into the trunk of the diseased palm may be effective. OTC antibiotic minimizes the protein production and replication of phytoplasma. Use of resistant host palm varieties is the best and long-term prevention strategy against LY disease. The tropical fodder grasses found as non-breeding hosts for insect vector should be used as surface cover on the palm fields, to minimize the vectors population density (Maust et al. 2003; Islas-Flores et al. 1999).

13.5 Leaf Spots

Fungal leaf spot diseases usually affects the ornamental plants and shade trees. Palm species become generally affected by various fungi causing leaf spot diseases. These spots are generally round to elliptical in shape, having brownish color and have an oily appearance. As various fungi are involved in leaf spot disease to diagnose the actual cause of the disease is a complex task, that cannot be carried out just through visual inspections (Daughtrey et al. 1995).

13.5.1 Etiology and Ecology

Numerous pathogens including *Helmintosporium*, *Pestalotiopsis*, *Cylindrocladium*, and *Cercospora* are responsible for leaf spot diseases in palm species (Meerow 2005).

The pathogens causing leaf spots have a wide host range within palms.Each palm species is specifically susceptible at the seedling stage to any of the above mentioned pathogens. Fungi causing leaf spot disease live on leaf litters, infected dropped leaves, stems and twigs. Some pathogens can survive on the infected tree by persisting in dead twigs (Daughtrey et al. 1995).

13.5.2 Dissemination

The spores produced by these fungi can be transmitted effectively through wind and water, either with rainfall splashes or overhead irrigation, as they provide extended wet period which facilitates the disease dispersion. Various insects, rodents or human activities favor movement from field to field. Pruning equipment can be a disease carrier from infected to healthy nursery fields or palms.

13.5.3 Symptoms

Appearance of small, water soaked lesions on leaves is the initial symptom. On the basis of infected plant species, variety, involvement of particular causal organism and plant developmental stage, the size and color of spots may vary. Mostly the spots are brown in color but can also be tan to blackish, with dark margins. Concentric rings are also usually observed. Fruiting bodies appearing as black dots can also be seen, forming rings insides the spot or clusters at the center of the spot. The leaf spots generally emerge on leaves of all ages, either old or young. Loss of foliage may be observed in the palms affected by leaf spot disease, but a mature plant can tolerate the defoliation completely if the disease appears late in the season. Seedlings or small plants are more sensitive to leaf spot, and huge defoliation can be noticed until plant gets mature. In case of a severe infection, the whole affected leaflets or leaf may shrink and eventually die when the lesions extend and merge, resulting in a leaf blight disease.

13.5.4 Diagnosis

The cause of the disease cannot be diagnosed in the field on the basis of visual symptoms, as the leaf spots resemble each other so the pathogen involved cannot be determined through this symptom. The accurate identification of the pathogen responsible for leaf spot disease can be performed in the laboratory by examining spore structure and hyphal arrangement with a compound microscope. The spores can either be directly taken from the affected tissues or produced on artificial media. Sometimes two different fungi can be found on the same diseased plant, one of which is the causal organism while the other is feeding on dead tissues as a saprotroph.

13.5.5 Management

The palms should be irrigated carefully to avoid wetting of the foliage, preferably during day time so that the foliar portion dries before night. Eradication of the infected leaves and twigs helps to reduce the pathogen population. Trimming the plants facilitates air circulation that will also help in keeping the foliage dry. The area around the palm should be well drained as a poor drainage promotes the various pathogens. Adding organic matter by mulching provides beneficial microbes that will compete with the pathogens. Application of fungicide sprays is generally not recommended as the leaf spots does not lead to death of the tree. However, in case of severe infections, copper-based fungicides can be applied, following the interval of fungicide application and using accurate amount as indicated on the label (Pearce 2005).

13.6 False Smut

False smut also termed as Graphiola leaf spot is a foliar disease generally found only on palms, in the regions where humidity is high. In Florida, it is thought to be a cosmetic disease because it does not have devastating effects on the palm growth. Nutrient disorders including K and Mg deficiencies, are considered as more severe disorders than false smut disease.

13.6.1 Etiology and Ecology

The causal organisms of false smut disease are a number of *Graphiola* species. These fungi have unique features including their appearance and life-cycle. After penetration into leaf tissues, the fungal growth is restricted to the leaf tissue and maximum growth can be found under the fruiting body of the fungus, i.e. a sorus. The duration from infection to symptoms development or spore production ranges from 10 to 11 months. This is a unique characteristic feature compared to other pathogens causing leaf diseases, as their life cycle usually is measured in weeks rather than months. In simple words, this disease shows symptoms about 1 year after initial development.

13.6.2 Dissemination

The disease is dispersed by insect vectors, rodents, human activities, wind, irrigation water and rain splashes.

13.6.3 Symptoms

Wart like structures which are small in size, usually 0.8 mm (1/32 inch) or even less, and brownish to blackish in color appear on both upper and lower leaf surfaces. Minute fibres i.e., sori (less than 1.6 mm or 1/16 inch in diameter) may arise from these black warts. The sori are generally black in color but as they mature, yellowish spores develop and small fibres of light colour originate from them. Generally, no visual symptoms develop on spear leaves. After the dispersion of the spores, the sori depress and look like a black cave or black, cup-shaped fruiting body. The sori can be easily seen and felt by touching as they are raised from the leaf epidermis.

13.6.4 Diagnosis

This disease can be diagnosed through visual observations. The fungus can be grown on artificial media but mostly this is not needed, as it is identified easily through the observation of affected leaves with the naked eye, or by using a simple magnifying lens for more prominent or close views.

13.6.5 Management

It may be needed to reduce the humidity through the plantation by separating plants at a significant distance, and promote aeration. Disease dispersal can be reduced by eradication or discarding leaves with 30% or more of their surface area being infected. Excessive or unnecessary removal of leaves from the diseased plants must be avoided, as the palms are more sensitive to nutritional disorders so the tree becomes weak, due to excessive removal of leaves.

Application of fungicide is not generally recommended but they can be sprayed during the spring season, as a preventive measure. Fungicide applications cannot eliminate or kills the already existing inoculum, but just prevent the plant from future infections, and symptomatic leaves remain in the same condition as they were, before fungicide application (Caldwell and Elliott 2015).

13.7 Ganoderma Root and Butt Rot

Ganoderma rot disease, also termed as butt rot disease, is a lethal disease of various palm species, including royal palm. The fungus infects the palms both in landscape and natural settings. Ganoderma spp. are distributed on gymnosperms (all types of wood), woody dicotyledons and palms, all over the world, and are considered as the wood decaying fungi. Many *Ganoderma* spp. are found in Florida but only one of them is pathogenic for palms in nature. In 1994, the disease was discovered for the first time in Florida. *Ganoderma* enters at the base or butt of the palm trunk at 9–12 cm (3–4 ft) above the ground surface.

13.7.1 Etiology and Ecology

The disease is caused by the fungus *Ganoderma zonatum*, which is unable to infect plants other than palms. The basidiocarp (fungal fruiting body), also known as conk, is sometimes found at the base of the trunk, especially when the palm is alive. It is indicative of *G. zonatum*. as other *Ganoderma* spp. are saprotrophs and mostly found on hardwood trees such as oak. However, they may occur on trunks and stumps of dead palms, but are only occasionally found on living palms. All palms trees are susceptible to this disease. Many enzymes are produced by *G. zonatum* due to which the degradation of woody tissues occurs. Initially lignin and then cellulose are degraded.

13.7.2 Dissemination

The disease is initially disseminated through the spores produced in the conk as they integrate in soil and germinate. Fungal hyphae then grow in the root zone of the palm.

The roots are not effected or damaged by the fungus as it uses them just as a starting, entry point for movement towards the tissues of the woody trunk. *Ganoderma zonatum* is transmitted with the infected palm to the final transplantation area. Additionally, soil with the transplanted palm may also carry fungal spores.

13.7.3 Symptoms

The initial disease symptom is a minor to severe wilting and logging of mature leaves, that collapse with a logging occuring to the trunk. The leaves emerging after infection are pale green to yellowish and show a stunted growth. The crown of the infected palms may collapse or drop down. In infected trees they may show mild to severe dieback resulting in ultimate falling off and death of the palm. Initially a white mycelium mat can be observed beneath the bark of the infected palm, that ultimately turn brownish. With the upward movement of the fungus towards the trunk and the crown bands and strands, rhizomorphs grow from which fan shaped bracket mushroom may develop at the trunk base. Finally, the disintegration and decomposition of infected spongy wood can be observed.

Death or decline of the palm tree occurs within 3–4 years after infection, depending on palm age and climatic conditions.

13.7.4 Diagnosis

The conk emerging at the base of the palm trunk is the consequence of fungal germination and infection. Primarily, the conk appears as a soft, solid white mass starting to emerge from the trunk side or stump. It is asymmetrical to spherical in shape and smooth. The conk extends or elongates as it becomes mature and remains white from both the upper and lower surfaces. Ultimately, a distinctive, comparatively hard glossy reddish-brown color is visible on the upper surface, whereas the lower surface is white. The conk exhibits a shape similar to a half moon, the straight portion of which is directly connected with the palm trunk.

If wilt and decline symptoms coincide with the conk presence at the trunk base, then it is easy to assume the disease as Ganoderma butt rot. Sometimes, the conk does not emerge before decline and death due to a severe infection. To diagnose the disease cause the infected trunk may be cut for a cross section view. The basidiocarp (conk) of *G. zonatum* is about 24 cm (8 inches) wide and 6 cm (2 inches) thick. Basidiospores produced inside the pores of the conk are microscopic and appear as reddish-brown in color when dropped on a white surface. Three cups of spores can be produced by one conk.

13.7.5 Management

There is yet no assurance of any palm trees resistant to ganoderma butt rot. In landscapes, as the fungus persists on plant tissues, trunks, stumps, root system parts of dead palm trees must be eradicated and discarded.

As *Ganoderma* lives in soil, it is not wise to cultivate another palm on the same area. No chemical control has been developed yet for this disease. There is a need of frequently monitoring the palm trunks and stumps for appearance of conks, as these produces million basidiospores. It is needed to remove the conk, putting them in a trash container for burning (Elliot and Broschat 2001).

13.8 Bud Rot

The bud or heart of the palm is the formal name of the apical meristem, from which all fronds arise. As the spear leaf and freshly expanded leaf emerge, they are connected with the bud. As the palm develops, all new emerging leaves develop in the bud. Hence, due to a bud (apical meristem) damage, the plant dies eventually as growth ceases in the bud. The wilting and death of palm heart fronds result in the death of the whole tree, due to the bud rot disease caused by the fungus.

13.8.1 Etiology and Ecology

Various fungal pathogens including *Phytophtora* spp., *Pythium* spp. and *Thielaviopsis* spp. are responsible for bud rot. The disease occurs after tropical storms and prolonged period of heavy rains.

13.8.2 Dissemination

Disease disseminates through rain splashes, irrigation, insect, snail and rodent activities, human activities including pruning or palms trimming equipment. The disease also may be spread by soil particles or through dead leaf litter and plant tissues fallen on the ground.

13.8.3 Symptoms

Black lesions can be found on young leaves and buds, and wilting of young leaves can also be observed, together with severe decaying of buds. With time, as disease progresses, the affected area may show an oily appearance due to its invasion by secondary organisms. Mature leaves can tolerate the disease for many months, remaining green until they die. Ultimately, the whole palm dies and only the trunk remains standing.

13.8.4 Diagnosis

As the bud rot disease can be caused by both fungal and bacterial pathogens and their symptoms resemble with each other, laboratory diagnosis including growing on culture medium, observing colony pattern and microscopic analyses are needed to confirm the disease cause. For species confirmation molecular analyses should be applied.

13.8.5 Management

Excessive or overhead irrigation should be avoided. After disease development, the plant recovery is not possible. Affected palms should be eradicated and destroyed to halt the disease dispersal. Copper-based fungicides can be used as a preventive measure. The amounts and application methods of fungicides should be followed, according to the label (Elliot 2018).

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Chapter 14
Fungal Diseases of Lady Palm (*Rhapis excelsa*) and Fishtail Palm (*Caryota mitis*)

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Abstract Lady palm (*Rhapis excelsa*) and Fishtail palm (*Caryota mitis*) are two important and beautiful palm species used extensively as ornamental plants in landscaping, worldwide. The genus *Rhapis* includes small bamboo like palms, while Fishtail palm has green leaf blades of medium size, divided into segments, each one resembling fancy goldfish tail. Like other ornamental palm species, both are also subjected to different fungal diseases which pose serious threats to their production and deteriorate their appearance. This chapter describes economically important fungal diseases including Pestalotiopsis leaf spot, Thielaviopsis rot, Pseudocercospora leaf spot, Stigmina leaf spot of Lady Palm as well as fungal leaf spots of Fishtail palm. Comprehensive information is also provided regarding etiology of diseases, distribution and dispersal, symptoms and management strategies.

Keywords Lady palm · Fishtail palm · Cluster fishtail palm

14.1 Introduction

Arecaceae family includes large number of members of commercial importance. The members of this family are vital source of food and feed (fruits, nuts, oils, fiber) and quality wood. Ornamental palms, slow growing in nature, are propagated through different ways such as cuttings, through suckers or seeds. If propagated through seed they may take months to germinate at an optimum temperatures, in the range of 30–35 °C. Ornamental palms are not only used for land beautification but, in their native regions, they are used for some vital purposes such as food, clothing,

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_14

mat, hats, rope and basket making etc. They are also used for medicinal purposes and relaxation for humans and are preferred in parks, buildings and other public places (Balick and Beck 1990; Akintoye et al. 2011). The genus *Rhapis* (Palmae, Coryphoideae) is a group of clustering, unarmed palms, usually termed as lady palms. The members of this genus are distributed from Southeastern Asia, Japan, China and Indochina to peninsular Thailand and Indonesian islands (North Sumatra). *Rhapis* is part of lowland forests characterized by small tropical evergreen palms. *Rhapis excels* (lady palm), is used in indoor and outdoor environments due to the capacity to improve air quality and making indoor environment cleaner (through evapotranspiration not only through leaves but also from other parts) and ultimately reducing air pollution hazards for humans which spend most of the time in indoor environments. Apart from its benefits as indoor plants it produces flavonoids, polyphenols, benzoic acid, vitexin, vicenin-s, iso-orientin, other herbal extracts with antibiotic and insect repellent properties. Its antibiotic activity was experimented with positive results against *Staphylococccus aureus* strains (Uhl and Dransfield 1987; Byg and Balslev 2001; Tan et al. 2007). The genus *Rhapis* includes about nine species of small, bamboo-like palms with leathery sheaths, and *R. excelsa* that grows well outdoor on different soils. Lady palm is a typical small clustering species being used for interiorscape, shady landscape or outdoors. These palms have smooth, shiny and dark green palmate leaves with bare petioles ending in a rounded fan. The stems are thin, branching at base and 3–4 m tall. Small white fruits are produced from densely branched inflorescences. Lady palms are used in landscapes as shrubs or as display and spreads from underground rhizomes, developing from dense clustering. However, these palms usually require periodic removal of side suckers. They are best suitable for low light interiorscape environments.

The inflorescence features are complex, due to the multiplicity and size of braches. Each leaf axil have an inflorescence bud which can expand randomly especially in summer, but many aborted inflorescence nodes looks like small flaps in axil of leaves, with complex vestigial of the vascular system. Normally these are either male or female. Inflorescences producing female perfect flowers are not very common but can be easily observed in some cases and are also referred to as “female inflorescences”. Male inflorescences have slender branching axes with characteristic small densely crowded flowers. Lady palm has another special feature of the inflorescence, with a terminal vegetative growth and singly borne young flowers at its top. It is also covered and protected by a tubular sheath and light but rigid basal bracts (Tomlinson and Zimmermann 1968; Zimmermann and Sperry 1983). Like other palms, seed propagation is the most common way of propagation. However, they can be propagated through division as well. For instance, variegated forms are only propagated by means of division to retain their variegation. Lady palms can best grow in moist soils with full or partial shade.

Caryota mitis (Fishtail palm) is a most important palm grown worldwide. Because of its beauty it is also commonly called in Pakistan as fishtail palm because its leaves look like a fishtail. The genus *Caryota* derived its name from Greek ‘caryon’ translated as “nut”. The species derived its name from Latin word ‘*mitis*’ meaning “unarmed”, which depicts the friendliness of this genus, whose members are unarmed. In 1790, Loureiro first described *Caryota mitis from Vietnam. This palm* is also famous for other names, such as "clustering fishtail palm", tukas, rabok, malay which are native to Southeast Asia and Indo-China, especially in tropical forest regions. *Caryota mitis is one of the 13 species enlisted in the genus Caryota (*Henderson 2009).

All species in genus *Caryota are* monocarpic, which means that they produce the flower and fruit only once in their whole lifespan. They have bipinnate leaves, charactersthat differentiate them from other palms and easily allow their identification. *Caryota mitis frequently grow in clusters of* stems that, after producing the flowering and fruits, die (that's why it is also called "clustering fishtail palm"). This palm is used as an ornamental, worldwide (Krempin 1995).

Caryota belongs to Coryphoideae family, with the characteristic features of having bipinnate leaves and imperfect florets. Every flower is merely a pistillate or a staminate reproductive part (Dransfield et al. 2008). The *Caryota genus is bisexual, meaning that male and female flowers are produced* separately. Male flowers are produced in different cream to dark purple colors, and are extended with three petals and many stamens with abundant amounts of pollen. They can be easily recognized from female flowers which are and protandrous within triads, meaning that female flowers are produced between two male flowers. Female flowers are globular in shape with a trilobed stigma. They have three petals as in male flowers, and are less attractive and fancy as compared to the male flowers. This is the reason why insects are not attracted by the female flowers and the mechanism of pollination still remains unknown (Glover 2014).

The red to dark purple color fruits normally have one seed 1–2 cm in size that many animals eat. *Caryota mitis is the onlyspecies in the genuswhich is commonly found in forests (Corner* 1966). *It* is especially abundant in disturbed areas and more abundantly on edges, as compared to interior forest areas, as it can bear harsh environments (Whitmore 1973; Baez and Balslev 2007). Various animals, i.e. birds, civets, jackals and squirrels are recorded to consume different parts of *C. mitis* (Corner 1966).

Caryota mitis fruit is nutritious, as riped fruits of C. mitis have an average caloric content of 3.36 kcal/g, comparable to an apple fruit which has an average caloric content of 3.59 kcal/g (Omar 2014; Walton et al. 1999). There are several uses of palms in India, i.e. the starch is extracted from stems, the leaves are used to make ropes or for thatching of roofs, whereas the young leaf fuzz is used for tinder and seeds are used as beads, in some Southeast Asian countries. The fuzz prepared from new leaves of palms is also used as firewood to start a fire and the stem has other major uses in house and furniture making (Balick 1988; Balick and Beck 1990). *Caryota mitis is the most popular* species of the genus as compared to others and is widely cultivated because of its small structure and clustering growth habit (Loo et al. 2014; Johnson 1995). For many years, palms have been used for therapeutic purposes and some extracted chemicals have been used as pesticides, herbicides and medicines to control diseases. The sap is extracted from different species of palms and a sort of wine may be also prepared from it, used for refreshment (Rochfort and Panozzo 2007).

14.2 Biotic Threats to *Rhapis excelsa*

Lady palms are generally considered as disease-resistant, but susceptible to insect pests (mites, scales and mealy bugs), particularly when they are grown in indoor environments. New emerging leaves are more susceptible to attacks by scale insects. The palms may be also attacked by leaf spot diseases, i.e. fungal brown leaf spot which primarily targets older leaves with development of brown spots or blemishes. The leaf sport fungus attacks in cold and moist conditions. Removal of infected leaves is essential to prevent spreading of the disease to healthy palms. Delicate variegated palm leaves are more vulnerable to strong sun light so the plants should be kept in shade. Root rot is a common problem associated with lady palms, initiated by poor cultural and agronomic practices such as overwatering and nutrient imbalances. In UK, *R. excelsa* grown under good agronomic and cultural practices were more resistant to pests and diseases. Whenever scale insects are observed in leaf joints, they can be just picked off and sprayed immediately. Monthly application of pesticides will prevent further pests attacks.

14.2.1 Pestalotiopsis *Leaf Spot*

Lady palms reported from California, China and Thailand are infected by leaf spots and blights followed by yellowing, necrotic lesions and stunted growth. Leaf spots are very harmful as they not only disturb the host physiology but also challenge the purpose of beautification for which they are mostly grown (Hallmann et al. 1997). Leaf spot, caused by *Pestalotiopsis* disease, was originally described from Florida on pygmy date palm, where it causes a lethal bud rot. Yellowish-brown or black, small pin head dots, expanding towards a larger size, are initially observed on infected leaves, eventually covering them and causing a further nutritional disturbance. *Pestalotiopsis* spp. have conidia comprised of 6 cells with four light brown median cells whereas apical and terminal cells are hyaline. Apical cells may produce appendages, branched or not. Based on appeandage numbers and branching types the genus *Pestalotiopsis* can be divided into different species. *Pestalotiopsis licualacola*, the causal agent of grey leaf spot disease in *Licuala grandis* (fan palm), shows unique characteristics such as greyish-brown conidia measuring 15–20 μm in length and 3–5 μm in width, with 1–3 apical appendages, whereas terminal appendages are absent (Geng et al. 2013).

Pestalotipsis versicolor was also isolated from lady palm in New Zealand during a survey during 2003–2004, in which plants were randomly selected to identify fungal pathogens associated with different hosts. Similar grey lesions with black margins were noted on petiole and rachis. Proper sanitation, water and nutrient management practices were proposed for reduction of disease and economic losses (Uchida 2004; Braithwaite et al. 2006).

Pestalotiopsis species are widespread and may be identified by using morphological, phylogenetical, ITS and species-specific genes. They have been reported on different palms in Yunnan (China) where they cause blight diseases. Some of these pathogens cause severe losses to ornamental palm export industry and hurdles in competition with international market (Zhang et al. 2013). *Pestalotiopsis* species also cause leaf spot and leaf blight on oil and date palm, two major economically important plants, in regions of Thailand and India (Suwannarach et al. 2013; Bhanumathi and Rai 2007). Disease samples of ornamental trees such as *Shorea obtusa* and *Pandanus* spp. were examined in lab and their causal organisms *Pestalotiopsis shorea* and *P. simitheae*, respectively, were confirmed on morphological characteristics, including colony growth and color, short appendages and brown colored median cells, as well as on molecular basis (Song et al. 2014).

Pestalotiopsis spp. are also severe pathogens of guava, mango, strawberry and sweet persimmon by causing economic losses in Egypt, Nigeria, Spain and New Zealand's fruit industry respectively (Chamorro et al. 2016). Another very important plant grown for its leaves, *Camellia sinensis* (tea plant), is affected by leaf spot diseases also caused by *Pestalotiopsis* spp. in Southern India, which affect not only yields but also quality (Nepolean et al. 2012).

14.2.1.1 Symptoms and Spread

Symptoms of Pestalotipsis leaf spot are not confined to leaf surface but are also occur simultaneously on petiole, in severe cases covering the whole leaf blade, not only in nurseries but also in adult plants, from indoor and outdoor environments. Initially, the symptoms resulting from primary infection appear as small brownish spots on the leaf surface with oval to irregular shapes. The spots may coalesce to form wider spots which are larger and irregular in size, and more brownish as the symptoms mature. These spots are surrounded by a dead tissue border dark brown in color. Symptoms are more prevalent and severe during March and April, months having an ideal optimum temperature for the pathogen growth. In most cases, the disease incidence is high during these months, as shown by different surveys performed around the world on ornamental plant diseases. Symptoms get more complex if temperatures rise joined by high air humidity in due to rains, which also spread the disease inoculum and provide optimum conditions for growth.

14.2.1.2 Causal Organisms

Many fungal pathogens, namely *Alternaria* alternata, *Fusarium oxysporum, Helminthosporium* spp., *Aspergillus* spp., *Colletotrichum* spp. and most commonly and highly distributed endophytic *Pestalotiopsis* spp., have been isolated from leaf spots in lady palms from different parts of the world. *Pestalotiopsis* spp. have been confirmed as leaf spot pathogen in *R. excelsa* not only on morphological, but also on phylogenetic basis. When studied *in-vitro*, *Pestalotiopsis* cultures give a white cottony mass appearance with undulated edges, which looks pale on the petri dish back. Conidia, generated on conidiophores which are swollen at their base, show five cells, fusiform to ellipsoid in appearance, with apical and terminal cells and three median cells. The apical and terminal cells may produce appendages of different sizes, branched or unbranched.

14.2.1.3 Control

Pestalotiopsis produces spores which need wind or water to reach susceptible host plants. Spores produced by these fungi are abundant in nature so sanitation techniques are of utmost importance in reducing the spread of this diseases, considering irrigation channels in nurseries, pruning equipments etc. The pathogen needs an entry site on the plant surface which may be provided by insects in natural conditions or may result by human activities during weed removing, pruning, transportation etc.

The disease spread will be fast and severe if the leaf surface remains wet for a long period of time, and high humidity occurs in greenhouse or naturally during rains, accompanied by optimal temperature for fungal growth. Irrigation management is important in *Pestalotiopsis* disease control which requires avoidance of irrigation during high humidity hours such as in the morning when leaves are already wet with drops. Eliminating overhead irrigation and increasing air circulation, especially in greenhouses and nurseries, by maintaining a proper plant to plant spacing, are needed to avoid an ideal micro-environment for these fungi.

Pruning is widely used in horticulture, especially for ornamental plants, not only to get beautiful and aesthetic plants, but also to shed extra leaf loads. Pruning causes wounds which, if not timely taken care of, can provide suitable entry sites for fungal pathogens. After pruning the plants should be completely aseptic by spraying chemicals or effective fungicides, if possible. Pruning also aims at removing infected plant parts so that the inoculum may not spread. If most of the seedling is damaged, then the whole plant is removed before it becomes a major source of secondary infection inoculum. Diseased leaves, confirmed as affected by the pathogen, should be eliminated, rather than cutting leaves because of any other nutritional deficiency or unsuitable environment. Pruning must be rational, as it will make the already affected plant more chlorotic, necrotic and susceptible to *Pestalotiopsis* by providing new entry sites and loss of sap. Problems related to nutrients deficiency are mostly observed in potted indoor lady palms, due to unsuitable or already deficient soil and unsuitable environmental conditions. These should be addressed on a priority basis, before the symptoms may be confused with the pathogen infection.

Chemicals, especially fungicides, are effective against spreading of Pestalotiopsis leaf spot but they cannot repair a spot. Fungicides should hence be the last choice rather than the first one. It needs to be understood that leaf spots as other lesions on the leaf surface last for life on a leaf, permanently affecting its look in an indoor environment. Other preventive strategies should hence be preferred for leaf spot control in lady palm, as foliar fungicides, with a broad spectrum activity, should be sprayed to avoid *Pestalotiopsis* leaf spot on nearby healthy plants.

14.2.2 Thielaviopsis Rot of Lady Palm

Trunk rot in palms is very devastating as it has potential to disturb palms globally. It has been reported in different states of USA (Arizona, Florida and California), with an increasing frequency especially in Florida. Many ornamental and palm species are susceptible to this pathogen including betel nut, fishtail, Kentia, date, true date and Canary island datepalms, as well as royal, cabbage, queen and Christmas palm, with Washington and Mexican Washington palms. Thielaviopsis bud rot, reported in South Florida, is also known as trunk or heart rot, stem bleeding and some other terms, depending on the symptoms which appear on the particular host. When this pathogen attacks the seedling it is called as bitten leaf or leaf scorch. *Thielaviopsis* sp. has been reported frequently on various palm including some hard woods and other herbaceous ornamentals other than palms Garofalo and McMillan 2004).

14.2.2.1 Causal Organism and Spread

Thielaviopsis are soil borne fungi with diverse distribution throughout palm growing regions, due to a highly efficient mode of spreading in soil and through water to healthy plants, due to human activities and natural causes such as storms, heavy winds etc. *Thielaviopis* spp., most commonly *T. paradoxa*, get entry through wounds, spear leaf, inflorescence, mechanical injuries, cracks due to growth, and bases of young leaves, pruning. The disease causes disintegration different parts of lady palm, and hence is named accordingly as of trunk, bud and root-rot. These soil borne pathogens can also attack leaves and stems of healthy lady palms.

14.2.2.2 Symptoms

Thieleviopsis cause different symptoms according to host plant and affected parts. Mature lady palms are infected through lower parts as trunk and roots, causing severe fall-over, followed by stem bending up to half way. Symptoms of trunk bleeding through small growth cracks can be observed before or after stem bending. The cracks are very minute and if are not no bleeding will be observed until they are fully formed, as plants will look normal from outside whereas the vascular pathogen completely invaded them. As bleeding starts, it does not run down the stem. It rather produces wet and soft spots which, at subsequent severe stages of attack, can be seen running downward on the lady palm trunk, turning it black, with an alcoholic smell of wine or beer. In lateral stages of trunk bleeding only stringy, fibrous tissues occur inside the hollow trunk, whereas bark is normal.

If the pathogen entered the plant through pruning cuts on leaves, the latter tend to die from oldest to younger. There is another special feature of *Thieleviopsis* fungus that it can move damage the upper trunk causing the crown to fall off (Chase and Broschat 1991).

14.2.2.3 Control

Prevention methods of disease spread should be followed to avoid infection in healthy lady palms. After confirmation all infected palms should be removed and destroyed, those in pots being replaced with healthy ones, after replacing the previously infected substrate with new and clean soil. It should be avoided to shift contaminated soil to other pots or move it close to equipment used for pruning, ploughing etc. The pruning equipment and tools should be properly disinfected with alcohol or chlorine bleach after cutting or pruning infected palms.

Thiphenate methyl and benomyl are important fungicides applied for chemical control of Thieleviopsis rot by curing lesions on stem and seedling infections. If plants are mature and uprooting an adult palm costs too much then the site of infection should be treated with an effective chemical slurry once in a month for a year, to kill and restrict the fungus (Meerow 1992; Garofalo and McMillan 2004).

14.2.3 Pseudocercospora Leaf Spot

14.2.3.1 Disease and Symptoms

The disease is characterized by minute, small circular spots less than 0.5 mm in diameter, with slight green to slightly chlorotic areas that begin to appear on leaves. The enlarged, circular to elliptic spots more than 0.88 mm long, appear along parallel veins. Mature leaf spots may be occasionally circular to elliptic, with a diameter of 6–12 mm. The spots frequently retain light green to chlorotic appearance, but few of them may develop dark to reddish brown or black flecks. Chlorotic areas eventually turn dark brown-black, than leading toward drying or death of infected leaf cells. Mature spots are slightly raised at the point of infection. Light infections covers small areas, however, heavy infections results in mosaic patterns.

14.2.3.2 Causes and Spread

Many fungal species are associated and isolated from infected leaves, but *Pseudocercospora rhapisicola* was isolated more frequently. The fungus is pathogenic on dwarf Rhapis. Healthy plants of dwarf Rhapis inoculated with a spore suspension of this fungus developed similar diseased symptoms as those visible in natural environments. Disease development is usually slow and humid conditions are essential for infection, as no disease occurs with a low humidity. Lesions development begins one month post-inoculation and typical lesion pattern can be observed after about 3 months. The disease can be easily distinguished from Rhapis necrosis (caused by *Phytopthora* spp.) by its slow progression. Under ideal environments, mature lesions develop fungal colonies producing conidia that spread to healthy plants via water splashes. Prolonged wet conditions are usually required by conidia to germinate and penetrate into the host tissues. The fungus multiplies within host tissues and results in the formation of visible leaf spots.

14.2.3.3 Control

The disease can be controlled by modifying environmental conditions and adopting good cultural practices. Removal of severely infected leaves of dwarf Rhapis palms significantly reduced the associated pathogenic fungi, followed by removal of spotted young leaves on maturity. After 1 year, newly emerged leaves were disease-free, clearly showing that removal of infected leaves, destruction of inoculum sources and reduction of free moisture from plant surfaces may disrupt the cyclic chain of events and ultimately control the disease. Removal of infected leaves followed by spray with mancozeb can efficiently control the disease. However, application of mancozeb under poor cultural and sanitation conditions will not reduce the disease incidence.

14.2.4 Stigmina Leaf Spot

The disease affects a variety of ornamental palms grown in Florida for their aesthetic value and unique appearance. Ornamental palms also undergo both biotic and abiotic stresses, some of which are of economic significance (Leahy 1988).

14.2.4.1 Causal Agent

Leaf spot caused by *Stigmina palmivora* is an important foliage disease of *Rhapis excelsa*. The fungus also causes frond necrosis in several palm species in Florida.

14.2.4.2 Symptoms

Symptoms of Stigmina leaf spot disease vary from host to host. Initial spots began as small dark circular-irregular water soaked lesions. As disease progress, the leaf spots are enclosed by a thin ring of dark tan necrotic tissues. Dark olivaceous to brown fungal proliferation can be seen easily with hand lens within the tan necrotic zones, on lower and upper leaf surfaces. The disease is most common on *Phoenix* spp. Formation of necrotic peripheral rings and dark water soaked centers are distinctive symptoms of *Stigmina palmivora*. Similar disease symptoms are produced also by some other leaf spot inducing fungi such as *Bipolaris* or *Cylindrocladium*, *Dreschslera* and *Exserohilum*.

14.2.4.3 Control

Like other leaf spot diseases proper air circulation, space, overhead irrigation and removal of plant leaf debris will not only limit the disease spread but also minimize the chances of stigmina leaf spot infection and severity. Iprodione, copper sulphate and Bordeaux mixture are fungicides registered against palm foliage diseases. Efficacy of these fungicides to control stigmina leaf spot was greatly enhanced when combined with good cultural practices. Benomyl is also registered against palms but its efficacy in controlling *S. palmivora* is debated.

14.2.4.4 Survey and Detection

The disease can be easily diagnosed by the formation on leaves of water soaked centers or peripheral tan necrotic rings. Under suitable natural conditions fungal growth can be seen on both sides of infected leaf tissues.

14.3 Fungal Diseases of *Caryota* spp.

14.3.1 Leaf Spot

Leaf spot diseases of *Caryota* spp., caused by various pathogens including *Fusarium, Pseudocercospora, Pestalotiopsis*, differ considerably according to susceptible host plant and causal agent. Leaf spot symptoms are characterized as dark brownish definite borders with reddish black, brown or black centers. In case of prolonged suitable environmental conditions the disease may become severe as the tiny spots merge together to form larger irregular spots, covering large area of the leaf blade. Some spots which are old or due to some other reasons of hypersensitive response, can drop off and give diseased leaf a shot holed appearance.

Leaf spot in most of cases is caused by fungal pathogens, such as *Bipolaris, Cercospora, Pestalotiopsis, Pestalotia* and *Pseudoperonospora*, that affec seedling and juvenile stages. These pathogens have a broad host range. Also some bacterial species of genera *Pseudomonas* and *Xanthomonas* may cause a leaf spot disease. The disease severity depends on the environmental conditions (humidity, temperature) and inoculum levels. Cool temperatures and high humidity favor the disease. The pathogens overwinter in fallen leaves and plant debris.

14.3.2 Symptoms and Morphological Features

Zhu et al. (2015) reported the symptoms caused by *Lasiodiplodia jatrophicola* in fishtail palm as small, initially chlorotic and light brown spots that become necrotic, latterly lesions as they mature, turning brown to black in color and forming large necrotic irregular patches, leading to the leaf death. On PDA the fungus colony color is white, turning into dark gray at maturity. Compact aerial, septate and branched mycelium is produced in colonies. After 30 days incubation pycnidia are produced, which are black in color. Conidia are initially hyaline, ellipsoidal to ovoid measuring 21.8–26.2 μm in length and 12.7–16.2 μm in width.

Mukhtar et al. (2019) described the leaf spot symptoms of fishtail palm caused by the fungus *Neodeightonia palmicola* as small irregular spots produced on the surface of leaves which turn into dark brown. Newly infected leaves are converted into pale brown color and irregular necrotic patches are produced which leads them to death. White color colonies are produced on PDA at 25 °C and mycelia are septate, branched and brown. Black pycnidia are produced on 30 days old culture. Conidia are dark brown, hyaline, ellipsoidal to ovoid measuring 17.5 to 24.5 × 9.5 to 12.5 μm.

Ashfaq et al. (2017) described brown leaf spot disease symptoms of fishtail palm caused by *Fusarium equiseti* as white margin, rounded brown necrotic spots produced on the surface of leaves. On PDA, the fungus produces a white dense mycelium colony which turns brown with time. Abundant, curved and septate macroconidia measuring 17.1 to 43.9 × 2.4 to 2.9 μm are produced, whereas microconidia are absent.

Identification of fungi has to be carried out on the basis of growth in laboratory cultures, studying morphological characters under the microscope at different magnifications (Leslie and Summerell 2006; Nag Raj 1993).

14.3.3 Prevention and Control

Fishtail leaf spot disease is managed by using different management techniques such as resistance, biocontrol agents i.e. *Trichoderma* spp., and fungicides.

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Part III
Fungal Diseases of False Palms

Chapter 15
Fungal Diseases of Traveler's Palm (*Ravenala madagascariensis*)

Rana Muhammad Sabir Tariq and Tanveer Ahmad

Abstract Ravenala palm (*Ravenala madagascariensis*) also known as Traveler's palm, is a tree native to Madagascar and a member of the monocotyledonous flowering plant family *Strelitziaceae.* This family is not in true sense a palm family, but they share some common characters with palms. Ravenala palm is preferred among ornamental perennials due to its aesthetic beauty. However, unlike other palms, it is susceptible to various pathogenic fungi that are cause of wilts, leaf spots and sooty blotches. This chapter will discuss the major fungal pathogens of Ravenala palm, their etiology and management strategies.

Keywords Ravenala · Traveler's palm · Pathogen · Fungi

15.1 Introduction

Strelitziaceae is a monocotyledon family, belonging to order Zingiberales (Kress 1990). *Strelitziaceae* are very similar with other related family members in terms of appearance and habitat. They can be recognized because of the broad leaves arranged vertically with transverse veins and colored inflorescences (Cron et al. 2012). This family was included into *Musaceae* because of similarities (Weberling 1989), but it is now recognized as a separate family.

Madagascar is composed of a multitude of natural environments having a remarkable wealth in terms of vegetation and endemic species. It is known to form typical vegetation called "Ravenala forest" because of its vast quantity. Known as monospecific, *Ravenala madagascariensis* is a complex aggregate of four recognized varieties. In eastern Madagascar, every single variety of *Ravenala* are well represented in the Ambalabe community. Three varieties match the recognized

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_15

vernacular names cited by Blanc et al. (2003) as: (i) Hirana (used to be called Menahirana as “mena” means red and hirana means fringes, and recognized by the red fringes sheath); (ii) Bemavo (in Betsimisaraka language, it means “many” and mavo means “gray”; it can be recognized be the gray powder along the sheath); and (iii) Horonorona (from the cespitose habit representing the name). While Bemavo and Horonorona are only encountered outside the Vohibe forest, Hirana variety occurs both inside and outside the forest. The fourth variety, called Menafalaka (in Malagasy language “mena” means red and “falaka” means sheath), only occurs inside the forest. Other than ornamental function, these trees serve for multiple purposes (Hladik et al. 2002; Razanamparany et al. 2005; Nambena 2004). The local population in the Ambalabe community uses all four varieties.

Ravenala madagascariensis is locally known as Fontsy in Madagascar. It is used as animal food, medicine, human food, house building, tools, utensils, environmental purposes, and other uses. Local people use all parts of the *Ravenala* tree. Ovitra, the heart of *Ravenala*, is eaten since it is edible while Bemavo is more preferred because it is sweeter than Hirana, that is slightly bitter. During a “starvation period”, *Ravenala* is consumed and the heart of the plant can be used as fodder. Flattened pieces of the trunk are widely used for floor in construction. Since Bemavo has the biggest trunk, it is preferred than others. In terms of roofs, Horonorona is widely used since it is more durable and can also be used for ropes.

15.2 Economic Value of Traveler’s Palm

Bemavo and Horonorona have economic value since both can be encountered outside the forest, making them more easily accessible. The uses of plants inside the forest is strictly regulated by community rules. For house construction with, beehives and ferment, they need authorization by the president of a local community-based regulation committee (locally called Vondron’Olona Ifotony or VOI), in charge of regulating the use of forest products. This practice is mostly limited to the traditional uses.

A payment must be done if the trees are for personal usage. The authorization will last for 3 months and can be renewed after. The trees cannot be sold since permit is intended for personal use only. In the market, leaves, petioles, and trunk from Horonorona and Bemavo are sold. Ravenala is still used by locals even when they are aware of the material’s short life span because of culture. It is used for house buildings as the primary materials in the Betsimisaraka tribe.

The locals do not have knowledge about how to create bricks, making the plant widely used because it is a preferred, easy material allowing fast constructions. Cyclones damage the area quite frequently (ONE 2009) making plants more meaningful than bricks. The other advantage of Ravenala is that it is a less expensive and renewable material, allowing direct harvest by locals.

The raw materials such as leaves and stem can be sold to people who need them but are unable to collect the materials. The handicrafts, such as winnowing trays or baskets, are also sold in local markets. Unfortunately, in present scenario it is very difficult to find mature trees because of the slash and burn cultivation that is still commonly practiced in this area (Aubert et al. 2003; Ramamonjisoa et al. 2003). The trees take 15–20 years to grow. But people tend to use less mature trees, making them do not last for long. This could lead to more usage of *Ravenala* and price fluctuations. To address the issue, some management practices are implemented. For instance, Ravenala trees less than 1 m in height cannot be used for logging.

15.3 Fungal Pathogens of Ravenala

15.3.1 Sooty Blotch and Flyspeck (SBFS)

Sooty blotch and flyspeck (SBFS) are epiphytes that colonize the waxy cuticle of a wide range of plants in humid regions, worldwide. They generally cause black or sooty appearance on cuticle that leads to a cosmetic damage (Batzer et al. 2008). This is, hence, more important in case of ornamental plants. For approximately 70 years, this disease was considered as involving two distinct species, but recent morphological and genetic analyses showed that SBFS disease is caused by more than 80 fungal species (Batzer et al. 2008; Frank et al. 2010; Li et al. 2010; Yang et al. 2010).

15.3.1.1 Etiology

SBFS in Ravenala palm is caused by *Ramichloridium strelitziae*. This fungus was first identified from infected stems of the Ravenala palm in China. The identification was based upon morphological and phylogenetic analysis of the ITS region (Hao et al. 2013).

15.3.1.2 Incidence

SBFS occurs during moist growing seasons. It grows over the surfaces of stems, twigs, leaves, and fruit of the host plants. It can cause an economic damage as much as 90%. This disease has been reported on many hosts, including apple, pear, persimmon, banana, orange, papaya, and several other cultivated tree and vine crops (Gold and Sutton 1986, 1988).

15.3.1.3 Taxonomic and Geographical Diversity of SBFS Complex

SBFS are hard to isolate for many generations. They grow slowly but easily overgrow on agar media. Colony morphology can differ radically on agar media than on fruit. Other aspects that can effect the morphology are the pH, source of nutrients and light source.

Initially, the SBFS complex was classified as caused by two species (Colby 1920), *Gleodes pomigena* causing the 'sooty blotch' on fruit, while *Schizothyrium pomi* (Von Arx 1959) with the presumed anamorph *Zygophiala jamaicensis* (Durbin et al. 1953), was the main suspect behind the cause of the "flyspeck" morphological type (a group of small, black spots). It was later recognized that the sooty blotch and the flyspeck were different pathologies caused by the same agent, as recorded in the scientific literature for almost 80 years (Jones and Aldwinckle 1990; Williamson and Sutton 2000). When the molecular analyses were applied, a broader image was shown. Two surveys, from 39 apple orchards from over 14 eastern U.S states, showed that SBFS included around 60 putative species (Batzer et al. 2008; Díaz Arias et al. 2010), with a huge leap since 1997, when it was considered to be caused by four species only.

Some of the species distribution on the biogeographic patterns are coming into focus. For instance, a survey carried out in China, especially in Henan, Liaoning, Gansu, and Shaanxi provinces revealed six *Zygophiala* spp., showing that the distribution of the species may differ based on the region of study (Li et al. 2010). Another example is the flyspeck fungus *S. pomi* that is common in Serbia, Germany, and US but could not be found in China (Ivanović et al. 2010; Li et al. 2010). *Peltaster fructicola, Microcyclospora malicola, Microcyclosporella mali* and putative species *Microcyclosporella* sp. RH1 could be found in German, Serbia, Montenegro, and US. Five out of 14 species found in Serbia and Montenegro could also be found in the US (Ivanović et al. 2010; Diaz et al. 2010).

15.3.1.4 Epidemiology

The time elapsed between appearance of SBFS colonies and the inoculation could differ from only a few weeks up to months. The incubation period in Poland was 29–45 days (Wrona and Grabowski 2004), and in Brazil up to 48 days (Spólti 2009). When 100% humidity level is introduced in the chambers, harvested apples produced SBFS signs sooner than the fruit left on tree (Rosenberger et al. 2002). This backed up the idea that environment is also a decisive factor in the timing of sign appearance. Apple cultivars that mature in summer could be safe from SBFS damage (Biggs et al. 2010), might be due to the insufficient time to develop the visible colonies (Biggs et al. 2010; Mayr et al. 2010).

In vitro studies showed that the disease progression is based on temperature (Batzer et al. 2010). Among five SBFS species, *Dissoconium* sp. DS1showed the fastest mycelial growth rate at 10 °C and the largest increase in colonies number, during storage at 4 °C (Sisson et al. 2008).

15.3.1.5 Sources of Inoculum for Orchard Infections

SBFS fungi affect the epicuticular wax layer. This happen on many species of trees, shrubs, and vines, as on several cultivated fruit crops (Baker et al. 1977; Hickey 1960; Johnson et al. 1997; Nasu et al. 1985). They might affect alternative plant species in poorly managed orchards. In spring, air temperature is the major factor determining the disease development (Williamson and Sutton 2000.) Molecular & genetic analysis have further allowed to explore host range, and also revealing the identity of cryptic species.

15.3.1.6 Management

On fruit crops, apart of using scab-resistant cultivars in organic orchards, fungicides are also required to be used during the summer to reduce the SBFS damage on a certain schedule (Tarnowski et al. 2003). In the USA, since 2000 the fungicides must be selected carefully corresponding to the SBFS causal agents, due to the registration withdrawl of ethylene bis-dithiocarbamate (EBDC) in 1989, for mid to late seasons (Williamson and Sutton 2000).

The strobilurin fungicides kresoxim-methyl and trifloxystrobin played a big role in controlling SBFS in the USA, with the same effect as existing standard treatments with captan, in addition to thiophanate-methyl (Babadoost et al. 2004; Rosenberger et al. 2002). Strobilurins might develop resistance due to specific action and their usage is now limited for use in consecutive seasons. Compared to EBDCs, captan, or thiophanate-methyl, strobilurins are also more expensive and so persuade growers to selectively use fungicides.

Effective organic methods especially regarding SBFS management are now growing intensively. On the other hand, K bicarbonate and other formulations are approved as organic fungicides in USA. These formulations gave a certain control of SBFS at 2-week intervals but, unfortunately, conventional fungicides are more effective than these formulations (Babadoost et al. 2004). A different formulation of K bicarbonate fungicide is also used in Switzerland, applied at 2-week intervals. The result was superior that the formulation used in the USA and also superior to the coconut soap commercial formulation (Tamm et al. 2006).

Other formulations using phosphates and Ca chloride gave excellent results regarding SBFS control when mixed with captan (Cooley et al. 2007; Rosenberger et al. 2002; Sutton et al. 2006, 2007). In conclusion, summer fungicide sprays give a better result compared to the dormant season. SBFS could be suppressed effectively using a formulation of K bicarbonate in addition to wettable sulfur, or of K carbonate (Mayr et al. 2010).

15.3.2 Leaf Spots

Palms are often affected by many leaf spot fungi. The disease causes cosmetic and economic losses in the ornamental plant industry. Leaf spots can be round to elongated, brown, and may be oily in appearance. It is difficult to distinguish leaf spot fungi by visual symptoms alone, as they are the result of infection by many fungal pathogens, with almost the same symptoms.

15.3.2.1 Fungal Pathogens

Potential causes of fungal leaf spots include *Bipolaris*, *Annelophora*, *Colletotrichum*, *Cercospora*, *Calonectria* (*Cylindrocladium*), *Gliocladium*, *Exererohilum*, *Pestalotiopsis*, *Phoeotrichoconis*, *Phyllachora*, *Pestalotia*, *Stigmina*, and *Pseudocercospora*. Diseases caused by these pathogens are transmitted through spores, which are easily transmitted by wind and water (rainfall or high irrigation) (Elliott 2005). However, there is a significant number of leaf spot fungus solely infecting *Ravenala madagascariensis* (Table 15.1).

15.3.2.2 Host

Almost all palms species, including Ravenala palms, are infected by fungal leaf spot disease. The host range for the pathogens mentioned above is considered to be broad within palms, and each species may be vulnerable to at least one of these pathogens.

15.3.2.3 Symptoms

Disease symptoms can appear on leaf blade (leaflets or leaf segments) as well as petiole and rachis. Infection starts as small yellow spots that turn brown-black later. If the infection does not indicate a systemic spread, the spots size usually are restricted to 6 mm (1/4 inch) in size. Under conducive conditions, these spots

Table 15.1 Fungal leaf spot of *Ravenala madagascariensis*[*]

Pathogen	Location	Reference
Alternaria spp.	**USA, Venezuela**	Alfieri et al. (1984) and Urtiaga (2004)
Curvularia lunata	**USA**	Alfieri et al. (1984)
Helminthosporium sp.	Mauritius	Orieux and Felix (1968)
Pestalotiopsis menezesiana	**China**	Zhang et al. (2003) and Ge et al. (2009)
Pestalotiopsis sp.	Myanmar	Thaung (2008)
Pestalotiopsis sp.	Venezuela	Urtiaga (2004)
Septoria sp.	Mauritius	Orieux and Felix (1968) and Wiehe (1948)

increase in size and number, later they merge (coalesce) to form a leaf blight or rachis blight. Sometimes the spots turn into grayish, outlined in black. The same type of lesions may even be seen on leaf spines (in spiny species). Young plants are most affected as compared to the older ones. Rachis and petiole blight due to *Pestalotia palmarum* are more injurious, as they can invade the vascular system, usually leading to the death of the young plants.

15.3.2.4 Management

Leaf spot fungi produce abundant spores that can be dispersed easily through wind and rain. Sanitation is hence the foremost protection advise for growers. As mentioned earlier, mechanical injuries are the soft corners for the infestation, hence care should be taken while performing the field operations. Pruning may be followed by spraying with a broad spectrum protective fungicide. Water management is also required to limit high humidity, particularly during winter seasons. Adequate plant spacing will decrease the leaf wetness by increasing the air circulation. Diseased leaves should be pruned and rouged well. Young infected plants with few leaves may be completely destroyed.

Developing an appropriate management strategy is essential in order to ensure the proper growth of palms without getting infected by pathogens that cause diseases like leaf spots. The best strategy to deal with these diseases is a comprehensive approach that combines prevention, exclusion, hygiene, with proper species selection and care. Good palm nutrition and preventing injuries is part of an overall management strategy, followed by sanitation and water management.

Seedlings in the nursery are more susceptible to leaf diseases, as hundreds of palms in the nursery are closely aligned. This condition locally increases the humidity and also the transfer of pathogens from infected plants to healthy ones, by reducing the distance required for spores to spread to new hosts. Therefore, increasing the distance within plants will improve their health by reducing the likelihood of infection. Regulardisease monitoring is also valuable because it spreads rapidly. It is important to notice early symptoms as soon as possible to limit the disease spread to other plants. Other methods of limiting humidity and moisture concern irrigation in the early morning, avoiding overhead irrigation and wetting leaves at night, when palms are growing in covered greenhouses.

Fungicides should not be used alone as a management tool. They should always be used as integrated control with other cultural methods of disease control. After removing the diseased palm or leaf tissues, a fungicide should be, applied to the palm. Even if a systemic fungicide is used, the product should be spread evenly on the leaf tissue (Elliott 2005).

15.3.3 Fusarium Wilt of Ravenala Palm

Fusarium wilt was reported in Ravenala palm in USA (Alfieri et al. 1984) and Papua New Guinea (Shaw 1984), and is caused by *Fusarium solani* (Alfieri et al. 1984; Shaw 1984).

15.3.3.1 Symptoms

There have been little details about symptomology of Fusarium wilts particularly over Ravenala palms. However, general symptoms of Fusarium wilts in the palms are due to the fungus blocking the vascular system of the host plant. Vascular clogging affects the water transport in the plant, inducing yellowing of younger leaves and dead leaflets which start on one side of the leaf blade. The disease normally progresses starting from the lower leaves and eventually moving upwards, killing all leaves. The internal stem tissue is stained reddish-brown when viewed in a cross section (Lester 2015).

15.3.3.2 Management

Management of *Fusarium solani has been proposed in literature. However, the most recent successful control of this pathogen has been reported in the Arecaceae family under greenhouse conditions. It was also indicated that most of the in vitro methods may not indicate consistent results in controlled conditions. Some fungicide treatments, however, were equally effective in vitro* as well as *in vivo*. Initially, Cidely® Top (difenoconazole and cyflufenamid) fungicide successfully provided *in vitro* inhibition of *F. solani* at 250 ppm up to 79.5–96.3%. This effect was later also found in a pot assay. The fungicide induced septal malformations and cytoplasmic coagulation in the *F. solani* hyphae, with conidial deformation (Alwahshi et al. 2019). Moreover, also Propizol© has been released in the USA as a broad-spectrum fungicide for the control of wilt diseases in ornamental palms.

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Chapter 16
Fungal Diseases of Kangi Palm (*Cycas revoluta*)

Anjum Faraz, Muhammad Zunair Latif, and Owais Yaseen

Abstract Cycas is the only genus in family Cycadaceae, comprising of about 100 species. Among them, *Cycas revoluta*, also known as kangi or sago palm, is a highly valued landscape palm, and a popular ornamental of interiorscape. *Alternaria* leaf spot, *Phoma* leaf necrosis or blight, *Fusarium* ovule rot and declines are most common fungal diseases of this palm, with an economic significance. Local environmental conditions determine the nature and frequency of these diseases and effective management requires knowledge of host, pathogen, environment and their interactions. In this chapter, we discuss fungal diseases of high economic impact of *C. revoluta*. We explore some mechanisms of the complex interactions of host-pathogen(s). Finally, various disease controlling strategies focusing on plant nutrition, cultural, antagonistic and chemical management are briefly described.

Keywords Sago palm · Foliage diseases · Alternaria leaf spot · Leaf necrosis · Phoma blight · Fusarium declines · Control strategies

16.1 Introduction

Cycas are gymnosperms belonging to the family Cycadaceae, that is comprised of only a single genus (Stevenson 1992). This is not a true palm family, but and is comprised of about 100 species that are native to China, Japan, India and Australian regions. The genus also occurs in USA, particularly in Georgia, Florida, California and Puerto Rico, as well as in Madagascar, East Africa, Japan, Malaysia, Micronesia and Polynesia (Lindstrom and Hill 2007; Northrop et al. 2010). The species name "*revoluta*" was derived from the Latin "revolutus" that means rolled back, due to its curled leaflets. *Cycas revoluta* is has also known as Sago Palm, King Sago Palm, Japanese Sago Palm. In Pakistan it is locally known as Kangi palm. It is a highly

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I. Ul Haq, S. Ijaz (eds.), *Etiology and Integrated Management of Economically Important Fungal Diseases of Ornamental Palms*, Sustainability in Plant and Crop Protection 16, https://doi.org/10.1007/978-3-030-56330-1_16

valued landscape and most popular ornamental palm of interiorscape (Lim 2012). Edible starch called "sago" is derived from these plants, which are used as food source particularly in New Guinea. *Cycas revoluta* grows well in full sunshine or partial shade. It is a slow growing palm and can attain height of about 5 m (15) feet in 50 years. Leaves are compound, pinnate, 1.2–1.5 m (4–5 feet) long and 22–24 cm (9 inches) wide. Leaflets are dark green with shiny appearance, 10 cm (4 inches) long, curled under margins and have pointed tips, used for floral decoration. The trunk is thick, dark brown and appears shaggy. Reproductive structures (cones) develop in the centre of the plant in spring to summer, and plants are dioecious (may be either male or female). Male reproductive structures are a large yellow cone having a length of up to 60 cm (2 feet), while female parts resemble a yellow furry globe, bearing bright red-orange seeds having a diameter of 5 cm (2 inches) and 3.7 (1.5 inches) long (Northrop et al. 2010). The flowers are naturally pollinated by wind. Pollens are viable for 4–10 days. Propagation is mostly through seeds, suckers and cuttings. Economically important fungal diseases of Kangi palm (*Cycas revoluta*) are:

1. Alternaria leaf spots (Upadhyaya and Gupta 2014);
2. Leaf necrosis or blight of *Cycas revoluta* (Weber 1944; Lazarevic 2009; Nayab and Akhtar 2016);
3. Fusarium ovule rot (Prasad et al. 1992);
4. Fusarium decline (Polizzi and Grasso 1994).

16.2 Alternaria Leaf Spot of Cycas revoluta

This is considered an important diseases of *C. revoluta*, first described in India in 2014. The fungus particularly attacks foliar leaflets. The disease is of immense importance as *C. revoluta* is particularly cultivated for floral decoration (Upadhyaya and Gupta 2014). Leaf spots and leaf blights are generally considered as minor diseases of ornamental palms, but in recent years they emerged as major problems for nursery growers, becoming a major hindrance in commercial marketing of nursery palms. Such kinds of diseases are capable to infect seedlings and mature stages, however juvenile plants are considered as more vulnerable. Leaf spots incited by *Alternaria* spp. rarely kill plants, but significantly reduce their aesthetic quality as well as commercial value.

16.2.1 Pathogen

The genus *Alternaria*, with *A. tenuis* as type species, was established in 1817 (type species was later re-named as *A. alternata* in 1912). The genus belongs to order Hypomycetes and family Dematiaceae (Rotem 1994). This ubiquitous fungal genus is comprised of endophytic, saprotrophs, human and plant pathogenic species (Pegg et al. 2014). Many *Alternaria* spp. are common saprotrophs that feed on dead organic matter, while others infect only weakened or stressed plants. Other species are destructive plant pathogens, some of which produce toxins. They are associated with a wide variety of substrates, including seeds, plants, agricultural products, animals, soil and atmosphere. These fungi can infect plant parts such as seeds, leaves, stems, flowers and fruits causing great losses in agricultural productions, either by infecting fruits or by impairing the plant photosynthetic capacity. Being seed-borne, the fungus may cause collar rot, stem lesions and damping off (Choi et al. 2010; Qiang et al. 2010; Harteveld et al. 2013). *Alternaria* spp. have a worldwide distribution and can proliferate under various environment(s). *Alternaria alternata* emerged as a human pathogen particularly in immune compromised patients. It is diversified fungal pathogen that can incite leaf spots, leaf blights, stem end rots, black rots and fruit rots (Michailides 2002; Wang and Chen 2010; Amin et al. 2011; Suwannarach et al. 2015). *Pleospora* is the known sexual stage of this fungus, but most species lack sexual stages altogether. *Alternaria* spp. are considered among hardy fungi that can survive in extreme conditions. *Alternaria alternata can overwinter in soil, seeds, crop* residues, bark, nodes or scaly leaves as dormant mycelia or conidia. The fungus produces numerous conidia on dead organic matter and their dispersal is associated with wind or water splashes. Sporulation is facilitated by high relative humidity and free moisture, and is triggered usually by external stimuli. In most cases, a minimum of 3–72 h wetting period is required for the successful establishment of most species. *Alternaria* spp. can germinate at different temperatures depending upon the host. In general, most species require an optimum temperature of 25 °C. However, with decline in temperature, a longer wetness period is needed (Rotem 1994). Pure colonies of the fungus are lettuce to olivacious green and have prominent white margins. The fungus can be distinguished by chains of conidia usually 6–14 in a primary chain and 2–8 in secondary and tertiary chains. Small sized conidia (20–50 μm long) are characteristic of *A. alternata*. They are ovate, beaked, with multiple cells, showing transverse and vertical walls (Upadhyaya and Gupta 2014). *Alternaria* species are destructive plant pathogens, causing economic impact and losses on a wide range of agronomic host crops (Pegg et al. 2014). *Alternaria alternata* is dominant and most common species of the genus cause leaf spots and leaf blights on ornamental plants, fruits and vegetables. There are about 4000 host associations for this single genus (Simmons 2007; Saharan et al. 2016). *Antirrhinum*, *Asclepias*, *Ficus*, apple, *Acacia*, *Chrysanthemum*, *Hedera*, *Petunia*, *Callistephus*, *Helianthus*, *Oenothera*, passionfruit, geraniums, *Dahlia*, *Hibiscus*, litchi, pelargonium, zinnia, citrus, date palm and fish tail palm are among most common ornamental host plants affected by *Alternaria* spp. (Pegg et al. 2014).

16.2.2 Disease Cycle

The *Alternaria* spp. inoculum is always present throughout the year in the atmosphere. The fungus overwinters as spores, mycelium or other surviving propagules in soil, on seeds and infected plant parts. It proliferates and sporulates on crop residues during periods of heavy dew, rainy seasons and soil moisture. In spring, these spores are transported to the lower leaves through splashing rain, wind or contact with the infested soil. Spore dissemination is accompanied by wind, water, contaminated tools and animals. They are usually wind-blown or water splashed, and free moisture is required for sporulation and infection. Short distance dispersal of airborne conidia may be at least up to 20 m (Bashan et al. 1991). The fungus can penetrate into the host tissues directly, through wounds or stomata. Mature conidia from the surface of fungal leaf spot provide inoculum for secondary infection and are transmitted to healthy plants by means of wind or water splashes. Older, stressed or weak tissues show greater vulnerability to infection as compared to healthy ones. The fungus survives in susceptible weeds or perennial plants between growing seasons. This sequence of events continues throughout the season as long as a favorable environment prevails (Pegg et al. 2014).

16.2.3 Epidemiology

Temperature range of 25–28 °C and high relatively humidity, usually up to 90%, favor symptoms and disease development. Heavy dew and rains also favor disease development (Pegg et al. 2014).

16.2.4 Symptoms

Alternaria generally attacks aerial parts, primarily foliar leaflets. Foliar symptoms appearing 8–10 days after infection, are small, circular, light to dark brown spots that may show a yellow halo. The spots enlarge and become lesions. Older lesions are round to irregular lyto elliptic, with a diameter of 1–4 mm. In acute infections the central necrotic portion of these lesions may fall off leaving an empty area similar to a shot hole. The lesions are more common on leaflet margins, but may occur on the leaf blade or petiole. In advanced stages of the disease the leaf lesions turn blighted (Upadhyaya and Gupta 2014; Suwannarach et al. 2015). However, the fungus does not have uniform growth patterns due to changes in the surrounding environment, thus it develops concentric rings in a target pattern. Lesions on leaves may be covered with a fine, blackish fuzzy or velvet fungal growth (Laemmlen 2002).

16.2.5 Cultural Practices

Integration of cultural, nutritional, biological, host resistance and chemical control strategies can be effective to control Alternaria leaf spot diseases. Among cultural practices soil moisture plays a significant role as *Alternaria* spp. are greatly affected by water deficiency and abundance. Crop rotation following non-host crops can be a promising tool in reducing inoculum pressure for primary infection. Destruction of plant debris and elimination of susceptible weeds are helpful in reducing the inoculum pressure and latent infections. Pruning of infected leaves, twigs and shoots will minimize inoculum build up. Avoiding injuries during pruning operations will prevent entry of the fungus through wounded sites. Surface disinfection of pruning tools with chemicals will minimize the chances of disease spread via contaminated pruning tools. *Alternaria* species require UV light for spore formation, so use of UV light absorbing films in greenhouse conditions will be helpful to reduce disease incidence.

Nursery and greenhouse sanitation is essential for effective disease management. Avoiding overhead irrigation, particularly at night times, may help in management, and watering should be practiced during sunshine hours. Leaf wetness periods may be reduced by proper air circulation and thinning plant canopy.

Soil and plant nutrition represent another important factor in the development of *Alternaria* infections, so nutrients management can play a key role in controlling leaf spot. Aerial application of Ca compounds significantly reduced disease in apple crops (Yoon et al. 1989). K deficient cotton plants showed greater susceptibility to *A. alternata* (Wright 1998). Potato plants deficient in N showed greater severity of early blight (MacDonald et al. 2007). In conclusion, proper nutrient, water and temperature management will minimize chances of stress that could ultimately be helpful in disease prevention.

16.2.6 Biocontrol

Trichderma viridae has an antagonistic potential against leaf spot and leaf blight caused by *A. alternata* (Gadhi et al. 2018; Khan et al. 2019). *Trichoderma harzianum* lowered Alternaria leaf spot disease severity up to 10% in field conditions (Viriyasuthee et al. 2019). *Trichderma viridae* followed by *T. harzianum* were effective against *A. alternata* leaf spot (Pandey et al. 2019). Foliar application of *T. asperellum (10*^{8} spores/mL) was very helpful in suppressing leaf spot disease symptoms (Ghosh et al. 2018).

Two bacterial strains of *Burkholderia cenocepacia* (VBC7) and *Pseudomonas poae* (VBK1) inhibited *A. alternata* growth both in controlled and greenhouse experiments (Ghosh et al. 2016). Strains of *Pseudomonas* fluorescens and *Bacillus subtilis* may act as potential biocontrol agents of *A. alternata*. Combined treatment of *Brevibacillus formosus* and *Brevibacillus brevis* significantly reduced brown leaf spot disease incited by *A. alternata* (Ahmed 2017). *Bacillus* pumilus, *B. subtilis*, *B. megaterium* and *T. harzianum* were also effective biocontrol agents of *A. alternata* and should be evaluated in field conditions (Tozlu et al. 2018). Essential oils of sesame followed by coconut, henna, mint, black seed, jasmine, clove, castor and neem can also inhibit the mycelial growth of the *A. alternata* (Gadhi et al. 2018).

16.2.7 Chemical Control

Antrcol and Cabriotop are effective fungicides against *A. alternata*. On the other hand Topsin-M and Alliette were effective in minimizing the incidence of leaf spot disease of grapes caused by this fungus (Khan et al. 2019). Cu- based chemicals, triazole, mancozeb and dicarboximide showed promising effects versus Alternaria brown spot disease of citrus (Vicent et al. 2007). Application of protectant fungicides such as chlorothalonil and iprodine can prevent primary infection. Chlorothalonil, imazalil, thiram, iprodione, mancozeb, maneb, captan, fludioxonil and Cu-based fungicides showed great efficacy against *Alternaria* spp. (Pegg et al. 2014). Amistar and Score were effective in inhibiting spore germination even at low concentrations as well as disease intensity of Alternaria leaf spot disease of *Aloe vera*, under local field conditions (Sharma and Amrate 2009). Fungicides such as Bavistin, Indofil, Thiram, M-45, Chlorothalonil and Vitavax completely inhibited *A. alternata* growth while Indofil M-45 was most effective against leaf spot disease, in pot and field experiments (Pandey et al. 2019).

16.3 Leaf Necrosis or Blight of *Cycas revoluta*

In the early 1900's a foliage unknown disease, usually resulting in rapid and widespread destruction of the pinnae or leaflets at their early development stage, was frequently observed on cycads for about 20 years in Florida, and particularly at Gainesville. The disease was named "blight". Among cycads, *Cycas revoluta* and *C. circinalis* were found to be susceptible to this blight disease. Weber (1944) reported that diseased individuals were found in several towns in Florida, (Pensacola, Lake city, Jacksonville, Thallahassee, Live Oak, Palm Beach, Sebring, Okeechobee Sarasota and Fort Myers). The disease became, year by year, increasingly severe and greatly reduced ornamental value of *C. revoluta* in its growing regions. It usually resulted in the removal of the cycads from landscape areas because of their unpleasant appearance and eventual death. A similar disease, named leaflets blight or dieback disease of *C. revoluta*, was reported from the Montenegro coast as well as in Belgrade (Serbia) on potted plants (Lazarevic 2009). In Pakistan, during 2014, *C. revoluta* trees were found to be affected with a similar symptomology and the disease was termed "leaf necrosis".

16.3.1 Pathogen Biology, Ecology and Host

Two Phoma species named *P. herbarum* and *P. glomerata* were identified as the etiological agent of leaf necrosis or blight disease of *C. revoluta*. *Phoma* blight can be a serious disease in nurseries or open fields where plants are closely grown. The genus *Phoma* was initially considered as a stem pathogen, but today it is comprised of opportunists, saprotrophs and pathogens. *Phoma* is taxonomically a controversial genus comprised of over 220 known species, found throughout the world in different ecological niches. In spite of having several saprotrophic and endophytic species, many *Phoma* spp. are imperative plant pathogens and few are pathogenic to humans and animals (Hoog et al. 2000; Balis et al. 2006). Most *Phoma* spp. colonise plant materials, some are associated with decaying leaves and wood, and others are opportunistic secondary invaders of plant tissues. However, more than 110 *Phoma* spp. are primary plant pathogens, causing significant crop losses. *Phoma herbarum* and *P. glomerata* are more ubiquitous and play an important role in organic degradation. They are common soil inhabitants or may be isolated from dying or dead plants or plant parts as parasites (Balis et al. 2006; Aveskamp et al. 2008).

Phoma anamorphs represent a polyphyletic group that has teleomophic relations with other genera. They cause root infections, leaf spots and blotches (Banerjee and Nath 2017). Single celled spore masses, usually known as pycnidiospores, are developed in pycnidia. However, cultural morphology of *Phoma* spp. may vary due to fluctuation in environmental conditions (Rajak and Rai 1983). *Phoma* spp. are also famous for the production of dyes and antibiotics. Fiji Island fan and Palmyra palms (El-Deeb et al. 2016), date palm (Abbas et al. 1991) and *Rhapis excelsa* (McKirdy et al. 1996) are other important host palms also affected by *Phoma* spp (Kliejunas et al. 1985).

16.3.2 Symptoms

The necrotic leaf tissues is extensively colonized by *Phoma spp.* Initial symptoms usually appear as typical leaf spots on lower to middle leaves. Infected plants exhibit small circular brown spots enclosed with yellow margins, covering almost 30% of leaf area along with marginal necrosis. The spots, ranging around 1–3 mm in size, usually mergeat maturity forming larger necrotic areas (Nayab and Akhtar 2016). In severe conditions the infected leaves eventually turn blighted with a burning appearance. The necrotic tissues are colonized by the fungal growth. The blighted leaves develop small, light to dark brown or black spots (pycnidia) that can be seen with a hand lens. The infected plants began to dieback and eventually die (Weber 1944; McKirdy et al. 1996; Lazarevic 2009; Nayab and Akhtar 2016; Banerjee and Nath 2017).

16.4 Fusarium Ovule Rot

During 1986, female plants of *C. revoluta* in the vicinity of Hardwar, Northern India, showed diseased ovules infected with a rot, during the months of November and December. The disease was also observed during 1987–89 resulting in a 60–70% prevalence. Infected ovules develop light to dark brown areas covered with a necrotic dry rot. Two isolates of *Fusarium moniliforme* were successfully recovered from the infected tissues. Self-inoculated plants of *C. revoluta* develop similar symptoms, thus confirming the isolates pathogenesis.

16.5 Fusarium Decline

Fusarium decline of *C. revoluta* characterized by a root rot and leaf wilting was reported from Sicily (Italy). *Fusarium solani* was frequently isolated from infected root tissues and basal stems. Pathogenicity tests, performed on *C. revoluta* seedlings, produced similar symptoms as those observed in natural infections, thus in the light of fungal identification and Koch's postulates *F. solani* was declared as the tiological cause of *C. revoluta* decline in Sicily (Polizzi and Grasso 1994).

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Index

A
Abiotic, 7, 86, 100, 146, 245
Acclimatization, 75
Acervuli, 212
Acetobacter, 187
Acholeplasma, 92
Acidovorax, 128
Acoelorraphe, 66
Acremonium, 178
Acrocomia, 94
Actinomycetes, 176
Aculeata, 94
Acuminata, 45
Acute, 268
Adaxially, 204
Adonidia, 96
Aerate, 22, 150, 187
Aeration, 117, 152, 230
Aerial, 44, 118, 179, 208, 247, 268, 269
Aesthetic, v, 5, 6, 19, 23, 44, 47, 48, 51, 57, 62–64, 86, 125, 126, 204, 242, 245, 266
Aetiological, 100
Agaricomycetes, 102
Agarose, 98
Agriculture, 5, 103
Agro-climatic, 27
Agronomic, 5, 183, 240, 267
Agro-systems, 207
Ailments, 49, 58
Aiphanes, 93
Airborne, 224
Airflows, 90, 135
Albedinis, 87, 144, 172–174, 176
Aleuroconidia, 178
Alkaloids, 14, 17, 23, 56, 58
Alternaria, 172, 184, 187, 241, 266–270
Amplification, 92, 97, 98
Analogous, 100
Anamorph, 89, 90, 145, 210, 256
Anatomy, 127
Angiosperm, 9, 198
Anilinopyrimidines, 208
Annellophora, 90, 127, 151
Antagonistic, 143, 269
Anthracnose, 199
Antibiosis, 176
Antibiotics, 101, 208, 227, 238, 271
Antibioticus, 144
Anti-diabetic, 14
Antihypertensive, 13
Anti-inflammatory, 23, 55
Antimicrobial, 23
Antioxidant, 22, 52, 56
Antiseptic, 64
Aphanidermatum, 144
Aphids, 138
Apical, 8, 10, 74, 95, 98, 103, 127, 128, 142, 146, 172, 174, 181–185, 205, 212, 227, 233, 240, 242
Appendages, 212, 240–242
Appendiculatus, 143
Arabidopsis, 208
Arborescent, 94
Archontophoenix, 32, 33, 43, 45, 46, 66, 86, 146, 197–200
Arecaceae, v, 8, 31, 41–43, 48, 52, 65, 73, 75, 94, 160, 198, 237
Areca-palm, 13–14, 57, 89, 150
Arenaria, 93
Arthroconidia, 179

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Ascomycota, 121, 136, 164, 223
Ascospore, 90
Ascus, 145
Aseptate, 210
Aseptic, 242
Asexual, 75, 89, 90, 105, 128, 136, 145, 174, 205, 210
Aspargaceae, 28
Aspergillus, 172, 176, 187, 241
Atrophy, 121
Attenuata, 94
Aureobasidium, 208
Aureus, 238
Australasia, 42
Auxiliary, 223
Axillary, 55

B
Bacillus, 176, 211, 214, 269, 270
Barcode, 42, 43
Barcoding, 42
Basal, 12, 48, 49, 58, 95, 98, 100, 119, 131–133, 143, 144, 238, 272
Basidiocarp, 102, 103, 120, 132, 153, 154, 162–164, 231, 232
Basidiomycota, 102, 119
Basidiospores, 103, 120, 132, 163, 164, 232
Bavistin, 88, 214, 270
Beauvericin, 88
Belmoreana, 89, 94
Benomyl, 137, 178, 214, 244, 246
Beta-sitosterol, 64
Bicellular, 174
Biflagellate, 155
Biocontrol, 137, 143, 144, 176, 211, 214, 247, 269, 270
Biodiversity, 20, 27
Bio-fumigation, 137
Biogeography, 256
Biomass, 176
Biosolarization, 137
Bipinnate, 18, 44, 239
Bipolaris, 90, 121, 127, 143, 151, 245, 246, 258
Bis-dithiocarbamate, 257
Bismarkias, 29, 164
Blemishes, 240
Blight, 86, 89, 90, 127–131, 142, 143, 146, 151–153, 164, 165, 179, 181, 199, 204–212, 224, 228, 240, 241, 266, 267, 269–271
Botany, 13, 15, 17–20, 22–25, 27–29, 31
Botrytis, 127, 178, 204–208
Broadcast, 118
Broadleaf, 59, 65
Broad-spectrum, 165, 166, 200, 242
Budding, 10
Bud-rot, 100, 103–106, 133–135, 142, 143, 146, 151, 155, 156, 181, 233–234, 240, 243
By-products, 15, 137

C
Cabriotop, 270
Callistephus, 267
Calyx, 95
Cambium, 9, 10, 127
Canariensis, 20–22, 86–88, 94, 144, 146, 156, 185
Canker, 146, 178, 205, 208, 212
Canopy, 19, 20, 23, 25, 65, 66, 77, 87, 100, 102, 106, 116, 117, 145, 153, 207, 224, 226, 227, 269
Captan, 214, 257, 270
Carbendazim, 137, 208, 211
Carboxylase, 53
Carcinogenic, 58
Carminative, 14
Carnation, 4, 142
Carotenoids, 23
Caryota, 18, 43, 55–56, 86, 93, 94, 96, 237–247
Cellulose, 162, 231
Ceratocystis, 172, 183
Cercospora, 121, 127, 151, 199, 227, 246, 258
Cespitose, 254
Characterization, 53, 87
Chinensis, 10, 18–19, 66, 89, 94
Chitin, 143
Chitinases, 144
Chlamydospores, 104, 105, 136, 143, 144, 155, 174, 175, 183, 210, 223
Chlorophyll, 59, 160
Chloroplast, 43
Chlorosis, 28, 87, 104, 135, 146, 160, 200, 212
Chlorothalonil, 208, 270
Chlorotic, 86, 87, 104, 122, 128, 131, 205, 209, 242, 244, 246
Chronic, 58, 160
Chrysanthemums, 4, 267
Clades, 43, 92
Cladosporium, 172, 187
Classification, 42, 43, 47, 92

Climate, 6, 7, 18, 25, 45, 48, 50, 51, 55, 56, 58, 61, 65, 77, 78, 104, 126, 137, 138, 170, 179, 181
Clonal, 46
Clones, 175
Clustering, 44, 93, 238, 239
Coagulation, 166
Coastline, 145
Coenocytic, 155
Colletotrichum, 90, 121, 127, 142, 151, 241, 258
Colombia, 4, 5
Colonies, 46, 144, 183, 224, 233, 241, 244, 247, 256, 267
Colonization, 163, 205
Compendium, v
Composts, 157, 208
Compounds, 8, 23, 52, 57, 228, 266, 269
Concentric, 228, 268
Conidia, 89, 90, 136, 146, 179, 180, 205–207, 210, 212, 213, 240, 242, 244, 245, 247, 267, 268
Conidial, 166, 205, 206, 208, 209
Conidiophores, 89, 90, 205, 210, 242
Conifers, 74
Contiguous, 204
Coryphoideae, 42, 43, 86, 160, 238, 239
Cotyledon, 9, 10, 66
Crysophileae, 42
Cultivar, 8, 49, 53, 101, 126, 172, 175, 256, 257
Cultivations, v, 7, 22, 52, 76, 78–80, 86, 101, 142, 169, 171, 187, 225, 255
Curvularia, 199
Cuticle, 255
Cyanobacteria, 58
Cyclospatheae, 42
Cyflufenamid, 166
Cylindrocladium, 89–91, 121, 127, 151, 227, 245, 258
Cyphophoenix, 93
Cytochrome, 42

D
Dactylifera, 8–10, 22–23, 52, 88, 94, 96, 101, 170
Damping-off, 78, 89, 135, 142, 205, 208, 209, 267
Database, 79
Debris, 12, 77, 136, 157, 174, 175, 182, 207, 210, 223, 225, 246, 269
Decay, 146, 162
Decomposition, 137, 232
Deficiency, 8, 12, 13, 28, 76, 77, 90, 100, 117, 122, 127, 129–131, 152, 160, 229, 242, 269
Defoliation, 155, 228
Deformation, 166
Dehydrogenase, 120
Dematiaceae, 266
Diagnostic, 98–100, 129, 133, 144, 146
Dicarboximides, 180, 270
Dicloran, 208
Dicots, 10, 102, 103, 162
Dicotyledons, 231
Dictyosperma, 89, 96
Dieback, 87, 88, 142, 176, 179, 180, 200, 205, 209, 212, 224, 232, 270, 271
Difenoconazole, 166, 178, 211
Dioecious, 14, 17, 22, 29, 50, 52, 54, 57–59, 61, 77, 170, 198, 203, 266
Diploid, 170
Disease, v, vi, 7, 11, 12, 14, 19, 22, 55, 58, 76–80, 86–106, 115–123, 125–139, 141–147, 149–166, 169–188, 199–200, 203–214, 221–234, 237–247, 253–260, 265–272
Disinfectant, 187, 213
Disinfected, 105, 158, 225, 244
Disinfection, 182, 213, 225, 269
Disintegration, 143, 232, 243
Dispersion, 46, 56, 61, 90, 91, 93, 96, 101, 228, 230
Dissemination, 96, 97, 101, 152, 174, 177, 180, 186, 224–226, 228, 230, 231, 233, 268
Disulphide, 187
Dithane, 123, 211, 214
Dithiocarbamates, 135
DNA, 42, 43, 93, 97–99, 227
Dormancy, 11, 60, 223
Dormant, 155, 257, 267
Dwarf, 15, 59, 96, 101, 244, 245

E
Ecofriendly, 211
Ecogeographical, 53
Ecological, v, 7, 271
Ecology, v, 8, 41–66, 96–101, 136, 137, 170, 206, 210, 212, 223, 226, 227, 229, 231, 233, 271
Ecospecies, 95
Ecosystems, 60
Ecotypes, 97, 101

Efficacy, 120, 137, 208, 246, 270
Electron-microscopy, 93
Electrophoresis, 98
Ellipsoid, 119, 222, 242
Ellipsoidal, 247
Elliptical, 227
Embryos, 10, 11, 23, 65, 97
Endangered, 20, 51, 65, 78, 150
Endemic, 25, 28, 29, 45, 46, 64, 97, 253
Endemism, 45
Endocarp, 20, 29
Endoconidia, 105
Endomycorrhization, 176
Endonucleases, 98, 99
Endophytes, 208
Endophytic, 241, 267, 271
Endosperm, 10, 11, 49
Enniatins, 223
Ensheathing, 95
Enzymatic, 95
Enzymes, 21, 144, 162, 231
Enzymogenes, 143
Epicuticular, 257
Epidemics, 87, 97, 199, 206–208
Epidemiological, 134
Epidemiology, 42, 133, 134, 137, 174, 179, 180, 206, 210, 213, 256, 268
Epidermis, 230
Epifluorescence, 98
Epiphytes, 255
Equiseti, 247
Eradication, 152, 181, 229, 230
Eragrostidis, 199
Ethnobotanical, 53
Etiology, v, vi, 127, 128, 131, 133, 135, 138, 151, 154–156, 163–165, 223, 226, 227, 229, 231, 233, 255
Evapotranspiration, 238
Evolution, 42
Excelsa, 43, 59, 237–247, 271
Exclusion, 122, 146, 225
Exserohilum, 90, 127, 151, 245
Extracellular, 144

F

Fabeaceae, 141
Famines, 9, 25, 49, 55
Ferbam, 188
Fermentation, 55, 184
Fertilization, 76, 77, 171
Fertilized, 51
Fibrous, 12, 56, 59, 198, 243
Ficus, 267
Filamentous, 93, 97, 136, 223
Fixation, 222
Flavonoids, 23, 56, 238
Flavus, 172, 187
Flesh, 12
Fleshy, 11, 55, 59, 198
Flexible, 48, 126
Flooded, 105
Floorboard, 204
Flora, 19, 45, 54, 60
Floral, 7, 94, 95, 179, 226, 266
Florescence, 14, 96
Florets, 48, 55, 239
Floriculture, 3–6, 8, 79, 80
Fluorescence, 98
Fluorochrome, 98
Foci, 8, 96, 121, 126, 256
Foliage, 3, 17, 30, 48, 57, 74, 78, 96, 99, 100, 102, 115, 116, 118, 119, 123, 126, 170, 228, 229, 245, 246, 270
Formaldehyde, 31, 48, 57, 63, 74
Formation, 103, 132, 136, 145, 146, 170, 175, 179, 205, 222, 223, 245, 246, 269
Formulate, 160
Formulations, 118, 257
Forsteriana, 89, 94, 204
Fort, 270
Fortune, 45
Fosetyl aluminum, 184
Fossil, 41, 45, 54, 58
Foxtail palms, 27–28, 56, 57, 115–123
Fragments, 42, 43, 92, 98
Fragrant, 48
Fronds, 12, 13, 23, 44, 54, 62, 76, 86, 87, 102, 115–120, 131, 133, 145, 157–160, 162, 164, 171, 173, 182, 184, 185, 198, 200, 233, 245
Fronts, 116
Frosts, 45, 46, 49, 50, 53, 54, 58, 62
Fujikuroi, 210
Fulfil, 6
Fulgoroidea, 96
Fumigation, 8, 137
Fumigatus, 172, 187
Fumonisins, 88
Function, 50, 254
Fundamental, 42, 44
Fungal Molecular Biology Lab. and Fungal Molecular Biology Laboratory Culture Collection (FMB-CC-UAF), 221
Fungicidal, 131, 184

Fungicides, 11, 88, 91, 105, 106, 120, 122, 127, 130, 131, 137, 138, 153, 154, 156, 157, 164–166, 179, 180, 182, 184–186, 200, 208, 211, 214, 225, 229, 230, 234, 242, 244, 246, 247, 257, 270
Fusaproliferin, 88
Fusaric, 88
Fusarium, 80, 86–106, 135–137, 142–144, 151, 156–158, 165–166, 172, 173, 176, 178, 181, 182, 184, 185, 187, 204, 208–211, 222–225, 241, 246, 247, 266, 272

G

Gains, 47, 56, 150, 161
Ganoderma, 86, 100–103, 119–120, 131–133, 151, 153, 154, 162–164, 231, 232
GDP, 5
Geminate, 55
Genera, v, 8, 41, 42, 45, 47, 86, 87, 121, 205, 246, 271
Genes, 42, 43, 53, 87, 92, 98, 99, 241
Genetics, 7, 53, 87, 93, 98, 137, 175, 186, 223, 255, 257
Gibberella, 210
Gigantic, 41, 61, 63
Glaucescens, 31
Glucosidase, 55
Graphiola, 172, 185, 229
Guba, 212
Gubler, W.D., 208
Gurevich, V., 170
Gymnosperms, 102, 162, 231, 265

H

Habits, 18, 19, 44, 74, 126, 170, 239, 254
Hadeler, B., 223
Hadrami, A., 176
Haese, 223
Haiti, 150
Hajibabaei, M., 43
Hajlaoui, M.R., 176
Halleen, F., 181
Hallmann, J., 240
Halo, 29
Haloes, 90, 121, 122, 152, 209, 212, 268
Hammond, R.W., 92, 98
Hamoud, A.S., 175
Hamweih, 53
Hansen, K.S., 43, 47
Hao, 255
Haplaxius, 94, 96, 99, 101, 226
Harbor, 174
Hardwar, 272
Hardy, 9, 58, 76, 267
Harley, M.M., 42
Harries, H.C., 93, 97, 101
Harrington, T.C., 255, 256
Harris, S.D., 144
Harrison, N., 98, 99
Harrison, N.A., 92, 94, 97–99
Harsh, 48, 50, 61, 155, 239
Hart, 100
Harvests, 179, 223
Harzianum, 269, 270
Hats, 15, 19, 45, 126, 204, 238
Haydu, J.J., 7
Hazir, A., 73
Heating, 207
Hebert, P.D.N., 42
Hectares, 55
Hedderson, T.A., 43
Hedera, 267
Helland, S.J., 257
Helmick, E.E., 98, 99
Helminothosporium, 138
Helminthosporium, 241
Helmintosporium, 227
Hemarthria, 101
Hemisphere, 4
Henderson, A., 41, 60, 239
Henna, 174, 270
Hepatitis, 49
Herbarum, 271
Herbicides, 8, 153, 225, 239
Hernandez, 209
Hernández-Hernández, J., 209
Hernández Rincon, S., 256
Herrmann, M., 223
Hesse, K., 120
Hildebrandtii, 43, 204
Hildebrantii, 94
Hildebrants, 94
Hill, K.D., 265
Hills, 54
Hindered, 43
HinfI, 98, 99
Hirana, 254
Hiranirana, 63
Historic, 6
Honolulu, 115
Hoog, 271
Hopes, vi
Hopf, M., 169, 170

Hopkins, 213
Hoppers, 94, 226
Horses, 36
Hossain, M., 214
Hosts, 78, 87–90, 92–94, 99, 101–105, 121, 122, 128, 130, 134–136, 142, 144, 145, 151–153, 156, 164, 166, 174, 177, 179, 180, 182, 183, 185, 186, 199, 204–207, 209, 210, 212–213, 223, 225–228, 240, 242, 243, 245, 246, 255, 257, 267–269, 271
Hotels, 13, 116
Howea, 86, 94, 204
Howeae, 89
Hyaline, 119, 136, 155, 174, 178, 179, 186, 205, 212, 240, 247
Hybrids, 5, 52, 95, 101, 145
Hygiene, 122, 126, 158, 213
Hyperplasia, 21, 24
Hyphae, 102, 119, 154, 163, 166, 178, 179, 210, 223, 231
Hyphaene, 11
Hyphal, 143, 223, 225, 228

I
Illiterate, 79
Images, 256
Immune, 267
Immunostimulant, 23
Imperfect, 239
Incubate, 12
Incubation, 94, 95, 143, 206, 210, 247, 256
Indoors, 5, 9, 13, 17, 18, 27, 29, 31, 46–48, 54, 55, 57, 59, 61, 63, 65, 74, 115, 116, 125, 126, 137, 150, 156, 198, 203, 238, 240–242
Infections, 86, 91, 94, 96, 97, 99, 102, 104–106, 120–122, 129, 132, 134–137, 143–146, 151, 155, 156, 163, 165, 173, 175–181, 183–186, 200, 204–213, 223, 228–232, 241, 242, 244, 246, 257, 258, 268–272
Infects, 90, 102–104, 142, 144, 145, 154, 184, 204, 205, 223, 231, 266, 267
Infestation, 117, 138, 165, 177
Infested, 119, 120, 122, 138, 161, 163, 164, 175, 177, 178, 268
Injuries, 9, 10, 12, 49, 54, 59, 61, 122, 127, 130, 146, 155, 164, 165, 182–184, 188, 212, 243, 269
Injurious, 165
Innocuous, 93
Inoculation, 88, 143, 200, 206, 210, 256
Inoculum, 96, 103, 130, 134, 135, 145, 152, 153, 155, 174, 180, 182, 206, 207, 210, 211, 213, 230, 241, 242, 245, 246, 257, 268, 269
Insecticides, 101, 138
Insects, 7, 9, 12, 17, 42, 50, 56, 58, 60, 78–80, 86, 87, 90, 92, 96, 99, 104, 122, 128, 130, 138, 145, 152, 155, 186, 188, 198, 200, 206, 208, 210, 213, 224–228, 230, 233, 238–240, 242
Insides, 10, 102, 139, 153, 162, 207, 222, 228, 232, 243, 254
Intercropping, 78, 174
Intercrops, 78, 174
Interiorscapes, 8, 141, 238, 266
Interveinal, 28, 103, 152
Investigations, 56, 183
Islands, 13, 17–20, 29, 51, 61, 62, 76, 86, 93, 94, 150, 181–184, 203, 204, 238, 243
Islas-Flores, I., 95, 227

J
Jamaicensis, 256
Jasmine, 270
Jatrophicola, 246
Judicious, 12
Juvenile, 62, 77, 88, 106, 118, 127–129, 151, 152, 181, 205, 246, 266

K
Kingdom, 5
Kingsbury, D.T., 92
Koch's, 272
Kunimoto, R.K., 134, 135

L
Lady-palm, 59, 237–247
Landscapes, v, 8, 9, 12–15, 17–25, 28–31, 48, 50, 54, 55, 57, 58, 60–65, 74, 76, 79, 91, 101, 102, 104, 106, 115, 116, 120, 126, 127, 129, 131, 132, 141, 144, 150, 164, 197, 231, 232, 238, 266, 270
Leaching, 118
Leaders, 4
Leads, 4, 7, 28, 89, 95, 96, 127, 162, 175, 183, 229, 247, 255
Leafstalk, 173
Legumes, v
Lemurs, 24, 64

Lesions, 9, 88, 90, 103, 119, 121, 122, 127, 128, 143, 145, 146, 151, 165, 177, 179–181, 186, 205, 206, 209, 212, 228, 233, 240, 242, 244–246, 267, 268
Lettuce, 267
Leu, L.S., 134, 135
Liberate, 134
Lifespan, 158, 239
Lifts, 17
Lignin, 162, 231
Livestock, 23, 24, 171
Livingston, 62
Lycopersicum, 142

M
Macroconida, 144
Macrophialides, 174
Madagascariensis, 24, 45, 63–64, 253–260
Madgascariensis, 9, 24
Majestic, 61
Majesty, 61, 89
Malama, 63
Mammals, 60, 64
Management, v, vi, 3, 53, 76, 79, 88–89, 101–103, 105–106, 117, 120, 122–123, 127, 129, 130, 133, 135, 137, 138, 143–147, 152–154, 156–158, 160, 164–166, 171–188, 200, 207–208, 211, 213, 214, 225, 227, 229, 230, 232, 234, 240, 242, 247, 255, 257, 269
Mancozeb, 123, 135, 137, 180, 211, 214, 245, 270
Maneb, 182, 186, 208, 270
Mango, 134, 180, 181, 210, 212, 241
Manila, 96, 98
Maypan, 101
Mayr, U., 256, 257
Mazmansi, M.A., 27
Mediterranean, 8, 52, 64, 76, 125, 141–143
Meloncon, 172
Mentha, 211
Merchandisers, 7
Mercier, J., 178
Metalaxyl, 184, 211
Metallic, 50
Metalxyl, 137
Metconazole, 211
Methyl, 244
Methylthiophanate, 182, 185
Mexican-fan-palm-washingtonia-robusta-h-wendl-palm-family-arecaceae, 27, 64, 75, 77, 87, 94, 134, 141–147
Michailides, T.J., 206, 207, 267
Micro, 79, 242
Microphalides, 174
Microphialides, 174
Micropropagules, 7
Microsatellite, 53
Microscope, 93, 228, 247
Molds, 138, 142, 205
Monecious, 56
Moniliforme, 177, 181, 272
Monocarpic, 49, 55, 239
Monoecious, 46, 49, 51, 55, 61, 62, 64, 65, 115, 198
Monophyletic, 41, 43, 47, 92, 212
Monospecific, 253
Monotypic, 56, 75
Monoxide, 48, 63, 74
Montgomery, 53, 96
Morphological, 42, 43, 47, 53, 129, 144, 241, 246–247, 255, 256
Morphologically, 61, 126, 141
Morphology, 8, 44–45, 52, 60, 87, 89, 91, 178, 205–206, 209, 223, 256, 271
Mosaic, 244
Moth, 207
Mushrooms, 139, 232
Mycoplasmas, 92
Mycorrhizal, 176
Mycotoxins, 210

N
Nannorrhops, 94
Necrosis, 77, 87, 95, 96, 135, 144, 146, 180, 182, 187, 200, 212, 224, 226, 244, 245, 266, 270, 271
Necrotic, 98, 104, 119, 122, 131, 143, 144, 146, 152, 160, 177, 180, 186, 205, 209, 212, 240, 242, 245–247, 268, 271, 272
Necrotrophic, 204
Niger, 172, 185, 187
Novel, 7, 212
Nuclear, 42, 43
Nucleotide, 53

O
Obligate, 97, 226, 227
Olivacious, 267
Olivain, C., 223
Olive, 19, 134, 159, 208

Ornamentals, v, vi, 3–39, 41–66, 73–80, 86–90, 101, 116, 117, 120, 126, 130, 132, 134, 142, 150, 153, 156, 166, 169, 198, 199, 204, 207, 208, 213, 222, 223, 227, 237, 239, 241–243, 245, 254, 255, 258, 266, 267, 270
Oxychloride, 179, 214
Oxysporum, 86–88, 144, 156, 165, 172–174, 176, 241

P
Palmae, v, 8, 31, 41, 42, 44, 92–101, 125, 198, 238
Palmarum, 87, 88, 144, 156, 164, 165, 199, 200
Palms, v, vi, 5, 6, 8–39, 41–66, 73–80, 86–106, 115–122, 125–139, 141–146, 149–166, 169–188, 197–199, 203–214, 221–234, 237–247, 253–260, 265–272
Pathogenicity, 87, 88, 144, 165, 176, 223, 272
Pathogens, v, 8, 9, 12, 86–91, 97, 99, 101, 103–106, 119–122, 127–130, 132–137, 142–145, 151–157, 162, 164–166, 171, 173–178, 180–183, 185–187, 199, 200, 204, 207–209, 211–214, 223–229, 233, 240–243, 246, 255–260, 266, 267, 271
Perfect, 150, 238
Persistent, 96, 134
Pestalotia, 90, 121, 127, 151, 172, 181, 199, 200, 214, 246, 258
Pestalotiopsis, 90, 121, 127, 151, 164, 165, 199, 204, 212–214, 227, 240–242, 246, 258
Pesticides, 100, 239, 240
Pests, 78–80, 117, 130, 161, 164, 171, 240
Petioles, 17, 19, 20, 22, 24, 27, 29, 42, 50, 57, 62–66, 86, 87, 142–146, 161, 164, 165, 181, 198, 199, 204, 207, 212, 238, 240, 241, 254, 268
Phailides, 144
Phenolic, 52
Phenology, 207, 210
Phenols, 56
Phenotypic, 42
Phenylamides, 135
Phoma, 172, 184, 271
Pinnae, 173, 185, 224, 270
Pinnate, 19, 20, 23, 31, 44–46, 54, 60, 61, 150, 266
Plant-microbe, 208
Plant-pathogenic, 151, 154, 267
Plastid, 43, 222
Polyphenolic, 23
Polyphenols, 14, 238
Poly-phialides, 210
Polyphyletic, 271
Polysaccharides, 14
Polythene, 66
Pomegranate, 181
Ponytail, 28–29
Powdery, 179
Practical, 100
Practices, 7, 12, 20, 47, 74–76, 78, 79, 91, 118, 119, 131, 133, 135, 138, 146, 147, 152, 161, 164, 171, 174, 178, 179, 182–184, 187, 200, 206, 207, 210, 213, 240, 245, 246, 255, 269
Practitioners, 145
Precipitation, 45
Precise, v, 100, 102
Predominant, 226
Predominantly, 52, 136
Pre-harvest, 204
Premature, 77, 95, 100, 102, 135, 153, 186, 226
Presence, 50, 55, 56, 60, 65, 97, 98, 146, 157, 162, 163, 205, 206, 209, 232
Preserve, 173
Preserved, 98
Pressure, 8, 14, 116, 269
Pretreatments, 161
Prevails, 162, 212, 268
Prevalence, 132, 183, 272
Prevalent, 93, 129, 182, 241
Prevent, 9, 118, 120, 126, 127, 152, 156, 160, 164, 165, 175, 207, 211, 213, 225, 230, 240, 269, 270
Prevention, 58, 63, 100–101, 122, 130, 146, 200, 207, 213, 227, 244, 247, 269
Preventive, 101, 160, 179, 183, 184, 188, 225, 230, 234, 242
Primary, 64, 66, 87, 92, 95, 102, 103, 129, 131–135, 151, 158, 179, 207, 210, 213, 241, 254, 267, 269–271
Primers, 97–99, 227
Priming, 11, 13, 17, 20, 29
Probes, 97, 98, 227
Problems, 10, 11, 13, 43, 75–79, 86, 98, 118, 121, 122, 126, 130, 131, 133, 138, 139, 142, 146, 156, 157, 160, 170–172, 175, 199, 200, 204, 207, 240, 242, 266
Progresses, 91, 96, 121, 131–134, 145, 155, 166, 173, 179, 182–184, 200, 205, 213, 224, 233, 245
Progressive, 87, 133, 144
Progressively, 87, 133, 144
Prohibited, 93

Prokaryotes, 226
Proliferates, 165, 267, 268
Prolonged, 94, 99, 106, 205, 210, 211, 233, 244, 246
Prominent, 25, 51, 52, 61, 95, 153, 223, 230, 267
Promising, 176, 269, 270
Promotes, 77, 104, 138, 223, 229, 230
Propagate, 12, 13, 15, 17, 20, 29, 51, 78
Propagation, 5, 7, 10, 13–15, 17–20, 22–25, 27–29, 31, 47, 49, 51, 54, 58, 59, 65–66, 74–76, 116–117, 150, 161, 170, 171, 175, 198, 238, 266
Propagules, 104, 154, 184, 206, 207, 210, 268
Proper, 75–77, 79, 80, 102, 105, 122, 127, 130, 137, 146, 158, 170, 171, 178, 182–184, 186, 240, 242, 246, 269
Propiconazole, 211
Propizol, 166
Proportion, 4
Prostate, 58
Protectants, 270
Protective, 23, 153, 156, 165, 208
Protects, 13, 138, 175, 176, 207, 225
Proteins, 14, 18, 21, 23, 55, 92, 171, 227
Prothioconazole, 120
Protocols, 88, 163
Protrudes, 132
Pruning, 12–13, 28, 51, 56, 61, 63, 87, 90, 128, 130, 131, 135, 145, 146, 152, 157, 158, 161, 165, 177, 186, 199, 200, 206, 224, 225, 228, 233, 242–244, 269
Pseudocercospora, 121, 127, 151, 244–246, 258
Pseudomonas, 137, 176, 208, 246, 269
Pseudophoenix, 94
Pulp, 49, 61
Pure, 267
Purification, 24
Purple, 18, 20, 50, 57, 77, 144, 170, 239
Purple-violet, 210
Purplish, 18
Pustules, 186
Pycnidia, 180, 183, 247, 271
Pycnidiospores, 271
Pygmy, 94, 204, 205, 212, 240
Pyriform, 210
Pythium, 144, 233

Q
Qualitative, 53
Quarantine, 8, 79, 93, 102
Quarterly, 101, 117
Queen, 60, 87, 90, 94, 146, 198–199, 243
Queensland, 45, 56
Quencher, 63
Quick, 18, 24
Quickly, 28, 87, 138, 156, 184, 224
Quiescent, 94
Quran, 9

R
Rachis, 61, 87, 90, 135, 145, 146, 164, 165, 173, 177, 180, 181, 185, 199, 204, 209, 212, 224, 240
Radically, 256
Radicals, 56
Rainfalls, 49, 55, 66, 76, 78, 103, 121, 128, 152, 155, 170, 228, 258
Rainforests, 45, 46, 54, 55, 62, 63
Rainy, 104, 106, 187, 268
Raises, 10, 15, 19, 64
Ralstonia, 144
Rambutan, 213
Ramichloridium, 255
Random, 96
Raphia, 125
Rapid, 27, 31, 118, 199, 200, 270
Rare, 10, 48, 58, 59, 63
Ravenalas, 9, 24, 45, 63–64, 253–260
Ravenea, 43, 61, 89, 94, 203–214
Ravenea-palm-majesty-palms, 61, 203–214
rDNA, 92, 99
Re-amplification, 99
Rearranging, 43
Recombination, 87
Recreation, 57
Re-cultivation, 101
Recurvata, 28–29
Recycled, 106
Regions, v, 4, 5, 8, 9, 18, 20, 25, 41, 45, 46, 48, 50–53, 55–61, 63–65, 73, 86, 87, 93, 96, 97, 99–101, 106, 115, 126, 131, 137, 142, 160, 169, 175, 179–181, 183–186, 198, 199, 226, 229, 237, 239, 241, 243, 255, 256, 265, 270
Registered, 28, 100, 246
Regular, 51, 61, 91, 118, 130, 153, 160, 226
Relatedness, 43
Relationships, 43, 58, 137, 206
Relative, 90, 179, 180, 187, 206, 207, 213, 267
Releases, 77, 90, 118, 132, 135, 155, 186, 206
Relevant, 10
Reliability, 7
Religious, 54, 62, 169
Remedy, 19

Renal, 15
Reservoir, 96, 130, 210
Residues, 11, 12, 155, 267, 268
Resin, 118
Resist, 49, 60
Resistance, 22, 101, 126, 137, 175, 176, 183, 208, 247, 257, 269
Resistant, 20, 23, 54, 79, 101, 120, 135, 145, 160, 164, 175, 178, 179, 182, 184–186, 204, 225, 227, 232, 240
Resources, 24, 75, 93
Respiration, 95
Resting, 184, 222, 223
Restrict, 45, 91, 175, 244
Retain, 145, 152, 238, 244
Retard, 153
Retention, 117
Rhapis excelsa (lady palm care), 43, 59, 60, 237–247, 271
Rhapisicola, 244
Rhinoceros, 155
Rhizobium, 222
Rhizoctonia, 143
Rhizomes, 59, 238
Rhizomorphs, 232
Rhizosphere, 118, 209, 223
Ribosomal, 92, 93, 98, 99
Ribulose, 53
Richness, v
Rigid, 238
Rings, 27, 31, 54, 62, 64, 100, 128, 151, 152, 228, 245, 246, 268
Ringworm, 121
Ritchieana, 94
Riverine, 49
Rivularis, 61, 89, 203–214
Rock, 102
Rodents, 128, 130, 152, 228, 230, 233
Roebelenii, 94
Romanzoffiana, 10, 43, 87, 90, 94, 33, 34, 60, 197–200
Root-infecting, 271
Root-rot, 86, 89, 139, 172, 180, 186–187, 209, 240, 243, 272
Rootspine, 93
Rosette, 45, 58
Roseum, 178
Rot, 59, 77, 86, 89, 95, 100–103, 119–120, 131–135, 139, 142, 143, 146–147, 151, 153–155, 157, 162–164, 172, 178–184, 187–188, 211, 212, 214, 231–232, 243–244, 266, 267, 272
Rotation, 225, 269
Rotundifolia, 62, 63, 94
Roubsta, 142
Royal palm tree, 23, 24, 61, 222–234
Roystonea, 23–24, 43, 61, 66, 86, 94, 221–234
rRNA, 92, 98, 99
Rupicola, 94
Rust, 143

S
Sabal, 86, 94
Sago, 17, 18, 45, 55, 58, 204, 265, 266
Sahiwal, 53
Salads, 62, 171
Salinity, 20, 52
Salt-tolerant, 51, 115
Sandpaper, 116
Sanitations, 11, 105, 122, 127, 129, 130, 146, 152, 165, 178, 182–184, 200, 213, 225, 240, 242, 245, 269
Saponins, 21
Saprobes, 162
Saprophytes, 208
Saprotrophs, 129, 229, 231, 267, 271
Sargentii, 94
Saribus, 62
Sativum, 211
Savannas, 142
Sawdust, 158, 225
Sayaca, 57
Scab, 212
Scab-resistant, 257
Scaettae, 172, 178, 179
Scales, 45, 54, 77–79, 86, 93, 98, 101, 138, 144–145, 240
Scatter, 120, 164
Sclerenchyma, 175
Sclerospermeae, 42
Sclerotia, 173, 174, 205–207, 210
Sclerotinia, 144
Sclerotiorum, 144
Scorches, 172, 177–178, 184, 243
Score, 214, 270
Scotland, 62
Scott, J.K., 60
Scott, P.T., 92
Segregate, 28
Segregation, 143
Senescence, 95
Sensitive, 19, 29, 31, 48, 98, 99, 137, 161, 228, 230
Sepals, 198

Separate, 28, 48, 50, 52, 54, 58, 61, 156, 159, 253
Separated, 77, 90, 103, 116, 127
Separately, 28, 239
Separation, 75, 90
Septal, 166
Septate, 119, 174, 205, 210, 247
Septoria, 258
Serological, 99
Serratia, 208
Sesame, 270
Severity, 130, 152, 176, 180, 183, 185, 213, 246, 269
Sheaths, 14, 49, 86, 126, 146, 204, 209, 238, 254
Shoots, 10, 14, 47, 89, 103, 150, 155, 209, 212, 269
Shrink, 90, 228
Shrubs, 5, 6, 8, 14, 19, 23, 29, 31, 41, 73, 156, 163, 199, 238, 257
Sicily, 272
Signs, 5, 9, 14, 22, 121, 146, 157, 163, 173, 182, 224, 256
Silt, 25, 27
Slight, 116, 244
Slurry, 244
Smokey-grey, 205
Smooth, 24, 28, 50, 51, 56, 61, 62, 64, 198, 205, 222, 232, 238
Smut, 86, 185, 229–230
Soaking, 11, 17
Socio-economic, 208
Sodium, 174
Solanacearum, 144
Solani, 87, 88, 135–137, 143, 165, 166, 172, 176, 177, 184, 185, 272
Solarization, 137, 225
Soluble, 57, 118
Solutions, 5, 13, 122, 127, 137, 139, 175, 225, 227
Solvents, 13
Somaclonal, 170
Sordariomycetes, 223
Sorghum, 209, 210
Sori, 186, 230
Sorus, 229
Spacer, 99
Spaces, 11, 13, 19, 63, 77, 91, 117, 130, 246
Spacing, 61, 165, 186, 207, 242
Sparsely, 200
Spears, 87, 95, 96, 98–100, 103, 104, 106, 119, 146, 162, 209, 224, 230, 233, 243
Speciales, 7, 17, 29, 57, 75, 76, 79, 238, 243
Specialis, 87, 136, 144
Species, v, 6–14, 17–20, 22, 23, 25, 27, 30, 41, 42, 44–48, 50–54, 56, 57, 59–62, 64–66, 73–79, 86–90, 92–94, 96, 100–103, 115, 121, 122, 125, 126, 128, 129, 132, 136, 142–144, 146, 150, 151, 153, 154, 156, 159–162, 165, 169, 176, 183, 186, 199, 200, 203–206, 208–210, 212, 222, 223, 225–229, 231, 233, 238–241, 243–246, 253, 255–257, 265–267, 269, 271
Specimens, 29, 93, 115, 116
Spicata, 101
Spindle, 94, 155
Spinulosum, 43, 54
Splashes, 46, 105, 134, 135, 152, 180, 185, 206, 210, 213, 224, 228, 230, 233, 244, 267, 268
Sporangia, 104, 134, 135, 143, 155, 184
Sporangiophores, 155
Sporangiospores, 104, 143
Spores, 11, 12, 88, 89, 91, 102, 104–106, 119, 121–123, 128–130, 145, 146, 152–154, 157, 162–165, 178, 183, 185–187, 200, 206, 208, 225, 228–232, 242, 244, 258, 268–271
Sporodochia, 173, 174, 210, 213
Sporophylls, 17
Sporulates, 146, 268
Sporulation, 129, 179, 186, 206, 267, 268
Spots, 28, 89–91, 96, 120–123, 126–131, 138, 142, 143, 146, 150–153, 160, 164–165, 172, 179, 181, 185–187, 199–200, 204–209, 212–214, 227–229, 240–247, 256, 258–259, 266–271
Sprays, 7, 116, 165, 184, 187, 225, 229, 245, 257
Sprouts, 59, 163
Staphylocotccus, 238
Starch, 49, 55, 58, 239, 266
Starchy, 49
Starvation, 9, 254
Statured, 51, 56, 59, 62
Stems, 8–10, 12, 14, 15, 18, 20, 22–25, 28, 29, 31, 44–47, 49–52, 54, 57, 59, 61, 64, 65, 77, 78, 86, 100, 103, 104, 115, 118, 119, 126, 127, 131–133, 139, 142, 143, 146, 154, 157, 166, 174, 177, 180, 198, 200, 204, 208, 222, 224, 228, 238, 239, 243, 244, 254, 255, 267, 271, 272
Sterilization, 137, 225
Steroids, 21

Sterols, 64
Stigmina, 90, 121, 127, 151, 245–246, 258
Stomata, 268
Strains, 86–88, 92, 98–100, 143, 144, 156, 208, 211, 238, 269
Stramenopila, 128
Stratification, 11
Strawberries, 214, 241
Streakings, 146, 160, 224
Streptomyces, 137, 211
Strictum, 179
Stripes, 59, 87, 144, 153
Strobilurins, 120, 257
Stroma, 145
Susceptibility, 88, 90, 101, 118, 146, 178, 207, 225, 269
Susceptible, 65, 88, 89, 95–97, 101, 121, 122, 127, 128, 145, 146, 151, 152, 162, 175, 180, 186, 187, 226, 228, 231, 240, 242, 243, 246, 268–270
Swelling, 222
Sylvestris, 52, 94, 185
Symptomatic, 91, 98, 173, 224, 230
Symptoms, 86–91, 94–97, 99–105, 118–122, 127–129, 131–136, 138, 142–146, 151–157, 160, 162, 165, 166, 173–187, 200, 205, 209, 212, 214, 224–233, 241–247, 258, 268, 269, 271, 272
Syndrome, 100
Syzygium, 213

T
Table/umbrella palm plants-in-india, 62, 63
Tails, 18, 28, 29, 55, 56, 115, 267
Tan, Y.A., 238
Tannins, 8, 23, 126
Taxonomy, v, vi, 41–66, 92, 160, 222
Tebuconazole, 120, 211
Teleomophic, 271
Teleomorph, 89, 90, 210
Termites, 204
Tetrazolium, 11
Thielaviopsis, 102, 103, 105–106, 134, 172, 177, 178, 181, 182, 187, 233, 243–244
Thinning, 269
Thin-walled, 119, 155, 210
Thiophanate-methyl, 106, 145, 211, 257
Thiram, 179, 182, 185, 208, 214, 270
Thrinax, 94, 143
Timorex, 208
Tolerance, 52, 65, 79, 200, 207, 210
Tolerants, 17, 29, 30, 48, 50, 51, 62, 75, 80, 160, 186
Toluene, 31, 57
Tolylfluanid, 208
Topsin-M, 214, 270
Tralucida, 172, 186, 187
Travelers-palm, 9
Trench, 176
Triazoles, 120, 180, 270
Trichderma, 269
Trichloroethylene, 57
Trifloxystrobin, 120, 257
Tumors, 19, 21, 58
Twigs, 228, 229, 255, 269

U
Ubiquitous, 77, 212, 266, 271
Ulcer, 56
Unaffected, 96, 98, 145
Unfavorable, 60, 181
Unicellular, 174
Uninfected, 93, 103, 145, 179
Unwounded, 163
Uromyces, 143

V
Valuable, 122
Van der Heyden, H., 206
Variegated, 59, 238, 240
Vectors, 92, 94, 96, 99, 101, 104, 128, 226, 227, 230
Velvet, 268
Ventilation, 188, 207
Ventricosum, 48, 49
Vera, 209, 270
Vermiculite, 19
Vermoeseni, 146
Verschaffeltii, 94
Viable, 11, 66, 78, 266
Vigor, 76, 145
Vines, 9, 212, 255, 257
Viridae, 269
Virulent, 176
Virus, 86
Vitro, 7, 129, 166, 180, 256
Vivo, 260
Vulgaris, 211
Vulnerable, 96, 97, 121, 204, 240, 266

W
Warehouses, 7
Warts, 230
Washington, 76, 243

Washingtonia, 9, 12, 25–27, 43, 64–66, 76, 86–88, 90, 94, 134, 141–147, 181
Washingtonian, 144, 145
Washingtonia-palm, 19, 141–147
Watering, 31, 47, 51, 66, 77, 117–118, 138, 269
Water-soaked, 90, 103, 121, 127, 128, 145, 146, 151, 228, 245, 246
Weakened, 267
Weevils, 80, 161
Well-drained, 7, 15, 19, 20, 22, 24, 25, 29, 47–49, 51, 54, 62, 64, 76, 102, 116, 117, 150, 198, 229
Wetness, 105, 165, 205–207, 267, 269
Whitish, 153
Wilts, 80, 86–106, 122, 135–137, 142, 144, 146, 151, 156–158, 165–166, 172, 176, 185, 205, 208, 222, 224, 225, 227, 232
Wounded, 161, 163, 269

X
Xanthomonas, 246
Xylariales, 164
Xylem, 10, 86, 87, 157, 162, 163, 175, 223, 226
Xylene, 57

Y
Yellowing, 86, 92–101, 119, 166, 185, 224, 226–227, 240

Z
Zinnia, 267
Zonatum, 100–102, 119, 131, 132, 153, 154, 162–164, 231, 232
Zoosporangia, 143
Zoospores, 104, 155, 184