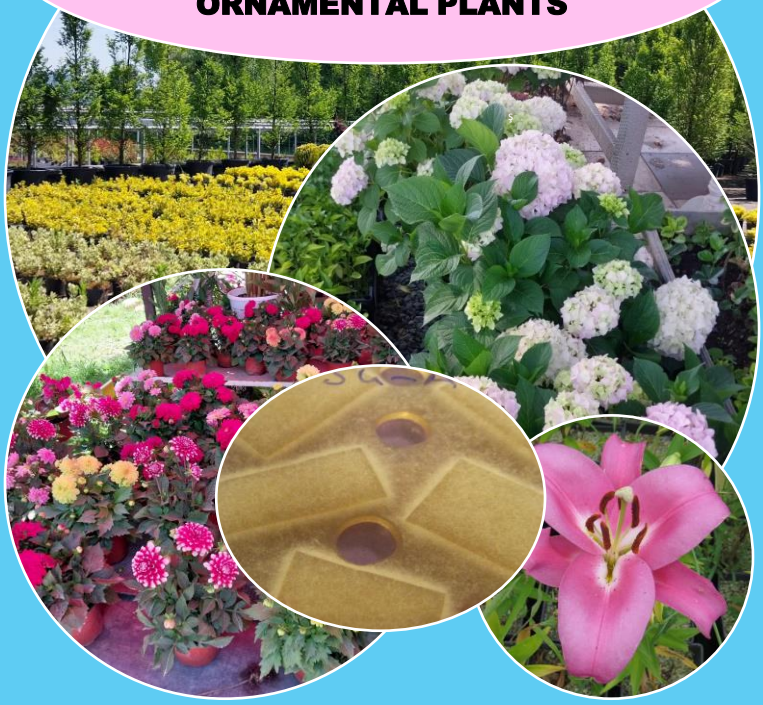
PHYTOPHTHORA SPP.
IN
ORNAMENTAL PLANTS



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PREFACE

Although *Phytophthora* is known as the archenemy of tomatoes and potatoes, in addition to ornamental plants, many vegetables, field crops, fruits, medicinal and aromatic plants, and forest trees are heavily affected, and the number of hosts increases every year.

Some of the reasons why *Phytophthora* disease is so common in ornamental plants may be the widespread international trade, mixed cultivation, and planting with many other species in nurseries, greenhouses, and gardens. The fact that nurseries are generally close to rural areas may cause the spread of *Phytophthora* spp. from diseased plant species to nature and perhaps cause new infections in forests and other cultivated plants. In addition, differences in mating and other reproduction types of *Phytophthora* spp., and climate change may lead to the emergence of more aggressive strains. The first and new reports about *Phytophthora* species on very different plant species that mean the devastating pathogen *Phytophthora* may has many unknown species that are unknown yet to be identified species that can be detected in different hosts. On this point, such a large host diversity in different parts of the world, even in ornamental plants alone, does warn us to be more aware,

and determined to intervene against this destructive pathogen *Phytophthora*.

This book is dedicated to the people that has suffered directly or indirectly from the *Phytophthora* spp., and to the scientists who have spent their lifetimes trying to cope with the pathogen.

Assoc. Prof. Dr. Aysun ÇAVUŞOĞLU
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September, 30, 2024

CONTENTS

1. INTRODUCTION

In order to continue living, human beings must first satisfy their needs for physiological, safety, love, esteem, and self-actualization which are related to each other. Human is motivated by the desire to achieve or maintain the various conditions upon which these basic satisfactions rest and by certain more intellectual desires (Maslow, 1943). For the first step of Maslow's hierarchy of needs, physiological step, plants have an extremely important place in life. Plants are primary producers in nature and satisfy all the most important physiological needs such as nutrition, clothing and shelter. For this purpose, the step was taken primarily in hunting and gathering continued with plant production. Carrying out the plant production and offering it to the service of humanity is not as easy as it seems. All cultivated plants also face more or less disease problems.

Like many other cultivated agricultural areas and natural vegetation, cultivated ornamental plants also face problems that can be mainly classified as diseases, pests, and weeds. In terms of ornamental plant diseases, oomycetes, fungi, bacteria, viruses, and viroid-related diseases can sometimes become difficult to diagnose, and deal with them. In addition, the fact

that they cause epidemics and the possibility of being hosts of cultivated fruits, vegetables, and field plants other than ornamental plants of the same disease type further increases the importance of the issue. At the same time, specific environmental conditions may favor sudden development and pandemics of well-known diseases. If three factors as a susceptible host, a favorable environmental condition, and a pathogen come together to make a disease triangle, the plant disease unavoidably occurs. One of the increasing problems related to plant pathogens *Phytophthora* spp. has enabled the detection of new species but has also made scientists concerned about the reasons for this increase in recent years.

Phytophthora (de Barry) taxon belongs to the Peronosporaceae family in the Peronosporales order in the Oomycetes class in the Oomycota phylum (European and Mediterranean Plant Protection Organization [EPPO], 2024; National Center for Biotechnology Information [NCBI], 2024). The plant pathogenic genus had some other synonyms long before and has dozens of species that cause diseases in the plant kingdom were revealed by many scientists from all over the world (Mycobank Database [MYCOBANK], 2024).

Although *Phytophthora* is known as the archenemy of tomatoes and potatoes, in addition to ornamental plants, many

vegetables, field crops, fruits, medicinal and aromatic plants, and forest trees are heavily affected, and the number of hosts increases every year. Most species of the pathogen genus cause cancer and dieback in addition to root rot and damping-off of seedlings, rots of tuber, corms, buds, fruits, twigs, foliage, and stems. The first symptom of the pathogen is water deficiency, but the plants quickly become susceptible to other pathogens and adverse environmental conditions and return to death (Agrios, 2005). This genus, which has asexual and sexual reproduction, can spend the winter in oospores, chlamydospores, or mycelium forms in infected tissue, and in most cases, the structures may survive in the soil. Zoospores derived from these forms can be disease-starters in next spring in some of the diseases (Hansen, 2015).

Two of the representative species of the pathogen *Phytophthora* genus are *Phytophthora infestans* and *Phytophthora capsici*. The first has become the most serious threat to the production of tomatoes and potatoes, and the second one of pepper and cucurbits from time to time (Göre et al., 2019; Hausbeck & Lamour, 2004; Nowicki et al., 2012; Saltos et al., 2022). In fruit trees such as citrus, apple, pear, quince, and cherry, *P. citrophthora*, and *P. cactorum* are the first

two pathogen species that come to mind (Grígel et al., 2019; Savita & Nagpal, 2012).

In natural ecosystems and world forests, *Phytophthora alni, P. austrocedrae, P. cinnamomi, P. lateralis, P. pinifolia, P. pluvialis, P.* ramorum, *P. cactorum, P. cambivora, P. citricola, P. kernoviae, P. nemorosa, P. pseudosyringae, P. quercina*, etc. (Hansen, 2015; Lehtijärvi et al., 2017; Schena et al., 2008) are considerable and mostly specific to plant species (alder, cedrus, eucalyptus, pine, chestnut, cedar, oak, bay laurel, box tree, etc.). Many *Phytophthora* species are featuring prominently in the worldwide rankings of emerging threats to natural ecosystems (Goss et al., 2009; Hansen, 2008; Hansen, 2015). Due to the importance of the subject, the phylogenetic studies on *Phytophthora* spp. are also progressing rapidly for woody plants (Andrade-Hoyos et al., 2023; Bregant et al., 2023; Ivors et al., 2004).

Ornamental plants that can be hosts of *Phytophthora* spp. can be classified as annual, biannual, and perennial or as botanical taxonomy starting with Cryptogamae and Phanerogamae, or as usage type in indoor and outdoor or as beauty preference of flowers and leaves. As for cultivated agricultural areas, cultivated ornamental plants also face problems. Presumably, ornamental plants may be more

susceptible to disease because they are exposed to very different growing conditions that are from their favorite environmental conditions. In this case, all the requirements (pathogen, susceptible host, and unfavorable environment) necessary for the disease triangle are met unintentionally if there is a potential pathogen. This book aims to make a general evaluation by discussing the scientific studies on the symptoms, diagnosis, control, and management methods of *Phytophthora* spp. in ornamental plants which have become the most common and destructive plant pathogen species.

2. LITERATURE SEARCH

Literature search is the most important and first step of a scientific study. The step includes primary, secondary and tertiary literature. Web-based literature review is widely used, and filters can also be used to refine a search (Grewal et al., 2016).

For this book the literature search was conducted using various scientific databases, including Scopus, Google Scholar, and Web of Science by using keywords such as "*Phytophthora*", "plant disease" "ornamental", "floriculture", "geophyte", "potted plants", "seasonal plants", "bedding plants", "cut flower plants", "nursery", "shrubs", "trees" and their cross combinations which were published from the earliest reachable date to the present day in English (Scopus, 2024; Google Scholar. 2024; Web of Science, 2024).

3. *PHYTOPHTHORA* SPP. IN ORNAMENTAL POTTED PLANTS

Potted ornamental plants have special attention in the ornamental plant sector because being indoors or outdoors around the home arouses curiosity, and gives hope, and happiness. The plants are like the single element that unites the entire household. It is a meaningful way to hold on to life in countries with long winter seasons. They are also important plants in that they remind the person who gave the gift for months or even years in the place where they are given as a gift (Figure 1, Figure 2, Figure 3). On the other hand, many potted indoor or open-door plants can become susceptible to the pathogen *Phytophthora* because they have been grown mixed with other plants in the greenhouse and perhaps on the same flooded tables. Even if this pathogen is marketed before it is known that it was contaminated during production, problems will be encountered in the future.

Phylodendron (*Phylodendron oxycardium* Schott; Araceae Family) is one of the most famous potted, -foliage plants. The plant can be infected with *Phytophthora* in nurseries. Water-soaked spots prior to dry browning with a yellow halo can be observed as symptoms. A study was conducted to identify the *Phytophthora* spp. related to the leaf symptoms, its

pathogenicity, and to evaluate chemicals for control of the disease. The results showed that obtained isolates from five nurseries and two isolates from culture collection can cause the disease on different *Phylodendron* cultivars. One of the cultivars was not affected by the pathogenicity test. In addition, *Monstera deliciosa* (Araceae family) which is another potted plant, was also affected by one of the isolates. The pathogenic *Phytophthora* was found as *P. parasitica* in two compatibility types A1 and A2 (Ridings & McRitchie, 1974).

Since nurseries contain many ornamental plants together, they are rich sources of diseases. A study was conducted at nurseries in three different regions to identify *Phytophthora* and *Pythium* species on plants. At the same time, two different growth substrates (compost heap or soil/potting mix) were analyzed. Data showed that *Archontophoenix alexandrae* and *Phylodendron* were infected with *Phytophthora palmivora,* and *Spathiphyllum* infection with *Phytophthora drechsleri. Phytophthora cinnamomi*, and *Phytophthora nicotianae* var. *nicotianae* also were found in compost hemp. The study showed that the diseased plant exhibited poor growth and root rots (Duff, 1993).

In glasshouses, ornamental pot plants are grown mostly on benches and water with a nutrient solution is given as table

flooding to save labor time. The system has a significant disadvantage in the spread of diseases. A study was conducted to obtain the spreading of the *Phytophthora* diseases with three pot plants, *Saintpaulia ionantha*, *Gerbera jamesonii*, and *Spathiphyllum wallisii*. The study included plant inoculation, soil infestation, zoospores in the tank, zoospores on the bench, and mycelium in the tank methods. *Phytophthora nicotianae* was used in *Saintpaulia*, *Phytophthora cryptogea* was used in *Gerbera* and three different *Phytophthora* spp. were used in *Spathiphyllum*. Briefly, the risk of spread of root diseases in the system may vary in plant-pathosystems. For example, *Gerbera* root rot caused by *Phytophthora cryptogea* could spread but in *Saintpaulia* had no spreading while *Spathiphyllum* had no significant *Phytophthora* spreading from diseases plant to healthy ones (Van Der Gaag et al., 2001).

Begonia spp. is the well-known potted plants which have a wide diversity of plant characteristics in growth form, longevity, habit, tuber presence, inflorescence sexuality, perianth colour, stem type, arrangement, symmetry, number of leaves etc. (Doorenbos et al., 1998). The plant is sometimes traded due to the beauty of its leaves and sometimes flowers. *Phytophthora niederhauserii* isolated from *Begonia elatior.* The pathogen was described with the morphological features and the molecular

tools in France as the first report. The diseased plants showed wilting with a dark basal stem rot and a serious outbreak of the disease affected the potted *Begonia* in glasshouse in a region of France in 2012 (Saurat et al., 2015). The pathogen *P. niederhauserii* was also described in some other ornamental plants, fruit trees, and native plants from thirteen countries (Abad et al., 2014).

Figure 1. The ornamental potted plants; *Kalanchoe* sp., *Rhodanthe* sp., *Pelargonium* sp., and *Nephrolepis* sp. under the shaded open-air condition (Photographed on June 5, 2024)

Figure 2. The ornamental potted plants under the shaded open-air condition; a) *Begonia* sp. (Photographed on June 5, 2024), b) *Dahlia* sp. (Photographed on May 29, 2024)

Figure 3. The ornamental potted plant *Begonia* sp. in a pot under the open-air condition in a balcony (Photographed on June 14, 2024)

4. *PHYTOPHTHORA* SPP. IN ORNAMENTAL GEOPHYTE PLANTS

Geophytes have specialized underground storage organs mainly corms, bulbs, and tubers. The geophyte plant species are placed in both monocotyledonous and dicotyledonous families. In addition to being an important part of various natural habitats, these plants have attracted attention and have been cultivated for reasons such as their attractive appearance, fragrant, or odorless flowers, and longevity (Figure 4, Figure 5, Figure 6, Figure 7). For these reasons, an important commercial market has emerged from these plants for many years. These plants also have disease and pest problems including *Phytophthora* spp. because of their cultivation in different environments.

Phytophthora lilii was isolated from Easter lily (*Lilium longiflorum, Liliaceae*) and represents a new *Phytophthora* clade in Japan. The pathogen was identified initially as *P. megasperma*. In the study, the isolates were obtained from diseased stems of lilies. After the isolation, morphological, physiological, and phylogenetic analyses based on eight genomic regions were made. In the diagnostic view, the species have hyphal swellings, chlamydospores, internal, extended proliferation of sporangia, oogonia, and unique colony types. The species has a higher optimum growth temperature (28 ^{0}C)

than being *P. megasperma* (22,5-25 ^{0}C). In addition, *Tulipa gesneriana* L., which is also a geophyte plant, showed some symptoms when the pathogen *Phytophthora lilii* isolates were inoculated. Because of the unknown primary inoculum source of *P. lilii*, the possibility that this pathogen may originate from Japan has been emphasized, since this geography is one of the natural habitats of Easter lilies (Rahman et al., 2015). This study is important because it shows that previously identified pathogenic species can be re-evaluated using new techniques such as genetic analysis, and this pathogen is the disease agent in easter lilies.

Dendrobium spp. is Orchidaceae family member, and it has pseudobulbs as storage organs that is found in many epiphytic and terrestrial orchids. A study showed that *Phytophthora palmivora*, *P. nicotianae*, and *P. cactorum* were found in different *Dendrobium* spp. and different locations across the world (Tao et al., 2011). In Yunnan province in China, *P. nicotianae* causing blight on *Dendrobium aurantiacum*, *Dendrobium chrysanthum*, *Dendrobium chrysotoxum*, and *Dendrobium thyrsiflorum* was confirmed by using molecular data parallel with morphological and pathogenicity tests.

Laelia spp. is another member of the Orchidaceae family, and it has been observed that diseases *Phytophthora palmivora*,

P. nicotianae, and *P. cactorum* can be transmitted to these plants. The first report of the disease *P. nicotianae* on the plant species revealed that the symptoms of the plant can be black rot of leaves, sharp discoloration of leaves, diseased leaves falling, rotting pseudobulbs, and pseudobulb withering (Rosetti, 1943). Simone and Burnett (2002) also confirmed the symptoms of the species. A detailed review article (Bag et al., 2024) showed that lots of Orchidaceae family members can be infected by different *Phytophthora* spp. all over the world and emphasized that there are lots of studies on flower color, durability, shape, and architecture for the plant but there is not any R-gene research that will be a great requirement in the future.

Alstroemeria spp. are Alstroemeriaceae family members in Liliales and have tuber clusters which make the plant a geophyte. In Poland, a study was conducted on isolated *Phytophthora cryptogea* from different host plants because of the increasing number of hosts for *Phytophthora* spp. in the last decade before the study. The isolates from *Alstroemeria* x hybrida were found one of the pathogenic isolates on three Alstroemeria cultivars. Pathogenicity test with artificial inoculation showed that the Alstroemeria cultivars highly susceptible than other test plants to *Phytophthora cryptogea* with quick necrosis spreading in four days, and causing rotting

at stem, and leaf bases in addition to root rotting (Ptaszek et al., 2009).

Tulip is a well-known, and highly marketable plant among the ornamental geophytes. According to a study from Japan, the pathogen *Phytophthora cactorum* occurred in the spring months after rain. Symptoms began from the basal part of the stem and quickly expanded the all above-ground parts of the tulip. The stem color changed to yellowish-white, bulbs turned dry and black. The blossom blight was another considerable symptom. In the study, it was firmly emphasized that the transmission of the pathogen is soil, and is not bulbs (Mukobata et al., 1987).

The reason for the limited studies on the disease *Phytophthora* spp. in ornamental geophyte plants may be that the focus has been on diseases such as grey mold, which were detected long ago. However, the fact that there are detailed and intensive reports of *Phytophthora* spp. diseases respectively in onion (Frech et al. 2011; Griffin & Jones, 1977) and potatoes (Çavuşoğlu, 2023; Göre et al., 2019; Göre et al., 2021) reveals that we need to be vigilant against this devastating disease in bulbous, cormous, and tuberous ornamental plants.

Figure 4. The ornamental geophyte; *Cyclamen* sp. under the plastic high tunnel (Photographed on December 19, 2022)

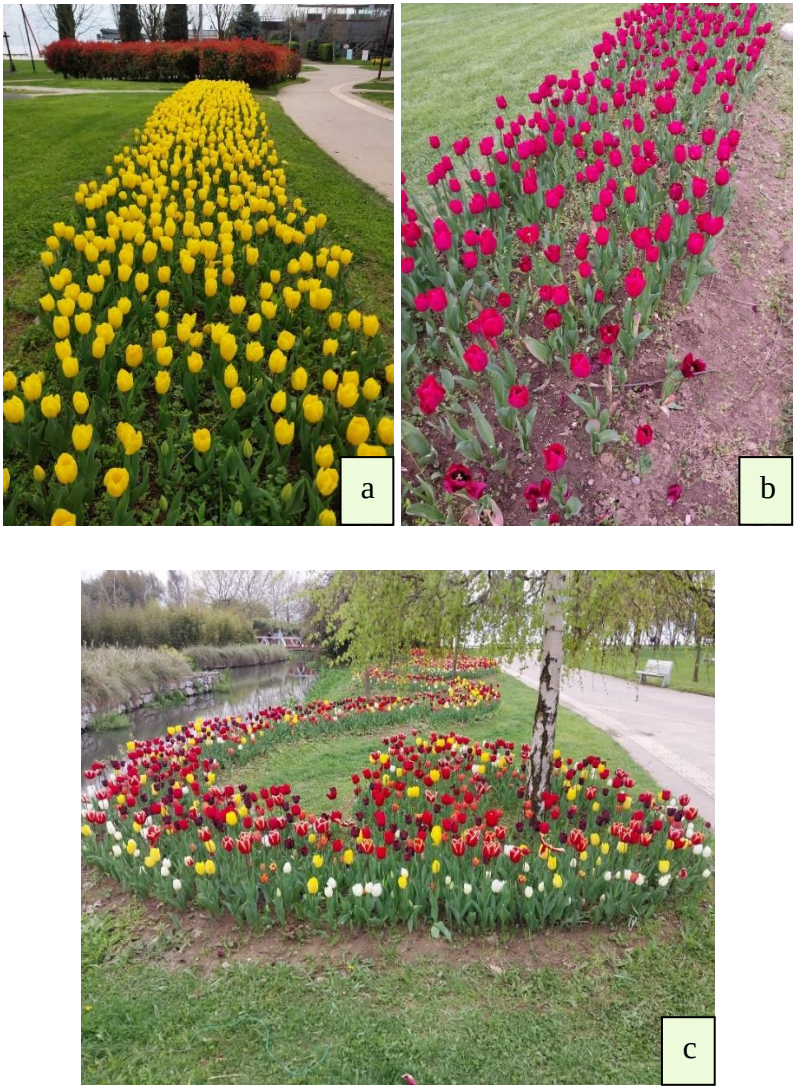

Figure 5. The ornamental geophyte in the recreation areas; a, b, c) *Tulipa* spp. (Photographed on April 9, 2023)

Figure 6. The ornamental geophyte; *Lilium* sp. at a graveyard (Photographed on June 6, 2024)

Figure 7. The ornamental geophyte in a scientific study area; *Lilium* spp. (Photographed on July 6, 2022)

5. *PHYTOPHTHORA* SPP. IN ORNAMENTAL SEASONAL BEDDING PLANTS

The bedding plants usually are seen, used, and marketed for gardens, parks, and municipal areas. The plants are mostly annual or tender perennials in fast growth short habit. The plants are grown mostly from seed that grows directly in soil or pots before being transplanted for colorful flowers and/or leaves. In some areas, bedding plants are used as live carpets (Figure 8) in festivals with more than one bedding cultivars in species. Some of *Antirrhinum* spp., *Calendula* spp. *Campanula* spp., *Viola* spp., *Brassica* spp., *Vinca* spp., *Impatiens* spp., and *Pelargonium* spp. are given as examples, and these can be chosen in planting areas according to cool or warm temperatures for outdoors (Figure 9, Figure 10). The plants may also be exposed to plant pathogens for various reasons. *Phytophthora* spp. may also be found in some of the plants because of over-watering or poor drainage.

A detailed study on the evaluation of bedding plant varieties to find out resistance to *Phytophthora nicotianae* was conducted in outdoor conditions. The used species in the study were the cultivars of *Ageratum houstonianum, Antirrhinum majus, Catharanthus roseus, Celosia argentea, Dahlia coccinea, Eustoma grandiflorum, Hibiscus moscheutos, Impatiens balsamina, Impatiens walleriana, Leucanthemum* x *superbum, Lobularia maritima, Melampodium cinereum, Nicotiana* x *sanderae, Pelargonium* x *hortorum, Petunia* x *hybrida, Portulaca grandiflora, Rudbeckia hirta, Salvia coccinea, Salvia farinacea, Salvia sclarea, Tagetes erecta, Tagetes patula, Torenia fournieri, Verbena tenuisecta, Viola* x *wittrockiana,* and *Zinnia angustifolia*. The growth index and the disease rating were calculated on different evaluation days to reach the results. Briefly, the

study emphasized that most of the cultivars belong to some species that thrived in experimental seasons. Some of the species showed low disease ratings although the pathogen was isolated from the plants. Some of the plants showed increasingly poor performance after following inoculation over time and symptoms were more visible from one period to the next evaluation time. *Antirrhinum, Catharanthus,* and *Viola* were found very susceptible to *P. nicotianae* attack. The symptoms of the plants occurred earlier, and all inoculated plants died (Banko & Stefani, 2000). This study is important as it shows that there may be differences even between cultivars within the same species and in performance in infected plants.

In floriculture, the management of the pathogen *Phytophthora* spp. can be required for fungicide application with other complementary protection methods. Mefenoxam sensitivity, because of being selective for Oomycete that includes *Phytophthora* spp. and being systemic fungicide, is one of the reliable factors to distinguish different characteristics between species and even isolates. In a study conducted with *Phytophthora* spp. isolates obtained from ornamental plants of different genera showing disease symptoms from greenhouses, detection of sensitivity to mefenoxam was searched. Some isolates were obtained from the symptomatic plant species including bedding plants such as pansy (*Viola x wittrockiana*), petunia (*Petunia x hybrida*), and gerbera daisy (*Gerbera jamesonii*). According to the results, the isolated pathogen was *Phytophthora nicotianae* in pansy which was A1 compatibility type and showed mefenoxam sensitivity. The petunia was infected with the same pathogen species but in the other compatibility type, A2, and was found insensitive to mefenoxam. Gerbera daisy hosts from different locations were infected with A1 compatibility type of *Phytophthora*

cryptogea, were found insensitive at 1 mg a.i./ml (Hwang & Benson, 2005). The study is important for the monitoring of the pathogen for fungicide resistance in different recombinations, and the bedding plants which are infected with *Phytophthora* spp.

Figure 8. The live carpet that made of ornamental seasonal bedding plants in Brussels (Photographed on July 18, 2018)

Figure 9. The ornamental seasonal bedding plants; a) *Tagates* sp. for spring-summer planting (Photographed on May 29, 2024) and b) *Primula* sp. for autumn-winter planting (Photographed on January 10, 2023)

Figure 10. The ornamental seasonal bedding plants; the planted area with *Primula* sp. in different colors (Photographed on February 3, 2023)

6. *PHYTOPHTHORA* SPP. IN ORNAMENTAL CUT FLOWERS

In addition to the cut greens that are added to the cut flowers for design bouquets, the cut flowers are an important branch of the international and national floriculture industry. The cut flowers vary by growth climate (cold, temperate, or hot), growth type (seed, geophyte, or cuttings), growth habit (annual, biannual, or perennials), and growth site (field, or greenhouse). These flowers, which are indispensable for weddings, funerals, parties, hotel lobbies, and official wreaths add beauty to human life. Although their most common use is to place them in vases, they have also begun to be used in decoration without a stem or a leaf. The cut flowers may also be exposed to several plant pathogens because of wide growth differences. *Phytophthora* spp. may also be found in some of the plants because of the rapid increase in host diversity in recent years. The rapid development of international ornamental plant production, material exchange, and trade may be important reasons for this as are the other ornamental plant groups. In this section, studies on *Phytophthora* spp. disease in well-known cut flowers (*Rosa* spp., *Dianthus* spp., *Calla* spp., *Strelitzia* spp., *Gerbera* spp. etc.) (Figure 11, Figure 12, Figure 13, Figure 14, Figure 15) were reviewed. *Phytophthora* spp. in cut flowers obtained from geophytes (*Lilium* spp. *Tulipa* spp.) are not discussed here again, as it is explained in the section above.

Carnation is one of the most popular cut flowers and has special importance for a relatively long vase life. *Dianthus chinensis* is one of the *Dianthus* spp. members, and widely cultivated in China. Based on a series of morphological and molecular detections *Phytophthora nicotianae* was firstly reported from the country after observing root

and foliage blight. The pathogen initially caused wilting and chlorosis according to the report. Severe infection also caused the death of whole plants. The study emphasized that because of its importance in ornamental plants and landscaping in the country, the diseased plants must be removed to prevent the spread of the pathogen (Xu et al., 2022).

Dianthus bartatus and *Dianthus japonicus* are important two *Dianthus* species. A study that is about *Phytophthora parasitica* on the two *Dianthus spp.,* and five other ornamental plants, was conducted in Taiwan. The symptoms of the Dianthus were bleached, water-soaking, and collapse-looking. In addition, root rot occurred after inoculation rapidly. In the end, all diseased plants wilted and died. The mating type of the pathogen *Phytophthora parasitica* was found as A2 from all isolates. The study emphasized that *Phytophthora parasitica* is common and known pathogen in other hosts. The source of diversity, having susceptible varieties, and having a moist climate in the country may make the pathogen more invasive. The fact that *P. parasitica* was found for the first time in the two species of *Dianthus* in this study may be proof of the hypothesis (Ann, 1992).

Arum lily, calla, and calla lily belong to *Zantedeschia* spp. and the members of the genus are not true lily. The perennial, Araceae plants are rhizomatous, and have long petioles, and attractive flowers which make the plant cut flower. In one of the first studies, *Phytophthora erythroseptica* was identified from Superba calla (*Zantedeschia rehmanii*) after visual symptomatic observation as distortion, wet and soft brownish petiols, rapid wilting, chlorosis, and leaves collapse. The rhizome symptoms were not observed in the plants. The research emphasized that wet, poorly drained soil, and cool and foggy weather are important factors in spreading out the

disease. Crop rotation and sanitation were recommended in the study (Tompkins and Tucker, 1947). In another study about *Phytophthora erythroseptica* on white calla (*Zantedeschia aethiopica*), rhizome rot was reported as symptoms (Tompkins & Tucker, 1950).

Rose is undoubtedly one of the most prominent plants in the cut flower industry. The perennial cut rose saplings are planted once, and the plant can be used as cut flowers for many years. There are reports of the detection of different species of *Phytophthora* from many parts of the world. For example, *Phytophthora citrophthora* on cv. Red France on *Rosa indica* cv. Major from Italy. The symptoms were reported as leaf chlorosis, wilt, stem-based dark-brown lesions, and root rot. Collapsing was within four months after the first symptom. The disease was associated with excessive irrigation (Salamone et al., 2011).

Another report of *Phytophthora nagaii* sp. nov. as a new species of rose was from Japan (Rahman et al., 2014) about rose cuttings. After the study same pathogen species *Phytophthora nagaii* were reported from Taiwan. The symptoms were reported as leaves yellowing and wilting, root and basal-stem necrosis, and death at the end in two-years-old plants (Yuan et al., 2020). All the first and new pathogen reports were just after unusual and widespread observations of the *Rosa* spp. from the countries. These data are worth taking into consideration, as the rose is the most well-known and sought-after species in the world.

Strelitzia reginae is a monocotyledonous, perennial, rhizomatous plants and that has aesthetic, unique flowers that are relatively longevity in flowers and leaves, and is relatively expensive, has special importance in the cut flower industry because of producing flowers after a long time following its production by seed or

separation. After more than ten years of a survey for *Phytophthora* in garden and field conditions in Taiwan, *Phytophthora nicotianae* was identified from twenty-three ornamental plants which belong to a very different family, including *Strelitzia reginae*, (Ann et al., 2018). Before the previous study, a new record was announced from Italy after observing dark leaf spots and leaf blight in addition to root rot. Based on morphological and genetic identification, the isolated pathogen was identified as *Phytopthora nicotianae* (Luongo et al., 2010). The new records in the studies are important to make us think about the host diversity of *Phytophthora* spp.

Figure 11. The ornamental cut flower; *Rosa* sp. under a greenhouse, Retrieved June 14, 2024, from https://www.youtube.com/watch?v=V8I-vvlfCYI

Figure 12. The ornamental cut flower; *Dianthus* spp. under a greenhouse in the images, Retrieved June 14, 2024, from https://www.youtube.com/watch?v=Y8LhX9aCmpE

Figure 13. The ornamental cut flower; *Calla* spp. under a greenhouse, Retrieved June 14, 2024, from https://www.youtube.com/watch?v=rnD_r2bgyvY&t=39s

Figure 14. The ornamental cut flower; *Strelitzia reginae*, Retrieved June 14, 2024, from https://www.youtube.com/watch?v=fRtvx88Vuq8

Figure 15. The ornamental cut flower in a greenhouse; *Gerbera* sp., Retrieved June 14, 2024, from https://www.youtube.com/watch?v=SGFw_n8p0ys

7. *PHYTOPHTHORA* SPP. IN ORNAMENTAL SUCCULENT PLANTS

Cactus spp. is a succulent plant, but not all of succulents are cactuses. *Cactus* spp. is a member of Cactaceae family. In addition to the family, Aizoaceae and Crassulaceae families include succulent plants (Figure 16, Figure 17, Figure 18). The most important features of the plant are water storage ability in stems or leaves. In this way, they can adapt to drought and extreme heat conditions. However, contrary to popular belief, they do not always have to live such environments. There are species that can easily live in more temperate environments than those mentioned. These interesting plants are not only an important part of the natural ecology but also a popular group in the ornamental plants sector. The succulents are preferred by consumers as house or open-air plant because of requiring little care. Although they require little care, succulent plants may sometimes face abiotic and biotic problems because they are planted in conjunction with other ornamental plants. In some cases, geophytes are also referred to as succulents because of having storage underground organs as in the corm, tuber etc. forms. *Phytophthora* spp. in geophytes that was mentioned under another section is not discussed here again, as it is explained in the section above. In this section, studies on *Phytophthora* spp. disease in well-known succulent plants (*Cactus* spp., *Aloe* spp., *Echeveria* spp., Kalanchoe spp., *Opuntia* spp. etc.) are review.

Phytophthora cactorum was the first reported in cactus with rotting symptom initially named as *Peronospora cactorum* (Lebert & Cohn, 1870). This pathogen has more than 200 species spread throughout the world (Waterhouse & Waterston, 1966). Although

some of the *Phytophthora* specialized to their hosts, the *P. cactorum* is not host specific pathogen (Chen et al., 2023).

Opuntia ficus-indica (prickly pear cactus) is a known fruity cactus species that has at least three usage types such as ornamental, as fruit and as hedge plant. A study was conducted to find out a disease of the plant which showed some symptoms associated with stem and all plants as wilted before dormancy period, water-soaked view on stem at soil line, softening and exudates oozed from internal tissue etc. It was notice that the disease in question appeared after prolonged rainfall. After isolation, setting up pure culture and pathogenicity tests the disease was identified as *Phytophthora nicotianae* which is a polyphagous pathogen, is not host-specific. The study was the first report on *Opuntia ficus-indica* affecting from *P. nicotianae* at this study time, although there are some finding about the pathogen species on another Cactaceae family members before (Cacciola & Magnano di San Lio, 1988).

Agave is a monocot plant genus and primarily known for its succulent, strong, and fleshy leaves. Different *Agave* species are used for different purposes such as fiber, feed for livestock, obtaining sugar, drink making etc. beside ornamental purpose. In a study, a rapidly spreading disease was observed in the Agave hybrid No. 11648 and other Agave plants distributed for intensive production for fiber purposes in Tanganyika in Africa. This labourious and pioneering study has revealed that this disease, called zebra disease, is caused by mainly *Phytophthora nicotianae*. The symptoms of the disease are spike and bole rot with zebra type spots on leaves. They also reported that *Phytophthora palmivora* isolated near sites from other Agaves and *Phytophthora nicotianae* was isolated from two other Agave hybrids (Wienk, 1968).

Aloe spp. have medicinal properties having fleshy leaves beside ornamental purposes. One of the first studies about crop diseases on aloe plants (*Aloe barbadensis* Mill) was done after observations of a serious problem along few years in Florida. The leaves were necrotic black and diseased plants were uprooted because of root rotting. Although the pathogen *Phytophthora* sp., *Rhizoctonia* sp., and *Fusarium* sp. were isolated, the occurrence of the disease due to waterlogging made it more likely that the *Phytophthora* sp. was responsible. Indeed, the isolation and pathogenicity studies revealed that the responsible pathogen was *Phytophthora nicotianae* var. *parasitica*. Low lying farm with excess water has been shown that there are conditions that the pathogen likes (Averre & Reynolds, 1964).

The first report of the disease *Phytophthora palmivora* on *Aloe vera* plant species revealed that after observation of the symptoms of the plant as browning vascular tissue and leaves from bottom to top, leaf abscission, stem and root rot, and plant death in China (Liu et al., 2023). In the isolation studies three different medium were used and the colony type, mycelial growth, color and shape were found different. Molecular characterization was also studied and the pathogen on the valuable plant corfirmed as *P. palmivora*. The study emphasized that the pathogen can be a potential risk for aloe production area and must be taken controlling and combating measures.

Phytophthora nicotianae produces zoospores and these zoospores can easily spread and cause disease in the presence of water. A study was conducted to examine the transmission of zoospore-producing *P. nicotianae* to a succulent ornamental plant *Kalanchoe blossfeldiana* (kalanchoe) in different pot irrigation

systems in greenhouse. In the study the pathogen was isolated from the plant and zoospores were produced in V8 juice agar for five days. Then the zoospore suspension was poured into the nutrient medium which was given the irrigation systems. The used recirculating subirrigation were an ebb-flow and a nutrient-flow wick culture. The results of the study showed that the disease is transmitted in both systems, but there may be differences in the time it takes for symptoms to appear and in the symptoms themselves (Oh & Son, 2008).

In a first report, *Phytophthora nicotianae* was reported on a Crassulaceae ornamental plant which is a cross between *Graptopetalum filiferum* and *Echeveria agavoides*. The starting point of this study was the observation of chlorotic leaves and root rot symptoms in plants in a greenhouse production area in Korea in 2023. The pathogen, *Phytophthora nicotianae* was found based on the morphological characteristics and molecular study. In the confirmation study the symptoms were observed after ten days after inoculation of zoospore. (Ochieng et al., 2024). This study is also important because it showed that *Phytophthora nicotianae* is found in the succulent plant that can be grown in many places in the world.

Figure 16. The different ornamental succulent plants in pots (Photographed on January 8, 2023)

Figure 17. The different ornamental succulent plants in pots; a) *Echeveria* sp. and b) *Gasteria* sp. (Photographed on June 5, 2024)

Figure 18. The different ornamental succulent plants at a home garden, Retrieved June 14, 2024, from https://www.youtube.com/watch?v=jUbiKmWTicw

8. *PHYTOPHTHORA* SPP. IN ORNAMENTAL SHRUBS

Shrubs have been preferred ornamental plant group in recent years because they do not cast shadows since they do not grow too tall, they can be found in leaf and flower forms in different colors, and they do not require new planting because of being perennial (Figure 19, Figure 21). *Lavandula* spp., *Rosa* spp., *Ziziphus* spp., *Vaccinium* spp., *Arbutus* spp., *Camellia* spp., *Coffea* spp. *Hydrangea* spp., *Jasminum* spp. etc. which have been used naturally for fragrance, fruit, wood, medicinal-aromatic purposes for many years, are placed into the ornamental group. Since urbanized people wanted to see these plants nearby, they had to be cultivated and their trade became intense. Unfortunately, these outdoor plants can cause the spread of *Phytophthora* spp. and other diseases because they are produced with plant parts taken from nature and are in both national and international circulation. In addition, if new orchards or plantation are established from the diseased shrubs (Figure 20) that came from the nurseries for purposes other than ornamental plants, the danger may become even more serious.

An important study highlighting that the international trade in ornamental plants is an overlooked factor in the spread of diseases was conducted in certain regions of Spain. In the 6-year survey of the pathogen *Phytophthora* species, 17 species were obtained from 37 different hosts. Most of the hosts among shrubs and trees belonged to plants *Arbutus unedo* from Ericaceae family which is known susceptibility to *Phytophthora ramorum*, and *Rhododendron* from which *P. citricola, P. syringae, P. ramorum, P. hedraiandra, P. nicotianae,* and *P. hibernalis* were isolated. At the same time, it was determined that *Laurus nobilis*, *Quercus ilex*, and *Persea indica* were

also infected with *Phytophthora* species. This study is important since it emphasized that it should be taken into consideration that a disease can become aggressive in newly infected areas, although it is not very aggressive in its original center for some reasons (Moralejo et al., 2009).

Rhododendron is a famous ornamental shrub and is widely grown in protected areas and commercially for sale nearly all over the world. The plant can be diseased by the pathogen *Phytophthora* spp. For this reason, a study was conducted at two different nurseries which mostly grow *Rhododendrons* to obtain knowledge about sampling at different growth stages on substrates, residues, wind-carried leaves and water or sediment, of propagation and cultivation of plants. *P. cactorum, P. citricola,* a complex of *P. drechsleri/P. cryptogea, P. gonapodyides,* a complex of *P. humicola/P. inundata, P. megasperma, P. plurivora, P. ramorum, P. rosearum, P. syringae, P. chlamydospora, P. lacustris*, and some non-clearly identified *Phytophthora* spp. were found in different degrees in the two different nurseries. The reached data were even in winter survival of many *Phytophthora* spp. are possible in containerized plants and other materials. The contaminated material as water and substrate causes the highest risk for the spread of the pathogen (Junker et al., 2016).

A long-term monitoring survey of plant diseases in forest nurseries is the first step in achieving reliable results. For this purpose, *Phytophthora*-related diseases in forest nurseries were monitored, and fourteen *Phytophthora* spp. were found to be associated with more than ten plant species including shrubs and trees. The found pathogen species were *P. acerina, P. bilorbang, P. cactorum, P. cinnamomi, P. citrophthora, P. mediterranea, P. megasperma, P. nicotianae, P. palmivora, P. parvispora, P. pistaciae, P. plurivora, P.*

pseudocryptogea, *P. pseudosyringae*, and *P. psychrophile*. They were grouped into rare, widespread, and new according to their hosts. The detailed study included the identification of morphological and molecular evaluations. Pathogenicity was tested on *Myrtus communis* and *Pistacia lentiscus*. The data showed that *Phytophthora mediterranea* sp. nov. is a new species for *Myrtus communis* which is a shrub, in Italy. In addition, the study emphasized that the species is very close based on molecular evidence to *P. cinnamomi* which is in the progressive expansion towards the coldest areas of the world (Bregant et al., 2021).

Hydrangeas are known less or more susceptible to *Phytophthora* root rot disease. The plant is indispensable all over the world in ornamental plant areas because of its attractive flowers which are mostly blue or pink due to soil acidity. The observed symptoms such as sudden wilting, foliage yellowing, discoloration of roots, and discoloration on the stem around the soil line were monitored in a study that was focused on the control of the disease. The identified pathogen was *Phytophthora nicotianae* on tested cultivars of hydrangea species (*Hydrangea quercifolia* and *H. macrophylla*). The study indicated that there were differences in susceptibility between the species both under greenhouse and field conditions and the result is noteworthy in terms of choosing more effective fungicides and biocontrol agents (Baysal-Gurel & Kabir, 2019). In another close study to the previous one from Japan, *Phytophthora hedraiandra* was first reported on *Hydrangea macrophylla* under greenhouse conditions after observation of some symptoms such as extended rot on the roots, gradually wilting, chlorotic leaves, stem base changing to dark brown and drying (Yosilia et al., 2020). The results are important for

choosing management of the pathogen in addition to monitoring that shrub species from different families can also be hosts.

Figure 19. The ornamental shrubs in a nursery with *Buxus* sp. in green color, *Euonymus* sp. in yellow color, and *Berberis* sp. in red color (Photographed on May 29, 2024)

Figure 20. The ornamental shrubs in a nursery; *Rose* spp. right next to the *Prunus avium* trees (Photographed on May 29, 2024)

Figure 21. The ornamental shrubs in the gardens; a) *Hydrangea* sp. (Photographed on June 5, 2024), b) *Chanenomeles* sp. (Photographed on March 6, 2009)

9. PHYTOPHTHORA SPP. IN ORNAMENTAL TREES

Trees are one of the most important components of ecology. Over time, people who moved away from rural areas and became urban wanted to see these sublime creatures around them, and they cultivated them in their parks and gardens. The plants have soft and hard wood types, flowering and leafy, usable fruity, bark, leaf, root, and seed types. The long-lived plants can be in Angiosperms or Gymnosperms (Figure 22, Figure 23, Figure 24, Figure 25). Besides their significant role in erosion controlling, moderating the climate, removing carbon dioxide from the atmosphere, and feeding humans, choosing them as an ornamental plant is another important subject. The ornamental plant group mostly originates from forests and can bring diseases with it or transmit diseases from ornamental trees to uninfected forests. However, it can also threaten cultivated orchards. In both cases, human beings may face great danger. For this reason, invasive diseases such as *Phytophthora* spp. have begun to be examined carefully. After the sudden oak death became significant in California (Garbelotto et al., 2001; Rizzo et al., 2002), studies on *Phytophthora* spp. in oaks and other forest trees have accelerated all over the world. Many of these studies also included ornamental plants in tree form at the nursery or last planted stages.

Genetic diversity of *Phytophthora* spp. densely is studied to find out host-pathogen interactions. In one of the studies, the pathogen was investigated via a metabarcoding approach in ornamental and fruit tree species. The data indicated that fifteen *Phytophthora* taxa of which nine defined taxonomic groups, three were found that associated with two or more taxa, and three of them were considered as representatives of novel *Phytophthora* taxa. Considered from the

perspective of trees, *P. niederhauserii* was isolated from both the root and soil of *Diospyros kaki*. *P. nicotianae*, *P. niederhauserii* from roots, and *P. nicotianae* from soil were isolated in *Olea europaea*. The two fruity trees like other fruity, are on a new trend as an ornamental plant. According to the results, being very complex and diverse within even the limited area at the nurseries of the pathogen, may lead the diseases easily introducing to new plant species. It was also understood from the study that the pathogen continues its evolution (Prigigallo et al., 2015).

In a study carried out in the Czech Republic with woody plants, the samples were taken from both natural and ornamental plant areas, since the disease *Phytophthora alni* in alder tree is becoming more and more destructive day by day. This study clearly shows that in addition to the presence of many *Phytophthora* species in forest trees, there are also *P. cactorum*, *P. cambivora*, *P. cinnamomi*, *P. citropthora*, *P. gonapodyides*, *P. megasperma*, *P. multivora*, *P. plurivora*, *P. ramorum*, and two another unidentified *Phytophthora* taxon raspberry and taxon salixsoii in ornamental plant areas such as ornamental nurseries, parks, and gardens. This study emphasizes that species *P. cinnamomi*, *P. citropthora, and P. ramorum* are currently limited to ornamental areas only and these types should not be taken lightly (Černý et al., 2011).

A study was conducted that focused on the detection and prevalence of *Phytophthora ramorum* in many nurseries in 2005 and 2006 in California. Interestingly 1% of the total number of samples were *P. ramorum*. The other isolates were identified as other *Phytophthora* spp. instead of *P. ramorum*. This study continued with testing on leaves, and it was observed that there were general symptoms such as dark, water-soaked lesions with irregular margins

on the leaves after testing host-genera combinations. *Arbutus*, *Camelia*, *Rhododendron*, *Magnolia*, *Syringa*, *Photinia*, *Pieris*, and *Rhamnus* were some of these genera in ornamental plants infected with the *Phytophthora* spp. (Yakabe et al., 2009).

Since the Mediterranean basin contains environments that can provide different climate types and different plant diversity, it would be a correct expectation to determine different types of diseases. For this purpose, the occurrence and prevalence rate of *Phytophthora* spp. were examined in detail with samples taken from symptomatic perennials in nurseries that showed blotch, chlorosis, defoliation of leaves, wilting, dieback, growth reduction, rot, and death symptoms, representing Spain. In addition, water sources were detected. The study revealed that this disease genus was found in twenty-two species in nineteen plant genera and water resources. In this study, it was clearly seen that *P. crassamura* was detected for the first time in Spain and *P. pseudocryptogea* was isolated for the first time from *Chamaecyparis lawsoniana* and *Yucca rostrata*. In this study, it was emphasized that *Phytophthora* disease is quite common in nurseries, that the disease can be transmitted from there to nature, and that for this reason, rules should be taken on a global scale and should be implemented (Mora-Sala et al., 2022).

Figure 22. The ornamental broad-leaved trees in a nursery right next to the natural ecology (Photographed on May 29, 2024)

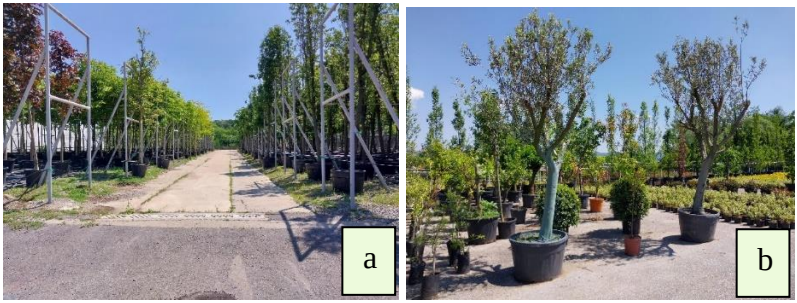

Figure 23. The ornamental trees; a) Broad-leaved and gymnospermae plants, b) Ornamental *Olea* sp. and *Citrus* sp. trees in the nursery (Photographed on May 29, 2024)

Figure 24. The ornamental *Nerium oleander* tree (Photographed on June 14, 2024)

Figure 25. The ornamental *Arbutus unedo* tree in a garden right next to the natural environment (November 12, 2008)

10. CONCLUSION

Some of the reasons why *Phytophthora* disease is so common in ornamental plants may be the widespread international trade, mixed cultivation, and planting with many other species in nurseries, greenhouses, and gardens. The fact that nurseries are generally close to rural areas may cause the spread of *Phytophthora* spp. from diseased plant species to nature and perhaps cause new infections in forests and other cultivated plants. In addition, differences in mating and other reproduction types of *Phytophthora* spp. and climate change may lead to the emergence of more aggressive strains. The first and new reports about *Phytophthora* species on very different plant species that mean the devastating pathogen *Phytophthora* may has many unknown species that are unknown yet to be identified species that can be detected in different hosts. On this point, such a large host diversity in different parts of the world, even in ornamental plants alone, does warn us to be more aware, and determined to intervene against this destructive pathogen *Phytophthora*.

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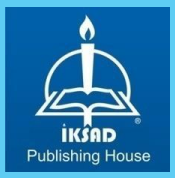

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