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Citrus Gummosis: A Formidable Challenge to Citrus Industry: A Review

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Abstract

Citrus is the most valuable fruit all over the world as well as Pakistan due to its taste, nutritional and medicinal qualities. All the citrus producing regions are facing threat due to a soil borne water loving pathogen *Phytophthora* species. Gummosis is the major disease which destroying the backbone of citrus industry. Several *Phytophthora* species was responsible for the citrus gummosis globally and leads to substantial yield losses annually. The infected tree shows decline symptom in combination with chlorosis of leaves, twigs dieback, discolored or poor colored fruits, wilting of tips and leaves withering. The infected twigs show gummosis, browning of the cortex, defoliation and desiccation. Symptoms are clearly seen on the above ground parts near the soil. Cracks and cankers are visible on the barks, branches and trunks and exude gum. Branches give a bleeding appearance. As it is a soil borne pathogen, so the symptoms are observed from the baseline to upward on the tree from main to secondary branches. While the taproots and crowns necrosis were observed with the increase severity of the infection expand necrotic lesions and the results showed tree declining and death. Many identification methods and control strategies are reviewed with more comprehensive management to use *Phytophthora*-free nursery, resistant rootstocks and economical phytochemical fungicides for the best management of citrus gummosis disease.

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Introduction

Citrus industry is known as the second largest global fruit industry. It is grown on a commercial scale in more than 135 countries all around the world (Naqvi, 2004). The origin of citrus has generally been considered to be in Southeast Asia (Swingle and Reece, 1967). Some citrus genera (*Eremocitrus, Fortunella, Microcitrus and Poncirus*) belong to the Rutaceae family, which is widely distributed across the monsoon region from west Pakistan to north-central China and south through the East Indian Archipelago to New Guinea and the Bismarck Archipelago, northeastern Australia, New Caledonia, Melanesia and the western Polynesian islands (Wu *et al.*, 2018). It consists of major citrus fruit species (Mandarins, Lemon, Oranges, Grapefruits, Pummelo, Citron, Trifoliate orange and Citranges). Citrus fruit is the most important tree fruit crop in the world with estimated production was 124,246 thousand tons in the year of 2016. Pakistan has favorable environmental conditions for fruit production and citrus holds 1st position in terms of area and production (GOP, 2016). In Pakistan citrus annual production was 1907.4 thousand tons (FAO, 2017). Punjab province contributes a main portion of the total acreage and production of citrus fruit in Pakistan. More than 95%of citrus is being produced in the Punjab (GOP, 2016). Citrus fruit is considered the best source of nutrients such as vitamins, amino acids, carbohydrates and some phytochemicals. Moreover, citrus is also considered medically valuable fruits in treating skin, liver and heart diseases (Anil *et al.,* 2004). In spite of such values, citrus industry is facing threat due to several abiotic and biotic stresses. The emerging and devastating disease of citrus now a day is citrus gummosis. It is associated with *Phytophthora* spp; a soil borne fungus. *Phytophthora* belongs to Chromista kingdom, class Oomycetes and Peronosporales order. Class Oomycetes further have four orders among which Peronosporales and Saprolegniales orders consist the major plant pathogens (Erwin and Ribeiro, 1996). Several most important plant pathogenic species are present in genus *Phytophthora* and all of these are responsible for huge agricultural losses all over the world every year (Drenth and Guest, 2004). Several *Phytophthora* species have been shown to cause most serious diseases of citrus plant (from nursery to tree) and infect almost every part of citrus plants right from damping off of seedlings in nursery beds, gummosis, crown rot, foot rot, decay of fibrous roots and brown rot of fruits in groves and as post-harvest decay during storage and transport.

Gummosis disease is mostly caused by *Phythoptora*, such *as P. nicotianae, P. palmivora, P. citrophthora,* but now, it has been shown that other fungal species, i.e. *Diplodia natalensis* in Ghana (Assuah *et al.*, 1999) and *Lasiodiplodia theobromae* in Chile (Guajardo *et al.*, 2018) can also be involved in citrus gummosis disease. However. The major disease caused by them is the gummosis, and it is present in every citrus producing region of the world. It has been reported that gummosis causes approximately 10-30% yield losses each year (Mounde *et al.,* 2009). Gummosis is extremely destructive disease and can result in complete decline of orchards. In different surveys, the disease was observed in 90% orchards with an average disease incidence of 45% (Mekonen *et al.,* 2015). Naqvi and Singh in 2002, explained that the spread of this pathogen is very rapid, and it is a soil-borne fungus which makes it difficult to manage and control. They said that once *Phytophthora* enters into a field, it establishes itself, there becoming an endemic issue. It is measured in the term of propagule count as much as 250 – 350/cc in highly infested orchard soil. Commonly the propagule counts in an orchard can be about 1-20/cc but it may exceed to 100-200/cc in less time. Population exceeding 10 propagules/cc can significantly affect the feeder and fibrous root causing their decay which results in sudden plant decline.

High temperature and humidity favor the disease to develop vigorously in the citrus orchards. Being a soil borne pathogen, it attacks the plant at the time when the scion comes in contact with soil or irrigation water. After a few days, the symptoms start emerging, such as root discoloration, reduced feeder roots, wilting and yellowing of young plants, formation of lesions and emergence of gummy material from them. Gummosis caused by *Phytophthora* spp., along with damping off and root rot is the most important fungal diseases economically in the citrus industry (Leoni and Ghini, 2004). *P. citrophthora* and *P. nicotianae* are the most known species in citrus producing regions worldwide. *P. nicotianae* grows on a higher temperature as compared to *P. citrophthora* while attacking the rootlets causing disease such as gummosis and brown rot of fruits (Cacciola *et al.*, 2007). The management of these diseases is based on appropriate integrated approaches such as use of resistant propagated material, tolerant rootstock and the use of cultural, chemical and biological control (Colburn and Graham, 2007). *Phytophthora* is the major problems of the citrus industry globally as well as Pakistan. There is an urgent need in order to save the declining citrus industry through management strategies. In contemporary review paper, efforts are directed to create awareness among researchers and scientists about history, symptomology, taxonomy, biology, ecology, epidemiology, mode of survival and spread along with detection methods of *Phytophthora* species causing citrus gummosis and different management strategies to reduce economic losses and to enhance farmer's economy and to earn reasonable foreign exchange through export of citrus.

Historical perspective of citrus gummosis

Gummosis is one of the longest-known diseases of citrus in the world. During 1832- 1836 the first *Phytophthora* epidemic was observed in citrus orchards of Azore Ireland. Later in 1841, it was reported in France and during 1845, it spread in Portugal and Mediterranean countries. By 1863, citrus orchard in Italy and Spain were under its infection. Later in 1876, citrus regions in California were reported to be infected by *Phytophthora* gummosis or citrus gummosis. Till 1914, the threatening fungal pathogen was found destroying citrus orchards all over the world (Fawcett, 1936). Several bacteria and fungi were thought to be the cause of this disease, but then Charles Moore traveled to Spain and discovered *Phytophthora* spp to be the exact cause behind the massive destruction. He stated that *Phytophthora citrophthora* was the real cause behind this disease, but later to other species *P. parasitica* and *P. palmivora* were also isolated from the infected samples in California (Grant *et al.*, 1953). Ho and Jong in 1989, reported *P. nicotianae* to be the cause of citrus gummosis.

Citrus gummosis symptoms

Citrus gummosis disease is a well-known disease and is mainly characterized by the formation of gummy material or rotting roots. On the trunk and branches of the plants, gum formation is observed. This gum exudes out from the blisters and each blister contains a gum pocket from where it secretes out on the plant surface. The wood beneath the blisters exhibits a pinkish orange color. The adult trees show decline symptom in combination with chlorosis of leaves, twigs dieback, discolored or poor colored fruits, wilting of tips and leaves withering. Symptoms are clearly seen on the above ground parts near the soil. Cracks and cankers are visible on the barks, branches and trunks and exude gum. Branches give a bleeding appearance. As it is a soil borne pathogen, so the symptoms are observed from the baseline to upward on the tree from main to secondary branches. On taproots and crowns necrosis (cell death) is observed, with the increase in severity of the infection the necrotic lesions expand and results in tree death (Naqvi, 2000). The gum exudes are observed proceeding from the longitudinal cracks of bark surrounding the necrotic regions. There appears a water-soaked discoloration that is persistent when the conditions are dry. The gummy material is water soluble in nature, so, it is washed out during the rain and results in discolored cortex. M'Hamdi *et al.*, (2017) reported that citrus varieties were infected viz *C. hernandina* (73%), T. navel (16%), Maltese (10%) and M. tangerine (1%). However, longitudinal cracks on bark with profuse gumming is the typical symptom. The bark near soil appears slimy, water soaked, and reddish brown that later turns black. Yellow sparse foliage is observed at an advanced stage. Later the tree collapses due to the girdling action of the pathogen. Cacciola and Lio (2008) demonstrated that the necrotic bark becomes soft and sloughs off from the middle where callous is formed. If the canker symptoms spread to more than 50% of the trunk, then canopy decline occurs. Chlorosis of leaf midrib and veins, philloptosis, canopy thinning, and dieback of branches occurs. Graham and coworkers reported small cracks on the bark with gummy material exuding out. Spread of lesions all around the trunk was reported. Dead trees were observed in infected orchards. Defoliated canopy, twig dieback and the stunted growth of the flush was also reported (Graham *et al.*, 2003).

Taxonomy and biology of Phytophthora species

The genus *Phytophthora* is classified in oomycetes includes about 120 species and cause devastating diseases of numerous crops, forest, fiber and ornamental plants worldwide (Hyun and Choi, 2014; Rajput *et al.*, 2015). At least twelve *Phytophthora* species, including *P. boehmeriae, P. cactorum, P. capsici, P. cinnamomi, P. citricola, P. citrophthora, P. drechsleri, P. hibernalis, P. megasperma, P. palmivora, P. nicotianae,* and *P. syringe* have been reported pathogenic on citrus from different citrus-growing areas of the world causing significant economic losses (Boccas and Leville, 1978; Erwin and Rebiero, 1996; Naqvi, 2004). Recently, two more species *Phytophthora insolita* and *P. humicola* isolated from soil in a citrus orchard. The most widespread and important *Phytophthora* species are *P. nicotianae, P. citrophthora* and *P. palmivora* causing citrus diseases (Ippolito *et al.*, 2004; Naqvi 2006). Alvarez *et al.,* (2008) explained that the oomycete formed by the *P. citrophthora* cause infection that induce the gum exudations from the trunks and branches. *Phytophthora palmivora* is most polyphagous species causing citrus disease in the tropical region. Also found in Florida (Zitko *et al.*, 1991; Graham & Timmer, 2006). Therefore, it has been found in different orchards, including citrus garden in Italy, but citrus orchards or to commercial citrus nurseries did not spread (Magnano di San Lio *et al.*, 2002). *P. nicotianae* consists of persistent, ovoid and papillate sporangia and have an amphigynous antheridia and a heterothallism (Alves *et al.,* 2016). Santos *et al.,* (2005), reported the size of sporangia 56 x 35 to 33 x 2.5µm with length and breadth ration of 1.4:1. Chlamydospores are intercalary or terminal with a diameter of 25.4 to 40.3 µm and the size of Oospores is 29 µm. The sporangiophore have swelled hyphae and are branched sympodially. The sexual structures have antheridia and spherical oogonia measuring diameter of 28.6 µm (M'Hamdi *et al.,* 2017). It grows from the temperature range of 7-37°C. Colonial characteristics are different in different media such as it gives rose color on corn meal agar. It is stoloniferous on PDA, fluffy on V8 juice agar, cottony uniform on frozen pea medium, radiate at oat grain agar and stoloniferous at malt extract agar (Ahmed *et al.,* 2012). *P. nicotianae* is a polyphagous that is why it have a wide range of host species where it causes infection. It causes different diseases in several crops such as crown rot and root rot, blight of foliar tissues and fruit in citrus, tobacco, tomato, pineapple and cotton (Chowdappa *et al.*, 2016). Cacciola and Lio (2008), stated that *Phytophthora nicotianae* is more active when present in warm conditions and attacks mainly on the rootlets. *P. nicotianae* occasionally reproduces sexually and in citrus orchards only one type of mating mycelium is observed. The sporangia are produced in the result of air contact and are present in superficial soil layers from where they are transported on plant parts by wind, rain or irrigation water. Citrus gummosis and root rot causing *P. citrophthora* damage aerial parts of the trunk and major branches of the tree. In Brazil, brown rot disease most common to attack citrus trees (Feichtenberger, 2001) and *P. hibernalis* also causing brown rot in a Mediterranean climate.

Survival and spread of Phytophthora gummosis

A single sporangium releases 5-40 zoospores. The production and germination of sporangium depend on the soil, water and potential temperature. The zoospores that are produced from sporangia are motile and show flagella movement in the water at a short distance and are carried to longer distance through soil water. These zoospores are attracted by root exudates and they swim toward them and encyst upon contact. The cyst upon germination penetrate into the cortex directly or through wounds, natural openings. Zoospores have the capability to infect any part of the plant if the surface remains wet for at least 18 hours. It has the ability to form a germ tube that can penetrate into the leaves, roots, twigs or fruits even in the absence of wounds (Graham and Timmer, 2006). Campanella *et al.,* (2002), concluded that soil those are rich in calcium repress the *Phytophthora* population. They also reported that using saline irrigation water accumulate NaCl in soil, which may stimulate the sporangial production. Graham and Timmer (2006), explained that the time when roots are damaged due to any mean or cause, excretion of exudates from the injured regions of roots increases, which attracts the zoospores and makes the host susceptible. Savita *et al.,* (2012), explained the disease cycle of *P. parasitica* (*P. nicotianae*). They stated that the cycle begins with the formation of sporangia that further releases a large number of zoospores (that are motile in nature), oospores and chlamydospores in favorable conditions. With the passage of time, the zoospores encyst, develop and germinate to form the mycelium. Mycelia requires an optimum temperature of 30-32°C for appropriate growth. Small deficit in meteoric water potential of -5 to -70 KPa, favors the sporangial growth. Depletion of nutrients and light stimulate the sporangial formation. It has the ability to germinate from the germ tube under moist condition, but in gummosis and root rot disease the indirect germination plays a key role. Further sporangia require low temperature and free water for the production of zoospores. During unfavorable conditions, such as low oxygen level, nutrient depletion and low temperature (15-18°C), chlamydospores are produced. Below 15°C, chlamydospores enter the dormant state and germinate when the temperature rises up to 27-30°C. The conditions required for the production of oospores are similar to that of chlamydospores. Production of chlamydospores is stimulated by poor aeration and the presence of high CO_2 in soil. Germination increases when the moisture and aeration increase. Oospores generally occur in less numbers, are thick walled and resistant to low temperature. Their maturation rate is slower than chlamydospores, but once they mature, they germinate and receive nutrients from the roots. Oospores mainly occur in citrus soil due to the presence of opposite mating types. Because of this sexual recombination, they provide a great source of variation in a population. During infection, the pathogen establishes intimate relationship with their hosts by forming haustoria, redirecting host metabolism and suppression (Alvarez *et al.,* 2008). Use of infested rootstock is the primary mean of pathogen spread in the citrus orchard. It has the ability to survive in the soil and roots without exhibiting disease symptoms. *P. nicotianae* is carried from infected soil of grooves and nurseries by equipment and vehicles. The spread is reduced when the soil is air dried. Through irrigation water, the pathogen is distributed to different areas. The irrigation water carrying the pathogen enters the canal, ponds and lakes. Further use of water from these sources spread the pathogen to the non-infected areas. As it is a soil and water borne pathogen, so the wind does not play a significant role in the spread of pathogen. Whereas the windblown rain disseminates the sporangia on the above ground plant parts (Graham and Timmer, 2006). Timmer *et al.,* (2003), mentioned that those orchards which are irrigated by submersion creates a favorable environment for infection. During this condition, fungal sporulation is favored as well as it reaches its destination (plant). Ristaino and Gumpertz (2000), reported that the main reason behind the inoculum dispersal of *Phytophthora* spp. from infected region to the healthy one is the surface water. Hence, climate change plays a key role in the dispersal activity and pathogen behavior (Brasier, 2000).

Ecology and epidemiology of Phytophthora gummosis

The epidemiological studies of *Phytophthora* diseases in citrus field are beneficial to view the dispersal pattern of *Phytophthora* spp. from disease foci and importance of inoculum sources. The study is helpful to develop forecasting models for prediction and management of occurrence of *Phytophthora* diseases which is one step forward towards sustainable agriculture (Gade and Lad., 2018). An experiment was conducted by Wagh *et al.*, (2018). They reported that, there was a consistent increase in the pathogen population in all plots with an increase in rainfall, relative humidity with decrease in temperature and vice versa. As the high rainfall condition intensity of root rot was increased in the month of August and gummosis was also increased in the month of October with average propagules of 25.84 cfu/g of soil. Increase in temperature decreased intensity of gummosis and root rot in the month of May, with the average propagules, i.e., 4.56 cfu/g of soil. Choudhari *et al.,* (2018) also monitored epidemics caused by *Phytophthora* spp in four commercial citrus orchards to correlate environmental and soil factors with root rot disease caused by *Phytophthora* spp. in citrus. The relationship of rainfall, temperature, relative humidity, soil moisture, soil pH and soil EC on disease development was investigated. Data was recorded for rainfall, temperature, relative humidity and converted to forth nightly interval. The disease progress and inoculum potential recorded at fortnightly interval from June 2016 to May 2017. There was significant progression in the disease development with the increase in the rainfall and soil moisture. There was a significant increase in the disease at the second fortnight of August and progression continued up to October. Progress in disease was attributed to increases in soil moisture, relative humidity and decrease in the air temperature. There was a positive correlation between rainfalls, soil moisture, relative humidity, soil EC with disease progression and the inverse correlation with air temperature.

P. nicotianae is affected by different environmental factors such as relative humidity, rainfall and temperature. Increased rainfall and relative humidity results in increased soil moisture, which increase the disease incidence and severity (Benson *et al.,* 2006). The time when soil temperature falls to 12°C the growth of citrus root stops, at this time *P. nicotinae* reproduces chlamydospores and become dormant in order to survive the unfavorable condition. Later, during spring when the temperature rise back again the roots start to grow and so the population of *P. nicotinae* subsequently starts increasing. In tropical regions, the roots grow all the year due to which the seasonal fluctuation of susceptibility of the plant toward fungal infection is less evident (Cacciola and Lio, 2008). Meng *et al.,* (2014), reported that *P. parasitica* has been found in different ecological niches among five continents. Prigigallo *et al.,* (2015), mentioned that it has a vast range and habitat as it is present in solanaceous crops as well as several vegetables and forest trees, watershed, medicinal herbs (Hulvey *et al.,* 2010), mountain ecosystems and natural ecosystem and also in recycled irrigation water system (Hong and Moorman, 2005; Beever *et al.,* 2009; Vannini *et al.,* 2009). Furthermore, Benyahia *et al.,* (2004), conducted an experiment by using troyer citrange as rootstock and mentioned that with the increase in salinity the severity of root rot infection which was caused by *P. nicotianae* also increased. The troyer citrange rootstock was used in Tunisian citrus orchards which resulted in the emergence of *P. nicotianae* infection. Hence it has been observed that emergence of disease greatly depends on the rootstock and soil composition, Jung *et al.,* (2000) reported that *P. nicotianae* is associated with loamy soil. Dhakad *et al.,* (2015), conducted an experiment in order to check the favorable factors in the development of citrus gummosis caused by *P. nicotianae*. The experiment was conducted in Punjab kinnow and sweet orange orchards and nurseries. The population of *P. nicotianae* was calculated by plating the soil sample on a selected medium. They reported that amount of the pathogen was significantly high in ten-year-old plants as compared to the five-year-old ones. The sweet orange cultivar represented the higher population of the pathogen as compared to kinnow. Highest CFU of >300 propagules/ cc of soil, was obtained in the month of July (2013). Choudhari *et al.,* (2018), monitored the soil and environmental factors on *Phytophthora* spp. causing root rot disease in four citrus orchards. The wireless sensors in selected plots were used to record meteorological data, soil moisture, soil EC and soil pH. The relationship of rainfall, temperature, humidity, soil EC, moisture and pH with the development of symptoms was investigated. A significant progress in disease with the increase in soil moisture and rainfall was observed. The disease spread increased with the increase in soil moisture and decrease in temperature. They reported that at the initial stage, the disease spread, and severity is slow but with the passage of time, it tends to increase. Hence, soil moisture, rainfall, relative humidity and soil EC showed a positive correlation with the disease while the inverse correlation with temperature was observed.

Detection methods of Phytophthora gummosis

For managing the disease, the first step is to detect the reason behind the disease. It is necessary to detect the *Phytophthora* specie and its level present. Different methods have been developed for the detection of *Phytophthora* species. Baits method is used to determine the quantity of *Phytophthora* inoculum in the soil of citrus orchard. For this purpose, it is checked that how frequently a ripped fruit presence on the ground become infected. Ripen lemon and sweet orange are used mainly to capture the *Phytophthora* from the soil. Leaf fragments of different cultivars of citrus are used as universal baits as they have the ability to capture all the species of *Phytophthora* present in the citrus orchards. A paper-glass filled with distilled water is used to incubate 10g soil and leaf pieces at ambient temperature. Davison and Tay (2005), found that the double baiting increases the recovery of positive samples taken from Western Australia. The water quality significantly affects the zoospores in Western Australia. For molecular detection, it is a highly sensitive method which is able to detect a very low population density of *Phytophthora*. Against *Phytophthora*, genus specific monoclonal and polyclonal antibodies are produced. Enzyme linked immunosorbent assay (ELISA) is developed to detect pathogen in soil debris and roots. The ELISA tests aren't specie specific, so to confirm it, PCR is performed. With the development in technology, the molecular detection method has been also developed, including nested PCR and multiplex PCR with genus and specific- specific primers for detection of *P. nicotianae and P. citrophthora* in citrus roots and soil (Ippolito *et al.,* 2002; 2004). The molecular method is very sensitive and can only be applied in specialized labs. Meng and Wang (2010), demonstrated specific primers for the validation of *P. nicotianae* against different fungal species. These primers were used in the detection of *P. nicotianae* in citrus tissues, tobacco tissues, soil samples and water suspensions. Therefore, the Loop-mediated isothermal amplification (LAMP) was recently described as a specific, rapid, cost-effective, and easy-to-use method for nucleic acid amplification technology (Tomita *et al*., 2008). LAMP has been successfully developed to detect several *Phytophthora* species, including *P. nicotianae*. Primary and correct detection of *P. nicotianae* is essential for controlling several diseases including citrus gummosis. LAMP and nested PCR assays based on the *P. nicotianae* protein gene Ypt1 were tested for their specific detection of this pathogen (Li *et al*., 2015). The use of molecular identification methods provides an accurate and rapid detection of *Phytophthora* gummosis which allows the citrus growers to make timely management strategies.

Management strategies for citrus gummosis

The nursery is the initial stage at which it is necessary to control the disease. In 1980s to 1990s the incidence of *Phytophthora* diseases increased due to the use of infested propagating material from the citrus nursery that was infected by *P. nicotianae* in Florida and Brazil (Feichtenberger *et al.,* 2005). For this purpose, the seeds to be sown are treated at 50°C for about 10 minutes to avoid the introduction of a fungus. The use of sterilized media also eliminates most of the *Phytophthora* issues at nursery stage. The site selection should be done carefully away from the diseased area. For using the site repeatedly, the land should be fumigated. Application of methyl bromide or metam-sodium at replanting can reduce the inoculum at that site (Savita *et al.,* 2012). By following sanitary practices, nursery and greenhouse production is kept free from *Phytophthora* spp. The disease propagating material should not be brought in the healthy area. All the tools, implements, personnel and machinery must be disinfected. Run-off water from the diseased to healthy area should be avoided.

If a portion or some plants in a nursery become infected, then those plants should be destroyed immediately. The use of systematic fungicides is highly effective such as metalaxyl and fosetyl-Al. It was discovered that there are strains which are resistant to metalaxyl. Some key points were then advised by Bayer crop science, such as discontinuation of the use of metalaxyl, destruction of infested nursery stock, fumigation of nursery bed, fallowing for one year and a proper monitoring of metalaxyl resistant strain, could suppress the pathogen population in the nursery (Graham and Feichtenberger, 2015).

For Cultural control, Soil preparation is the first and main step in controlling the soil-borne fungus. Planting site is prepared, 80-100 cm deep ditches are dug, underground drainage system is properly managed to prevent stagnation and consequent water saturation. As water saturation is the main predisposing factor for the infection of *Phytophthora*. Six to twelfth months of fallowing before planting reduces the *Phytophthora* population present at that site. While planting young trees, collar burying should be avoided (Schillaci and Caruso, 2006). Soil solarization is an effective management against the soil-borne pathogen. Gade and Giri (2005), conducted a study in which they minimized the use of fungicides and solarized the soil to check the population of pathogens. They mentioned that it is a disinfectant method that is the most eco-friendly. Next comes the management of irrigation system which is a fundamental part of the *Phytophthora* life cycle as it is a water loving pathogen. *P. nicotianae* produces zoospores from their sporangia which are mobile in the presence of water. These zoospores move in the water and reach the target sites and establish themselves there. When the host surface remains moist for some hours, it provides the best site for the pathogen invasion. In order to prevent it, some simple principles are followed such as the use of clean irrigation water (contamination free), keep the trunk dry, avoid flood irrigation and provide proper water drainage. It is necessary to avoid the premature irrigation during the spring season when the roots are inactive. Irrigation should be done for a shorter period and water status should be monitored regularly with the help of tensiometer in order to avoid the soil saturation (Ohr and Menge, 2006).

Thinning and pruning of the lower branches creates unfavorable habitat for trunk gummosis, which reduces the infection risk. Top working and pruning reduce the canopy and prevent the plant from collapsing. During grafting the bud union must be far from the ground level in order to prevent the *Phytophthora* inoculum that might be present in the soil. Resistant species should be used for grafting. Graham and Timmer (2006), reported that by removing soil from the collar region creates unfavorable habitat for the pathogen because doing this prevents the bark at the foot region from remaining wet. It also helps the canker to heal up. They also mentioned that removal of weeds around this region also dry up the area, since the weeds prevent the bark from drying. For the removal of weeds, herbicides are used as they kill weeds and also reduce the risk of wound on the trunk which might provide the penetration point to the pathogen. Cacciola and Lio (2008), reported that mechanical tilling should be avoided, as it buries the trunk in the soil and makes it prone to the infection. Deep tilling damages the roots and makes it susceptible. Grass growing between the rows during winter prevents the pathogen from coming in contact with fruits and leaves.

Biological method involves an eco-friendly, economic and effective manner of managing the plant diseases. It includes many different micro-organisms (bacteria and fungi etc.). These bioagents induce systematic resistance in the plants that help to fight the diseases. Some plant species are also used against the gummosis disease. In a previous study, using leaf extract of neem, eucalyptus, Acacia, Glyricidia, Dhatura, Lawsonia inermis and bio agents such as *Trichoderma viride, T. hamatum, T. harzianum, T. lignorum, Gliocladium virens* and *Pseudomonas fluorescens* against *Phytophthora* spp (Jagtap *et al.*, (2012a). They used poisoned food technique and dual culture technique. According to the results, Lantana was most effective in inhibiting the fungal growth in *in vitro* conditions. Among bioagent, *Trichoderma harzianum* was found effective significantly by inhibiting up to 91.86% mycelial growth (Jagtap *et al.,* 2012b). Melo *et al.,* (2015), evaluated the antagonistic properties of *Trichoderma spp.* and alfalfa seedling bioassay against *P. nicotianae*. All the isolates inhibited the mycelial growth of pathogen. *Trichoderma* produced thermostable compounds and cell free antimicrobial compounds. Bairwa *et al.,* (2015) conducted a field experiment to manage gummosis disease in kinnow mandarin. They used bio agents (*T. viride* and *P. fluorescens*) with Bordeaux paste. They noted decrease in lesion size and minimum fruit dropping. The stem was painted with Bordeaux pastes and *T. harzianum* and *P. fluorescens*. The reduction in symptoms was mild to moderate. Gade and Koche (2012), recorded a reduction in disease intensity of gummosis in Nagpur mandarin by using *P. fluorescens* and Bordeaux mixture. Sadeghy *et al.,* (2014), conducted an experiment in Kerman in which they used 20 isolates of *Streptomyces* sp. from soil against gummosis. They observed high inhibitory actions against the mycelial growth in *in vitro* conditions. They suggested to make new bio fungicides using *Streptomyces* sp. as it had high antifungal properties and shows resistance to gummosis. Quyet *et al.,* (2016), used a saprophytic mesophilic fungus named *Chaetomium globosum* that resides on plants, straw, soil and dung against citrus gummosis. They mentioned in their studies that this fungus produces Chaetoglobosin-C that have high inhibition abilities. It was tested against gummosis at different pH of soil (3, 4, 5, 6 and 7). The results showed highly significant reduction in the disease incidence as compared to the result shown by metalaxyl fungicide. It reduced about 64% of the disease and was considered a good and reliable bio fungicide.

Chemical control is the fastest and effective way to overcome the disease and save the crop. Different fungicides are used to treat different fungal diseases. It is the most used method to control disease. Metalaxyl combined with mancozeb are known as best systematic and proactive fungicide that inhibits mycelial growth and kills oomycetes (Rather *et al.,* 2012). Gade and Koche (2012), suggested metalaxyl paint to be most effective in treating gummosis in Nagpur mandarin. Metalaxyl paint in combination with Bordeaux paint inhibits the production of oospores and chlamydospore quickly and recovers the tree from disease in speed. Lende *et al.*, (2015) found significant increases in shoot length and canopy volume of tree in mandarin when bioagent *T. harzianum* incorporated in combination with chemicals and organic amendments and also found a significant reduction in root rot intensity. Rather *et al.,* (2012), evaluated ten fungicides and among them thiophanate methyl gave the efficient results against *Phytophthora* spp. In *in vitro* conditions, it significantly inhibited mycelial growth of *Phytophthora* spp as well as other soil borne fungus. Iqbal and coauthors evaluated three concentrations of different fungicides such as Topsin-M, Success, copper oxychloride and cumulus against *Phytophthora* species causing a citrus decline (Iqbal *et al.,* 2020), among these, Topsin-M showed the best results (87.3% inhibition) because it is a broad-spectrum systematic fungicide followed by Success (73.3% inhibition), kumulus (17% inhibition) and copper oxychloride (13.3 inhibition). However, future studies are needed to adopt actual integrated disease management (IDM) strategy which included to use *Phytophthora*-free nursery, resistant rootstocks and economical phytochemical fungicides for the best management of citrus gummosis disease.

Conclusion

Chemicals have been used systematically are now questioned in many aspects as they increase the risk of pathogen adaptation and harmful effects on human and animal health as well as the ecosystem. Therefore, there is a need to develop several policies and strategies to reduce the use of chemicals and banning the hazardous ones. Regulations, policies and phytosanitary policies must take into account the social, economic and cultural factors and their differences. Environmental care should be observed carefully in order to produce food and plant products. Developing countries where there is warm climate, gummosis disease is common. To save the citrus orchards in such areas, some low-cost, efficient management strategies must be developed. Biological methods of disease control should be adopted to residual effects of chemicals. Phytoextracts should be evaluated against this pathogen to get an environmentally friendly way to control the citrus gummosis disease.

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References

Ahmed Y, D'onghia AM, Ippolito A, El Shimy H, Cirvilleri G, Yaseen T. 2012. *Phytophthora nicotianae* is the predominant *Phytophthora* species in citrus nurseries in Egypt. Phytopathologia Mediterranea **1,** 519-527.

Alvarez LA, Vicent A, Bascón J, Abad-Campos P, Armengol J. 2008. Branch cankers on citrus trees in Spain caused by *Phytophthora citrophthora*. Plant Pathology **57,** 84–91.

Alves TCA, Tessmann DJ, Ivors KL, Ristaino JB, Santos AF. 2016. First Report of Gummosis Caused by *Phytophthora frigida* on Black Wattle in Brazil. Plant Disease **100,** 2336.

Anil KS, Arun KS, Vashishtha B. 2004. Fruit breeding approach and achievements. Central Institute for Arid Horticulture Beechwal Industrial Area, Shri Ganganagar Highway Rajasthan, India.

Assuah M, Oduro K, Ofuso Budu K. 1999. *Diplod ia natalensis* Pole Evans, the causal agent of citrus gummosis disease in Ghana. Ghana Journal of Agricultural Science **32,** 11-18.

Bairwa SR, Srivastava AK, Kumar P, Meena RS, Koli CR. 2015. Developing strategies for integrated management of *Phytophthora* root rot and gummosis in kinnow mandarin (*Citrus reticulata*). Indian Phytopathology **68,** 101-105.

Beever RE, Waipara NW, Ramsfield TD, Dick MA, Horner IJ. 2009. Kauri (*Agathis australis*) under threat from *Phytophthora*. Phytophthoras in forests and natural ecosystems **74,** p 74-85.

Benson DM, Grand LF, Vernia CS, Gottwald TR. 2006. Temporal and spatial epidemiology of *Phytophthora* root rot in Fraser fir plantations. Plant Disease **90,** 1171-1180.

Benyahia H, Mouloud MAH, Jrifi A, Lamsettef Y. 2004. Effect of salinity in irrigation water on the colonization of citrus rootstocks by *Phytophthora parasitica*. Fruits **59**, 101-108.

Brasier CM. 2000. The role of *Phytophthora* pathogens in forests and semi-natural communities in Europe and Africa. Phytophthora Diseases of Forest Trees p 6-13.

Boccas B, Leville E. 1978. *Phytophthora* diseases of Citrus (Les maladies a *Phytophthora* des agrumes. Institute de recherches sure les Fruits et Agrumes) 162 p.

Cacciola SO, di San Lio GM. 2008. Management of citrus diseases caused by *Phytophthora* spp. integrated management of diseases caused by fungi, Phytoplasma and bacteria (p 61-84). Springer, Dordrecht.

Cacciola SO, Raudino F, Lo Gidice V, Magnano San Lio G. 2007. Citrus root system disease. Phytopathological informant -The defense of plants **57,** 9-22.

Campanella V, Ippolito A, Nigro F. 2002. Activity of calcium salts in controlling *Phytophthora* root rot of citrus. Crop Protection **21**, 751-756.

Choudhari RJ, Gade RM, Lad RS, Adinarayana J, Phanindra KB. 2018. Epidemiological relations to *Phytophthora spp.* causing citrus root rot in Nagpur Mandarin. International journal of current microbiology and applied sciences **6,** 406-417.

Chowdappa P, Kumar BJN, Kumar SPM, Madhura S, Bhargavi BR, Lakshmi MJ. 2016. Population structure of *Phytophthora nicotianae* reveals host specific lineages on brinjal, ridge gourd, and tomato in South India. Phytopathology **106,** 1553-1562.

Colburn GC, Graham JH. 2007. Protection of citrus rootstocks against *Phytophthora* spp. with a hypovirulent isolate of *Phytophthora nicotianae.* Phytopathology **97,** 958-963.

Davison EM, Tay FC. 2005. How many soil samples are needed to show that *Phytophthora* is absent from sites in the south-west of Western Australia? Australasian Plant Pathology **34,** 293-297.

Dhakad UK, Kaur S, Thind SK, Badaya VK. 2015. Factors favouring the development of foot rot pathogen (*Phytophthora nicotianae* var. *parasitica*) in Punjab. The Ecoscan **7**, 135-138.

Drenth A, Guest DI. 2004. Diversity and management of *Phytophthora* in Southeast Asia. Australian Centre for International Agricultural Research.

Erwin DC, Ribeiro OK. 1996. Phytophthora Diseases Worldwide. American Phytopathological Society.

FAO - Food and Agricultural Organization of the United Nations, Rome. 2017. Citrus fruits fresh and processed statistical bulletin 2016. 1-53.

Fawcett HS. 1936. Citrus diseases and their control (Second Edition), p 656.

Feichtenberger E. 2001. Doenças incitadas por Phytophthora em citros. In: Luz EDMN, Matsuoka K, Santos AF, Bezerra JL, editors. Doenças causadas por Phytophthora no Brasil. Campinas. Livraria Rural p 283-342.

Feichtenberger E, Bassanezi RB, Spósito MB, Belasque J Jr. 2005. Doenças dos citros. In: Kimati H, Amorim L, Filho AB, Camargo LEA, Rezende JAM, editors. Manual de fitopatologia. 4th ed. São Paulo (BR): Editora Agronômica Ceres. (Doenças das plantas cultivadas) **2,** 239-269.

Gade RM, Koche MD. 2012. Integrated disease management for root rot and gummosis in Nagpur mandarin. Indian Phytopathology **65,** 272-275.

Gade RM, Lad RS. 2018. Biological management of major citrus diseases in Central India-a review. International Journal of Current Microbiology and Applied Sciences **6**, 296-308.

Gade RM, Giri GK. 2005. Integration of soil solarization and fungicides for management of *Phytophthora* sp. in citrus nursery. Indian Phytopathology **58,** 114-116.

GOP - Government of Pakistan. 2016. Ministry of National food security and research Economic wing Islamabad. Fruit, vegetables and condiments Statistics of Pakistan p 1-107.

Graham J, Feichtenberger E. 2015. Citrus *Phytophthora* diseases: Management challenges and successes. Journal of Citrus Pathology **2,** 1-11.

Graham JH, Timmer LW. 2006. *Phytophthora* diseases of citrus. University of Florida, IFAS extension.

Graham JH, Bright DB, McCoy CW. 2003. *Phytophthora-Diaprepes* weevil complex:

Phytophthora spp. relationships with citrus rootstocks. Plant Disease **87,** 85-90.

Grant T, Klotz L, Wallace J. 1953. Foot Rot of Citrus Trees. Yearbook of Agriculture p 734.

Guajardo J, Riquelme N, Tapia L, Larach A, Torres C, Camps R, Besoain X. 2018. First Report of *Lasiodiplodia theobromae* Causing Bot Gummosis in *Citrus limon* in Chile. Plant Disease **102,** 818.

Ho HH, Jong SC. 1989. *Phytophthora nicotianae* (*P. parasitica*). Mycotaxon **35,** 243-275.

Hong CX, Moorman GW. 2005. Plant pathogens in irrigation water: challenges and opportunities. Critical Reviews in Plant Sciences **24,** p 189-208.

Hulvey J, Gobena D, Finley L, Lamour K. 2010. Co-occurrence and genotypic distribution of Phytophthora species recovered from watersheds and plant nurseries of eastern Tennessee. Mycologia **102,** 1127-1133.

Hyun IH, Choi W. 2014. *Phytophthora* species, new threats to the plant health in Korea. Plant Pathology Journal **30**, 331-342.

Ippolito A, Schena L, Nigro F, Ligorio VS, Yaseen T. 2004. Real-time detection of *Phytophthora nicotianae* and *P. citrophthorain* citrus roots and soil. European Journal of Plant Pathology **110,** 833-843.

Ippolito A, Schena L, Nigro F. 2002. Detection of *Phytophthora nicotianae* and *P. citrophthora* in citrus roots and soils by nested PCR. European Journal of Plant Pathology **108,** 855-868.

Iqbal Z, Ahmad S, Asim M, Rehman MA, Rehman A, Raza W, Raza M, Bilal MS, Abid HU. 2020. Management of *Phytophthora* species associated with citrus decline in Pakistan. International Journal of Botany Studies **5,** 98-103.

Jagtap GP, Dhavale MC, Dey U. 2012a. Evaluation of natural plant extracts, antagonists and fungicides in controlling root rot, collar rot, fruit (brown) rot and gummosis of citrus caused by *Phytophthora* spp. *in vitro*. International journal of Microbiology **1,** p 27-47.

Jagtap GP, Thosar RU, Dey U. 2012b. Evaluation of plant extracts and bioagents for the control of gummosis of mandarin orange (*Citrus reticulata* blanko) caused by *Phytophthora* species. African Journal of Agricultural Research **7,** 4553-4558.

Jung T, Blaschke H, Obwald W. 2000. Involvement of soilborne *Phytophthora* species in Central European oak decline and the effect of site factors on the disease. Plant Pathology **49,** 706-718.

Lende AS, Gade RM, Shitole AV. 2015. Management of *Phytophthora* root rot in Nagpur mandarin by using integrated approach. In: Proceedings of National Conference on Harmony with Nature in Context of Bioresources and Environmental Health. The Bioscan 332-336.

Leoni C, Ghini R. 2006. Sewage sludge effect on management of *Phytophthora nicotianae* in citrus. Crop Protection **25,** 10-22.

Li B, Liu P, Xie S, Yin R, Weng Q, Chen Q. 2015. Specific and Sensitive Detection of *Phytophthora nicotianae* by Nested PCR and Loop-mediated Isothermal Amplification Assays. Journal of Phytopathology **163,** 185-193.

Magnano di San Lio G, Cacciola SO, Marziano F, Pane A, Raudino F. 2002. Protezione integrata dell'agrumeto dalle malattie fungine. Informatore fitopatologico – La difesa delle piante **52**, 13-23.

Mekonen M, Ayalew A, Weldetsadik K, Seid A. 2000. Assessing and Measuring of Citrus gummosis (*Phytophthora* spp.) in Major Citrus Growing Areas of Ethiopia. Journal of Horticulture **2,** 1-4.

Melo JF, da Silva Martins E, Kupper KC. 2017. Production of antifungal compounds by Trichoderma spp. to control *Phytophthora nicotianae*, causal agent of gummosis on citrus. Citrus Research & Technology **36,** 37-46.

Meng Y, Zhang Q, Ding W, Shan W. 2014. *Phytophthora parasitica*: a model oomycete plant pathogen. Mycology **5,** 43-51.

Meng J, Wang Y. 2010. Rapid detection of *Phytophthora nicotianae* in infected tobacco tissues and soil samples based on its Ypt1 gene. Journal of Phytopathology **158,** 1-7.

M'hamdi NB, Benfradj N, Migliorini D, Luchi N, Santini A. 2018. *Phytophthora nicotianae* and *P. cryptogea* causing gummosis of citrus crops in Tunisia. Tropical plant pathology **43,** 36-48.

Mounde LG, Ateka EM, Kihurani AW, Wasilwa L, Thuranira EG. 2009. Occurrence and distribution of citrus gummosis (*Phytophthora spp.*) in Kenya. African Journal of Horticultural Science **2,** 56-68.

Naqvi SAMH, Singh S. 2002. Fungal diseases of citrus: Diagnosis and Management. Technical Bulletin National research Centre for citrus (NRCC) **5**, 61-67.

Naqvi SAMH. 2000. Managing *Phytophthora* diseases on citrus. Indian Horticulture **44,** 5-9.

Naqvi SAMH. 2004. Diagnosis and management of certain important fungal diseases of citrus. In Diseases of Fruits and Vegetables, Springer, Dordrecht **1**, p 247-290.

Naqvi SAMH. 2006. Distribution of citrus *Phytophthora* spp. and mating types pathogenic to citrus in Central India. Journal of Mycology and Plant Pathology **36,** 44-48.

Ohr HD, Menge JA. 2006. Diseases. UC IPM Online pest management guidelines: Citrus. UC ANR Publication 3441.

Prigigallo MI, Mosca S, Cacciola SO, Cooke DE, Schena L. 2015. Molecular analysis of *Phytophthora* diversity in nursery-grown ornamental and fruit plants. Plant pathology **64,** 1308-1319.

Quyet NT, Cuong HV, Hong LT, Soytong K. 2016. Control mechanism of *Chaetomium* spp. and its biological control of Citrus root rot in pot and field experiments in Vietnam. Journal of Agricultural Technology **12,** 329-336.

Rajput NA, Zhang M, Shen D, Liu T, Zhang Q, Ru Y, Sun P, Dou D. 2015. Overexpression of a *Phytophthora* Cytoplasmic CRN Effector Confers Resistance to Disease, Salinity and Drought in *Nicotiana benthamiana*. Plant and Cell Physiology **56,** 2423-2435.

Rather TR, Razdan VK, Tewari AK, Shanaz E, Bhat ZA, Hassan MG, Wani TA. 2012. Integrated management of wilt complex disease in bell pepper (*Capsicum annuum L.).* Journal of agricultural science **4,** 141-147.

Ristaino JB, Gumpertz ML. 2000. New frontiers in the study of dispersal and spatial analysis of epidemics cause by species in the genus *Phytophthora*. Annual Review of Phytopathology **38,** 541–576.

Sadeghy B, Salari M, Shahidi Bonjar GH, Panjekeh N, Aminnaee M. 2014. A preliminary study of biological control of citrus gummosis by soil-borne *Streptomyces* sp. isolates *in vitro* condition. Archives of Phytopathology and Plant Protection **47,** 774-779.

Santos AF dos, Luz EDMN, Souza JT. 2005. *Phytophthora nicotianae*: agente etiológico da gomose da acácia negra no Brasil. Fitopatologia Brasileira **30,** 81–84.

Savita GS, Nagpal A. 2012. Citrus diseases caused by *Phytophthora* species. Green Earth Research Foundation Bulletin of Biosciences **3,** 18-27.

Schillaci G, Caruso L. 2006. Problematiche della difesa meccanizzata degli agrumi nel bacino del mediterraneo. Informatore Fitopatologico-La difesa delle piante **56,** 21-24.

Swingle W T, Reece PC. 1967. The botany of Citrus and its wild relatives. In: Reuther W, Webber HJ, Batchelor LD (eds) The Citrus Industry, History, world distribution, botany, and varieties, Revised Edition. University of California Press, Berkeley **1,** p 190-430.

Timmer LW, Peever TL, Solel Z, Akimitsu K. 2003. Alternaria diseases of citrus novel pathosystems. Phytopathologia Mediterranea **42,** 99–112.

Tomita N, Mori Y, Kanda H, Notomi T. 2008. Loop-mediated isothermal amplification (LAMP) of gene sequences and simple visual detection of products. Nature Protocols **3,** 877- 882.

Vannini A, Brown A, Brasier C, Vettraino AM. 2009. The search for *Phytophthora* centers of origin: *Phytophthora* species in mountain ecosystems in Nepal. Phytophthoras in Forests and Natural Ecosystems p 54-61.

Wagh SP, Gade RM, Lad RS, Adinarayana J, Phanindra KBVN. 2018. Epidemiological relations to population dynamics of *Phytophthora spp*. in mandarin. Indian Phytopathology **71,** 213-218.

Wu GA, Terol J, Ibanez V, López-García A, Pérez-román E, Borredá C, Domingo C, Tadeo FR, Carbonell-caballero J, Alonso, R, Curk F, Du D, Ollitrault P, Roose ML, Dopazo J, Gmitter FG, Rokhsar DS, Talon M. 2018. Genomics of the origin and evolution of Citrus. Nature **554,** 311–316.

Zitko SE, Timmer LW, Sandler HA. 1991. Isolation of *Phytophthora palmivora* pathogenic to citrus in Florida. Plant Disease **75,** 532-535.