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Revealing the current scenario and prospective outlook of citrus gummosis in Pakistan

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ABSTRACT

Citrus is an important fruit crop in terms of economic and nutritional value. *Citrus* production is threatened by many biotic and abiotic factors. Among the biotic factors, Brown rot, gummosis, and root rot are common prevailing diseases around the globe. Gummosis is one of the primary diseases that cause damage to citrus orchards. *Citrus gummosis*, caused by *Phytophthora citrophthora*, is widely distributed in citrus-growing areas of Pakistan. The affected plants show signs of decline, including twig die-back, chlorosis, wilted leaves, tips, and discolored fruits. Symptoms manifest visibly on the aerial parts of the tree in close proximity to the soil. The presence of cracks and cankers can be observed on the trunk, branches, and bark, often accompanied by the exudation of gum. The branches exhibit a characteristic bleeding appearance. Given that the pathogen is soil-borne, the symptoms typically progress from the base of the tree upwards, affecting both primary and secondary branches. As the severity of the infection increases, necrosis of taproots and crowns becomes apparent, leading to the expansion of necrotic lesions. Finally, the tree experiences a decline in health, culminating in death. Although the preventive or therapeuticcontrol of citrus gummosis cannot be guaranteed by chemical and horticultural measures, the utilization of resistant rootstocks remains the most dependable management strategy for destructivethe disease. It is imperative to assess phytoextracts for their efficacy against this particular pathogen in order to identify an eco-friendly method for managing citrus gummosis disease. The geographical pattern of gummosis disease has the potential to be utilized in developing predictive models and designing effective disease management strategies.

Pakistan'da turunçgillerde gözlenen zamk akıntısı hastalığının mevcut ve gelecekteki durumunun ortaya konulması

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ÖZET

Narenciye ekonomik ve besin değerleri açısından önemli bir meyve bitkisidir. Narenciye üretimi birçok biyotik ve abiyotik faktör tarafından tehdit edilmektedir. Biyotik faktörler arasında Kahverengi çürüklüğü, diş eti çürüğü ve kök çürüklüğü dünya çapında yaygın olarak görülen hastalıklardır. Gummosis, narenciye bahçelerine zarar veren hastalıkların başında gelmektedir. *Phytophthora citropphthora'nın* neden olduğu narenciye gummosis'i Pakistan'ın narenciye yetiştirilen bölgelerinde yaygın olarak görülmektedir. Etkilenen bitkiler, dalların ölmesi, kloroz, solmuş yapraklar, uçlar ve renksiz meyveler dahil olmak üzere düşüş belirtileri göstermektedir. Belirtiler ağacın toprağa yakın toprak üstü kısımlarında gözle görülür şekilde ortaya çıkar. Gövde, dallar ve ağaç kabuğunda çatlaklar ve kanserlerin varlığı gözlemlenebilir ve buna sıklıkla sakız sızıntısı da eşlik eder. Dallar karakteristik bir sıvı akıntısı görünümü sergiler. Patojenin toprak kaynaklı olduğu göz önüne alındığında, semptomlar tipik olarak ağacın tabanından yukarıya doğru ilerleyerek hem birincil hem de ikincil dalları etkiler. Enfeksiyonun şiddeti arttıkça, kazık köklerde ve kronlarda nekroz belirgin hale gelir ve bu da nekrotik lezyonların genişlemesine yol açar. Ağaçta hastalık hali ve sonucunda ölüm gözlenir. Narenciye gummosisinin önleyici veya iyileştirici kontrolü kimyasal ve kültürel önlemleriyle garanti edilemese de, dayanıklı anaçların kullanılması hastalıkla mücadelede en güvenilir yönetim stratejisi olmaya devam etmektedir. Narenciye gummosis hastalığının mücadelesi için çevre dostu bir yöntem belirlemek amacıyla bitkisel kökenli ekstratları bu özel patojene karşı etkinlikleri açısından değerlendirilmesi zorunludur. Gumoz hastalığının coğrafi yapısı, öngörücü modellerin geliştirilmesinde ve etkili hastalık yönetimi stratejilerinin tasarlanmasında kullanılma potansiyeline sahiptir.

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1. Introduction

One of the most significant fruit crops worldwide is citrus, which is a member of the *Rutaceae* family having 130 genera and 7 sub-families (Mubeen et al., 2015a, b; Khan, 2015). It is usually grown in tropical and subtropical regions of the world (Mubeen et al., 2024). The correlation between soil infestation by *P. nicotianae* and the severity of root rot suggests that indirect germination plays a more significant role in the life cycle (Ahmed et al., 2012). In comparison with other fruits, antioxidants are more abundant in citrus, catalyzing our immune system and triggering protection from life-threatening diseases (Rafiq et al., 2018). Citrus can be grown in Pakistan due to its good soil and favorable climate. There was a time when Pakistan was ranked 13th but dropped to 16th by the end of 2020 with an annual production of 2.89 million metric tons (FAO, 2020). Different commercially grown citrus cultivars in Pakistan include Kinnow mandarin (*Citrus reticulata* Blanco), Mosambi (*C. sinensis* (L) Osb.), grapefruit (*C. paradise* Macf.), lemon (*C. limon* (L) Burm), lime (*C. aurantifolia* (Christm) swingle), and sweet lime (*C. limettioides* Tanaka). Kinnow and Feutrell's Early represent 80% of all citrus cultivars grown in Pakistan (Iftikhar et al., 2021). Citrus is cultivated in all provinces of the country, with Punjab having favorable growing conditions and contributing over 95% of total citrus production (Rasool et al., 2020). Punjab, Pakistan, produces 2,315,895 tons annually, which is 98% of the total national production, with Kinnow occupying 70% of the share (FAO, 2020).

Citrus production accounts for 34% of the total fruit production in the country. *Citrus* production in Pakistan is lower than that of neighboring countries like China and India. Citrus yield per hectare in Pakistan is 10-12 tons compared to up to 26 tons per hectare in other citrus-producing countries worldwide (Iqbal, 2014). This decline in citrus production is attributed to numerous abiotic and biotic factors. Among the biotic factors, *citrus tristeza virüs (CTV)*, citrus viruses and viroids, citrus greening disease, citrus canker, and Gummosis have been reported as major contributors to citrus decline (Iftikhar et al., 2022; Sajid et al., 2022; Riasat et al., 2020; Nauman et al., 2023; Ali et al., 2022; Ali et al., 2023). Due to numerous fungal infections that can affect citrus, the crop suffers enormous losses. The occurrence of a specific pathogen, its virulence, survival, and spread are directed by soil type, varietal susceptibility and agro-climatic conditions. Among fungal diseases, soil-borne diseases of citrus are widely distributed. The soil-borne plant pathogen becomes an endemic problem in a given location once it enters, especially if there are vulnerable hosts and ideal environmental circumstances for its growth and reproduction. *Phytophthora* spp. is widely spread in citrus-growing regions of Punjab and poses a threat to citrus production. *Phytophthora citrophthora* is prevalent in all citrus-growing areas of Pakistan. Regular monitoring of the fungus is lacking in Pakistan. The limited literature is available on the effect of gummosis disease on citrus plants in Pakistan. Chemical controls on the pathogen become an ongoing expense and environmental problem. Chemicals used to control soil-borne plant diseases may lead to the development of resistance (Nauman et al., 2023).

2. Important fungal pathogens of *Citrus*

Citrus fruit is susceptible to many fungal pathogens that cause significant crop losses. Agroclimatic conditions, varietal resistance, and soil type are factors involved in the appearance of pathogens, their survival, spread, and threshold level of damage. Soil-borne fungal diseases in citrus are widespread, while foliage diseases depend on the weather. Fusarium dry rot is an important soil-borne fungal disease caused by *Fusarium solani*, affecting the plant's root system and reducing its nutritional uptake ability. This fungus also produces toxins that move in the plant's xylem system, causing vessel plugging. Other fungal pathogens involved in soil-borne diseases are *Diplodia natalensis*, *Armillaria mellea*, *Pythium* spp., and *Thielaviopsis basicola*, which have a negative effect on yield. Mal secco is a vascular disease caused by the fungus *Phomatra cheiphila*, first observed in Greece in the 1880s. It enters the stomata systemically and occupies the xylem, leading to wilting, discoloration of wood, veinal chlorosis, leaf wilting, and twig die-back. Soil-borne infections caused by *Phytophthora* spp. and post-harvest pathogens are widespread, leading to heavy yield losses. Infections in producing trees cause canopy decay, leaf chlorosis defoliation, and reduction in production and fruit quality. Brown spot of citrus, stem-end rot of citrus, and black rot of citrus are well-known diseases that produce brown to black spots on fruit and leaves. Black rot infects the fruit internally. These diseases are caused by *Alternaria citri*. Citrus melanose is an important fruit and foliar disease caused by *Diporthe citri*, resulting in tear drops, blemishes, and mud cake symptoms. It does not affect the fruit pulp but reduces its market value. Citrus scab is caused by Elsinoë australis, affecting citrus fruit, leaves, and shoots under warm and humid weather conditions. Several species of *Colletotrichum* cause important diseases of citrus, with citrus anthracnose being a significant disease characterized by withering twigs and lesions on fruits and leaves. Numerous fruits produced by citrus species are consumed worldwide. However, several pathogenic fungi, such as *Penicillium italicum*, *Penicillium digitatum*, *Geotrichumcitri-aurantii*, *Aspergillus flavus*, and *Aspergillus niger*, can cause postharvest decay in citrus fruits (Iqbal, 2014; Ali et al., 2022; Ali et al., 2023).

3. *Phytophthora* species

Phytophthora species are commonly found not only in citrus-growing areas around the world but also in Pakistan (Lad et al., 2020). There are about 70 species in the genus *Phytophthora*, family Pythiaceae of phylum Oomycota under the kingdom Stramenopila. *P. boehmeriae Sawada, P. cinnamomic, P. cactorum Schröeter, P. citrophthora, Leonian, P. citricola Sawada, P. megasperma Drechsler, P. hibernalis Carne, P. nicotianae* van Breda de Haan (*P. parasitica* Dastur), *P. syringae* Klebahn, and *P. palmivora* Butler are the key species that pose a threat to citrus trees worldwide. The most prevalent species in citrus orchards are *P. citrophthora* and *P. nicotianae*. Gummosis caused by *Phytophthora* species has been identified as a significant barrier to maintaining optimal output, reducing plant yield by 46% annually (Dandurand and Menge, 1993). It is responsible for 10 to 30% of global citrus crop losses (Timmer et al., 2000; Rajput et al., 2020). The term "*Phytophthora*" is of Greek origin and means "plant-destroyer" (Riisberg et al., 2009).

Phytophthora spp. cause root rot, foot rot, crown rot, and gummosis in citrus orchards. These diseases are caused by several *Phytophthora* species (Wagh et al., 2018; Verniere et al., 2004), but among them, the most widespread and devastating are *Phytophthora citrophthora* and *Phytophthora nicotianae* (var. *parasitica*) (Erwin and Ribeiro, 1996; Graham and Timmer, 2011; Gade, 2012). In citrus groves, fibrous root rot and gummosis have been the cause of tree decline and yield losses. The two *Phytophthora* species cause similar diseases, making it difficult to differentiate them based on host symptoms. Generally, *P. citrophthora* causes root and collar rots in cooler areas and is more abundant than other *Phytophthora* species (Mound et al., 2012).

4. Symptomology

Bark infection commonly emerge in close proximity to the soil level, presenting as lesions at the trunk or crown that encircle the tree by forming a belt around its circumference. This infection then spreads to secondary branches, leading to the dieback of trees, as documented in previous studies involving clementine cultivars and their hybrids. Gum exudations and cankers are often observed on the aboveground portions, especially on main branches (Alvarez et al., 2008). The fungus has an active mode of entry, and its haustoria invade intercellular and intracellular spaces. Root discoloration, leaves yellowing, wilting of plants, and hardly any growth of capillary roots are the symptoms of *Phytophthora* gummosis (Rehman et al., 2022). Foot rot lesions develop on the trunk to a height of 60 cm from the ground, extending to the roots of the crown as crown rot below the ground. Brown discolored, slippery areas were observed when the dead bark of the lesions was rubbed. The spots were soggy and dark, mostly hollow and greasy. Such active lesions began to ooze gum. This was observable on the trunk as brownish-black blotches known as gummosis (Das et al., 2016).

In the dry season, the dead bark became firm, shredded, curled, and split. In severe cases, rot of conductive tissue near the bark damage a substantial portion of the root system and killed long branches of the diseased plant. Citrus fruits can also be infected by spores that erupt from the soil, causing a hard, leathery, brown rot with a strong odor of fermentation (Naqvi, 2004). Symptoms of gummosis disappear with abundant rainfall but persist during periods of drought. These symptoms gradually deteriorate along the edge of the tree trunk and are often accompanied by leaf symptoms such as a pale color and yellowing of leaves. Once infection stops, the lesion stops spreading, and the injured bark region becomes enclosed by callus tissue. Young plants and recent saplings in nurseries die rapidly due to their small stem diameters. Mature trees have higher tolerance levels, although dieback can occur at times. In orchards, trunk infections commonly only partially affect the trees, accompanied by the shedding of leaves and withering of branches in severe instances (Alvarez et al., 2008). The pathogen rarely attacks leaves in comparison to fruits. Yet, when the weather conditions are favorable, translucent dotted-like frost symptoms might show up on the surfaces of leaves. These symptoms become blackish and watery with time, and the green leaves fall prematurely (but dotted with black). Total removal of leaves might happen (Fadli et al., 2022).

5. Disease life cycle of *Phytophthora*

Phytophthora spp. Produces and disperses a significant amount of zoospores, oospores, and chlamydospores. In favorable conditions (30-32°C), zoospores transform into cysts and then into mycelium. Mild water shortages (-5 to -70 kPa), lack of nutrients, and light stimulate the formation of sporangia from mycelium, which has the ability to sprout either indirectly or directly to harvest zoospores. The interaction between soil infestation by *P. nicotianae* and the severity of root rot suggests that indirect germination plays a more significant role in the life cycle (Figure 1) (Fadli et al., 2022).

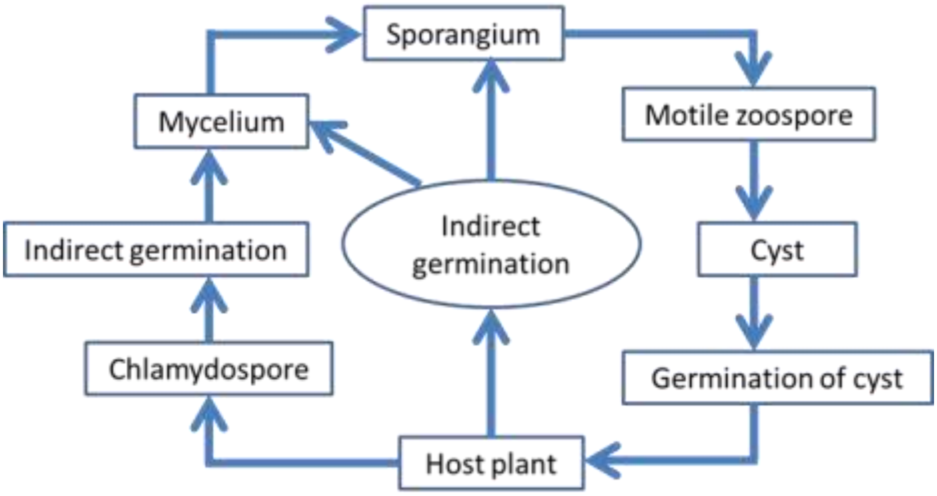

Figure 1. Disease Life cycle of *Phytophthora* spp.

6. *Phytophthora* isolation, disease incidence and pathogenicity

Twelve *Phytophthora* species have been identified as capable of infecting citrus globally, including *P. capsici, P. boehmeriae, P. citricola, P. cinnamomi, P. drechsleri, P. citrophthora, P. hibernalis, P. palmivora, P. megasperma, P. syringae* and *P. Nicotianae* (Erwin and Ribeiro, 1996). Timmer et al. (1998), discussed citrus diseases caused by *Phytophthora* spp., in Florida. They discussed gummosis, damping off, brown rot, fibrous root rot of foot rot of fruits. Smiley et al. (1999), reported collar rot and root rot diseases of ornamental plants caused by *Phytophthora* spp. *Phytophthora* is a water mold, so in poorly drained soil, its disease-causing ability is high. *Phytophthora cactorum* causes collar rot, while *P. cinnamomi* is the causal organism of root rot. Andres et al. (2003), checked the pathogenicity of *Phytophthora nicotianae* against pepper in Spain. In Spain, Alvarez et al. (2008) conducted a study on the branch cancers found on citrus trees. The cause of these cankers was identified as *Phytophthora citrophthora*. The great citrus losses had been determined inside the essential citrus growing areas of Spain. Cacciola and San Lio (2008), reported the citrus diseases caused by *Phytophthora* responsible for root rot, citrus gummosis, and brown fruit rot. They observed the different aspects of ecology and biology of *Phytophthora* spp., such as *P. citrophthora* and *P. nicotianae*. The spread of inoculum, reproduction, and epidemiology of the fungus was discussed.

Biological and instrumental diagnoses, along with regular laboratory tests, were examined for monitoring procedures, population dynamics and sampling. Mounde et al. (2009) described the distribution of citrus gummosis caused by *Phytophthora* species in Kenya. Citrus gummosis was widely distributed in citrus-producing areas of Kenya. The disease was found in different cultivars of citrus in Kenya. *Phytophthora* gummosis produced a considerable loss in major citrus growing areas of the country. Orlikowski et al. (2009), conducted a study to detect whether water is a source for spreading *Phytophthora* spp. to infect horticultural plants in Poland. Tennant et al. (2009), while studying various citrus diseases found *Phytophthora citrophthora* as the major inducer of gummosis and brown rot of trunk and major limbs. Molina et al. (2014) isolated the causal agent of crown rot of red pepper, which is *Phytophthora nicotianae* in Spain. Yaseen et al. (2010), examined the predominant *Phytophthora* species in citrus orchards in Syria. Razi et al. (2011), studied citrus plant nutritional profile in relation to Huanglongbin (HLB) prevalence in Pakistan. He suggested that poor crop nutrition alters the genetic resistance of plants to invading pathogens, reduces yield, and shortens the productive life of the plant. This study suggested that there is no relationship between the state of nutrient deficiency and the incidence of HLB in citrus; however, nutritional treatments can help relieve stress on infected plants.

Ahmed et al. (2012) studied the most common *Phytophthora* spp., in citrus nurseries in Egypt. Jagtap et al. (2012) conducted a large survey in different regions in India. In another study, Savita & Nagpal (2012) investigated different citrus diseases caused by *Phytophthora* spp., in India. Bawage and colleagues (2013) conducted research on the morphological and molecular characterization of *Phytophthora* spp., obtained from citrus orchards in India. Mounde et al. (2012) morphologically characterized and identified *Phytophthora* spp., associated with citrus gummosis in Kenya. Vicent et al. (2012) conducted research on the correlation between agronomic variables and occurrences of citrus *Phytophthora* cancer in the southwestern region of Spain.This study suggested that disease occurrence was not associated to genetic drift or changes in host specificity in the *P. citrophthora*. Cultural practices, such as pruning, regulated deficit irrigation, supplemental phosphonate spraying, as well as abiotic and pathological factors like frost damage and the presence of brown rot of fruit, did not show a significant correlation with the occurrence of the disease. Ali et al. (2015) conducted a survey in main citrus cultivated areas of Punjab, Pakistan in 2006-07 to examine the association between different pathogens, which may cause citrus decline. This study investigated the association between phytoplasma, fungi, and bacteria in plants suffering from citrus dieback in Punjab. Mahdavian & Javadi (2014) in Mazandran province of Iran studied crown and root rot of citrus. A survey of different orchards was conducted, and disease samples were collected from infected orchards. Isolation was performed from disease specimens. Isolated pathogens were *Phytophthora nicotianae* and *P. citrophthora*. Brentu and Vicent (2015), studied *Citrus gummosis* in Ghana. In Ghana, citrus trees were severely affected by gummosis, which caused tree death followed by trunk cankers. Trunk canker disease was originally associated with *P. parasitica*, but recently with *P. citrophthora*. Graham and Feichtenberger (2015), discovered *Phytophthora* spp., in nearly every citrus orchard in

Florida and Brazil, and *Phytophthora*-triggered diseases, particularly root rot can cause economically significant crop losses. Losses related to root rot diseases were difficult to estimate because fibrous root damage and yield loss were not always directly proportional. Hung et al. (2015), identified *Phytophthora* spp., as the causative organism of citrus root rot in Thailand. Khan et al. (2015), carried out a study for the identification and characterization of pathogens involved in the degradation of citrus fruit quality. Different fungi were identified up to the genus level by their macroscopic and microscopic characteristics. Mekonen et al. (2015), found that citrus production in Ethiopia is threatened by a number of biotic and abiotic factors.

Among these, citrus fruits, gummosis was one of the most important biotic limitations in the country. Roberts et al. (2015), discussed diseases of vegetables produced by *Phytophthora capsici* in Florida. In his study, he discussed disease symptoms, disease cycle, and management of *Phytophthora* fruit rot, *Phytophthora* blight, *Phytophthora* root and crown rot produced in tomato, eggplant, pepper, watermelon, and other cucurbits. Boudoudou et al. (2024), studied the influence of *Phytophthora* spp. on citrus rootstock in the Gharb region. Das et al. (2016), also detected, identified, and characterized *Phytophthora* spp. infecting citrus in India. *P. nicotianae* was found to be the predominant species followed by *P. palmivora* and *P. citrophthora* in five major citrus-growing states of India. Hao et al. (2019), evaluated the brown rot pathogen of citrus fruit in California. *Phytophthora syringae, P. citrophthora, P. nicotianae*, and the little-known *P. hibernalis* were found as the main causal pathogens of citrus brown rot. Fateh et al. (2017), described the incidence of citrus decline in Pakistan. He suggested that the quantity and quality of fruit produced were low due to the attack of different pathogens and enhanced the magnitude of the disease in the presence of abiotic factors. Among the biotic factors, different diseases caused by different pathogens lead to citrus decline. Hao et al. (2019) conducted studies in California and other citrus-growing regions and identified *Phytophthora* root rot as a significant disease. Citrus gummosis and associated difficulties for the citrus business in Pakistan were examined by Rajput et al. (2020). They discovered that a soil-borne *Phytophthora* species was posing a threat to all citrus-producing regions. Numerous *Phytophthora* species were in charge of the citrus gummosis, which caused significant crop losses every year and spread around the world. The diseased tree displayed decline symptoms along with leaf chlorosis, twig dieback, discolored or poorly colored fruits, wilting of the tips, and withering of the leaves. Desiccation, gummosis, defoliation, and browning of the cortex were all visible in the infected twigs. Munir et al. (2022), stated in his study that early detection of citrus diseases and pests was essential for effective phytosanitary control and plant health. Citrus productivity was hampered by the numerous illnesses brought on by fungi, bacteria, viruses, and pests.

7. Management of *Phytophthora gummosis*

Dandurand & Menge (1993), studied how *Fusarium solani* affects citrus root growth and the population dynamics of *P. parasitica* and *P. citropathora*. In relation to the usage of systemic fungicides for the management of trunk gummosis, root rot, and brown rot of fruits, they also reviewed the chemical control strategies. Gade and Koche in 2012 carried out a study to compare different combinations of fungicides, biocontrol agents, and organic amendments to manage gummosis and root rot in mandarin caused by *Phytophthora* spp. This study was conducted in citrus-affected orchards with root rot and gummosis. Root rot intensity was significantly reduced in the experiment. Jagtap et al. (2012), also investigated various biocontrol agents and plant extracts for controlling citrus gummosis caused by *Phytophthora* spp. They used leaf extracts of *Neem*, *Acacia*, *Eucalyptus*, *Mehendi*, *Dhatura*, *Glyricida*, and *Lantana*. Different biocontrol agents such as *Trichoderma* spp. and *Pseudomonas fluorescens* were used to evaluate in vitro through dual culture and poisoned food techniques. *Eucalyptus* was found to be the best biocontrol agent against fungal growth among all the plant extracts. Roberts et al. (2015), studied disease symptoms, disease cycle, and management of *Phytophthora* fruit rot, *Phytophthora* blight, *Phytophthora* root, and crown rot produced in tomato, eggplant, pepper, watermelon, and other cucurbits in Florida. Management included the production of disease-free material, seed treatment, well drainage, fumigation of soil, and disinfection of equipment and hands of workers. Thakre et al. (2017), evaluated different fungicides against *Phytophthora* spp., in Madhya Pradesh, India. Bordeaux mixture was found to be the best option for controlling *Phytophthora* spp. in this study. Jaouad et al. (2020), worked on root rot and dry root rot, respectively caused by *Phytophthora* spp. and *Fusarium* spp. They determined that the usage of chemicals was necessary for citrus pest control.

The most effective strategy for reducing the damaging impacts of pesticides on the environment is to utilize integrated orchard management techniques. To treat *Phytophthora* root rot, two fungicides, Fosetyl-Al and Metalaxyl, were frequently utilized. Additionally, the control of *Fusarium* species caused dry root rot disease necessitated the optimization of irrigation and fertilization inputs. Rajput et al. (2020), evaluated many strategies to manage gummosis as they increased the danger of pathogen adaptation and adverse effects on animal and human health including ecology. Many chemicals that have been used routinely are now being questioned in many respects. Choudhary et al. (2021), reported that the most significant citrus disease was foot rot/gummosis, which was brought on by *Phytophthora* spp. and caused yield losses of 10 to 30% in fruit production in major citrus-growing nations. The current study was conducted to assess various native *Trichoderma* spp. powerful strains against citrus foot rot/gummosis in light of the disease load. da Silva et al. (2021), worked on foot rot or gummosis, fruit brown rot and fibrous root rot disease that attacked the fruits, roots and trunk citrus trees caused by *Phytophthora* spp. and resulted in significant financial losses. This study offered an updated systematic analysis of the tactics used to control *Phytophthora* diseases and citrus defense mechanisms applying a novel search strategy based on a clear, thorough, and open methodology. Heydari et al. (2007), Keswani et al. (2014), Bisen et al. (2015), described the side effects of chemicals. They concluded that chemicals are deteriorating the environment, causing harmful effects on people, and killing non-target organisms, including bio-control agents. In healthy and gummosis-infected plant cells, Iftikhar et al. (2022), assessed the total soluble phenols, total soluble sugars, antioxidants, and minerals like zinc, iron, and manganese. Infected plant tissues contained more antioxidant enzymes than healthy plant tissues. Management of citrus gummosis/foot rot by using chemicals, bioagents, and plant extracts has been mentioned in Table 1 (Singh et al., 2015).

Table 1. Effects of chemicals, bioagents, and plant extracts on yield and canopy, and management of *citrus gummosis*/foot rot in sweet orange cv Blood Red.

Treatments	Citrus gummosis/foot rot lesion size recovery rate (%)			Fruit yield (*kg/plant*)		Canopy volume (m^3)		Yield increase (%)
	2012	2013	2014	2012	2014	2012	2014	
Bordeaux paste + copper oxychloride @ 0.3% spray (recommended dose)	31.7	36.4	38.4	43.5	44.6	15.1	15.6	2.5
Bordeaux paste (2 Kg copper sulphate +3 Kg lime +30 l water)	10.9	14.5	18.5	43.1	44.1	15.1	15.2	2.3
Bordeaux paste @ 25 g/l + metalaxyl M @ 2.5 g/l (soil application)	54.6	57.6	59.6	45.1	49.1	15.2	15.9	8.8
Bordeaux paste + metalaxyl M (soil application) + copper oxychloride @ 0.3% spray	63.0	66.7	69.6	46.3	50.7	15.5	16.5	9.5
Metalaxyl M paste @ 25 g/l + metalaxyl M (soil application) @ 2.5g/l	73.3	77.8	83.3	46.5	56.8	15.8	16.7	22.2
Metalaxyl M paste @ 25 g/l + metalaxyl M (soil application) @ 2.5g/l + Fosetyl Al @ 0.1% spray	75.0	80.0	88.9	46.7	58.5	15.9	16.9	26.3
Bordeaux paste + *Trichoderma harzianum* (soil application)	30.0	33.0	33.3	43.3	44.8	15.2	15.6	2.7
Bordeaux paste + *Trichoderma harzianum* (soil application) + copper oxychloride @ 0.3% spray	49.3	51.7	54.7	43.6	45.4	15.7	15.7	2.7
Garlic bulb extract (20%,w/v) pasting + garlic bulb extract (10%,w/v) spray	37.3	42.3	47.4	44.1	45.8	15.2	15.3	3.9
Neem seed kernel extract (20%,w/v) pasting + neem seed kernel extract (10%,w/v) spray	35.7	38.8	45.3	43.6	45.5	15.1	15.2	3.6
Bordeaux paste + metalaxyl M (soil application) @ 2.5g/l + Fosetyl al spray @ 0.1%	65.0	71.1	76.7	46.5	54.1	15.6	16.6	16.3
Untreated control	-11.5	-12.9	-16.7	42.7	40.1	15.1	15.0	-6.08
CD at (P = 0.05)	9.6	6.9	7.4	2.94	3.86	NS	NS	

8. Conclusion and future prospects

P. citrophthora severly influenced not only the fruit production but also the fruit quality. Until now, utilizing disease-resistant rootstocks continues to be one of the most efficient and eco-friendly ways to avoid *Phytophthora* diseases while decreasing the reliance on harmful chemicals. Future molecular technologies and advanced biochemical analyses will offer greater insights into *Phytophthora-citrus* interactions, taking towads towards an improved understanding of the pathosystem and the development of more targeted breeding strategies for controlling *Phytophthora* diseases in *citrus*. *Citrus gummosis* management can be done effectively through botanical extracts. We need to enhance our understanding of the molecular mechanisms behind disease development, which will aid in developing sustainable and targeted control strategies for *P. citrophthora*. More research is need of the time to study the detailed impact of *P. citrophthora* on the physiology of citrus.

Author Contributions

A.M.B. and H.M.U.: Conceptualization, writing original draft, and Figure preparations.

A.I., M.T., M.M.K., M.I.Z., A.A. and T.S.: Project administration, collecting literature, writing–review & editing, finalization, validation and visualization.

Conflict of interest statement

The authors declare that the research was carried without any commercial or financial relationships that could be construed as a potential conflict of interest.

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