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ETIOLOGY, EPIDEMIOLOGY AND MANAGEMENT OF CITRUS BLACK ROT CAUSED BY ALTERNARIA CITRI- AN OUTLOOK

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ABSTRACT

Citrus is an important fruit crop of the world. It is the most important commercial fruit crop having higher moisture contents and nutrient composition. Citrus losses are mainly due to diseases that highly affect their quality and quantity. Black rot of fruit caused by *Alternaria citri*, is a significant fungal disease of citrus that causes severe losses in citrus orchards of the world. It affects most of the members of the citrus family and often causes severe losses. The disease primarily affects the aboveground parts of plants, leaves explicitly, and fruits. The first symptoms, however, usually appear on the leaves as black necrotic lesions. Later black necrotic lesions are also formed on fruits, and with the age of plants, the fruits become soft and black rot. The disease has been controlled by cultural practices and by growing resistant cultivars that do not allow the entry of the pathogen. Preharvest fungicides are also applied to prevent the disease but are not highly effective. Postharvest sprays with fungicides have also controlled the disease. However, fungicides are not eco-friendly, and demands for alternatives are arising. Other options are the application of biological control agents; however, biological agents are not effective under field conditions. The present review summarizes the current status of black rot of citrus and its management strategies.

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INTRODUCTION

Citrus is the most important commercial fruit crop having higher moisture contents and nutrient composition. Citrus fruit is a mix of acidic and sweet fruit that belongs to the family *Rutaceae,* generally from the genus Citrus. It attracts the consumer due to its refreshing taste and many vitamins A, B, and C. It is a perishable crop with low pH and is very susceptible to disease (Mubeen et al., 2015a). The common sweet oranges are widely grown and commercially important and constitute about two-thirds of orange production worldwide. The most popular orange varieties are the Navel and Valencia (Anwaar et al., 2020). The world with a total plantation area of 8.6453 million hectares giving 128 million tones production during the crop year 2018-19 (Iftikhar et al., 2020). The harvesting of citrus is very critical, as the fruit may be affected by improper handling, transportation, storage, and marketing resulting in decay. The pathogenic fungi destroy the fruit by producing mycotoxins and make them unfit for consumption (Mubeen et al., 2015b). In the fresh fruit market, the infected fruits lose their commercial value. Many diseases attack citrus, and a large number of pathogens are involved causing serious economic losses. Fungi are destructive pathogens of citrus diseases (Singh. D. and Jain, 2004). Greening, canker, Tristeza virus, wither tip, slow decline (citrus nematode), gummosis, spreading decline (burrowing nematode), *Alternaria* brown rot, greasy spot, *Phytophthora* diseases, fruit blemishes, and postharvest decay are common diseases of citrus (Zaragoza and Alonso, 1975). Black rot of citrus is caused by *A. citri,* which causes serious economic losses in citrus production. Black rot of citrus is widespread and more severe in humid climates. The pathogen infects the leaves, branches, twigs, and fruits. It produces black necrotic lesions on twigs, young leaves, branches, and fruits. The fruit may dry and become black to brown in appearance (Smith et al., 1997). Timmer et al. (2000) introduced *Alternaria* black rot caused by *A. citri* in Florida citrus groves about 35 years ago. The disease was also reported in Australia in 1903 on Emperor Mandarins. It is still a mystery how this disease arrived in Florida, but it may develop locally from other *Alternaria* spp. or imported from other locations. *Alternaria* black rot has been reported in South Africa, Turkey, Israel, Iran, Spain, Italy, Greece, Brazil, Argentina, Peru, and Colombia. The disease occurs in other countries that grow susceptible varieties. The disease can severely affect citrus fruits. The fungus is present throughout the citrus-producing areas of the world. Fruits are susceptible to infection in mid-summer. In many countries of the world, citrus is damaged by *Alternaria* brown spot (Berraf-Tebbal et al., 2020; Timmer et al., 2000). Black rot of citrus is a fungal disease caused by *A. citri*. *Alternaria* mostly attacks citrus fruit. *Alternaria* rot is a postharvest disease and the most damaging in those areas where citrus is processed for juice because the juice is contaminated by masses of black fungal mycelium (Arras and Piga, 1995; Vitale et al., 2021). *Alternaria* is the most severe pathogen of citrus in India. It is reported that this pathogen is the cause of citrus fruit blemishes in India. This pathogen causes deep infection in many areas, and if no control measures are adopted, it may cause fruit decay. This disease is controlled by suitable cultural practices, proper irrigation, and chemicals (Peever et al., 2004). *A. citri* is an ascomycete fungal pathogen that causes black rot in citrus plants. Almost all species of citrus are susceptible hosts for this pathogen. Under an ideal environment, the host is more susceptible to this disease, especially in wet weather conditions that are more favorable for rapid growth. A black hypha is formed on the plant's surface, which shows the actual pathogen (Miri et al., 2018). The disease is usually controlled by different fungicides (Canihos et al., 1999). Mancozeb and copper-based fungicides are used to control the disease. However, due to their accumulation in the soil, copper-based fungicides may create health hazards. Various non-chemical control measures have been tested and found effective in controlling plant diseases. The mandarins are the loose-skinned oranges belonging to the species *Citrus reticulata* Blanco (Niaz, 2004). Kinnow demands a shorter crop season (December to April) at the start of winter. The production of citrus fruits in large quantities over a short harvesting period increases the risk of high postharvest losses. The postharvest losses are significantly higher and range 35-40% (PHDEB, 2006). The main problems of the citrus are the attack of the insects and pests and less production with inferior quality. The availability of the low quality of the nursery stock, disease-infected seeds, and poor cultural practices are the main causes for the underdevelopment of this sector (Alférez et al., 2003; Chen et al., 2020). Among all other crucial pathogens, *A. citri* also causes different pathogenic disorders in the foliage, fruits, and overall canopy of the citrus, mainly including the rotting of citrus fruits (Ellis and Subramanian, 1968; Jaouad et al., 2020). In advanced stages of black rot of oranges, the internal rotting area expands and turns dark green or black. The condition may be aggravated by weather and the nutrient balance of the host. Depending on disease incidence and disease severity of the crop, proper management through chemicals should be done. The chemicals have the potential to manage the disease. The time and crop stage must be in mind at the application of chemicals. Among the chemicals, fungicides are the most widely used for the control of this disease. Normally three fungicidal applications per season may be required to manage the disease, especially if leaves are highly infected from the previous inoculums. Start spraying before the flowering stage, during the seasonal flush of leaves with a second application at petal fall and a third when fruit formation starts (Neal, 1991). The availability of fungicides that have post-infection activity can enhance the flexibility of growers in the management of these diseases (Bushong and Timmer, 2000). The chemical control method has been used in many areas. People mostly prefer chemical control because of its efficiency and fast action(Jeger and Plumbley, 1988). Reasonable control of *A. citri* was obtained using copper and mancozeb fungicides. Mondal et al. (2007) tested different plant extracts against *Alternaria* spp. The tested pathogen was sensitive to *Acorus calamus* extract. Riaz et al. (2012) evaluated different methanolic plant extracts against *A. citri* and found extracts have great potential to manage the *Alternaria* spp.

Symptomatology

Symptoms may appear in 20-24 h after infection, and the lesions continue to expand and cover a large leaf site. No external signs or symptoms are visible on the fruit until it is attacked at the stalk end. The observable symptoms and signs appeared on the surface after fruit drop because the fruit becomes detached from the stalk end. The fruit becomes softened and black rot develops leading to further infection. This pathogen causes the disease, which infects the leaves, branches, and twigs. It produces black necrotic lesions on twigs, young leaves, branches, and fruits. The pathogen has a host-specific toxin that may spread through the lesions, resulting in the twigs dieback or the leaf drop. The fruit lesions vary from small dark necrotic spots to giant sunken pockmarks that reduce the fruit value in the fresh market (Figure 1) (Anwaar et al., 2020).

Figure 1: Symptoms of black rot on the leaves and fruits.

Disease cycle and transmission

A. citri has no sexual spores but germinates by asexual spores called conidia (Figure 2). The conidia production begins in ten days and continues up to fifty days after symptom appearance on fruit. The conidia are spread by air and rainfall. Conidia can infect the leaf within 12 hours. They can enter the leaf by stomata or from the top of the leaf by using appressorium. The disease can be avoided by keeping the fruit and plant healthy (Farooqi et al., 1981).

Epidemiology

A. citri is found in hot semi-arid areas compared to humid areas. In many areas, fruits are susceptible to infection in mid-summer. Fruit may be susceptible for much longer in cooler climates (Hendricks et al., 2020). *A. citri* can grow between 15-35°C with 25°C as the ideal temperature for growth (Long and Roberts, 1958). It mainly infects stressed and overripe fruits. The exposed healthy fruit tissues increased the chance of infection from diseased fruits by having a cut or wound for the pathogen to enter. Infection begins soon after the entrance of the pathogen into the susceptible host. Black rot is the cause of severe losses of citrus fruits when stored. The pathogen damages the internal tissues of the host and causes decay, and fruit may drop prematurely. In many semi-arid and arid areas, the temperature cools down at night when dewdrops appear, and the temperature goes below to optimum level. *Alternaria* produces a large number of conidia and needs a wet period for infection. These conidia disperse and germinate on the host and continue their development (Rotem, 1994). In large humid areas, such as Brazil, Colombia, and Florida, the temperature along with rainfall causes high susceptibility in plants to cause the infection by *A. citri*. The occurrence of black rot during storage is due to low temperature and is highly significant at all storage temperatures (Rippon and Morris, 1981). *Alternaria* is an active saprophyte. It grows on dead citrus tissue during wet weather conditions. The fungus produces airborne conidia during growing periods (Verniere et al., 2003). These spores germinate to develop fungus from the bottom of the fruit and cause decay. The pathogen quickly enters the fruit after the splitting of tissues. Entrance of the pathogen into the fruit becomes easy when splits of tissue occur.

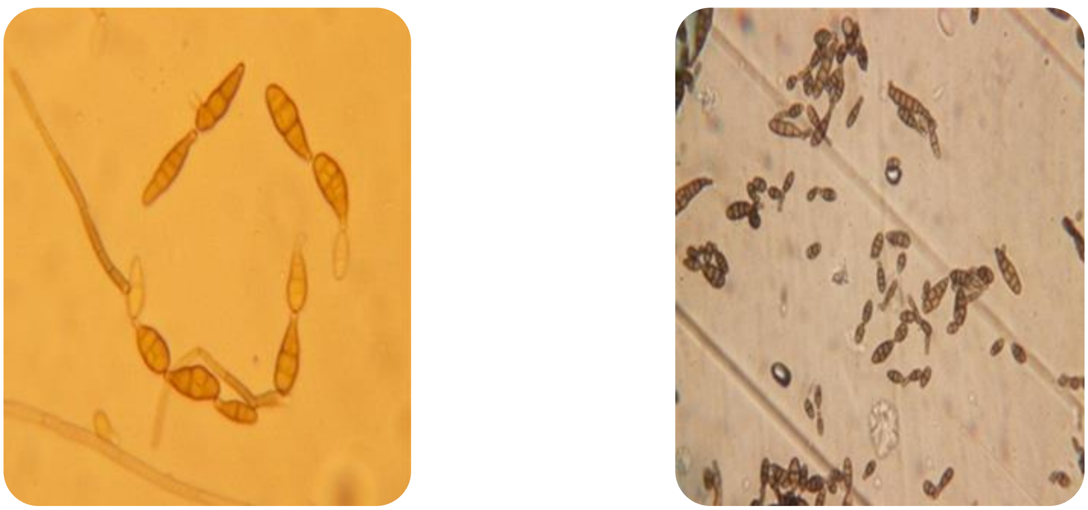

Figure 2: Microscopic (100X) view of conidia of *Alternaria citri.*

Management

The pathogen decreases the quality and nutrient values of fruits. Another complication with black rot is the potential delay in harvest time (Kaplan and Dave, 1980; Naqvi, 2004). Depending on disease incidence and disease severity of the crop, proper management through chemicals should be done. Without appropriate management, the pathogen can lead to huge losses. The 10-30% of citrus crops were lost in California due to *A. citri*. In India in the mid of 1988-90 about 20% of mandarins were lost in transport due to *A. citri*. *A. citri* is present in areas that store and produce citrus. *A. citri* infects citrus through wounds on the surface or by the end of the stem from the stylet location (Ahmad et al., 1997). Pathogen produced a key enzyme known as endo polygalacturonase (endoPG) that is highly significant in the pathogen's success. It helps the pathogen to take over the plant's nutrient source. *A. citri* cannot produce endoPG because it is unable to penetrate through the cell wall. The water loss is controlled by wax treatment or using certain lining materials (Farooqi et al., 1981).

Chemical control and its mechanism

Fungicides have proved unhelpful in stopping the infection of citrus fruits. Chemical control methods are commonly used on fruit crops because the value of the produce earned usually offsets the relatively expensive inputs in terms of machinery, material and labour, and storage and transportation, which are needed. The chemical control method is the most effective control in many areas. People mostly prefer chemical control

(Jeger and Plumbley, 1988). From 1945 onwards, a massive number of synthetic fungicides with many new modes of action became available. These fungicides were much efficient and quick in action. The new spraying system was also adopted to exploit their curative, preventive, and eradicative properties. These fungicides are developed in a specific range. Szkolnik (1978) developed four main times for application treatment based on the fungicidal efficacy of fungicides of the active substances. The first of these is called 'protection,' i.e. before infection; the second is called 'post-infection, or just after infection; the third is called 'pre-symptom', i.e. applied until symptoms appear; and lastly, the fourth, called 'post symptom, where a treatment can be used after symptoms have appeared. The time and crop stage must be in mind at the application of chemicals. Among the chemicals, fungicides are the most widely used for the control of this disease. Usually, three fungicide applications per season may be required to manage the disease, especially if leaves are highly infected from the previous inoculums. Start spraying before flowering starts, during the seasonal flush of leaves, with a second application at petal fall and a third many weeks after fruit formation started (Neal, 1991). Application of adequate amounts of plant macronutrients can stop plant stress (Farooqi et al., 1981). The product that contains or produces salicylic acid and phosphates significantly reduces the disease severity. These materials have some promising combinations with systemic fungicides (Cobb, 1903). Fruits must be protected from mid-summer infection. The infection after that period is not much damaging because disease levels are usually low and lesions are small. As a result of late infection, black lesions may occur in Israel and induce fruit drop (Masunaka et al., 2000). It is essential to protect spring flush to build up the high infection in fruits. In the areas where rainfall is high, it is necessary to control the disease periodically. Timmer et al. (2000) reported that fungicides effectively managed *Alternaria* black rot of citrus.

Application of pre-harvest fungicides

Fungicides can be applied as a pre-harvest spray (Benlate), with bin drenchers as an initial treatment of fruit on arrival and on the packing-house line (thiabendazole or TBZ). Types of fungicides and application methods used in the packing sheds vary. The latter may include dipping/drenching, inline flood, inline controlled droplet application (CDA), and mixing with wax. Timmer et al. (2000) determined the number of fungicidal applications needed to manage severe infestations. In the worst cases, the first spray should be applied when the new flush is 1/4-1/2 of full expansion to prevent *Alternaria* on the spring flush. It is not economical to try management of the disease in late summer. In Brazil, 3-5 sprays are given for citrus orchards against blemishes of diseases. Some species of citrus acquire resistance against certain fungicides. Triazole group fungicides are the best choice against fungal diseases of citrus. The significant advantage of these fungicides is that no host resistance has been observed against these fungicides. Score and tilt are most widely used in the world and are much effective against *Alternaria* black rot. In Brazil, the specific action of these fungicides has been studied and found to have much specific in their mode of action (Nalumpang et al., 2002). There is a great need to investigate different methods and fungicides that could control black-rot in stored citrus fruits. It is reported that *A. citri* rot can significantly be controlled by applying imazalil, tridemorph, or gauzatine (Rippon and Morris, 1981). Fungicides were evaluated for control of *Alternaria* black rot caused by *A. citri*.

In most cases, three fungicide applications were made to susceptible tangerines or tangerine hybrids from March to May. Iprodione (Rovral), captafol (Difolatan), chlorothalonil (Bravo), azoxystrobin, and copper fungicides provided control of *Alternaria* black rot. Neem oil (Trilogy) was effective in some tests but not in others. Tebuconazole (Folicur), fosetyl-AI (Aliette), propiconazole (Tilt), captan, thiophanate-methyl, and benomyl (Benlate) were ineffective against *Alternaria* black rot of citrus. Benomyl, ferbam (Carbamate), fluazinam, fenbuconazole, tebuconazole, thiophanate-methyl + ziram, kresoxim-methyl, and copper fungicides reduced the severity of the disease. Iprodione, fosetyl-AI (Aliette), and Neem oil (Trilogy) were ineffective for disease control. Those fungicides are also much effective against the control of citrus fruit rot. Protectant and systemic fungicides are used against citrus black rot (Zitko and Timmer, 1998).

Application of post-infection fungicide

Some fungicides such as fenbuconazole and azoxystrobin were effective as protectants and post-infection sprays for citrus rot. These types of fungicides are also similarly much effective for foliar fungal pathogens of many fruit crops. The thiabendazole and imazalil treatments applied at 5°C reduced chilling injury. They inhibited the decay of grapefruit more effectively than when these fungicides were applied at room temperature, suggesting that the relationship between fungicide activity and temperature may be complex. Moderate control of *Alternaria* brown spot was obtained using copper and mancozeb (Zitko and Timmer, 1998). Mancozeb applied at 2-weekly intervals was the most effective spray program followed in order of efficiency by the program using maneb plus zinc oxide, and mancozeb applied at 3-weekly intervals. Iprodione and tebuconazole were not particularly effective in this evaluation, although they performed significantly better than the control treatment (Swart et al., 1998). Chemical named 2,4 dichlorophenoxyacetic acid (2,4-D) + gauzatine effectively controls the rot in oranges (Gillespie, 1981). Antibiotic F also effectively checked the sporulation in the artificially inoculated fruit (Farooqi et al., 1981). Swart et al. (1998) reported the efficacy of different fungicidal groups by comparing copper fungicide with mancozeb for their potential to control *Alternaria* black rot on citrus. Different variables were used for comparing the effectiveness of fungicides in order of importance. The exportable percentage of fruits is not a reliable variable parameter for comparing treatment efficiency. During 1992-93, evaluations of iprodione, procymidone, and difenoconazole exhibited promising control of the pathogen. Moderate control of *A. citri* was obtained using copper and mancozeb fungicides. This disease caused extreme leaf drop and defoliation or necrotic spots on citrus fruits. The basic purpose of this work was to evaluate the brown spots chemical control and the appropriate dosage of fungicide to manage it properly. The split-plot was applied with ten treatments and three doses of fungicides with five replicates. The fungicides included pyraclostrobin, azoxystrobin, trifloxystrobin + propinebe with two applications followed by three applications of mancozeb, trifloxystrobin + propiconazole, difenoconazole, iprodione, trifloxystrobin + tebuconazole with two applications followed by three applications of copper, copper + oil, and control without adding any fungicide. Among the tested fungicides, treatment with trifloxystrobin + propiconazole proved to be more effective. Katoh et al. (2006) reported that *A. citri* causes *Alternaria* black rot, a postharvest fruit disease on a broad range of citrus cultivars. *A. citri* causing the *Alternaria* black rot disease in many hybrids of tangerines throughout the world. They aimed to identify species of plants that have antifungal properties against *A. citri*. For that purpose, extracts were prepared from barks, flowers, leaves, and stalks collected from 105 plant species from Brazil. Extracts were tested for activity against the fungus *A. citri* under *in vivo* and *in vitro* conditions. The results obtained in vivo and in vitro recommended that the fungal growth test with the 96 well polypropylene plates looked to be suitable for selecting the potential plant species for testing new methods to manage black rot of citrus. The effect of plant pathogenic fungi viz. *A. citri*, *Aspergillus flavus, A. niger, Fusarium oxysporum,* and *Rhizoctonia solani* by the leaf, stem, and roots. Sastry et al. (1989) reported that Bavistin, Difolatan, and Thiram inhibit *A. citri*. Pampanagouda (2000) reported that benomyl and thiophanate methyl proved the best result against citrus blemishes. Bordeaux mixture is widely used as a protector against all fungi. Non-systemic such as mancozeb has been found to inhibit the pathogen. The use of triazole fungicides is now increasing because they are target-specific (Sawant and Sawant, 2006). Recently some strobilurin fungicides were reported as more effective for managing *Alternaria* brown spots (Timmer et al., 2000). In the strobilurin group, Pyraclostrobin and Azoxystrobin have proved effective than trifloxystrobin. Strobilurins are much specific in that they are the single site of action fungicide (Sierotzki et al., 2000). They provide much resistance and can alter with many other products. The strobilurin fungicides are more effective and safer than the others and show promising results against many destructive pathogens. Copper fungicides have the best control and are mostly used to control *Alternaria* disease in Florida (Timmer et al., 2000).

Copper-based fungicides

Copper fungicides provide reasonable control against diseases when they are applied timely. When they are applied at high temperatures, they may cause the stippling of fruit. So these should be used with caution. Other fungicides that are much effective in Israel are triazole, dithiocarbamates (Sadowsky et al., 2002).

Foliar fungicides

Foliar fungicides are mainly used for the control of this disease. In areas where *Alternaria* is in much severe form, systemic fungicides are needed to produce food with good qualities. The application of the fungicides depends upon climatic conditions (Ferreira et al., 2020). Three to 10 applications of fungicides may be required in different climatic conditions (Canihos et al., 1997; Canihos et al., 1999). Fungicides should be used at the proper timing of crop. Difenaconazole can be used as a spray for the control of *Alternaria* spp. Two applications of fungicides should be made, one at the time of petal fall and a second 3-4 weeks later. It is much effective and will provide some control of the disease. Usually, these two sprays are enough for proper disease control. More application should be required where effective management is needed when the incidence of the disease is much high (Diepenbrock et al., 2020). The damage caused to the citrus trees by lime Sulphur was often large (Mills, 1947). Attention was diverted to developing less toxic and more suitable fungicides than inorganic fungicides (copper, sulphur, and mercury). The new fungicide dithiocarbamate was formed in 1936. That was the age of synthetic organic fungicides (MacHardy et al., 2001).

Captafol has a high effect and hence is restricted. Only some application is needed for reasonable control. The problem with this product is that it is not still registered in many areas due to health concerns. Another chemical, iprodione, is also very effective for managing disease (Zitko and Timmer, 1998), but against this, chemical resistance has been developed in Israel (Solel et al., 1996). There is a wide range of fungicides that are approved and used to manage foliar fungal diseases of citrus trees. Some protectant fungicides, such as chlorothalonil, dithiocarbamates, and captan, have been approved for many years. These fungicides are much specific in their action. Now protectant fungicides are used in large areas and are much effective, but the problem is that these have not a prolonged effect. Some pathogens adopt resistance against these fungicides (Szkolnik, 1978, 1980).

Systemic fungicides

The systemic fungicides are mostly recommended against foliar fungal diseases. The systemic fungicides have a broad action and give the best result than any other fungicides in foliar fungal diseases. During the late 1960s and 1970s, systemic fungicide benomyl was confirmed to have post-infection activity and was thought to reduce inoculum of several foliar fungal diseases of deciduous fruits trees (Wilcox, 1990). Azoxystrobin (Amistar 250) and extract of grapefruit (Biosept 33 SL) *in vitro* for their effectiveness to inhibit the linear growth of *A. citri*, *Botrytis cinerea, Fusarium avenaceum, F. culmorum, F. equiseti, F. oxysporum, Rhizoctonia solani* and *Trichoderma hamatum*. The azoxystrobin (0.05-0.1%) and grapefruit extract (0.1-0.2%) were applied in different concentrations. The studies made use of a Petri dish method recommended for testing fungicides in laboratory conditions. Extract of grapefruit was more effective than azoxystrobin. The extract of grapefruit inhibited the growth of *A. citri, B. cinerea, R. solani* and *T. hamatum* after four days and was the most effective after 12 days of the experiment. During the late 1970s, SBI fungicides were established and subsequently approved for use on many fruit crops. Some fungicides, such as triforine, tebuconazole, fenarimol, fenbuconazole, and propiconazole have protectant and localized systemic action in the apoplast. SBI fungicides have post-infection action and give the best control.

Sterol biosynthesis-inhibiting SBI fungicides

SBI fungicides may prevent sporulation and thus reduce the chance of disease (Zitko and Timmer, 1998). Strobilurin fungicides are modern fungicides and have been developed more recently. Some strobilurin fungicides have been registered for use on fruit crops. The strobilurin fungicides also have locally systemic action in the cuticle and leaf boundary areas and post-infection against many kinds of foliar fungal diseases (Kuramoto and Yamada, 1975). No sterol-biosynthesis-inhibiting (SBI) or strobilurin fungicide has ever been approved to manage foliar fungal diseases of citrus.

On the other hand, in contrast to the condition for citrus, there is a wide range of fungicides approved and used to manage foliar fungal diseases of many deciduous trees and small or big fruit crops. Some protectant fungicides, such as chlorothalonil, dithiocarbamates, and captan, have been approved for many years. These fungicides are much specific in their action. Now protectant fungicides are used in large areas and are much effective, but the problem is that these do not have a prolonged effect. Some pathogens adopt resistance against these fungicides (Szkolnik, 1978). Sastry et al. (1989) reported that bavistin, difolatan and thiram inhibit the pathogen. Pampanagouda (2000) said that benomyl and thiophanate methyl gave the best results against citrus blemishes. Bordeaux mixture is widely used as a protector against all fungi. Mancozeb, as non-systemic, was also found to inhibit the pathogen. The use of triazole fungicides is increasing because they aretarget-specific (Sawant and Sawant, 2006).

Another possible approach to control citrus postharvest diseases involves the application of natural chemicals. Several researchers have reported antimicrobial activity of plant extracts and essential oils that can meet the requirement for non-hazardous eco-friendly treatments to control citrus postharvest diseases. The proper amount of fungicide is applied and avoid excessive doze. Usually, two to three sprays are enough for proper control. Folpet and carbendazim proved best against citrus diseases (Mondal et al., 2007). Other than chemical controls, many different methods are effective in disease management. One of the alternatives is applying environmentally friendly allelochemicals and showing promising results (Hasan et al., 2020). Riaz et al. (2012) stated that many plant extracts or allelochemicals show broad-spectrum activity against pathogens. Such products are more attractive alternatives to synthetic chemical pesticides because they pose a minor environmental threat or human health. The use of plants as pesticides has been practiced since time immemorial. Masunaka et al. (2000) tested *Acorus calamus* L extracts with different concentrations (0.01-0.15%) on PDA for antifungal activity against *Alternaria* spp isolated from the leaf spot. The results indicated that the pathogen examined was sensitive to *A. calamus* extract. The tested fungal growth was inhibited at the concentration of 0.10% upward. Riaz et al. (2012) evaluated the antifungal activity of some plants species extracts against *A. citri.* Methanolic sections from different *Polygonum perfoliatum*, *Cymbopogon citrates, Lantana camara* and *Mimosa pudica* were evaluated for potential antimicrobial activity against *Alternaria* strains. They reported that these plants could find natural bioactive products that can play an essential role in developing new pharmaceuticals. They concluded that aqueous and methanol extracts of *Aloe vera, Polygonum pe foliatum, Cymbopogon citratu, Lantana camara,* and *Mimosa pudica* possess the ability to inhibit the growth of *A. citri*. Riaz et al. (2012) carried out *in vitro* studies to evaluate the antifungal activity of *Aloe vera* shoot extract in aqueous and organic solvents against few pathogenic species of genus *Alternaria* viz., *A. alternata, A. citri,* and *A. tenuissima*. The assessments revealed that *Aloe vera* contained substantial antimicrobial efficacy. The aqueous shoot extracts caused significant inhibition in the growth and biomass production of the three tested fungi. In the case of n-hexane extraction, the inhibitory effect was variable with the applied concentration.

Use of resistant cultivar

The use of resistant plants is the most secure way to manage the disease. Resistant plants are produced by breeding hybrid cultivars to avoid infections (Long and Roberts, 1958). Many resistant varieties of citrus have been evaluated to control *Alternaria* black rot (Agostini et al., 2003). The disease can be prevented by planting a disease-free nursery, although the spores are air born but cannot cover long distances. So, planting healthy trees is better management to prevent that disease from coming. The disease builds to a significant population if the pathogen is present during the vegetative growth on young trees, which becomes difficult to manage. Wet areas favoured the disease of *Alternaria* black rot of citrus. In establishing new groves, it is better to locate susceptible varieties such as Minneola in higher areas where ventilation and air drainage are good. There should be more expansive space between the plants to dry the leaves and canopy more rapidly to manage the disease better.

CONCLUSION AND FUTURE ASPECTS

Citrus black rot is the significant postharvest problem of citrus in the world. However, recent reports suggest that citrus black rot may be caused by more than one morph species in addition to *A. citri* and can be morphologically diversified. Therefore, more research regarding molecular aspects of pathogens is required in the future. In conclusion, the information present in this review paper is constructive for understanding black rot disease and its control measures.

AUTHOR CONTRIBUTIONS

All authors equally contributed in gathering literature and in writing and formatting the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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