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Citrus diseases caused by fungi

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Abstract
The world production of citrus is the highest among other types of fruit. At the University of Florida 4200, it was recorded that citruses contributed about 10 billion to the economy of the United States of America this year. Citrus fruits include many species, all of which belong to the family *Rutacea* the most important *Citrus aurantium, Citrus paradise, Citrus sinensis,,* C*itrus lemon* and *Citrus reticulate,* Citrus fruits are infected with different types of fungi such as *Pencilium* spp., *Alternaria* spp. and *Rizopus* spp., Which are found either in the soil, in irrigation or airborne, as well as in harvesting equipment and people working in the harvest, The most common cause of citrus rot around the world is *Pencilium*, especially *P. italicum* and *P. digitatum*, Gum disease in citrus is called by several names such as Brown rot gummosis, foot rot and rot of fibrous roots, and the causative agent was *Phytophthora parasitica* and *P. citrophthora***,** Brown heartwood rot of lemons was found that two types of wood rotting fungi cause the decay and death of the branches of citrus trees, they are *Antrodia sinuosa* and *Conophora eremophila*, Alternaria brown spot Causative agent was *Altternaria alternata*, *Phytophthora* diseases are a complicated pathology produced by soil-borne *Phytophthora* species, and they are widely recognized as the most common fungal disease of citrus fruits practically everywhere in the globe.

Keywords: *Citrus* diseases, *Citrus sinensis,* fungi

Introduction
Citrus fruits are of great nutritional importance to humans because they contain important nutrients, as it has become known that citrus fruits are important sources of many sugars, organic acids and vitamins, especially vitamin C, in addition to containing soluble fiber, which has a major role in reducing cholesterol levels in the body (Liu *et al*., 2021 and Cheng *et al*., 2020) [6]
The world production of citrus is the highest among other types of fruit **(**Tian *et al*., 2016) [22]. At the University of Florida 4200, it was recorded that citruses contributed about 10 billion to the economy of the United States of America this year. Citrus fruits include many species, all of which belong to the family *Rutacea* the most important *Citrus aurantium, Citrus paradise, Citrus sinensis,* C*itrus lemon* and *Citrus reticulate* (Arekemase *et al.*, 2007) [4]. The consumption of this fruit has increased in the past decades due to its entry into the food industries such as juices and jams, in addition to about 20% of these fruits are lost every year due to damage and infection with fungi and other microorganisms. Post-harvest and caused by microorganisms, especially fungi, Citrus fruits are infected with different types of fungi such as *Pencilium* spp., *Alternaria* spp. and *Rizopus* spp., Which are found either in the soil, in irrigation or airborne, as well as in harvesting equipment and people working in the harvest (Wuryatmo *et al*., 2003) [26].

1. Citrus rot
Causative agent: *Penicillium italicum* and *Penicillium digitatum*
Kingdom: Fungi
Division: Ascomycota
Class: Eurotiomycetes
Order: Eurotiales
Family: Trichocomaceae
Genus: *Penicillium*
Species: *italicum digitatum*
(Hine, Richard, 2012)
The most common cause of citrus rot around the world is *Pencilium*, especially *P. italicum* (Figure 1) and *P. digitatum* (Figure 2) known as blue and green rot (Droby *et al*., 2008) [8], which cause huge economic losses annually, especially on fruits destined for export. Citrus fruits are infected with these types of fungi in any time after harvest, by smashing the fruit wall or any wound or scratch on the wall, as the rot spreads through contact between the infected fruit and the healthy fruit, and these molds grow well and quickly at a temperature of 20-30

° C, but growth slows significantly in less than 5°C and above 30°C (Macarisin *et al*., 2007 and Marcet-Houben *et al*., 2007).

Fig 1: *P italicum* (Abd and Ramadan, 2009).

Fig 2: *P. digitatum*

2. Gum disease in citrus
This disease is called by several names such as Brown rot gummosis, foot rot and fibrous roots rot.

Causative agent: Two species of *Phytophthora* that is *P. parasitica* and *P. citrophthora*
Kingdom: Chromista
Phylum: Oomycota
Order: Peronosporales
Family: Peronosporaceae
Genus: *Phytophthora*
Species: *paerasitica citrophthora*
(Hong *et al*., 2011)

Conditions conducive to the spread of the disease
1. Increase moisture in the soil.
2. Water contact with tree trunks.
3. Low temperatures.
4. The occurrence of a wound or cracks in the foreskin.
5. Use of susceptible assets (Al-Wakeel, 2010) [2].

Gum disease symptoms.
1- Symptoms above the soil surface
- Death of some areas of the bark trunk above the soil surface.
- Secretion of small or large quantities of gum, according to the prevailing weather conditions.
- Leaking gums and browning a thin layer of wood.
- The appearance of yellow-colored gum areas at the cambium area behind the infected or dead areas.
- Dryness and longitudinal cracking along the bark of the trunk. If the trunk is infected above the soil surface, these symptoms are known as foot rot

2- Symptoms below the surface of the soil
If there is a high level of moisture, the following symptoms appear:

1. There are dead areas of phloem tissue at the base of the stem.
2. It is difficult to see the gum as it dissolves in water and spreads in the soil.
3. As a result of the infection, secondary parasites enter that kill and discolor the wood tissues for greater lateral distances than that caused by the causative agent of wood above the surface of the soil, and the infection also spreads to greater distances in the lateral roots. This helps the emergence of the so-called dry root rot, as it attacks wood with many other fungi, yeasts and bacteria (Al-Wakeel, 2010) [2].

Methods of resistance

1. Using resistant assets, the most important of which is *Citrus aurantium*.
2. Not to plant trees that are deep, but rather high, so that the primary lateral roots are allowed to be covered with a thin layer of soil because the bark of the roots is less susceptible to gum infection than the bark of the stem.
3. When grafting on resistant assets, the height of the graft should not be less than 30-50 cm above the ground.
4. Immediately after planting, paint the tree trunk from the surface of the soil to a height of 30 cm with a thick water suspension of Bordeaux mixture.
5. Avoid excessive nitrogen fertilization.
6. Avoid placing organic fertilizers close to tree trunks.
7. Using clean soil that has not been previously planted with citrus when making seed beds so that it is free from any contamination, whether fungal or bacterial. (Al-Wakeel, 2010) [2].

3- Brown heartwood rot of lemons

It was found that two types of wood rotting fungi cause the decay and death of the branches of citrus trees, they are *Antrodia sinuosa* and *Conophora eremophila*, which invade the tissues of the branches through wounds resulting from broken and partially broken ends. These wounds usually result from wall damage, heavy fruit bearing, wind damage, and deposition of scattered, In live heartwood, fungal spores in these wounds cause later colonization of woody tissues and the development of wood breakdown. The infection causes the demise of branches above the infection location.

Symptoms

The death of a lemon tree limb is the first visible indication. The tree's branches are frequently snapped in half. The color of broken wood is pale brown. On coniophora infected wood, there was no sign of fungal development (Figure 3), While fungal white fungus were found within *Antrodia* infected brown wood that was degrading. As the wood rot progresses, branches break off from the tree, eventually rotting whatever remains of the trunk.

Biology of the pathogen

Antrodia produces aerobic coniophora, Coniophora was not found on lemon peel infected, so wood with infection on lemon plantations does not produce spores that can infect other trees. On the contrary, *Antrodia* has been spotted to aggravate on lemonwood so that spores released by rotting lemonwood can cause further infection.

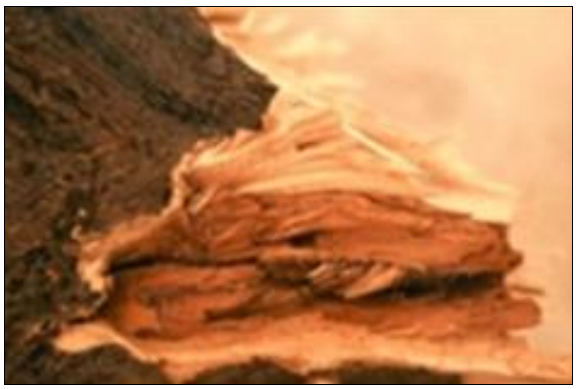

Fig 3: Cut lemon branch due to infection with *Coniophora* (Anon, 2012)

Control

To prevent wood rot at wound sites, broken or dead branches should be removed using clean cuts near the main branch, If *Antrodia* is the cause of wood rot, eliminating wood waste eliminates a potential source of spores and lowers the likelihood of new infections, Maintaining tree vigor through correct watering and fertilization would aid wound healing and limit the spread of wood rot, There are currently no fungicides available for use on citrus that will control this disease (Anon, 2012)

4- Alternaria brown spot

Causative agent: *Altternaria alternata*

Kingdom: Fungi
Division: Ascomycota
Class: Dothideomycetes
Order: Pleosporales
Family: Pleosporaceae
Genus: *Alternaria*
Species: *A. alternata*
It is a fungus that spreads mainly by wind-driven spores. Spores grow on mature and thawed twigs and overripe leaves produce brown lesions on leaves and fruits, Brown spot can also be transmitted through feed, pole and tree transport activities. Brown spot can affect the quality of the fruit because it creates pits, holes and seepage from depressions when fungal lesions on the fruit ripen. Tangerine cultivars are particularly susceptible to brown spot (Peever, 2005) [18].

Symptoms
- Brown spots on the fruits.
- Clogged and depressed spots in advanced stages. (Peever, 2005) [18].

5- Phytophthora disease
"*Phytophthora* diseases" is term refers to a *Phytophthora* pathology is a complicated pathology caused by soil-borne *Phytophthora* species that is recognized as the most common fungal disease of citrus fruits practically everywhere in the globe, *Phytophthora* spp. infect citrus trees at all phases of development and can infectstems, roots, twigs, branches, fruits and leaves, Root rot, foot rot (often referred to as canopy blight), and seedling rot are some of the diseases caused by *Phytophthora* (known as quenching seedlings).
The most dangerous characteristics of this category of diseases are root rot and Gummi stem, which have become endemic in all citrus-growing regions of the world following an epidemic in the eighteenth century and the widespread use of resistant rootstocks at the same time. At least 10 species of *Phytophthora* have been recorded to infect citrus around the world, although *P. nicotianae*, *P. citrophthora* are the most common ones seen in commercial citrus orchards in the Mediterranean (Pattron, 2006).

Fig 4: Citrus tree trunk gummosis infected by *phytophthora citrophthora*.

Fig 5: Brown rot symptoms on sweet orange fruit caused by *Phytophthora citrophthora*

Fungi isolated from citrus fruits in Mosul city
We note from Table (1) that the frequency of *Aspergillus* isolation was the most among the other isolated fungi, and it was isolated from citrus fruits as shown in the table. and grief conditions, in addition to the fact that *Aspergillus* mushrooms are fast-growing and have large numbers of conidia. The conidia help spread and infect the stored fruits, and the fungus *Aspergillus* secretes enzymes that degrade plant cell walls such as pectinase enzyme. Infection of fruits and vegetables during transportation and storage encourages infection with the fungus conidia, which finds in the nutritional contents fruits a suitable medium for their germination. *Aspergillus*

conidia are usually spread in air, water, breeding, plant residues, rotting plants, manure, sawdust, sugarcane, garbage, animal feed, on animals and indoor air due to its rapid growth and formation. It has a wide range of temperatures, and has a high ability to withstand critical environmental conditions such as lack of moisture (dryness) and has a high ability to produce secondary metabolites that enable it to exploit different food sources (Valero *et al.*, 2007) [24].

Table 1: Fungi isolated from citrus fruits in Mosul city (Al-Omari, 2015)

Scientific name	Isolated fungi
Citrus sinensis	*Trichoderma* spp. *Aspergillus niger Aspergillus flavus Aspergillus fumigatus Aspergillus flvipes Alternaria spp. Mucor spp.*
Citrus limon	*Aspergillus flavus Aspergillus niger penicillium digitatum penicillium italicum*
Citrus paradisi	*Aspergillus fumigitus Aspergillus flavus*
Citrus reticulate	*Alternaria spp. Aspergillus niger Rhizopus spp. Trichoderma spp.*
Fortunella margarite	*Aspergillus flavus Penicillium digitatum*
Citrus aurantium	*Penicillium digitatum Asperigillus niger Asperigillus fumigitus*
Citrus aurantifolia	*Fusarium spp. Aspergillus niger Penicillium digitatum*

In general, *Aspergillus* compete with *Penicillium* and *Fusarium* for dominance of the fungal flora in the environment, and it can be said that *Aspergillus* are one of the most polluting and rotting fungi in tropic zones, while *Penicillium* dominates the pollution in temperate regions (pitt and Hocking, 2009). Then it comes in second place after *Aspergillus* and *Penicillium*, as the frequency of its isolation was 15.95%, and it was isolated from citrus in the first *P. digitatum* (Buron-Moles *et al*., 2012 and Ghooshkhaneh *et al*., 2018) [5, 9]. This genus is called storage fungi due to the ability of this fungus to excrete toxins during storage and secondary metabolites help it to exploit the medium as a food source for its growth and reproduction less than 5 microns, which facilitates its movement in the air and ease of spread, *P. digitatum* is the main reason for 90% of citrus losses during storage, which results in economic damage (Harries *et al*., 2015) [11]. For example, this fungus causes huge losses in the tangerine crop in northern Thailand, and most of the injuries are the result of mechanical wounds at harvest (Inkha and Boniyakiat, 2010). *Trichodderma* was also isolated, and the frequency of its occurrence was 11.59%, as it was isolated from citrus and strawberries, and this is due to the proximity of the strawberry fruits to the ground, so they are infected with most soil fungi, which facilitates the isolation of this fungus from them. This fungus is considered a soil fungus, and this genus includes species related to symbiosis with plants, some of which are fungal pathogens for humans and plants, Biological control, and due to its ability to secrete different secondary metabolites and its aggressive competitive nature, makes it one of the largest natural decomposers of organic materials, as it was used in the analysis of solid household waste quickly and without odors (De Ramon-Carbonell and Sanchez-Torres, 2017) [7].

Recommendations

1. To reduce infection, attention should be paid to hygiene during harvesting, packaging and transportation of the crop, and to ensure the cleanliness of the water used for washing the crop, as well as sterilizing containers and storage places using the sterilization methods designated for that.
2. Adopting biological control methods to eliminate fungi instead of chemical pesticides.

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