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Review

# Pythium-induced damping-off disease and its management in tomato (*Solanum lycopersicum* L.): A review

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***Abstract.*** *Pythium-induced damping-off is a disease that causes the decay of germinating seeds and young seedlings of tomato, and it is one of the most significant yield constraints for farmers in both nurseries and fields. Conventional fungicides are widely used to manage this disease, leading to two major consequences. Excessive fungicide use not only endangers human health and raises environmental concerns but also promotes the emergence of pesticide-resistant microorganisms in the environment. Consequently, there is growing interest in developing long-term damping-off management strategies that minimize reliance on conventional pesticides. To facilitate decision-making, a better understanding of pathogen biology and disease epidemiology is required. The major findings of this review works are as follows: i) Pythium-induced damping-off is an emerging disease that affects tomatoes in nurseries and fields and causes economic loss; ii) Epidemiological factors identified as most favorable for disease development include high soil moisture (70% or higher), low light, and moderate soil temperatures around 25°C.; and iii) Considerable research efforts in recent years have focused on developing bio-control solutions for damping-off, showing promising future prospects. To ensure higher tomato production, researchers and growers should manage Pythium-induced damping off in their fields. This review serves as a useful guide for the management of this disease.*

**Keywords:** biocontrol, *Pythium*, distribution, integrated, mortality, seedling

## Introduction

Tomato production is seriously hampered by pests and diseases, including microorganisms such as bacteria, nematodes, and fungi, leading to significant production losses (Barone and Frusciante, 2007). Anthracnose fruit rot, early blight, septoria leaf spot, and late blight are all prevalent tomato diseases, with damping-off being the most frequent disease (Buchenauer, 1998). Damping-off affects nearly every crop grown across all countries (Ben-Yephet and Nelson, 1999). Damping-off has been regarded as the most challenging issue encountered in raising nursery seedlings, making it one of the most actively researched topics since its initial

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description (Hartley and Pierce, 1917). Damping-off of seedlings is a soil-borne disease caused by *Fusarium, Pythium, Rhizoctonia*, and *Verticillium* (Pretorius et al., 2003) and is widely distributed around the world. Damping-off disease caused by *Pythium* species kills more than 60% of seedlings in the nursery and main field (Manorantitham et al., 2001). Damping off causes 25-75% losses per year, depending on the host type and environmental variables. A variety of microorganisms, including *Pythium*, *Phytophthora*, *Rhizoctonia*, and *Fusarium*, as well as *Alternaria*, *Botrytis*, *Phoma*, *Sclerotinia*, *Sclerotium*, *Aphanomyces*, *Pyrenochaeta*, *Ozonium Glomorella*, and others, can induce damping off (Gupta and Paul, 2001).

*Pythium* species such as *P. aphanidermatum, P. spinosum, P. myriotylum*, and *P. echinogynum* have been linked to damping-off disease in tomatoes (Salman and Abuamsha, 2012; Balghouthi et al., 2013). The microorganisms that induce damping-off can be found in almost any soil and can survive for extended periods. The best conditions for damping off are usually cool and rainy, and seedlings are struggling (Bhandari et al., 2021). Epidemiological factors such as high soil moisture (60-70%) and moderate soil temperature of 25°C were found to be most favorable for the development of this disease (Kumar et al., 2018). Damping-off of tomato occurs in two stages: pre-emergence and post-emergence. Seedlings are killed just before they reach the soil surface during the pre-emergence phase. The young radical and plumule are killed, and the seedlings decay completely. The infection of the young, juvenile tissues of the collar at the ground level characterizes the post-emergence phase. The diseased tissues soften and become water drenched. The seedlings collapse or topple over.

Understanding the symptoms, losses, and management of *Pythium*-induced damping-off is crucial for tomato production. Given the high economic impact of damping-off, alternative and sustainable damping-off management solutions are required. The goal of this review was to i) highlight the major characteristics of damping-off diseases caused by *Pythium* spp.; ii) report and discuss current disease management strategies and knowledge gaps; and iii) suggest key challenges and future priorities for the management of damping-off disease.

## Distribution of *Pythium* species

*Pythium* has been found in Australia, Canada, Brazil, China, Korea, Japan, South Africa, and many other countries in the world including most states within the United States of America (Allen et al., 2004). *Pythium* spp. has a diverse host range that includes grasses and a variety of dicotyledonous plants (Navi et al., 2019). The genus *Pythium* is one of the largest genera in the class Oomycete, with over 130 recognized species dispersed throughout the world (Van der Plaats-Niterink, 1981; Paulitz et al., 2006). *Pythium* spp. reduces seedling development, kills seedlings, and reduces plant life (Kirkpatrick et al., 2006; Broders et al., 2009). In India, about 20 *Pythium* species have been identified, of which only seven are recognized as parasites, producing disease primarily in the seedbed and occasionally in the fields, such as “damping-off,” “seedling blights,” and “foot rots” (Rao, 1963). Belonging to the family Pythiaceae, the genus *Pythium* comprises damaging root parasites (phylum oomycete, domain Chromista) with filamentous sporangia, smooth-walled spherical oogonia, and following antheridia that are frequently responsible for true disease such as damping-off and decay (Mendoza et al., 1996). *Pythium* spp. mycelium is occasionally glossy and faintly yellowish or grayish lilac in color (Owen-Going et al., 2008). The oogonia are sub globose, lemon-shaped, or ellipsoidal, and can be terminal or intercalary, with smooth or decorated divider antheridia ranging from 0 to a few per oogonium, monoclines, diclinous, or hypogynous, followed, or sessile, and of various forms. Oospores are normally single, but occasionally 2-4 in an oogonium, plerotic or aplerotic, and have a thin or thick (inspissate) wall. The male organs, the antheridia, are made up of an antheridia cell, which can be sessile on a hypha, intercalary, or terminally generated on an antheridial stalk (Postma et al., 2009). During sexual reproduction, the antheridial cell strikes the oogonium and creates a fertilization tube that penetrates the oogonium (Van der Plaats-Niterink, 1981). The genus *Pythium* was first introduced by Nees von Esenbeck, but it was given its current sense by Pringsheim (1858).

The genus *Pythium* Pringsh. has traditionally been classified as "Phycomyetes," with 305 recognized species, together with other filamentous, coenocytic, sporangia-producing fungi (Fitzpatrick, 1930). *Pythium* species (phylum Oomycota; class Oomycetes; subclass Peronosporomycetidae; order Pythiales; and family Pythiaceae) are fungal-like microorganisms known as water molds. They can be found in a variety of habitats, including terrestrial and aquatic areas, as well as cultivated and fallow soil. *Pythium* species are cosmopolitan in nature, ranging from tropical to temperate (Van der Plaats-Niterink, 1981), and even in the Arctic (Hoshino et al., 1999) and Antarctic regions (Knox and Paterson, 1973). With over 130 known species isolated from diverse regions of the world, *Pythium* is one of the largest genera within the oomycete genus (Van der Plaats-Niterink, 1981; Paulitz et al., 2006). Although widely acknowledged, *Pythium* species are not particularly well-known for hosting specific relationships.

## Host range, epidemiology, and disease cycle of *Pythium* species

*Pythium* survival is favored by conditions such as excessive soil moisture (70% or higher), low light, poor nutrient availability, and certain temperature ranges. *Pythium* species thrive in moist soils. The movement of spores requires the presence of water. Moist soils, due to their low oxygen levels, promote the development of *Pythium*-related diseases. Saprophytic species such as *Pythium ultimum* Trow, *Pythium irregulare* Buisman, and *Pythium debaryanum* Hesse live on crop residues in cool, moist soils (Van der Plaats-Niterink, 1981; Ben-Yephet and Nelson, 1999).

*Pythium* spp. are excellent soil saprophytes that can grow indefinitely as vegetative mycelium in soil on a variety of organic substrates. *Pythium* species can survive in soil saprophytically because they do not compete with other plant diseases (Hendrix and Campbell, 1973). Tomato fruits that encounter soil or have soil splashed onto their surfaces in very wet conditions may be invaded by certain *Pythium* spp. The separation of host cells caused by the breakdown of the middle lamella allows fungus to spread from sick seedlings, and the breakdown of these cells is the consequence of pectinolytic enzymes produced from *Pythium* hyphal points (Goodwin, 1997). When conditions are ideal, sporangia and zoospores are formed particularly in terms of free moisture (Jones, 1991). During asexual reproduction, the coenocytic mycelia within the host produce sporangia containing multiple nuclei. The cytoplasm is transferred to the vesicle formed on top of the sporangium, and cytoplasmic cleavage results in the formation of many zoospores within minutes (Goodwin, 1997). Damping-off disease is caused by *Pythium* spp. and typically begins as root rot. This water molds survives in the soil as oospores, which germinate and attack root hairs and tips, gradually deteriorating the root system. The seedling is withering, with lesions above ground that may rot later. *Pythium* spp. are typically responsible for pre-developing Damping-off, and it can also contaminate lower stem and cause soft, water-soaked stem rot, which is commonly associated with Damping-off disease.

According to (Waterhouse and Waterston, 1964), the plant pathogen infects a wide variety of plant species from various families, including Amaranthaceae, Amaryllidaceae, Araceae, Basellaceae, Bromeliaceae, Cactaceae, Chenopodiaceae, Compositae, Coniferae, Convolvulaceae, Cruciferae, Cucurbitaceae, Euphorbiaceae, Gramineae, Leguminosae, Linaceae, Malvaceae, Moraceae, Passifloraceae, Rosaceae, Solanaceae, Umbelliferae, Violaceae, Vitaceae and Zingiberaceae. *Pythium*, the largest genus within the family Pythiaceae, is a microscopic organism commonly classified within the class Oomycetes. Oomycetes differ from real fungi (Eumycota) in that they have coenocytic hyphae with cell walls made of cellulose and β-1–3 glucans (Cheung et al., 2008).

Damping-off of tomato seedlings in nurseries is a significant disease in the country, with disease incidence ranging from 41.3 to 85.0% due to favorable epidemiological conditions for disease development, such as high soil moisture (60-70%) and moderate soil temperature (25°C) (Kumar et al., 2018). *Pythium* spp. are most active in the spring when soil temperatures are still cool and soil moisture is abundant (Flint and Dreistadt, 1998; Yang, 2001). It was discovered that *Pythium* damping-off increased progressively as soil moisture rose (Hansen et al., 1923; Roth and Riker, 1943). *Pythium* spp. flourished well at temperatures ranging from 18°C to 30°C, with the highest growth occurring at 24°C. Warm temperatures are thought to promote either the amount of damping-off or the rate at which it appears (Roth and Riker, 1943; Kailidis and Strong, 1960). *Pythium* species require different circumstances for disease development, with *Pythium ultimum* requiring chilly, wet soils and *P. aphanidermatum* requiring warmer soil temperatures (32-37°C). Seedbed density also influences damping-off; denser and more overcrowded seedbeds suffer greater disease damage. Beds that do not receive enough light appear to incur bigger losses (Hartley and Pierce, 1917; Hansen et al., 1923).

## Symptoms of Damping-off

*Pythium* spp. contribute to both pre-emergence and post-emergence damping-off (Weindling and Fawcett, 1936). *Pythium* often attacks the root tips and the soil line, where damaged plants may exhibit moldy fungal growth. Typically, affected plants emerge in patches within nursery beds or fields at lower elevations (Olson et al., 2016). Infected seeds may not germinate and may turn brown and decompose. Young seedling stems become constricted near the soil line, develop a soft, dark lesion, and frequently topple over. Brown discoloration and root thinning are visible on the roots. The prevalence of top lateral root growth may increase due to the rotting and degradation of lower roots. A less severe root infection in older plants may only cause stunted growth. In severe cases of sickness, the entire root was discovered to be rotted, and the plants were dried (Jiskani et al., 2007). *Pythium myriotylum* has been associated with dark lesions on aerial parts of tomato plants, such as stems and leaves. *Pythium* spp. fruit rot usually begins as a small water-soaked lesion on mature green or ripe fruit in contact with or near the soil. *Pythium myriotylum* has been linked to dark, aerial lesions on tomato stems or leaves.

## Pre-emergence Damping-off

Pre-emergence damping-off occurs before seed germination, caused by biotic stressors that destroy the seeds and their tissues while still underground (Horst, 2013). Infected seeds may become brown and disintegrate, and they may or may not germinate. In the first scenario, seeds become mushy, decay, and fail to germinate, but in the second scenario, emerging seed stems exhibit unique water-soaked sores below the soil line (Cram, 2003; Landis, 2013). Pre-emergence damping-off is another term for germination loss. The organisms attack the roots of the seedling not long after they emerge from the seed coat and before the seedlings appear on the dirt surface, causing their mortality.

## Post-emergence Damping-off

When seedlings rot, wilt, and die after emergence, this is a sign of post-emergence damping-off (Horst, 2013). Seedling stems exhibit water-soaked, indented damage, typically at or below ground level (i.e., on the roots), causing the plant to fall over (Wright, 1957). Post-emergence, also known as typical damping-off, occurs when organisms attack the tasty seedlings after they have emerged from the soil's outer layer. Young seedling stems are constricted close to the dirt line, causing a delicate, dim damage, and causing them to overturn. It is possible to see earthy colored stains and shrinking roots. As prominent symptoms, leaf spotting and full root rot may occur (Lamichhane et al., 2017). Lower segments of the stem at ground level or a short distance under this line are polluted, whilst the higher portions of the stem and roots are healthy. The parasite multiplies swiftly, and the attacked tissues degrade, become water splashed and flabby, and are currently unable to assist the plant's higher portion. In this fashion, the seedling falls and bites the dust. The other post-emergence symptom damping-off occurs when surviving plants grow in a stunted and uneven manner (Lamichhane et al., 2017).

## Loss caused by damping-off

Tomatoes are sensitive to several biotic and abiotic diseases, which can result in severe losses for growers. One of them is damping-off disease, which costs producers a lot of money. Soda is responsible for 90% of plant mortality in nurseries and fields, either as pre-emergence or post-emergence damping-off (Sowmini, 1961). These vegetable and field crop diseases are frequently recognized as a substantial hindrance to effective crop plant production around the world. Overall, economic losses from damping-off include both direct costs from seed or seedling damage and indirect costs from higher replanting costs and reduced yields because of later planting dates (Babadoost and Islam, 2003; Bacharis et al., 2010; Horst, 2013). Although a precise global economic assessment of damping-off's impact in monetary terms is lacking, a careful examination of the literature revealed that damping-off can impact anywhere from 5% to 80% of people (Table 1). Pre-emergence damping-off losses typically range from 5% to 40% of planted seed, with additional post-emergence losses ranging from 10% to 20%. Growers frequently over sow to produce a high yield. Several cases of damping-off and root rot diseases have been reported in Pakistan, with incidences ranging from 13% to 46% (Hyder et al., 2018; Ali et al., 2019; Dubey et al., 2020).

Table 1 presents the percentage of yield loss attributable to *Pythium*-induced damping-off.

**Table 1.** Yield loss by Pythium-induced damping-off in tomato

| S.N. | Yield loss (%) | Country | References |
|---|---|---|---|
| 1 | 30 | Kenya | Muriungi et al., 2014 |
| 2 | 10-50 | Sri Lanka | Gunaratna et al., 2019 |
| 3 | 45 | India | Ramyabharathi et al., 2012 |
| 4 | 90-95 | Tunisia | Hibar et al., 2006 |
| 5 | 13-46 | Pakistan | Arora et al., 2021 |
| 6 | 30-40 | China | Yangui et al., 2008 |

## Management of damping-off

*Preventive methods*

Damping-off spreads quickly, so seedlings should be identified as soon as possible. Efficient methods for controlling damping-off include using disease-free plots, sterilizing soil, sowing seeds at proper distances and depths, employing good cultural practices, maintaining appropriate soil moisture levels, and applying suitable fungicides. Annually, there are severe losses due to damping-off disease (Zaki, 2007). Seed treatment, soil application, and foliar spraying with systemic chemical fungicides have long been the pillars of disease management (Kazempour, 2004). Several researchers have developed unique biocide approaches using essential oil compositions (Bowers and Locke, 2000). According to Stephens and Stebbins (1985), there are numerous methods in use and costly for farmers, such as disease prevention, which has been strengthened by the present overview of soilless potting media. In nurseries, using good quality seeds and pathogen-free substrates are helpful techniques for reducing damping-off disease of fruit seedlings (Botelho et al., 2014). Platinum 701 F1 and Rajitha are resistant to damping-off disease, but Thilina and Money Maker are sensitive kinds. K.C. 01 appears to be mildly resistant to this disease (Komahan and Prasannath, 2017).

## Chemical method

Chemical fungicides have been used for a long time because they provide quick and effective control most of the time, but they also pose environmental and health risks. Aktar et al. (2009) note that fungicides may pose risks to human health and the environment, and their effectiveness can diminish as crop plants develop resistance to diseases. Captan was suggested by Gupta and Kumari (2018) for papaya seed protection, while Posse (2005) reported that benomyl and the mixture (iprodione + benomyl) were effective in the reduction of papaya damping-off. Campo et al. (2009) evaluated the ready-to-use details of the fungicides captan, tolylfluanid, thiabendazole, difeconazole, pencycuron, and fludioxonil and concluded that they were not harmful to papaya seeds and seedlings at the tested concentrations. The increased usage of synthetic information sources has a few negative implications, including the expansion of microorganism protection from applied professionals and their non-target environmental effects (Gerhardson, 2002). Because *Pythium* species develop resistance to the fungicides, their use for disease control is discouraged (Whipps and Lumsden, 1991). In some species populations, resistance to fungicides such as metalaxyl, mefenoxam, and propamocarb has been observed (Garzón et al., 2011). Certain systemic fungicides are commonly believed to be at risk of resistance development if used frequently (Bardin et al., 2004). When the first signs appear, a 0.1% bavistin drench can be applied to protect the nursery from damping-off (Sharma et al., 2022).

The doses of fungicides to control Pythium-induced damping off is given in Table 2.

**Table 2.** Dose of fungicides to control Pythium-induced damping-off in tomato

| S.N. | Common Name | Trade Name | Rate of application g/kg seed | Reference |
|---|---|---|---|---|
| 1 | Thiram | Thiram SD 75% WP | 3 | Zagade et al., 2012 |
| 2 | Captan | Captan 75% WP | 3 | Zagade et al., 2012 |
| 3 | Carbendazim | Bavistin 50% WP | 3 | Sharma et al., 2022 |
| 4 | Metalaxyl | Apron 35 SD | 3 | Lamichhane et al., 2017 |
| 5 | Cyamoxanil | Curzet | 3 | Zagade et al., 2012 |
| 6 | Mancozeb | Diathane M-45 | 2 | Muthukumar et al., 2016 |

## Biological method

Because of increased public concern about the health risks and polluting impacts of pesticides, biological management of soil-borne plant diseases has attracted great interest on a global scale (Ooijkaas et al., 1998). Biological control of a plant disease has long been thought to be the greatest disease management control measure. Biological management is essential in sustainable agriculture, particularly when soil-borne disease is present (Harman, 2007). As biocontrol agents, seed treatment with microorganisms such as *Talaromyces variabilis*, *Trichoderma viride*, and *Pseudomonas aeruginosa* has proven successful. Biocontrol measures offer a safe, sustainable, and eco-friendly approach to disease control. *Trichoderma* strains are important biocontrol agents because they are more stress tolerant than the plant pathogens against which they can be used for biological control in the field. *Trichoderma* has previously been used to successfully manage damping-off caused by *Pythium* species in various crops (Jayaraj et al., 2006). The use of the biological agent *Trichoderma* also resulted in a significant reduction in pre- and post-emergence disease incidence and a greater germination percentage, as well as higher dry root and shoot weight (Sharma et al., 2022). *Trichoderma* has a variety of properties, including growth promoter, which aids in raising plant height and dry weight, as well as a broad antifungal mechanism. *Trichoderma* spp. are hostile to other fungi (Papavizas, 1985) and are particularly strong bio-control agents of various soil-borne plant pathogenic fungi in greenhouse (Inbar et al., 1994) and field conditions (Sivan and Chet, 1993). Pseudomonas fluorescens and other bacterial species are commonly reported as effective in preventing damping-off (Martin and Loper, 1999). The main objective of the study is to evaluate the effectiveness of treating tomato seeds with biological agents against damping-off disease.

The various biological control organisms used in controlling damping off in tomato are listed in Table 3.

**Table 3.** Biological control against Pythium spp.

| Pathogens | Host | Biological Control | References |
|---|---|---|---|
| *Pythium aphanidermatum* | Cucumber | *Paenibacillus* spp. with organic compounds; *Streptomyces griseoviridis, Trichoderma* spp., *Gliocladium catenulatum* | Bai et al., 2011 |
| Pythium spp. | Chilli | *Bacillus megaterium* | Arora et al., 2021 |
| *Pythium aphanidermatum* | Tomato | *Pseudomonas fluorescens* | Arora et al., 2021 |
| *Pythium aphanidermatum* | Tomato | *Trichoderma harzianum strain* | Jayaraj et al., 2006 |
| *Pythium ultimum* | Cucumber | Different bacterial and fungal isolates | Carisse et al., 2003; Georgakopoulos et al., 2002 |
| *Pythium ultimum* and *Rhizoctonia solani* | Bedding plants | *Gliocladium catenulatum* | Mcquilken et al., 2001 |
| *Rhizoctonia solani* | Tomato | *Streptomyces* | Sabaratnam and Traquair, 2002 |
| *Pythium* spp. | Tomato | *Trichoderma harzianum* | Sharma et al., 2022 |
| *P. graminicolum* | Tomato | *Trichoderma viride* | Padmanaban and Alexander, 1984 |
| Pythium Spp. | Pea | *Trichoderma harzianum* | Lifshitz et al., 1986 |
| *Rhizoctonia solani* and *Fusarium solani* | Tomato | Olive mill wastewater and its indigenous bacteria | Yangui et al., 2008 |

## Botanical method

Various botanicals are often proposed as alternative strategies for disease control. Several plant species have been found to have fungitoxic effects against a variety of diseases (Grayer and Harborne, 1994). Botanicals and bio-products are more environmentally friendly than chemical pesticides because they break down quickly in the presence of heat, light, and bacteria. Neem leaves, garlic cloves, and neem oil can be used to treat tomato seeds for damping-off disease. Due to increasing resistance to antifungal drugs and a scarcity of treatment options, we explored novel antifungal possibilities in aromatic plants and their essential oils. The antifungal activity can be attributed to components like carvacrol, cymene, thymol, pinene, and linalool, which are known for their antimicrobial activity against plant diseases (Cimanga et al., 2002).

The essential oils and their antifungal compounds for controlling *Pythium*-induced damping off is given in Table 4.

**Table 4.** Essential oils and their antifungal compounds for controlling *Pythium*-induced damping off in tomato

| Common name | Scientific name | Antimicrobial compounds | References |
|---|---|---|---|
| Basil | *Ocimum sativum*<br>*Ocimum basilicum* | Thymol<br>Thymol | Soliman and Badeaa, 2002 |
| Celery | *Apium graveolens* | Angelicin, bergaplant, columbianctin, xanthotoxin | Afek et al., 1995 |
| Clove | *Syzygium aromatium* | Eugenol | Paranagama, 1991 |
| Datura | *Datura metel* | Enzyme, peroxidase, β-1,3-glucanase, and chitinase | Devaiah et al., 2009 |
| Eucalyptus | *Eucalyptus citriodora* | Essential oil | Pattnaik et al., 1996 |
| Himalayan May Apple | *Podophyllum hexandrum* | 4′-O-demethyldehdropodophllotoxinand picropodophllone | Atta-ur-Rahman et al., 1995 |
| Long Pepper | *Piper longum* | Eugenol, piperine, piper longumine and piperettine | Lee et al., 2009 |
| Lemon Eucalyptus | *Eucalyptus citriodora* | Citronellal, isopulegol | Chuang et al., 2007 |

However, some research has been conducted in suppressing a wide range of seed-borne pathogens by diverse botanicals, and little research has been done at the field level to examine the effectiveness of botanicals against soil-borne diseases. Antibacterial activity of neem extract has been demonstrated against clinical bacteria such as *Pseudomonas aeruginosa*, *Escherichia coli*, and *Staphylococcus aureus*, as well as phytopathogenic bacteria and fungi such as *Xanthomonas vesicatoria, Ralstonia solanacearum, Pythium aphanidermatum, Alternaria alternata, and Bipolaris soro* (Sukanya et al., 2009; Al-Hazmi, 2013). Treatment with Lantana camara and neem cake extract resulted in the greatest control of pre-emergence rot in the case of pre- and post-emergence damping-off of tomatoes under field conditions (Hooda et al., 2011). The essential oils of peppermint, caraway, and thyme demonstrated the most antifungal efficacy against the identical species studied, *Rhizoctonia solani* (Helal, 2017).

Botanicals, their parts used, and fungal inhibition percent are given in Table 5.

**Table 5.** Botanicals, their parts used and mycelium inhibition percent of *Pythium* spp.

| Botanical Control | Part used | Inhibition percent (%) on growth | References |
|---|---|---|---|
| Garlic | Clove | 100 | Begum et al., 2015 |
| Adulsa | Leaf | 75 | Gholve et al., 2014 |
| Datura | Leaf | 60 | Gholve et al., 2014 |
| Neem Extract | Leaf and oil | 32 | Sharma et al., 2022 |
| Pepper mint | Leaf | 100 | Helal, 2017 |

Bio-products are livestock waste materials such as cow dung, urine, and so on. Cow urine inhibits the vegetative growth of *R. stolonifer, Sclerotium rolfsii*, and *F. oxysporum*. Several researchers have discovered that cow urine has inhibitory action against fungal infections (Basak et al., 2002). Fresh and dry leaf mass, fresh and dry stem mass, stem length, fresh root mass, fresh head mass, and commercial yield are all increased by cow urine. Cow urine is a more sustainable alternative to costly synthetic chemicals and can be used as a bio-pesticide (Sharma et al., 2022). Many other researchers have looked into the impact of utilizing compost to manage soil-borne disease, with some claiming success in decreasing *Pythium* species (Chen et al., 1988; Ben-Yephet and Nelson 1999).

## Integrated management

Under field conditions, seed treatment, seedbed treatment, and the addition of *T. viride* and *T. harzianum* to farmyard manure may give a better damping-off solution for cauliflower, as well as boost seedling vegetative development and health (Lawrence et al., 2012). To fight damping-off diseases, chemical seed treatments are still frequently employed in agriculture (Babadoost and Islam, 2003; Bradley, 2007; Howell, 2007; Dorrance et al., 2009; Kandel et al., 2016). *T. harzianum* consortium seed treatment reduced damping-off incidence while enhancing shoot length, chlorophyll content, and yield (Kipngeno et al., 2015).

Resistance and cultural management methods are crucial strategies for organic growers in dealing with disease challenges (Fernandez-Cornejo et al., 1998; Koike et al., 2000; Sullivan, 2004). As a management strategy, resistant and/or tolerant plant cultivars that have reduced disease populations or can withstand pathogen damage can be used. Platinum 701 F1 and Rajitha were discovered to be resistant to damping-off disease, whilst Thilina and Money Maker were discovered to be sensitive. K.C. 01 appears to be mildly resistant to this disease (Komahan and Prasannath, 2017). Since most *Pythium* species thrive in moist conditions, controlling irrigation to avoid excessive soil moisture is a straightforward strategy to reduce damping-off (Rao et al., 1978; Gaskell et al., 2000). Organic manure is extremely significant in damping-off control since it not only gives nutrients and organic matter to the soil, but also enhances microbial population, biodiversity, and activity while also changing soil structure and physical, chemical, and biological properties (Subedi et al., 2022). One of the most significant techniques for preventing damping-off and root diseases is fertilization. Higher vigor and faster emergence may be attained with sufficient nitrogen availability in the soil, reducing the time pathogens can infect seeds and seedlings during the autotrophic stage. Fertilizer treatment has previously been shown to promote seed germination and seedling emergence (Cook et al., 2000). Fertilizers put directly under or slightly to one side of the seed at the time of planting or sowing promote seed germination and emergence since relatively immobile minerals like phosphorus are not easily available for plants, especially those with few or no lateral roots.

## Conclusion

Damping-off caused by *Pythium* spp. is a destructive tomato disease. The high economic value of disease prevention and the growing interest in finding long-term solutions to this problem suggest that opportunities to develop IPM strategies exist. This will necessitate a better understanding of the ecology, genetics, and pathogenicity of disease-causing microbes. The management of damping-off appears to be more difficult than one might expect. Given that several pathogenic organisms interact and cause damping-off, it is critical to have prior knowledge of the interaction in question, as even a very low population density of soil-borne pathogens can lead to severe epidemic development. As a result, preventing or controlling one pathogen may not solve the interaction problem. There is an urgent need for a better understanding of the interactions between plants, the environment, and naturally resident microbial agents or communities under the influence of cropping practices.

### Authorship contribution statement

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## References


**Afek U, Aharoni N and Carmeli S**, 1995. Increasing celery resistance to pathogens during storage and reducing high-risk psoralen concentration by treatment with GA3. Journal of the American Society for Horticultural Science, 120, 562-565. DOI: https://doi.org/10.21273/JASHS.120.4.562

**Aktar W, Sengupta D and Chowdhury A**, 2009. Impact of pesticides use in agriculture: their benefits and hazards. Interdisciplinary Toxicology, 2, 1-12. DOI: https://doi.org/10.2478/V10102-009-0001-7

**Al-Hazmi RHM**, 2013. Effect of neem (*Azadirachta indica*) leaves and seeds extract on the growth of six of the plant disease causing fungi. Global Advanced Research Journal of Microbiology, 2, 89-98.

**Ali M, Shahid AA and Subhani MN**, 2019. Mapping and monitoring for the valuation of soil fungi and chili damping off. Journal of Animal and Plant Sciences, 29, 737-745.

**Allen TW, Martinez A and Burpee LL**, 2004. *Pythium* blight of turfgrass. *The Plant Health Instructor.* DOI:10.1094/PHI-I-2004-0929-01

**Arora H, Sharma A, Sharma S, Haron FF, Gafur A, Sayyed RZ and Datta R**, 2021. *Pythium* damping-off and root rot of *Capsicum annuum* L.: Impacts, diagnosis, and management. Microorganisms, 9, 823. DOI: https://doi.org/10.3390/microorganisms9040823

**Atta-ur-Rahman, Ashraf M, Choudhary IM, Habib-ur-Rehman and Kazmi MH**, 1995. Antifungal aryltetralin lignans from leaves of *Podophyllum hexandrum*. Phytochemistry, 40, 427-431. DOI: https://doi.org/10.1016/0031-9422(95)00195-D

**Babadoost M and Islam SZ**, 2003. Fungicide seed treatment effects on seedling damping-off of pumpkin caused by *Phytophthora capsici*. Plant Disease, 87, 63-68. DOI: https://doi.org/10.1094/pdis.2003.87.1.63

**Bacharis C, Gouziotis A, Kalogeropoulou P, Koutita O, Tzavella-Klonari K and Karaoglanidis GS**, 2010. Characterization of Rhizoctonia spp. isolates associated with damping-off disease in cotton and tobacco seedlings in Greece. Plant disease, 94, 1314-1322. DOI: https://doi.org/10.1094/PDIS-12-09-0847

**Bai Q, Xie Y, Wang X, Li Y, Gao J, Li J, Li Z, Li G and Li H**, 2011. First report of damping-off of *Rhodiola sachalinensis* caused by Rhizoctonia solani AG-4 HG-II in China. Plant Disease, 96, 142. DOI: https://doi.org/10.1094/pdis-07-11-0559

**Balghouthi A, Jonathan R, Gognies S, Mliki A and Belarbi A**, 2013. A new species, *Pythium echinogynum*, causing severe damping-off of tomato seedlings, isolated from Tunisia, France, and India: morphology, pathology, and biological control. Annals of Microbiology, 63, 253-258.

**Bardin SD, Huang HC and Moyer JR**, 2004. Control of *Pythium* damping-off of sugar beet by seed treatment with crop straw powders and a biocontrol agent. Biological Control, 29, 453-460. DOI: https://doi.org/10.1016/j.biocontrol.2003.09.001

**Barone A and Frusciante L**, 2007. Molecular marker-assisted selection for resistance to pathogens. Marker-Assisted Selection: Current Status and Future Perspectives in Crops, Livestock, Forestry and Fish, 151.

**Basak AB, Lee MW and Lee TS**, 2002. Inhibitive activity of cow urine and cow dung against *Sclerotinia sclerotiorum* of cucumber. Mycobiology, 30, 175-179.

**Begum S, Devi RKT and Singh NI**, 2015. Evaluation of fungicides, biocontrol agents and botanicals for management of damping-off in cabbage seedlings caused by *Fursarium moniliforme* sheld. Journal of Applied and Natural Science, 7, 106-110.

**Ben-Yephet Y and Nelson EB**, 1999. Differential suppression of damping-off caused by Pythium aphanidermatum, *P. irregulare*, and *P. myriotylum* in composts at different temperatures. Plant Disease, 83, 356-360.

**Bhandari R, Neupane N and Adhikari DP**, 2021. Climatic change and its impact on tomato (*Lycopersicum esculentum* L.) production in plain area of Nepal. Environmental Challenges, 4, 100129. DOI: https://doi.org/10.1016/J.ENVC.2021.100129

**Botelho Sde CC, da Silveira SF, da Silva RF and Viana AP**, 2014. Chemical treatment of papaya seeds aiming at long-term storage and control of damping off. Revista Ceres, 61, 384-391. DOI: https://doi.org/10.1590/S0034-737X2014000300013

**Bowers JH and Locke JC**, 2000. Effect of botanical extracts on the population density of Fusarium oxysporum in soil and control of Fusarium wilt in the Greenhouse. Plant Disease, 84, 300-305. DOI: https://doi.org/10.1094/PDIS.2000.84.3.300

**Bradley CA**, 2007. Effect of fungicide seed treatments on stand establishment, seedling disease, and yield of soybean in North Dakota. Plant Disease, 92, 120-125. DOI: https://doi.org/10.1094/pdis-92-1-0120

**Broders KD, Wallhead MW, Austin GD, Lipps PE, Paul PA, Mullen RW and Dorrance AE**, 2009. Association of soil chemical and physical properties with Pythium species diversity, community composition, and disease incidence. Phytopathology, 99, 957-967.

**Buchenauer H**, 1998. Biological control of soil-borne diseases by rhizobacteria. Journal of Plant Diseases and Protection, 105, 329-348.

**Campo RJ, Araujo RS and Hungria M**, 2009. Nitrogen fixation with the soybean crop in Brazil: Compatibility between seed treatment with fungicides and bradyrhizobial inoculants. Symbiosis, 48, 154-163. DOI: https://doi.org/10.1007/BF03179994

**Carisse O, Bernier J and Benhamou N**, 2003. Selection of biological agents from composts for control of damping-off of cucumber caused by *Pythium ultimum*. Canadian Journal of Plant Pathology, 25, 258-267. DOI: https://doi.org/10.1080/07060660309507078

**Chen H-C, Brown JH, Morell JL and Huang CM**, 1988. Synthetic magainin analogues with improved antimicrobial activity. Febs Letters, 236, 462-466.

**Cheung F, Win J and Lang JM**, 2008. Analysis of the *Pythium ultimum* Transcriptome using Sanger and Pyrosequencing approaches. BMC Genomics, 9, 542-552.

**Chuang PH, Lee CW, Chou JY, Murugan M, Shieh BJ and Chen HM**, 2007. Anti-fungal activity of crude extracts and essential oil of *Moringa oleifera* Lam. Bioresource Technology, 98, 232-236. DOI: https://doi.org/10.1016/J.BIORTECH.2005.11.003

**Cimanga K, Kambu K, Tona L, Apers S, De Bruyne T, Hermans N, Totté J, Pieters L and Vlietinck AJ**, 2002. Correlation between chemical composition and antibacterial activity of essential oils of some aromatic medicinal plants growing in the Democratic Republic of Congo. Journal of Ethnopharmacology, 79, 213-220. DOI: https://doi.org/10.1016/S0378-8741(01)00384-1

**Cook RJ, Ownley BH, Zhang H and Vakoch D**, 2000. Influence of paired-row spacing and fertilizer placement on yield and root diseases of direct-seeded wheat. Crop Science, 40, 1079-1087. DOI: https://doi.org/10.2135/cropsci2000.4041079x

**Cram MM**, 2003. Damping-off. Tree planter's notes, 50, 9-13.

**Devaiah SP, Mahadevappa GH and Shetty HS**, 2009. Induction of systemic resistance in pearl millet (*Pennisetum glaucum*) against downy mildew (*Sclerospora graminicola*) by Datura metel extract. Crop Protection, 28, 783-791.

**Dorrance AE, Robertson AE, Cianzo S, Giesler LJ, Grau CR, Draper MA, Tenuta AU and Anderson TR**, 2009. Integrated management strategies for *Phytophthora sojae* combining host resistance and seed treatments. Plant disease, 93, 875-982.

**Dubey MK, Zehra A, Aamir M, Yadav M, Samal S and Upadhyay RS**, 2020. Isolation, identification, carbon utilization profile and control of *Pythium graminicola*, the causal agent of chilli damping-off. Journal of Phytopathology, 168, 88-102.

**Fernandez-Cornejo J, Greene C, Penn R and Newton D**, 1998. Organic vegetable production in the US: Certified growers and their practices. American Journal of Alternative Agriculture, 13, 69-78.

**Fitzpatrick HM**, 1930. The Lower Fungi Phycomycetes. McGraw-Hill, New York.

**Flint ML and Dreistadt SH**, 1998. Natural enemies handbook: the illustrated guide to biological pest control. Univ of California Press, 3386.

**Garzón CD, Molineros JE, Yánez JM, Flores FJ, del Mar Jiménez-Gasco M and Moorman GW**, 2011. Sublethal doses of Mefenoxam enhance *Pythium* damping-off of geranium. Plant Disease, 95, 1233-1238. DOI: https://doi.org/10.1094/pdis-09-10-0693

**Gaskell M, Fouche B, Koike S, Lanini T, Mitchell J and Smith R**, 2000. Organic vegetable production in California—science and practice. HortTechnology, 10, 699-713.

**Georgakopoulos DG, Fiddaman P, Leifert C and Malathrakis NE**, 2002. Biological control of cucumber and sugar beet damping-off caused by *Pythium ultimum* with bacterial and fungal antagonists. Journal of Applied Microbiology, 92, 1078-1086. DOI: https://doi.org/10.1046/j.1365-2672.2002.01658.x

**Gerhardson B**, 2002. Biological substitutes for pesticides. Trends in Biotechnology, 20, 338-343. DOI: https://doi.org/10.1016/S0167-7799(02)02021-8

**Gholve VM, Tatikundalwar VR, Suryawanshi AP and Dey U**, 2014. Effect of fungicides, plant extracts / botanicals and bioagents against damping off in brinjal. African Journal of Microbiology Research, 8, 2835-2848. DOI: https://doi.org/10.5897/AJMR2013.6336

**Goodwin SB**, 1997. The population genetics of Phytophthora. Phytopathology, 87, 462-473.

**Grayer RJ and Harborne JB**, 1994. A survey of antifungal compounds from higher plants, 1982-1993. Phytochemistry, 37, 19-42.

**Gunaratna LNR, Deshappriya N, Jayaratne DL and Rajapaksha RGSAS**, 2019. Damping-off disease of big onion (*Allium cepa* L.) in Sri Lanka and evaluation of *Trichoderma asperellum* and *Trichoderma virens* for its control. Tropical Plant Research, 6, 275-292.

**Gupta AK and Kumari K**, 2018. Management options for control of damping off and root rot diseases in papaya Biotic stress management. View project Genetic Improvement of Papaya View project. DOI: https://doi.org/10.5958/2348-7542.2016.00129.7

**Gupta VK and Paul YS**, 2001. Fungal diseases of tomato, chilli and brinjal. Diseases of Vegetable Crops. Kalyani Publishers, Ludhiana, pp. 87-101.

**Hansen TS, Kenety WH, Wiggin GH and Stakman EC**, 1923. A study of the damping-off disease of coniferous seedlings. The University of Minnesota Agricultural Experiment Station, pp. 1-20.

**Harman GE**, 2007. Overview of mechanisms and uses of Trichoderma spp. Phytopathology, 96, 190-194.

**Hartley CP and Pierce RG**, 1917. The control of damping-off coniferous seedlings. Library of Congress, 453. https://www.loc.gov/item/agr17000220/

**Helal IM**, 2017. Control of damping-off disease in some plants using environmentally safe biocides. Pakistan Journal of Botany, 49, 361-370.

**Hendrix FF and Campbell WA**, 1973. Pythiums as plant pathogens. Annual Review of Phytopathology, 11, 77-98.

**Hibar K, Daami-Remadi M, Jabnoun-Khiareddine H and El Mahjoub M**, 2006. Control of fusarium crown and root rot of tomato, caused by *Fusarium oxysporum* f. sp. radicis-lycopersici, by grafting onto resistant rootstocks. Plant Pathology Journal, 5, 161-165. DOI: https://doi.org/10.3923/PPJ.2006.161.165

**Hooda KS, Joshi D, Dhar S and Bhatt JC**, 2011. Management of damping-off of tomato with botanicals and bio-products in North Western Himalayas. Indian Journal of Horticulture, 68, 219-223.

**Horst RK**, 2013. Westcott's plant disease handbook. Springer Science and Business Media.

**Hoshino T, Tojo M, Okada G, Kanda H, Ohgiya S and Ishizaki K**, 1999. A filamentous fungus, *Pythium ultimum* Trow var. ultimum, isolated from moribund moss colonies from Svalbard, northern islands of Norway.

**Howell CR**, 2007. Effect of seed quality and combination fungicide-Trichoderma spp. seed treatments on pre- and postemergence damping-off in cotton. Phytopathology, 97, 66-71. DOI: https://doi.org/10.1094/phyto-97-0066

**Hyder S, Inam-ul-Haq M, Ashfaq M, Ahmad A, Gondal AS and Iqbal M**, 2018. First report of *Pythium myriotylum* D., causing damping off and root rot in chili pepper (*Capsicum annum* L.) from Punjab, Pakistan. Plant Disease, 102, 687.

**Inbar J, Abramsky M, Cohen D and Chet I**, 1994. Plant growth enhancement and disease control by *Trichoderma harzianum* in vegetable seedlings grown under commercial conditions. European Journal of Plant Pathology, 100, 337-346. DOI: https://doi.org/10.1007/BF01876444

**Jayaraj J, Radhakrishnan NV and Velazhahan R**, 2006. Development of formulations of *Trichoderma harzianumstrain* M1 for control of damping-off of tomato caused by *Pythium aphanidermatum*. Arch Phytopathol Plant Protection, 39, 1-8. DOI: https://doi.org/10.1080/03235400500094720

**Jiskani MM, Pathan MA, Wagan KH and Abro H**, 2007. Studies on the control of tomato damping-off disease caused by *Rhizoctonia solani* kuhn. Pakistan Journal of Botany, 39, 2749-2754.

**Jones JB**, 1991. Compendium of tomato diseases. American Phytopathological Society, St. Paul, MN (USA).

**Kailidis DS and Strong FC**, 1960. Damping-off of Black Pine, Pinus nigra. Am. Quarterly Bulletin, Michigan State University, Agricultural Experiment Station, 43, 1.

**Kandel YR, Wise KA, Bradley CA, Chilvers MI, Tenuta AU and Mueller DS**, 2016. Fungicide and cultivar effects on sudden death syndrome and yield of soybean. Plant Disease, 100, 1339-1350.

**Kazempour MN**, 2004. Biological control of *Rhizoctonia solani*, the causal agent of rice sheath blight by antagonistics bacteria in greenhouse and field conditions. Plant Pathology Journal, 3, 2.

**Kipngeno P, Losenge T, Maina N, Kahangi E and Juma P**, 2015. Efficacy of Bacillus subtilis and Trichoderma asperellum against Pythium aphanidermatum in tomatoes. Biological Control, 90, 92-95.

**Kirkpatrick MT, Rupe JC and Rothrock CS**, 2006. Soybean response to flooded soil conditions and the association with soil-borne plant pathogenic genera. Plant Disease, 90, 592-596.

**Knox JS and Paterson RA**, 1973. The occurrence and distribution of some aquatic phycomycetes on Ross Island and the dry valleys of Victoria Land, Antarctica. Mycologia, 65, 373-387.

**Koike ST, Gaskell M, Fouche C, Smith R and Mitchell J**, 2000. Plant disease management for organic crops. University of California, Division of Agriculture and Natural Resources Publication, 7252.

**Komahan DHS and Prasannath K**, 2017. Screening of tomato (*Solanum lycopersicum* L.) varieties against damping off disease under the climatic conditions of Batticaloa district, Sri Lanka. Scholars Journal of Agriculture and Veterinary Sciences, 4, 264-266. DOI: https://doi.org/10.21276/sjavs

**Kumar R, Gupta SK and Gupta M**, 2018. Investigation on etiology and epidemiology of damping-off of tomato seedlings in mid hills of Himachal Pradesh. Indian Phytopathology, 71, 513-518. DOI: https://doi.org/10.1007/s42360-018-0092-1

**Lamichhane JR, Dürr C, Schwanck AA, Robin MH, Sarthou JP, Cellier V, Messéan A and Aubertot JN**, 2017. Integrated management of damping-off diseases. A review. Agronomy for Sustainable Development, 37, 1-25. DOI: https://doi.org/10.1007/S13593-017-0417-Y

**Landis TD**, 2013. Forest nursery pests: damping-off. Forest Nursery Notes, 2, 25-32.

**Lawrence R, Kumar EJ and Badri ZA**, 2012. Comparative efficacy of *Trichoderma viride*, *T. harzianum* and carbendazim against damping-off disease of cauliflower caused by *Rhizoctonia solani* Kuehn. Journal of Biopesticides, 5, 23.

**Lee SW, Han SW, Sririyanum M, Park CJ, Seo YS and Ronald PC**, 2009. A type I-secreted, sulfated peptide triggers XA21-mediated innate immunity. Science, 326, 850-853.

**Lifshitz R, Windham MT and Baker R**, 1986. Mechanism of biological control of pre-emergence damping-off of pea by seed treatment with Trichoderma spp. Phytopathology, 76, 720-725.

**Manorantitham SK, Prakasam V and Rajappan K**, 2001. Biocontrol of damping off of tomato caused by Pythium aphanidermatum. Indian Phytopath, 54, 59-61.

**Martin FN and Loper JE**, 1999. Soilborne plant diseases caused by *Pythium* spp.: ecology, epidemiology, and prospects for biological control. Critical Reviews in Plant Sciences, 18, 111-181.

**Mcquilken MP, Gemmell J and Lahdenper**ä **ML**, 2001. *Gliocladium catenulatum* as a potential biological control agent of damping-off in bedding plants. Journal of Phytopathology, 149, 171-178. DOI: https://doi.org/10.1046/J.1439-0434.2001.00602.X

**Mendoza L, Ajello L and McGinnis M**, 1996. Infections caused by the oomycetous pathogen *Pythium insidiosum*. Journal de Mycologie Médicale, 6, 151-164.

**Muriungi SJ, Mutitu EW and Muthomi JW**, 2014.

Efficacy of cultural methods in the control of *Rhizoctonia solani* strains causing tomato damping-off in Kenya. African Journal of Food, Agriculture, Nutrition and Development, 14, 124-147.

**Muthukumar A, Udhayakumar R and Naveenkumar R**, 2016. Eco Friendly Management of Damping-off of Solanaceous Crops Caused by *Pythium* Species. In: Kumar P, Gupta V, Tiwari A, Kamle M (eds) Current Trends in Plant Disease Diagnostics and Management Practices. Fungal Biology, Springer, Cham. https://doi.org/10.1007/978-3-319-27312-9_3

**Navi SS, Huynh T, Mayers CG and Yang X-B**, 2019. Diversity of Pythium spp. associated with soybean damping-off, and management implications by using foliar fungicides as seed treatments. Phytopathology Research, 1, 1-10. DOI: https://doi.org/10.1186/S42483-019-0015-9

**Olson JD, Damicone JP and Kahn BA**, 2016. Identification and Characterization of isolate of *Pythium* and *Phytophthora* spp. from Snap Beans with Cottony Leak. Plant Disease, 100, 1446-1453.

**Ooijkaas LP, Tramper J and Buitelaar RM**, 1998. Biomass estimation of *Coniothyrium minitans* in solid-state fermentation. Enzyme and Microbial Technology, 22, 480-486.

**Owen-Going TN, Beninger CW, Sutton JC and Hall JC**, 2008. Accumulation of phenolic compounds in plants and nutrient solution of hydroponically grown peppers inoculated with *Pythium aphanidermatum*. Canadian Journal of Plant Pathology, 30, 214-225.

**Padmanaban P and Alexander KC**, 1984. Biological control of cane seedling root rot. Sugarcane, 1, 11.

**Papavizas GC**, 1985. Trichoderma and Gliocladium: biology, ecology, and potential for biocontrol. Annual Review of Phytopathology, 23, 23-54.

**Paranagama P**, 1991. Lemon grass. Analysis of Sri Lankan essential oils by gas chromatography and mass spectroscopy, 39-40.

**Pattnaik S, Subramanyam VR and Kole C**, 1996. Antibacterial and antifungal activity of ten essential oils in vitro. Microbios, 86, 237-46.

**Paulitz TC, Okubara PA and Schillinger WF**, 2006. First report of damping-off of canola caused by *Rhizoctonia solani* AG 2-1 in Washington State. Plant Disease, 90, 829.

**Posse SCP**, 2005 Production of papaya seedlings: seed treatment, substrate, and mechanical conditioning. Thesis for DSc, Universidade Estadual do Norte Fluminense, Campos dos Goytacazes.

**Postma J, Stevens LH, Wiegers GL, Davelaar E and Nijhuis EH**, 2009. Biological control of *Pythium aphanidermatum* in cucumber with a combined application of Lysobacter enzymogenes strain 3.1 T8 and chitosan. Biological Control, 48, 301-309.

**Pringsheim N**, 1858. Beitrag für Morphologie und Systematik der Algen. Die Saprolegnieen. Jahrbücher für Wissenschaftliche Botanik, 1, 284-306.

**Pretorius JC, Magama S and Zietsman PC**, 2003. Growth inhibition of plant pathogenic bacteria and fungi by extracts from selected South African plant species. South African Journal of Botany, 69, 186-192. DOI: https://doi.org/10.1016/S0254-6299(15)30344-6

**Ramyabharathi SA, Meena B and Raguchander T**, 2012. Induction of chitinase and β-1,3-glucanase PR proteins in tomato through liquid formulated *Bacillus subtilis* EPCO 16 against Fusarium wilt. Journal of Today's Biological Sciences, Research and Review, 1, 50-60.

**Rao B, Schmitthenner AF, Caldwell R and Ellett CW**, 1978. Prevalence and virulence of *Pythium* species associated with root rot of corn in poorly drained soil. Phytopathology, 68, 1557-1563.

**Rao VG**, 1963. An account of the genus *Pythium pringsheim* in India. Mycopathologia et Mycologia Applicata, 21, 45-59.

**Roth LF and Riker AJ**, 1943. Influence of temperature, moisture, and soil reaction on the damping-off of red pine seedlings by Pythium and Rhizoctonia. Journal of Agricultural Research, 67, 273-293.

**Sabaratnam S and Traquair JA**, 2002. Formulation of a *Streptomyces biocontrol* agent for the suppression of Rhizoctonia damping-off in tomato transplants. Biological Control, 23, 245-253. DOI: https://doi.org/10.1006/BCON.2001.1014

**Salman M and Abuamsha R**, 2012. Potential for integrated biological and chemical control of damping-off disease caused by *Pythium ultimum* in tomato. BioControl, 57, 711-718.

**Sharma LK, Sharma N, Dhungana B, Adhikari A, Shrestha SM and Yadav D**, 2022. Comparative efficacy of Biological, Botanical and Chemical Treatments Against Damping Off Disease of Tomato in Chitwan. International Journal of Social Sciences and Management, 9, 67-74. DOI: https://doi.org/10.3126/ijssm.v9i2.44168

**Sivan A and Chet I**, 1993. Integrated control of Fusarium crown and root rot of tomato with *Trichoderma harzianum* in combination with methyl bromide or soil solarization. Crop Protection, 12, 380-386.

**Soliman KM and Badeaa RI**, 2002. Effect of oil extracted from some medicinal plants on different mycotoxigenic fungi. Food and Chemical Toxicology, 40, 1669-1675. DOI: https://doi.org/10.1016/S0278-6915(02)00120-5

**Sowmini R**, 1961. Studies on phycomycetes in agricultural soils with special reference to Pythiaceae. Thesis for MSc (Agriculture), University of Madras.

**Stephens CT and Stebbins TC**, 1985. Control of damping-off pathogens in soilless container media. Plant Disease, 69, 494-96.

**Subedi S, Dhunagana B, Adhikari A, Regmi V, Dhungana S**, 2022. Effect of organic manures on growth and yield of cowpea in Chitwan, Nepal. Nepal. Plant Physiology and Soil Chemistry, 2, 43-46. DOI: https://doi.org/10.26480/ppsc.02.2022.43.46

**Sukanya SL, Sudisha J, Hariprasad P, Niranjana SR, Prakash HS and Fathima SK**, 2009. Antimicrobial activity of leaf extracts of Indian medicinal plants against clinical and phytopathogenic bacteria. African Journal of Biotechnology, 8, 6677-6682.

**Sullivan P**, 2004. Sustainable management of soil-borne plant diseases soil systems guide. National Sustainable Agriculture Information Service, Fayetteville, Arkansas (PO Box 3657, Fayetteville, AR 72702).

**Van der Plaats-Niterink AJ**, 1981. Studies in Mycology No. 21. Centraal Bureau voor Schimmel Cultures, Baarn, The Netherlands, pp. 1-242.

**Waterhouse GM and Waterston JM**, 1964. CMI descriptions of pathogenic fungi and bacteria. CMI Descriptions of Pathogenic Fungi and Bacteria, Set 4.

**Weindling R and Fawcett HS**, 1936. Experiments in the control of Rhizoctonia damping-off of citrus seedlings. Hilgardia, 10, 1-16. DOI: https://doi.org/10.3733/HILG.V10N01P001

**Whipps JM and Lumsden RD**, 1991. Biological control of *Pythium* species. Biocontrol Science and Technology, 1, 75-90.

**Wright E**, 1957. Influence of temperature and moisture on damping-off of American and Siberian elm, black locust, and desert willow. Phytopathology, 47, 658-662.

**Yang XB**, 2001. Identification of soybean seedling diseases. Integrated Crop Management News.

**Yangui T, Rhouma A, Triki MA, Gargouri K and Bouzid J**, 2008. Control of damping-off caused by Rhizoctonia solani and Fusarium solani using olive mill wastewater and some of its indigenous bacterial strains. Crop Protection, 27, 189-197. DOI: https://doi.org/10.1016/J.CROPRO.2007.05.005

**Zagade SN, Deshpande GD, Gawade DB, Atnoorkar AA and Pawar SV**, 2012. Biocontrol agents and fungicides for management of damping off in Chilli. World Journal of Agricultural Sciences, 8, 590-597. DOI: https://doi.org/10.5829/idosi.wjas.2012.8.6.1689

**Zaki MJ**, 2007. Use of Eucalyptus sp., in the control of root infecting fungi on mung bean and chick-pea. https://www.researchgate.net/publication/261991132