



# *Pythium* soft rot (PSR): A Review with Special Reference to Sikkim Himalaya

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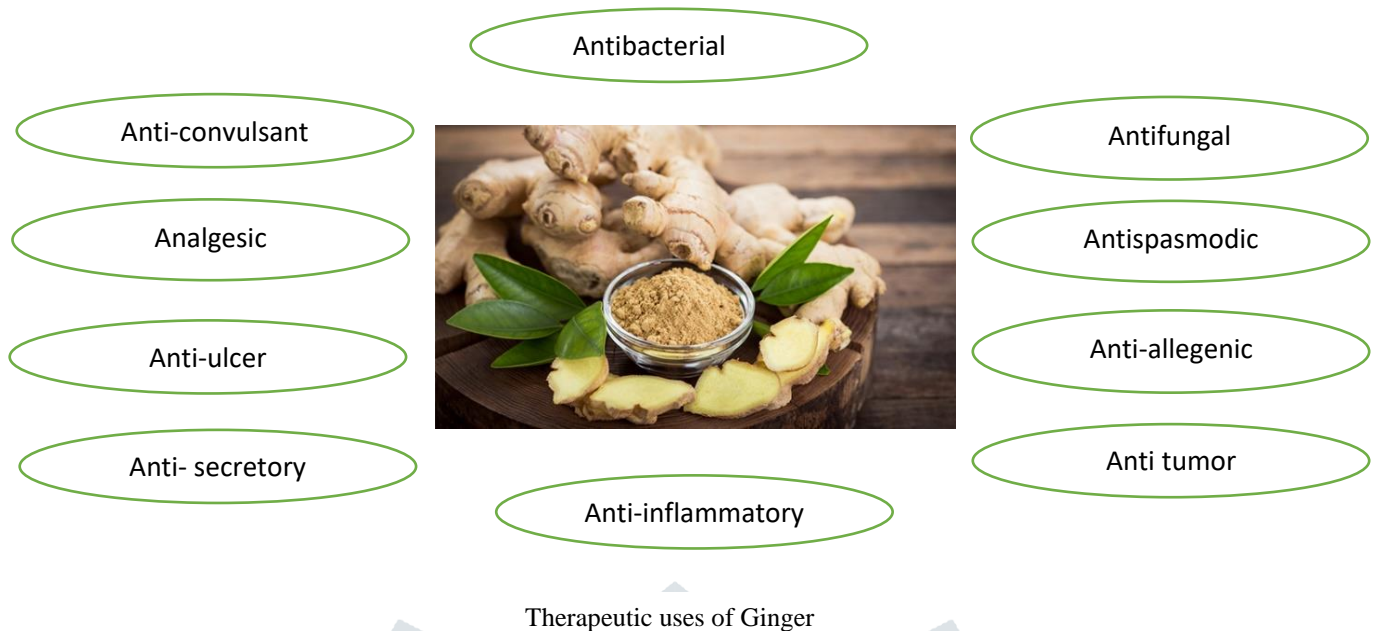
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**Abstract:** Ginger (*Zingiber officinale* Roscoe) is the chief cash crop for smallholder farmers in the state of Sikkim. Sikkim is among the third largest producer of ginger in North-Eastern India. Ginger has been utilized in culinary and medicinal practices since ancient times, owing to its diverse therapeutic attributes. These include antibacterial, antiviral, antifungal, antiemetic, anti-inflammatory, and carminative properties. Ginger is vulnerable to numerous pests and diseases globally, resulting in significant yield and economic losses. In Sikkim, ginger is frequently affected by *Pythium* spp., *Fusarium oxysporum*, and *Ralstonia solanacearum*. However, the severity of *Pythium* soft rot has emerged as a significant challenge for farmers over the past two decades, leaving them uncertain whether to continue ginger cultivation or shift to alternative crops such as seasonal vegetables and fruits. Additionally, marketing-related challenges, such as the lack of organized primary and terminal markets, uneven price information among growers, and high transportation costs, have further contributed to the decline of ginger cultivation in Sikkim. *Pythium* spp. is ubiquitous in soil and water, and it infects a wide variety of host plants, rendering management with synthetic fungicides particularly challenging. It causes diseases like root rot, damping off, and serious crop damage across a wide range of host plants. The use of chemical fungicides has faced extensive criticism due to their detrimental effects on the environment, human health, animal welfare, and soil health. Consequently, these issues have led numerous researchers to explore alternative disease management approaches, particularly the utilization of biocontrol agents (BCAs). This review paper gives insight on the incidence of *Pythium* soft rot (PSR), the current scenario of different control measures including BCAs, integrated management against PSR, and problems regarding controlling disease effectively. Further, the details of soft rot disease history and its management in Sikkim are also summarized in brief. This review is anticipated to provide valuable insights for policymakers, emerging scholars, ginger cultivators, and students for future reference.

**Keywords:** *Pythium* spp.; *Pythium* Soft rot; Bio-control agents; Sikkim

## 1. Introduction

*Zingiber officinale* Roscoe is one of the widely used spices of the Zingiberaceae family. Ginger and its extract have remarkable uses in everyday lives, Pharma industry, food industry, and various confectionaries such as wine, oil, bread, spice, drink, candy, etc. (Bijaya, 2018; Sharma et al., 2010). It is universally called as “Mahaoushadha” the great cure due to its extensive medical applications. Gingerol is one of the principle components, further, it contains other bioactive compounds viz. shogaols, zingerone, paradols with potent activities like antibacterial, anticonvulsant, analgesic, antiulcer, anti-secretory, antitumor, antifungal, antispasmodic, antiallergenic, anti-inflammatory, etc. (Hamilton, 2011; Krell and Stebbing, 2012; Dhanik et al., 2017).



The crop is cultivated mostly in the tropical and sub-tropical region and 40% of the world's production is from India. Major ginger-growing states in India are Assam, Meghalaya, Maharashtra, Kerala, Sikkim, Tamil Nadu, West Bengal, Orissa, Karnataka, Andhra Pradesh, and Himachal Pradesh (Meenu and Kaushal, 2017). In the North-Eastern region, Sikkim is the third largest producer of ginger i.e. 14.07 % after Assam and Meghalaya (Government of India, 2015). Ginger cultivated in North East are reported to have high oleoresin content and oil as a comparison to other parts of India (Rahman et al., 2009).

Ginger is a host for 24 different plant pathogens viz. bacteria, fungi, oomycetes, viruses (Dake, 1995). Among these phytopathogens, the widely distributed throughout ginger growing fields is *Pythium spp.* which causes *Pythium* soft rot (PSR). In, India and Australia 100 % losses have also been recorded, though losses are usually from 5-30% (Le, 2016). PSR was first reported by Butler in 1907 in India as a casual organism being *Pythium gracile* (Le et al., 2014). There are different *Pythium spp.* which causes soft rot in India viz. *Pythium vexans*, *Pythium deliense*, *Pythium ultimum*, *Pythium splendens*, *Pythium pleroticum*, *Pythium myriotylum*, but commonly distributed are *Pythium aphanidermatum* and *Pythium myriotylum* (Dohroo et al., 2012; Lokesh et al., 2012).

In all ginger growing areas, soft rot is a threat as it is very destructive leading to complete crop failure (Dohroo et al., 2012; Pradhan, 2013). PSR is reported to be more damaging when it occurs in association with *Fusarium spp.* or *Ralstonia spp.* or *Meloidogyne spp.* (Dohroo, 2001; Gupta et al., 2010; Rajan et al., 2002). *Pythium spp.* attacks ginger at any growth stage as well as at the postharvest stage resulting in losses up to 100% and 90%, respectively. Young rhizomes tend to be more susceptible to soft rot attacks (Dohroo, 2005; Stirling et al., 2009). Fields infection with *Pythium spp.* remained to be at risk for disease outbreaks for several years as it produces encysted zoospores, oospores, and sporangia that sustain in air-dried soil up to 12 years (Hoppe, 1966; Madsen et al., 1995). *Pythium spp.* has a wide range of hosts and they survive for prolonged periods in the field on alternative hosts including many weeds. Therefore, after fallows or rotation, if susceptible crops are replanted in the infested plot, they might get affected.

It was in 1998, the problems faced by growers were identified by ICAR, Sikkim through intensive surveys into cultural practices and insights about pests and diseases management. The survey revealed that 15 to 35 percent of the ginger field was affected by soft rot (Rahman et al., 2009). Although, Horticulture Department, the Government of Sikkim is giving its full input in disbursing disease-free ginger rhizome seeds, though the control measures of ginger disease are being propagated with little success (ISPS, 2005). As reported by Srivastava (1995) the disease intensifies in unmanaged and poorly drained fields. Smith and Abbas (2011) also recommended that a proper drainage system is crucial in managing soft rot as *Pythium spp.* produces zoospores that can swim and spread in free water.

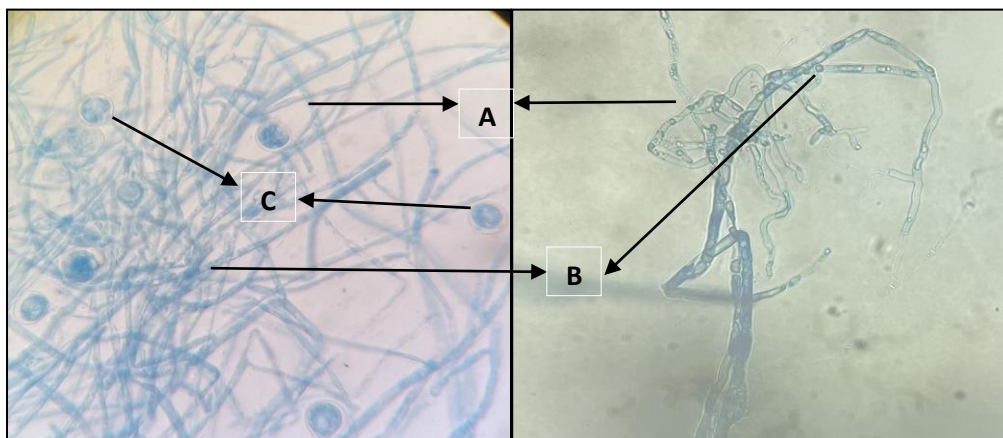
In Sikkim, *P. aphanidermatum* is mostly isolated from infected plants and rhizomes in addition to lesion nematode (*Pratylenchus coffeae*) and other fungi (Kumar et al., 2012). Local varieties like Bhaise, Charinagrey, and Majauley are popular among farmers (Pradhan, 2013). However, all cultivars are susceptible to soft rot and

rhizome rot (Pradhan, 2013; Bhat, 2001). In the last decade, the area under cultivation and average productivity of ginger has shown a drastic decline due to *Pythium* attack and other associated diseases. During a recent survey conducted by a team of researchers from the Department of Science and Technology, Government of Sikkim to different ginger growing fields all over Sikkim concludes the prevalence of soft rot in all three districts with considerably less occurrence in the north district. However, the earlier researcher reported East district (Dohroo et al., 2012) and South district with the highest disease incidence (Gopi et al., 2016).

Unfortunately, in Sikkim maximum numbers of ginger growers are switching over to large cardamom cultivation and other crops. About 60% of the ginger progressive farmer's converted ginger fields into large cardamom fields, kiwi plantations, Avocado, vegetables, etc. for better opportunity and sustenance in livelihood. Approximately 20% of ginger farmers left their ginger fields barren for many years because other crops are not suitable in those fields. Farmers are losing interest in the mass cultivation of ginger; they prefer growing them in a small amount for their own culinary and traditional use (Pradhan, 2013). Apart from disease, there is a huge price gap between producers and consumers in North East India due to which farmers are unable to get in return how much they have invested in crop production. Hence, the agricultural framework needs to be strengthened concerning the marketing of spices for poor and small-scale farmers (Singh and Feroze, 2018). Sikkim needs a very good and reliable marketing strategy for ginger and other crops like E-marketing and modern marketing strategy, further, the establishment of ginger processing units at different districts focusing more on high ginger production areas, manufacturing units for the production of by-products, mass awareness and training on how to export ginger in international markets is requisite.

## 2. The causal organism of PSR

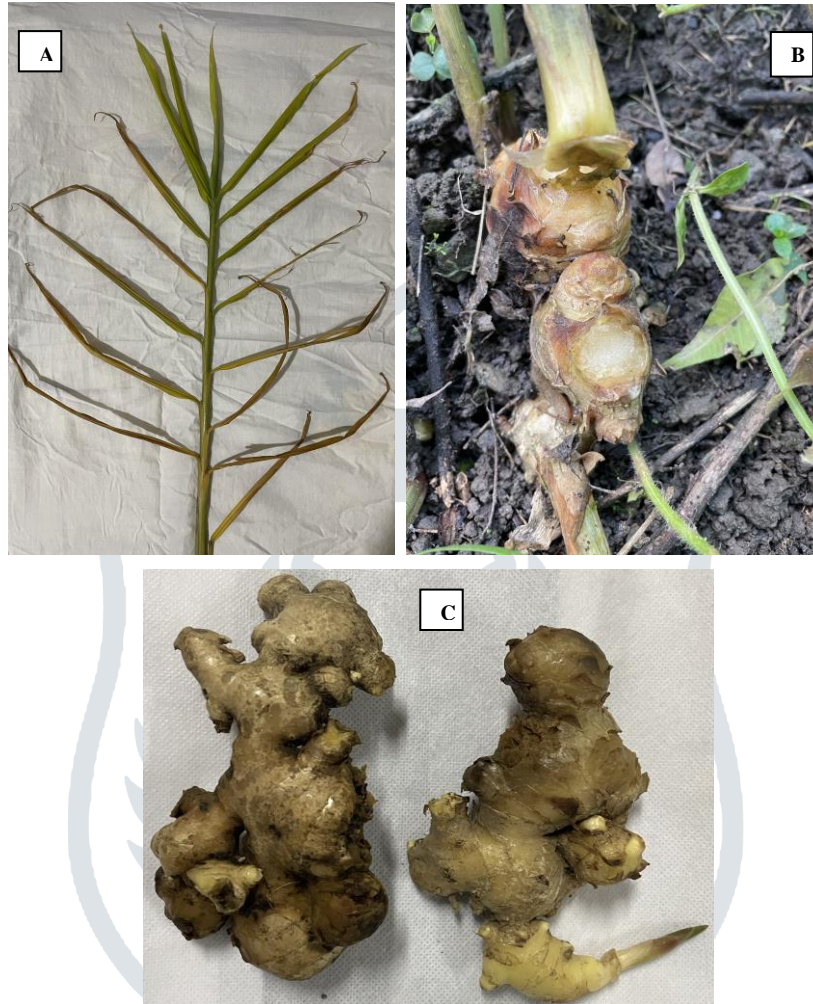
*Pythium* spp. is a casual organism for PSR. They belong to the largest genus of the family Pythiaceae and class Oomycetes (water molds). They differ from Eumycota (true fungi) in having coenocytic (aseptate) hyphae with dark blue stained prominent nuclei. The mycelium is colorless, sometimes lustrous, bright white fluffy, and occasionally beige to yellow due to abundant oospores (Dohroo et al., 2012). The fungus produces aerial mycelium on cornmeal agar, white fluffy mycelium on potato dextrose agar whereas on oatmeal agar it produces abundant aerial mycelium (Praveen and Sharma, 2014). The sporangia of *Pythium* spp. exhibit significant morphological diversity, which is crucial for their identification and classification. Recent studies have highlighted various characteristics of sporangia across different *Pythium* species, emphasizing their filamentous, globose or ovoid and cylindrical and elongated forms (Jia et al., 2020). Usually, the main hyphae are 10  $\mu\text{m}$ . Zoosporangia consist of terminal complexes of swollen hyphal branches of varying length and up to 22  $\mu\text{m}$  wide. Oogonia are terminal, globose, smooth and of 20-26  $\mu\text{m}$  diameter. Antheridia mostly intercalary, sometimes, broadly sac shaped, 10-14  $\mu\text{m}$  wide, 2 oogonium, monoclinal or diclinal, oospores aplerotic (18-22  $\mu\text{m}$ ) in diameter, wall 1-2  $\mu\text{m}$  thick (Niterink and Van Der, 1981; Waterhouse and Waterson, 1964; Dick, 1990). The distribution of *Pythium* spp. is worldwide from tropical to temperate sites and even in the Arctic and Antarctic regions. They are common pathogens of fruit, vegetable, and ornamental crops and they usually cause seed rot, seedling damping-off, and root rot, or any combination (Agrios, 2005).



A- Coenocytic hyphae; B- Nuclei; C-Sporangia of *Pythium* spp.

### 3. Symptoms of PSR

The ginger crop is susceptible to infection throughout its growing stages and almost all parts are vulnerable (Gupta and Kaushal, 2017). Initially, symptoms start appearing as yellowing of the leaves, eventually shifting downwards to leaf blade and leaf sheath. This is followed by drooping, withering, and toppling of the plants (Gogoi et al., 2008). The collar region of the pseudostem appears pale brown, later becomes water-soaked, and gradually progresses towards rhizome resulting in soft rot (Dohroo, 2005).

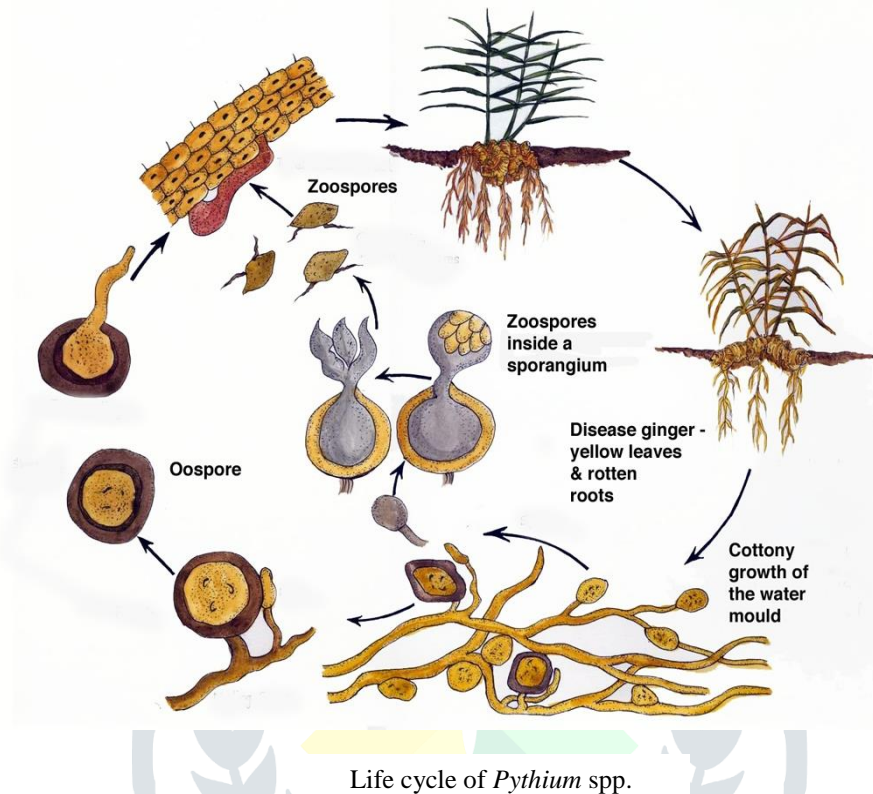


**A**-Infected plant showing yellowing of leaves; **B**- Easily uprooted stem of infected plant; **C**-Brown and water-soaked rhizome

Infection through contaminated seed rhizome leads to failed sprout growth, resulting in pre-emergence damping off. If the disease strikes after sprouting, it manifests as translucent brown lesions at the collar region, which later become water-soaked and soft, extending to the entire shoot. Infected plants can be easily uprooted. The soft rot progresses from the collar region to the rhizome, leading to the rhizome becoming discoloured and eventually degrading into a watery, putrefying mass enclosed by a tough skin. The fibrovascular strands are typically remain unaffected. Roots emerging from the diseased rhizome undergo decay and become weakened. Rotting is also observed in rhizomes harvested from infected ginger plants during storage.

#### 4. Life cycle of *Pythium* sp. and their dispersal mechanism

*Pythium* represents a genus of oomycetes that generate resilient oospores, thereby facilitating the persistence of the disease within the soil matrix until environmental conditions become conducive for germination. They represent aquatic fungal pathogens that initiate their life cycle through the development of oospores, which are characterized by their robust and resilient thick walls. These oospores allow the fungi to survive in harsh conditions, such as dry periods or cold weather, by remaining dormant in the soil for long periods until favourable conditions arise. The oospores germinate when environmental conditions improve, such as with increased moisture and suitable temperatures. This germination process involves the oospore breaking open and producing a germ tube. The germ tube subsequently differentiates into hyphae, elongated filamentous structures that proliferate and disseminate



within the substrate of the soil. These hyphae establish contact with the roots or seedlings of plants and subsequently invade the plant tissue, initiating a pathogenic infection. Within the plant host plant, the hyphae persist in their growth, resulting in deleterious effects on the plant cellular structure leading to symptoms like root rot, damping-off in seedlings, and overall toppling of the entire plant. As the fungi grow, they can produce asexual spores called sporangia, which release motile spores known as zoospores. These zoospores can swim in water and infect new plants by reaching their root systems. Furthermore, *Pythium* species possess the capability for sexual reproduction through the formation of oospores upon the convergence of two distinct mating types, thereby facilitating genetic variation. This reproductive cycle enables *Pythium* spp. to endure within their ecological niche and perpetually infect host plants, resulting in the manifestation of recurrent plant disease.

The dispersal mechanisms of *Pythium* species play a crucial role in the propagation of diseases within agricultural ecosystems. These pathogens exhibit remarkable adaptability characterized by diverse modes of transmission that facilitate their proliferation across diverse ecological niches. A comprehensive understanding of these mechanisms is imperative for the formulation of effective management strategies.

#### Dispersal Mechanisms

- Soil and Water Ubiquity:** *Pythium* species are prevalent in both soil and water, allowing them to spread through irrigation and rainfall runoff, which can transport spores over considerable distances (Parveen & Sharma, 2015). This ability to thrive in various environments not only enhances their survival but also increases the likelihood of infecting new host plants, thereby complicating disease management efforts for farmers.
- Seed Transmission:** Certain species, such as *P. aphanidermatum*, are seed-borne, leading to pre-emergence damping-off and subsequent crop losses (Parveen & Sharma, 2015).

c) **Host Density Influence:** The concentration of host vegetation exerts a significant influence on the propagation of diseases; elevated densities promote a more efficient dispersion among plants, subsequently increasing disease incidence (Burdon & Chilvers, 1975).

### Environmental Factors

a) **Soil Characteristics:** The moisture and temperature of soil exert a considerable effect on the virulence of *Pythium* as well as the susceptibility of its hosts, thereby influencing the dynamics of disease progression. (Martin & Loper, 1999).

b) **Genetic Diversity:** The genetic diversity present among *Pythium* species facilitates their capacity to adapt to a variety of environmental conditions, thereby enhancing their survival and spread (Cai et al., 2023).

While *Pythium* species are widely recognized for their deleterious impact on agricultural systems, a contingent of researchers promotes the utilization of biological control strategies some researchers advocate for biological control methods as sustainable alternatives to chemical treatments, which may result in the development of resistance and environmental harm (Parveen & Sharma, 2015).

### 4. Disease Management

Numerous agricultural techniques are adopted by farmers to combat PSR in the field which includes different cultural agro-techniques viz. crop rotation, tillage, organic amendment, drainage, propagating in isolated places like the jungle, near bamboo growing areas, mixed cropping with turmeric, red pepper (chili), *Artemisia vulgaris*, application of different mulching material, etc. Planting disease-free ginger rhizome seeds is another alternative but due to the formation of oospores and sporangia, the fungus can survive for a prolonged time in soil which makes these practices less significant (Le et al., 2014). Physical techniques involving soil solarization have widely been used for the control of the disease (Katan, 2000; Usman *et al.*, 1996). Mathur *et al.*, (2002), successfully demonstrated soil solarization against *Pythium* spp. in Rajasthan. Solarization has a positive impact on the vegetative growth of the crop as well (Deadman *et al.*, 2006). However, with less intensity of heat in the hilly regions, soil solarization techniques were not successful to control PSR (Samuel Rai, 2006). The application of organic matter in the field enhances soil health thereby suppressing the disease-causing pathogens (Theodore and Toribio, 1995; Erhart and Burian, 1997). Researchers found that sugarcane residues, poultry slurry, municipal biosolids proved to be good controlling agents against *Pythium* spp. (Hadar and Mandelbaum, 1986; Mandelbaum and Hadar, 1990). For a better result, soil solarization with appropriate organic materials was recommended by Parveen and Sharma (2014). Many researchers have suggested the control of soft rot through the application of various chemical fungicides such as metalaxyl, mancozeb, carbendazim, ridomil MZ, propyl carbonate hydrochloride, etc. (Lokesh *et al.*, 2012). In controlling PSR, the usage of fungicides is inevitable due to the lack of available resistant varieties. The chemical pesticide residues in the agricultural commodities are an issue in food safety aspects by several imported countries apart from their high cost. Chemical fungicides usually enter the food chain causing detrimental effects on the biosphere, human, animal, and soil health. Nevertheless, with the successful isolation of R gene from a donor *Z. zerumbet*, a PSR resilient cultivar is anticipated to develop in the future (Le *et al.*, 2014).

In context to Sikkim, application of chemical fertilizers like Thiodan, ginger rhizome seed treatment with carbendazim followed by soaking in zineb or mancozeb or metalaxyl were successful to some extent (Srivastava 1992; Srivastava, 1994). Indian Council of Agriculture Research (ICAR), Sikkim successfully suppressed soft rot disease on local cultivar “Gorurabthane” by using chemical fertilizer Dithane Z-78 and Dithan M-45 in the three years field experiment. However, the use of chemical pesticides and fertilizer is strictly prohibited as the state was declared an organic state in 2015. Techniques like seed rhizomes solarization and uniform exposure to sunlight could be effective remedial measures, though, exposure shouldn't exceed two hours (Singh, 2011). Ginger is a high-value crop particularly for small and marginal farmers and they are being infested with pests and diseases severely hampering the production and limiting yield to great extent. Most of the farmers in the state have small holdings; ginger is cultivated on un-irrigated lands or as an intermediate crop in paddy fields. Therefore, the other control measures to combat PSR apart from fungicides are needed to be considered. There is an immediate need for appropriate biological disease control measures, especially in the state where no other synthetic pesticides are allowed to rejuvenate ginger cultivation.

## 5. Bio-control agents (BCAs) to control PSR

Scientific researchers are extensively investigating approaches to mitigate *Pythium* soft rot in ginger cultivation. Numerous scholars have undertaken empirical investigations regarding various phytochemical extracts, conventional formulations, and antagonistic biocontrol agents. Both in-vitro and in-vivo experiments were conducted. Research suggested that the most effective mechanism for regulating PSR involves the generation of inhibitory metabolites, secretion of enzymes, competition for spatial and nutritional resources, mycoparasitism, hyphal interactions, and predation on *Pythium* propagules (Praveen and Sharma, 2014). In conventional formulations, both fresh and preserved bovine urine at a concentration of 20% (v/v) demonstrates significant efficacy in the regulation of *P. aphanidermatum* (Rakesh *et al.*, 2013b). *Jeevatu* (organic liquid manure) showed good activity against soft rot with no further spreading after its application in Nepal (Poudyal, 2012).

### a) Use of Microorganism

One of the best possibilities is the isolation of biocontrol agents from nature that inhibits the plant pathogen PSR. Many Rhizobacteria including *Pseudomonas fluorescense* were reported to have antagonistic activity against *Pythium* spp. (Bhai *et al.*, 2005; Bardin *et al.*, 2004). The amendment of antagonistic agents was also found to enhance the growth and yield of ginger (Gupta *et al.*, 2010; Shanmugam *et al.*, 2013a). A cellulolytic actinomycetes, *Streptomyces rubrolavendulae* (Yen) S4, isolated in Kanchanaburi, Thailand from a termite mound was reported to control the seedling damping-off disease caused by *P. aphanidermatum* (Loliam *et al.*, 2013). *Glomus intraradices* and *Trichoderma asperellum* could be used as biocontrol agents to reduce the infection caused by *Erwinia carotovora* and *P. aphanidermatum* on young Okra seedlings (Idowu *et al.*, 2016). The commonly used biocontrol agent for PSR in India is *Trichoderma* spp. *Trichoderma harzianum* is found to be most effective in inhibiting *Pythium* species with increased crop germination (Elad *et al.*, 1982; Shanmugam *et al.*, 1999). *T. hamatum*, *T. aureoviride*, *T. virens* and *T. reesa* were reported to have activity against *P. aphanidermatum* (Manorajitham and Prakasam, 2000). Although, in field condition, the activity of *T. harzianum* and other spp. in controlling PSR was just recorded around half as compared to pot culture, and after three seasons of application its activity declined continuously almost 1.5 times (Singh, 2011). A recent study conducted by Jain *et al.*, (2020) reported the seed and soil treatment with *T. harzianum* and *T. viridae* are found to be moderately effective against infection caused by *Pythium aphanidermatum*.

### b) Use of Plant extract

The various in-vitro and in-vivo experiment was conducted by different researchers on different plant extract against PSR pathogen. In vitro experiment was carried out with extracts of onion, garlic, lantana, and agave resulted in significant growth reduction of *P. aphanidermatum* (Dohroo *et al.*, 2012). Praveen and Sharma (2014) reported the efficacies of 20 different plant extract against *P. aphanidermatum* *in vitro* and recorded *Jacaranda mimosifolia* and *Moringaolifera* with the antagonistic activity of 27.7%. The crude extracts of plants could efficiently control *Pythium drechsleri* (Abdolmaleki *et al.*, 2010; Kim *et al.*, 2000). Spider lilly (*Crinum asiaticum*) is reported to have antagonistic activity against *P. aphanidermatum* (Ramnathan *et al.*, 2004). Extract of *Oxyspora paniculata* with 94.4 % inhibition activity against *P. aphanidermatum* was reported (Bhatt, 2000). Uma *et al.*, (2012), reported antifungal activity of *A. zapota*, *T. indica*, *C. papaya*, *P. granatum*, *V. vinifera*, *C. colocynthis* against *P. aphanidermatum*. Parveen and Sharma (2014) reported the antifungal activity of crude aqueous, 50% hydroalcoholic and alcoholic leaf extracts as recorded (Table 1) against *P. aphanidermatum* and *Pythium myriotylum*. Timorex gold, tea tree oil based biofungicides was shown to possess slow fungi, toxic effect against *P. aphanidermatum* in Serbia (Mihajlovic *et al.*, 2013). The high altitude macro lichen *Usnea pictoides* is a potential antifungal agent against infection caused by *Fusarium oxysporium* and *P. aphanidermatum* (Vinayaka *et al.*, 2014).

In Greenhouse conditions, the consortium of *Burkholderia cepacia* + *T.harzianum* showed production efficiency of 84% with a decrease in soft rot incidence by 79.7%. In field trials, a similar mixture could decrease rhizome rot to 49.3% and an increased rhizome yield by 60% (Shanmugam *et al.*, 2013b). In Sikkim, the occurrence of soft rot incidence has been increasing every year. Though the effort to find out appropriate biological agents to control the disease has been carried out but still lacks concrete results. Bhat, 2000 reported *in vitro* antagonistic activity of 37 medicinal plants and weeds against *P. aphanidermatum*. *Oxyspora paniculata* extracts showed (94.4 %) inhibition against *P. aphanidermatum* and extracts of *Macaranga denticulata* exhibited complete inhibition of *Pythium* spp. Mulching materials such as forest litter, titeypati (*Artemisia vulgaris*), chilouney (*Schima wallichii*), Utis (*Alnus nepalensis*) and banmara (*Chromolaena odorata*) were reported to protect the ginger from the pests and disease,

inhibit weed, and enhance germination as well (Rahman et al., 2009). Kumar et al., (2012), concluded that *Schima wallichii* and *Datura* spp. be the best mulches controlling soft rot caused by *P. aphanidermatum*.

A total of 23 *Trichoderma* spp. was isolated from rhizosphere soil of disease and non-disease ginger at ICAR Farm, Bermoik, South Sikkim. Among them, *T. viride*, *T. koningii* and *T. harzianum* were found effective against *F. solani* and *P. aphanidermatum* (Bhat and Srivastava, 2003). Field trial of *T. harzianum* was carried out at Mangalbaria (West Sikkim) and Maniram (South Sikkim), it was reported that their efficacy was reduced by more than 50% (ISPS, 2005). The study conducted by Gopi et al., 2016, resulted in 62.3 % inhibition of *P. aphanidermatum* by 10% garlic concentration. *T. harzianum* isolated from Today busty, South Sikkim also exhibited 72% inhibition against a pathogen. Among the several integrated measures evaluated against the soft rot, the hot water treatment at 47°C for 30 min +*T. harzianum*+COC (0.3%), recorded maximum germination of 91.3 and 90.3 % and highest yield of 158 and 126 q/ha (Gopi et al., 2016). The report depicting BCAs (except *T. harzianum*) and their effectiveness against PSR and field trial studies from Sikkim are limited. However, most of them could give effective results *in vitro* but their efficacies in the field are usually inconsistent (Le et al., 2014). Lowered efficiency of BCAs in fields could be enhanced by applying a mixture of many BCAs together (Shanmugam et al., 2013). Many researchers reported the effectiveness of BCAs depends on application procedure, inoculum concentrations, ecological competence in native soils, and competition with soil microflora (Papavizas, 1985). Also, biocontrol agents may not be effective when the population of pathogens is in high concentration, it works when pathogen pressure is low to moderate. The major difficulty in controlling PSR on the ginger field is its disease complex with *Fusarium oxysporum* and *Ralstonia solanacearum*. Mostly the activity of *T. harzianum* and BCAs decreased greatly in the presence of *F. oxysporum* f. sp. *zingiberis*, therefore considering them to be complete remedial disease treatment wouldn't be appropriate (Rajan et al., 2002, Bardin et al., 2004).

Table 1. List of plants/ microorganisms with antifungal activity against *Pythium* soft rot

SI no.	Reported by	Plant/ Microorganisms used as BACs	Fungal pathogens
1	Jain et al., 2020	<i>T. harzianum</i> , <i>T. viridae</i>	<i>Pythium aphanidermatum</i>
2	Gopi et al., 2016	<i>T. harzianum</i> , Garlic extract	<i>Pythium aphanidermatum</i>
3	Idowa et al., 2016	<i>Glomus intraradices</i> and <i>T. asperellum</i>	<i>Pythium aphanidermatum</i>
4	Vinayaka et al., 2014	<i>Usnea pictoides</i>	<i>Fusarium oxysporum</i> and <i>Pythium aphanidermatum</i>
5	Abdolmaleki et al., 2014; Kim et al., 2010	<i>Zataria multiflora</i> , <i>Pinus halepensis</i> , <i>Carum carvi</i> , <i>Cinnamomum zelanicum</i> and <i>Xanthium strumarium</i>	<i>Pythium drechsleri</i>
6	Praveen and Sharma, 2014	<i>Jacarand mimosifolia</i> , <i>Moringaolifera</i> ,	<i>P. aphanidermatum</i>
7	Praveen and Sharma, 2014	<i>Azadiracta indica</i> , <i>Aegle marmelos</i> , <i>Cassia fistula</i> , <i>Clitoria ternatae</i> , <i>Delonix regia</i> , <i>Eucalyptus globules</i> , <i>Jacarandas mimosifolia</i> , <i>Justicia gendarusa</i> , <i>Moringa olifera</i> , <i>Murraya koenigii</i> , <i>Nigella sativa</i> , <i>Pongamia pinnata</i> , <i>Polyalthia longifolia</i> , <i>Tecomella undulate</i> and <i>Terminallia arjuna</i>	<i>P.aphanidermatum</i> , <i>P.myriotylum</i>
8	Lalfakawma et al., 2014	Neem	<i>Pythium sp.</i> , <i>Fusarium oxysporum</i>

9	Dohroo and Gupta, 2014	<i>T.harzianum+P.fluorescens+ B. subtilis</i>	
10	Mihajlovic et al., 2013	Tea tree oil	<i>P. aphanidermatum</i>
11	Shanmugam et. al., 2013	<i>Burkholderia cepacia + T.harzianum</i>	<i>Pythium spp.</i>
12	Uma et al.,	<i>A. zapota, T.indica, C.papaya, P.granatum, V.vinifera, C.colocynthis</i>	<i>P. aphanidermatum, P.myriotylum</i>
13	Kumar et. al., 2012	<i>Schima wallichii, Datura spp.</i>	<i>Pythium aphanidermatum</i>
14	Dohroo et al., 2012	<i>Onion, lantana, agave, garlic</i>	<i>P. aphanidermatum</i>
15	Bhai et al., 2005	<i>Bacillus sp., Pseudomonas fluorescence</i>	<i>Pythium spp.</i>
16	Bardin et. al., 2004	<i>Pseudomonas fluorescence</i>	<i>Pythium spp.</i>
17	Ramanathan et al., 2004	<i>Crinum asiaticum</i>	<i>P. aphanidermatum</i>
18	Vaker and Patel, 2004	<i>Lawsonia inermis, Emblica officinalis</i>	<i>P. aphanidermatum</i>
19	Bhat and Srivastava, 2003	<i>T. virde, T.koningii, T.harzianum</i>	<i>P. aphanidermatum, F.solani</i>
20	Rajan et al., 2002	<i>T. harzianum</i>	<i>P. aphanidermatum, F. oxysporum</i>
21	Bhatt, 2000	<i>Oxyspora paniculata, Macaranga denticulate</i>	<i>P. aphanidermatum</i>
22	Manorajithan and Prakasam, 2000	<i>T. hamatum, T.virens, T. reesa, T. aureoviride</i>	<i>P. aphanidermatum</i>
23	Elad et al., 1982; Shanmugam et. al., 1999	<i>T. harzianum</i>	<i>P. aphanidermatum</i>
24	Ram et al., 1997	<i>T. harzianum, Pseudomonas fluorescence</i>	<i>P.myriotylum, F. solani</i>

### c) Nano Technology based Management

Nanotechnology offers promising approaches for managing *Pythium* soft rot which is a substantial threat to crops like ginger. The utilization of nanoparticles provides an environmentally friendly alternative to traditional chemical fungicides to combat pathogenic fungi. The integration of nanotechnology-based strategies into disease management practice can enhance the effectiveness of interventions while concurrently reducing adverse environmental consequences. Nanotechnology offers promising strategies for managing *Pythium* soft rot, a significant threat to crops like ginger. This approach utilizes nanoparticles (NPs) to combat pathogenic fungi, providing an eco-friendly alternative to traditional chemical fungicides. The integration of nanotechnology in disease management can enhance efficacy while minimizing environmental impact. Research has identified Zinc oxide (ZnONPs) and sulfur nanoparticles (SNPs) possess potent antifungal capabilities against *Pythium* sp. and *Fusarium* sp. infecting ginger, demonstrating significant inhibition of fungal growth (Ingle et al., 2024; Rai et al., 2018). Nanotechnology offers innovative mechanisms for managing *Pythium* soft rot, a significant threat to crops like ginger and turmeric. By utilizing various nanomaterials, researchers have identified multiple pathways through which these technologies can combat fungal pathogens effectively.

## Mechanisms of Action

- I. **Antifungal Properties:** Metal oxide nanoparticles, such as CuO and ZnO, exhibit strong antifungal effects against *Pythium* spp., with CuO showing higher toxicity by eliminating pathogen culturability (Zabrieski et al., 2015). NPs disrupt fungal cell membranes and inhibit spore germination, leading to reduced disease incidence (Rai et al., 2018).
- II. **Induction of Defense Responses:** Nano-glucan treatment in turmeric enhances plant growth and activates defense enzymes, such as chitinase and peroxidase, which help in reducing rot incidence (Anusuya & Sathiyabama, 2014).
- III. **Targeted Delivery:** Nanoparticles can serve as carriers for fungicides, allowing for controlled release and targeted action, thereby minimizing environmental toxicity (Nizamani et al., 2024).
- IV. **Interference with Pathogen Metabolism:** Nanoparticles disrupt iron uptake processes in *Pythium*, affecting their growth and survival (Zabrieski et al., 2015).

## Advantages of Nanotechnology

- I. **Eco-friendliness:** Unlike conventional fungicides, NPs are less harmful to the environment and human health, addressing concerns associated with chemical pesticide use (Tripathi et al., 2020).
- II. **Cost-effectiveness:** The synthesis of NPs through biological methods, such as using plant extracts, reduces production costs and enhances sustainability (Tripathi et al., 2020).
- III. **Improved Crop Resilience:** Nanoparticles can enhance plant defence mechanisms, triggering systemic acquired resistance and increasing antioxidative enzyme activity, which helps plants cope with stress from pathogens (Cao et al., 2023).

Although nanotechnology offers promising strategies for managing *Pythium* soft rot, potential risks to non-target organisms and environmental concerns necessitate thorough evaluation and regulation of these technologies before widespread adoption in agricultural practices. Carefully balancing innovative solutions with ecological safety remains crucial for sustainable agricultural applications.

## 6. Integrated disease management

It is quite difficult to manage soft rot using one approach alone because it fails to suppress pathogens in field conditions. Hence, many scientists recommended integrated disease management to combat disease effectively. An integrated approach proposed by Smith and Abbas, (2011), was focused on cultural practices and a strict quarantine procedure. Soft rot caused by *P. myriotylum* could be treated with soil solarization followed by the application of fungicides (Mathur et al., 2002). In Rajasthan, rhizome treatment with Ridomil MZ (metalaxyl + mancozeb) plus soil drench with Thimet (Phorate) and Ridomil MZ at 60 days after sowing resulted in the best control of *P. myriotylum* on the experimental ginger field. The seed solarization at 47°C under 200 mm polyethylene sheet for 30 min successfully inhibits *Pythium* spp. (Lokesh et al., 2012). Soil solarization for longer periods i.e. up to 4 weeks resulted in a significant decrease in disease incidence and reduction in *Pythium* spp. (Deadman et al., 2006). Dohroo and Gupta (2014) have suggested combination of one or more bio-agents together could greatly reduce PSR incidence. Consortium of *T. harzianum*+*P. fluorescens*+*B. subtilis* resulted in minimum rhizome rot. Rhizome treatment with Copper oxychloride (COC) followed by neem extract was found to be significant in controlling rhizome disease development (Lalfakawma et al., 2014). A two years field study on rhizome treatment in hot water at 47 °C for 30 min and application of *T. harzianum* @ 2.5 kg/ 50 kg FYM/ha, followed by three drenchings of mancozeb @ 0.25% were most effective in limiting the incidence of soft rot on ginger besides having their significant response in improving the growth and yield (Dohroo et al., 2015).

In Sikkim due to high annual rainfall, humidity and unpredictable weather, control of PSR have become a challenging task with no synthetic inputs for crop protection. Therefore, integrated management practice is the essential component, though requires a lot of intervention. Application of well-rotted FYM/ compost is thoroughly applied in the soil. Dolomite at 2 % is supplemented in the soil to maintain the pH. Leaves and twigs of *Schima wallichii*, *Eupatorium* spp., *Alnus nepalensis*, *Artemisia vulgaris*, were mostly used as mulches in ginger beds (Ashok kumar et al., 2012). Depending on the severity of the disease, crop rotations are usually done every 2 to 4 years as it reduces the incidence of rhizome rot to large extent. Several recommended approaches to avoid the

spread of PSR in the field are disease-free seed selection, proper organic amendment, tillage, Phytosanitation, and good quarantine practices.

## 7. Challenges in controlling PSR

With available chemical, biological and cultural control measures of PSR, the ginger disease caused by PSR could not be controlled completely. The use of resistant variety would certainly help in the management to a large extent but none of the edible ginger varieties is resistant to *Pythium* spp. (Nair and Thomas, 2013). Senapati and Sugata (2005) reported one *P. aphanidermatum* resistant ginger cultivar and eight with moderate resistance at Koraput, India. Though, this report is not yet supported by any other researchers in the country. Sterility and obligatory vegetative propagation of ginger (Nair and Thomas, 2013) continue to hinder breeding efforts and edible ginger remains a monomorphic crop even in the assumed center of origin, India (Kizhakkayil and Sasikumar, 2011; Nair and Thomas, 2012).

In Sikkim, “Majauley” cultivar is moderately resistant while other cultivars were found to be fully susceptible to rhizome rot (Sharma et al., 2012) while wild *Zingiber* species reproduce both sexually and asexually, and they exhibit high genetic diversity including potential resistant traits (Kavitha and Thomas, 2008c). By mRNA differential display analysis, a pool of RCGs of *Z. zerumbet*, a putative soft rot-resistant species was studied (Kavitha and Thomas, 2008b). However, none of the identified R-genes from *Z. zerumbet*, were able to bring resistance in edible ginger cultivars (Nair and Thomas, 2013). Nevertheless, the association of ZzR1 gene in *Z. zerumbet* which protects against PSR is thought to be a major genomic resource for PSR resistant variety in the future and this arena offers research worth exploring.

## 8. Conclusion

Ginger occupies a crucial economic position within India, particularly in Sikkim, and its therapeutic attributes have increasingly garnered substantial interest. PSR represents a significant threat to the cultivation of ginger, and its effective control and management are challenged by the extensive diversity of its host ranges. A variety of strategies, encompassing chemical, biological, cultural, and induced resistance measures, have demonstrated considerable promise in the mitigation of PSR. Nevertheless, the efficacy of each individual strategy has not reached satisfactory levels of regulation in practical applications. Therefore, to abate losses caused by PSR in the field, it is recommended to integrate all applicable approaches, though such integration has proven to be of limited efficacy. Examining the concerns associated with the application of fungicides and their adverse impacts on human health as well as environmental integrity, there exists a pressing necessity to identify an environmentally sustainable and cost-effective strategy to enhance the yield of ginger while ensuring its resistance to disease. The use of bio-fungicides derived from plant materials and antagonistic microbial sources has proven to be a cost-effective alternative that can be implemented at the farm level, particularly in Sikkim's organic agriculture system. Consequently, there is an immediate need for extensive research to provide new insights into the disease and challenges in developing effective bio-fungicides to protect ginger. Practical and implementable strategies for the complete management of *Pythium* soft rot must be developed and made accessible to farmers to support their livelihoods. Further,

- a) An effective agro-technique needs to be developed, (Phytosanitation of field, seed treatment, mixed cropping, etc.)
- b) Additional research is necessary to develop disease-resistant ginger cultivars.
- c) Cultivation of superior quality planting material in controlled environments.
- d) The potential of nanotechnology in managing *Pythium* soft rot is significant, further research is necessary to fully understand its long-term effects and optimize its application in agricultural practices.
- e) Formulate comprehensive strategies and guidelines for the cultivation of ginger in mountainous regions

## References

1. Abdolmaleki, M., Bahraminejad, S., Abassi, S. and Mahmodi, S.B. (2010). Inhibitory effect of some plant extracts on mycelia growth of *Rhizoctonia solani* and *Phytophthora drechsleri*, sugar beet root rot agent. *Journal of Sugar Beet*, 25: 193-205.
2. Agrios, G.N. (2005). *Plant Pathology*. Elsevier Academic Press, Burlington, Mass.
3. Ashok Kumar, Ravikant Avasthe, Tasvina R. Borah and Boniface Lepcha (2012). Organic mulches affecting yield quality and diseases of ginger in mid hills of North Eastern Himalayas. *Indian Journal of Horticulture*, 69(3): 439-442.
4. Bajaree Loliamia, Tsutomu Morinagab and Saipin Chaiyanana (2013). Biocontrol of *Pythium aphanidermatum* by the cellulolytic actinomycetes *Streptomyces rubrolavendulae* S4. *Science Asia*, 39:584-590.
5. Bardin, S.D., H.C. Huang and J.R. Moyer (2004). Control of *Pythium* damping-off of sugar beet by seed treatment with crop straw powders and a biocontrol agent. *Biological Control* 29(3): 453-460.
6. Bhai, R.S., Kishore, V.K., Kumar, A., Anandaraj, M. and Eapen, S.J. (2005). Screening of rhizobacterial isolates against soft rot disease of ginger (*Zingiber officinale* Rosc.). *Journal of Spices and Aromatic Crops*, 14(2): 130-136.
7. Bharat Kumar Poudyal (2012). *Jeevatu: One of the Best Bio-Agents for the Control of Soft Rot of Ginger*. 2nd International Conference on Environment Science and Biotechnology IPCBEE IACSIT Press, Singapore, pp: 66-70.
8. Bhat, M. N. and Srivastava, L.S. (2003). Evaluation of some fungicides and neem formulations against six soil borne pathogens and three *Trichoderma* spp. in vitro. *Plant Disease Research*, 18(1): 56-59.
9. Bhat, N. (2001). In vitro cultivation of some leaf extracts against *Fusarium* spp. causing dry rot / yellows of ginger in Sikkim. *Plant Disease. Research*, 16(2): 259-262.
10. Bhatt, M. N. (2000). In vitro valuation of some leaf extracts against *Pythium* species causing soft rot of ginger in Sikkim: *Plant Disease Research*, 15(1): 97-100.
11. Bijaya, B.B. (2018). Ginger processing in India (*Zingiber officinale*): A review. *International Journal of Current Microbiology and Applied Sciences*, 7(4): 1639-1651.
12. Daguang Cai, Wilken Boie, Markus Schemmel, Wanzhi Ye, Mario Hasler, Melanie Gol and Joseph Verreet (2023). *Pythium* Survey Europe provides deep insights into the genetic and structural diversity of *Pythium* communities and their disease potential in Europe. <https://doi.org/10.21203/rs.3.rs-3345451/v1>
13. Dake, G.N. (1995). Diseases of ginger (*Zingiber officinale* Rosc.) and their management. *Journal of Spices and Aromatic Crops*, 4(1): 40-48.
14. Deadman M., Hasani H. Al and A. Al Sa'di (2006). Solarization and Biofumigation Reduce *Pythium aphanidermatum* induced Damping off and Enhance Vegetative Growth of Greenhouse Cucumber in Oman. *Journal of Plant Pathology*, 88(3): 335-337.
15. Dhanik, J., Arya, N. and Nand, V.A. (2017). Review on *Zingiber officinale*. *Journal of Pharmacognosy and Phytochemistry*, 6(3): 174-184.
16. Dick, M.W. (1990). *Keys to Pythium*. Department of Botany, School of Plant Sciences, University of Reading, Reading, U.K.
17. Dohroo, N.P. (2001). Etiology and management of storage rot of ginger in Himachal Pradesh. *Indian Phytopath.* 54: 49-54.
18. Dohroo, N.P. (2005). Diseases of ginger. In: *Ginger, the Genus Zingiber* (Ravindran, P.N. and Babu, K.N., Eds.), CRC, Press.
19. Dohroo, N.P. and Gupta, M. (2014). Effect of bioagents on management of rhizome diseases, plant growth parameters and nematode population in ginger. *Agricultural Science. Digest*, 34: 41-44.
20. Dohroo, N.P., Kansal, S. and Ahluwalia, Neha. (2015). Studies on eco-farmer-friendly practices for management of soft rot of ginger (*Zingiber officinale*). *Indian Phytopathology*, 68: 93-96.
21. Dohroo, N.P., Kansal, S., Mehta, P. and Ahluwalia, N. (2012). Evaluation of eco-friendly disease management practices against soft rot of ginger caused by *Pythium aphanidermatum*. *Plant Disease. Research*. 27: 1-5.
22. Duy Phu Le (2016). *Characterization of Species Associated with Pythium Soft Rot of Ginger and Evaluation of Pythium Oligandrum as a Biocontrol*, PhD Thesis, The University of Queensland, Australia.
23. Duy Phu Le, Mike Smith, George William Hudler and Elizabeth Aitken (2014). *Pythium* soft rot of ginger: Detection and identification of the causal pathogens, and their control. *Crop Protection*, 65: 153-167.
24. Elad, Y., Kalfon, A., and Chet (1982): Control of *Rhizoctonia splanii* in cotton by seed-coating with *Trichoderma* spp. spores. *Plant Soil*, 66: 279-281.

25. Erhart, E. and K. Burian (1997). Evaluating quality and suppressiveness of Austrian biowaste composts. *Compost Science and Utilization*, 5: 15-24.
26. Frank, N., Martin. And Joyce, E., Loper. (1999). Soilborne plant diseases caused by pythium spp: ecology, epidemiology, and prospects for biological control. *Critical Reviews in Plant Sciences*, 18(2): 111-181.
27. Gogoi R, Nath HKD., Borah T.R. (2008). Diversity of the pathogens inciting rhizome rot disease of ginger in Assam and Arunachal Pradesh. *Journal of Mycology and Plant Pathology*, 38(2): 291-294.
28. Gopi, R., Kalita, H and Avasthe, Ravikant (2016). Organic management of soft rot of ginger (*Zingiber officinale*) in Sikkim Himalayan region. *Indian Journal of Agriculture Sciences*, 86(12). 1586-90.
29. Government of India (2015), Horticulture Statistics at a Glance, New Delhi.
30. Gupta Meenu and Manisha Kaushal (2017). Diseases infecting ginger (*Zingiber officinale* Roscoe): A review. *Agricultural Reviews*, 38(1): 15-28.
31. Gupta Meenu and Tannyson Jebasingh, (2019). Diseases.of.Ginger.DOI: <http://dx.doi.org/10.5772/intechopen.88839>.
32. Gupta, M., Dohroo, N.P., Gangta, V. and Shanmugam, V. (2010). Effect of microbial inoculants on rhizome disease and growth parameters of ginger. *Indian Phytopathology*, 63: 438-441.
33. Hadar Y. and Mandelbaum R. (1986). Suppression of *Pythium aphanidermatum* damping off in container media containing compost liquorice root. *Crop protection*, 5:88-92.
34. Hamilton, K. (2011). Ginger and chemotherapy: A literature review. *Shadows: New Zeal. Journal of Medical. Radiation. Technology*, 54: 23-28.
35. Haware, M.P. and Joshi, L.K. (1974). Studies on soft rot of ginger from Madhya Pradesh. *Indian Phytopathology*. 27: 158-161.
36. Hoppe, P.E. (1966). *Pythium* species still viable after 12 years in air-dried muck soil. *Phytopathology*, 56, 1411.
37. ISPS (Indo Swiss Project Sikkim), 2005. Experience in Collaboration-Ginger Pests and Diseases, Inter-cooperation India Programme. Series 1. Indo-Swiss Project Sikkim, Hyderabad, India, pp: 57.
38. J. J. Burdon and G. A. Chilvers (1975). Epidemiology of damping-off disease (*Pythium irregulare*) in relation to density of *Lepidium sativum* seedlings. *Annals of Applied Biology*, 81(2): 135-143.
39. Jain D.K., Swami H. and Gangwar R.K. (2020). Management of fungi, *Pythium aphanidermatum* causing rhizome rot disease of ginger (*Zingiber officinale* Rose) in Southern Rajasthan, India. *International Journal of Current Microbiology and Applied Sciences*; 9(6): 903-911.
40. Jia-Jia, Chen., Hui, Feng., Wei, Song., Xiaobo, Zheng. (2020). Two new *Pythium* species from southern China based on morphological and molecular characters. *Phyotaxa*, 432(3):263-273.
41. Katan, J. (2000). Physical and culture methods for the Management of Soil borne Pathogens. *Crop Protection*, 19,725-731.
42. Kavitha, P.G. and Thomas, G. (2008b). Expression analysis of defense-related genes in *Zingiber* (*Zingiberaceae*) species with different levels of compatibility to the soft rot pathogen *Pythium aphanidermatum*. *Plant Cell Reports*, 27: 1767-1776.
43. Kavitha, P.G. and Thomas, G. (2008c). Population genetic structure of the clonal plant *Zingiber zerumbet* (L.) Smith (*Zingiberaceae*), a wild relative of cultivated ginger, and its response to *Pythium aphanidermatum*. *Euphytica*, 160: 89-100.
44. Kim, J.S., Kwon, C.S. and Son, K.H. (2000): Inhibition of  $\alpha$ -glucosidase and amylase by luteoline, a flavonoid. *Bioscience, Biotechnology and. Biochemistry*, 64(11): 2458-2461.
45. Kizhakkayil, J. and Sasikumar, B. (2011). Diversity, characterization and utilization of ginger: a review. *Plant Genetic Resources -Characterization and Utilization* 9, 464-477.
46. Krell, J. and Stebbing, J. (2012). Ginger: the root of cancer therapy?. *The Lancet Oncology*, 13: 235-236.
47. Kumar, A., Avasthe, R.K., Borah, T.R., Lepcha, B. and Pandey, B. (2012). Organic mulches affecting yield, quality and diseases of ginger in mid hills of North Eastern Himalayas. *Indian Journal of Horticulture*, 69: 439-442.
48. Lalfakawma, C., Nath, B.C., Bora, L.C., Srivastava, S. and Singh, J.P. (2014). Integrated disease management of *Zingiber officinale* Rosc. rhizome rot. *The Bioscan* 9: 265-269.
49. Lokesh, M.S., Patil, S.V., Gurumurthy, S.B., Palakshappa, M.G. and Anandaraj, M. (2012). Solarization and antagonistic organisms for management of rhizome rot of ginger in Karnataka. *International. Journal of. Plant Protection*, 5: 195-200.
50. Madsen, A.M., Robinson, H.L. and Deacon, J.W (1995). Behaviour of zoospores cysts of the mycoparasite *Pythium oligandrum* in relation to their potential for biocontrol of plant pathogens. *Mycological Research*, 99: 1417-1424.

51. Mahendra, Rai., Avinash, P., Ingle., Priti, Paralikar., Netravati, Anasane., R., M., Gade., Pramod, Ingle. (2018). Effective management of soft rot of ginger caused by *Pythium* spp. and *Fusarium* spp.: emerging role of nanotechnology. *Applied Microbiology and Biotechnology*, 102(16):6827-6839.
52. Mandelbaum, R. and Y. Hadar (1990): Effects of available carbon source on microbial activity and suppression of *Pythium aphanidermatum* in compost and peat container media. *Phytopathology*, 80: 794-804.
53. Manoranjitham, S.K. and V. Prakasam (2000). Management of chilli damping off using biocontrol agents. *Capsicum Eggplant News Lett*, 19: 101-104.
54. Mathur, K., Ram, D., Poonia, J., Lodha, B. C. (2002). Integration of soil solarization and pesticides for management of rhizome rot of ginger. *Indian Phytopathology*, 55: 345-347.
55. Milica Mihajlovic, Emil Rekanovic, Jovana Hrustic, Brankica Tanovic, Ivana Potocnik, Milos Stepanovic and Svethana Milijasevic Marcic (2013). *In vitro* and *In vivo* toxicity of several fungicides and timorex gold Biofungicide to *Pythium aphanidermatum*. *Pesticide and. Phytomedicine*, (2): 117-123.
56. Mir, Muhammad, Nizamani., Alice, C., Hughes., Hai-Li, Zhang., Yong, Wang. (2024). Revolutionizing agriculture with nanotechnology: Innovative approaches in fungal disease management and plant health monitoring. *Science of The Total Environment*, 172473-172473.
57. Nair, R.A. and Thomas, G. (2012). Functional genetic diversity at nucleotide binding site (NBS) loci: Comparisons among soft rot resistant and susceptible *Zingiber* taxa. *Biochemical. Systematics and. Ecology*, 44: 196-201.
58. Nair, R.A. and Thomas, G. (2013). Molecular characterization of ZzR1 resistance gene from *Zingiber zerumbet* with potential for imparting *Pythium aphanidermatum* resistance in ginger. *Gene*, 516: 58-65.
59. O. O. Idowu, O. I. Olawole, O. O. Idumu and A. O. Salami (2016). Bio-control Effect of *Trichoderma asperellum* (Samuels) Lieckf. and *Glomus intraradices* Schenk on Okra Seedlings Infected with *Pythium aphanidermatum* (Edson) Fitzp and *Erwinia carotovora* (Jones) 2016. *American Journal of Experimental Agriculture*, 10(4): 1-12.
60. Osman, K.A. and Al-Rehiayam, S. Saudi (2003). Risk assessment of pesticide to human and the environment. *Saudi Journal of Biological Sciences*, 10: 81-106.
61. Papavizas, G.C. (1985). *Trichoderma and Gliocladium*: biology, ecology and potential for biocontrol. *Annual. Review of. Phytopathology*, 23: 23-54.
62. Plaats-Niterink and A.J. Van Der.(1981). Monograph of the Genus *Pythium*. *Studies in Mycology No. 21*. Baarn, Netherlands: Centraal Bureau Voor Schimmelcultures.
63. Pramod U. Ingle, Mahendra Rai, Patrycja Golińska and Aniket K. Gade (2024). Phytomediated zinc oxide and sulfur nanoparticles for management of soft-rot causing pathogenic fungi in ginger. *Biocatalysis and Agricultural Biotechnology*, 58.
64. Rahman, H., Karuppaiyan, R., Kishore, K., Denzongpa, R.. (2009). Traditional practices of ginger cultivation in Northeast India. *Indian Journal of Traditional Knowledge*, 8(1): 23-28.
65. Rai, Samuel. (2006). Management of Ginger (*Zingiber officinale* Rosc.) Rhizome Rot in Darjeeling and Sikkim Himalayan Region. Darjeeling Krishi Vigyan Kendra Uttar Banga Krishi Viswavidyalaya Kalimpong, District Darjeeling, WB, India.
66. Rajan, P.P., Gupta, S.R., Sarma, Y.R. and Jackson, G.V.H. (2002). Diseases of ginger and their control with *Trichoderma harzianum*. *Indian Phytopath.* 55: 173-177.
67. Rakesh, K.N., Dileep, N., Junaid, S., Kekuda, P.T.R., Vinayaka, K.S. and Nawaz, N.A.S. (2013b). Inhibitory effect of cow urine extracts of selected plants against pathogens causing rhizome rot of ginger. *Science Technology and Arts Research Journal*, 2(2): 92-96.
68. Ram Singh and S.M. Feroze (2018). Price Gap between Producers and Consumers of Ginger: Empirical Evidence from North Eastern Hill Region. *Indian Journal of Agriculture Economics*, 73(3): 309-327.
69. Ram, P., Mathur, K. and Lodha, B.C. (1997). Response of application methods of BCAs either as rhizome pelleting, or as soil application, or as both against rhizome rot of ginger. *Annals of Biology, Ludhiana*, 13: 293-296.
70. Ramanathan A., Marimuthu T. and Raguchander T. (2004). Effect of plant extracts on growth in *Pythium aphanidermatum*. *Journal of Mycology and. Plant Pathology*, 34: 315-317.
71. Sathiyarayanan, Anusuya and Muthukrishnan, Sathiyabama (2014). Application of nano-glucan to turmeric rhizome induce defence response against *Pythium aphanidermatum*. *Archives of Phytopathology and Plant Protection*, 47(20):2429-2441.
72. Senapati, A.K. and Sugata, G. (2005). Screening of ginger varieties against rhizome rot disease complex in eastern ghat high land zone of Orissa. *Indian Phytopathology*. 58: 437-439.
73. Shanmugam V., Varma A.S. and Surendran M. (1999): Management of rhizome rot of ginger by antagonistic microorganisms. *Madras. Journal of Agricultural Sciences*, 86: 339-341.

74. Shanmugam, V., Gupta, S. and Dohroo, N.P. (2013a). Selection of a compatible biocontrol strain mixture based on cocultivation to control rhizome rot of ginger. *Crop Protection*, 43: 119-127.
75. Shanmugam, V., Gupta, S., Dohroo, N.P. (2013). Selection of a compatible biocontrol strain mixture based on co-cultivation to control rhizome rot of ginger. *Crop Prot.* 43, 119-127.
76. Shanmugam, V., Thakur, H., Kaur, J., Gupta, S., Rajkumar, S. and Dohroo, N.P. (2013b). Genetic diversity of *Fusarium* spp. inciting rhizome rot of ginger and its management by PGPR consortium in the western Himalayas. *Biological. Conservation*, 66: 1-7.
77. Sharma, B.R., Dutta, S., Ray, S. and Roy, S. (2012). Influence of plant spacing, seed rhizome size and cultivars on the incidence of rhizome rot and wilt disease complex of ginger. *Journal of. Horticulture and. Forestry*, 4: 105-107.
78. Sharma, B.R., Dutta, S., Roy, S., Debnath, A. and De Roy, M. (2010). The effects of soil physico-chemical properties on rhizome rot and wilt disease complex incidence of ginger under hill agro-climatic region of West Bengal. *The Plant Pathology Journal*, 26(2): 198-202.
79. Singh, A.K. (2011). Management of rhizome rot caused by *Pythium*, *Fusarium* and *Ralstonia* spp. in ginger (*Zingiber officinale*) under natural field conditions. *Indian Journal of. Agricultural. Sciences*, 81: 268-270.
80. Smith, M. and Abbas, R. (2011). Controlling *Pythium* and associated pests in ginger. RIRDC Publication No. 11/128, Canberra.
81. Srivastava, L.S. (1992). Management of soft rot of ginger in Sikkim. *Research in Plant Disease*, 9(2): 146-149.
82. Srivastava, L.S. (1995). Review of ginger diseases. In: *Ginger Disease Workshop: proceedings and Strategic Plan*. 12-13 September 1995, Gangtok, Sikkim.
83. Srivastava, L. S. (1994). An outbreak of bacterial wilt of ginger in Sikkim. *Sikkim Science. Society. Newsletter*. Oct-Dec, pp.11.
84. Stirling, G.R., Turaganivalu, U., Stirling, A.M., Lomavatu, M.F., Smith, M.K. (2009). Rhizome rot of ginger (*Zingiber officinale*) caused by *Pythium myriotylum* in Fiji and Australia. *Australas. Plant Pathology*, 38: 453-460.
85. Sushen Pradhan (2013). Development of tissue culture system for in-vitro regeneration, biochemical and molecular characterization of ginger varieties grown in Sikkim, PhD Thesis, Gauhati University, Guwahati, Assam, India.
86. Tahira Parveen and Kanika Sharma (2015). *Pythium* Diseases, Control and Management Strategies: A Review, *International Journal of Plant, Animal and Environmental Sciences*, 5(1), 244-257.
87. Theodore, M. and J.A. Toribio (1995). Suppression of *Pythium aphanidermatum* in composts prepared from sugarcane factory residues. *Plant Soil*, 177: 219-233.
88. Uma T., Sravani Mannam, Jyotsna Lahoti, Kanchal Devi, Radha D. Kale and D. J. Bagyaraj (2012). Biocidal activity of seed extracts of fruits against soil borne bacterial and fungal plant pathogens, *Journal of. Biopesticides*, 5(1): 103-105.
89. Usman MN., Balakrishnan P. and Sarma YR (1996). Biocontrol of rhizome rot of ginger. *Journal of Plantation crop*. 24 (Supply). 184-191.
90. Vankar, H.J. and B.N. Patel (2004). Efficacy of leaf extracts and botanical pesticide in conjunction with fungicide against damping off of bidi tobacco. *Journal of Mycology and Plant Pathology*, 34(1)-198.
91. Vinayaka K.S, Prashitha Kekuda T.R., Noor Nawaz A.S., Syed Junaid, Dileep N. and Rakesh K.N. (2014). Inhibitory Activity of *Usnea pictoides* G.Awasthi (Parmeliaceae) against *Fusarium Oxysporum F. Sp. Zingiberi* and *Pythium aphanidermatum* isolated from Rhizome Rot of Ginger. *Life Sciences Leaflets*, 49: 17-22.
92. Waterhouse, G.M. and Waterston, J.M (1964). *Pythium aphanidermatum*. CMI descriptions of pathogenic fungi and bacteria, No. 36. Common wealth Mycological Institute: Kew, Surrey, UK. Waterhouse.
93. Xue, Song, Cao., Yulin, Liu., Xing, Luo., Chuan-hua, Wang., Le, Yue., Wade, H., Elmer., Om, Parkash, Dhankher., Jason, C., White., Zhen, Wang., Baoshan, Xing. (2023). Mechanistic investigation of enhanced bacterial soft rot resistance in lettuce (*Lactuca sativa* L.) with elemental sulfur nanomaterials. *Science of The Total Environment*, 884: 163793.
94. Yashoda, Nandan, Tripathi., Chetan, Keswani., Walia, Zahra., Kumari, Divyanshu., Ram, Sanmukh, Upadhyay. (2020). *Trichoderma*-Based Nanopesticides: Next-Generation Solution for Disease Management. 85-106.
95. Zac, Zabrieski., Elliot, Morrell., Joshua, Hortin., Christian, O., Dimkpa., Joan, E., McLean., David, W., Britt., Anne, J., Anderson. (2015). Pesticidal activity of metal oxide nanoparticles on plant pathogenic isolates of *Pythium*. *Ecotoxicology*, 24(6):1305-1314.