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Pythium Soft Rot Management in Ginger (*Zingiber officinale* Roscoe) – A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Ginger crop is affected by various diseases. Among them rhizome/soft rot is the most damaging one and main production constraint in ginger growing areas. This disease is mainly caused by the *Pythium* spp. along with association of some others micro-organisms. The severity of *Pythium* soft rot disease is influenced by different factors related to seed, environment and soil. This study was focused on *Pythium* soft rot of ginger with special reference to different management strategies. Different cultural measures viz. seed rhizome treatment before storage and sowing, selection of disease free seed rhizome, sowing time, application of soil amendments, good drainage of soil, soil solarization etc. are the important measures for management of ginger soft rot. Seed treatment and soil drenching are the two options of chemical control of soft rot. Seed rhizomes treated with fungicides azoxystrobin 25%, tebuconazole 25.9%, copper oxychloride 50%, carbendazim 50%, propiconazole 25%, metalaxyl-M 4% + mancozeb 64%, metiram 55% + pyraclostrobin 5%, carbendazim 12% + mancozeb 63%, tebuconazole 25% + trifloxystrobin 25% and metalaxyl 8% + mancozeb 64% resulted in effective management. Different fungicide formulations viz.

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carbendazim 50%, copper oxychloride 50%, metalaxyl-M 4% + mancozeb 64%, metiram 55% + pyraclostrobin 5%, carbendazim 12% + mancozeb 63%, tebuconazole 25% + trifloxystrobin 25% etc. found effective for spraying. Seed treatment and application of *Trichoderma* spp. found suitable for effective biological management.

Keywords: Disease management; favourable condition; ginger; Pythium; soft rot.

1. INTRODUCTION

The important spice crop Ginger (*Zingiber officinale* Roscoe) belongs to family Zingiberaceae. Different cultivars, sowing time, climatic condition and maturity time are the major dependable factors for variability in productivity of ginger [1]. The infections by different diseases are the major limitations for ginger cultivation. Among them, rhizome rot or soft rot has been considered to be most destructive disease, causing huge economic losses in ginger growing areas [2,3,4]. This disease is caused by the *Pythium* spp. [5,6,7] along with association of *Fusarium* spp. [8,9,10,11], *Ralstonia solanacearum* [11], *Collectotrichum dematum* [12] and *Sclerotium rolfsii* [11,12]. Among the different causal micro-organisms, *Pythium* is important one because various species of *Pythium* are responsible for rotting as well as loss in yield of ginger [13]. Different species of *Pythium* viz. *P. aphanidermatum*, *P. graminicola*, *P. deliense, P. myriotylum, P. splendens, P. spinosum*, *P. pleroticum*, *P. ultimum* etc. are responsible for rotting of ginger [5,6,7,14]. In India, *Pythium* soft rot firstly reported by Butler in 1907 with the description of the causal agent being *P. gracile* [15] and it was considered as a synonym for *P. aphanidermatum* [2]. Further, it was found in different parts of India viz. Bihar [16], Kerala [17], Maharashtra [18], Karnataka [11] and in Madhya Pradesh [19]. *P. aphanidermatum* was also responsible for soft rot of ginger in Australia [5], Bangladesh [20], China [21] and Japan [22]. On other hand, rhizome rot caused by *P. butleri* was reported in Malabar and South Kanara districts of South India [23]. The soft rot caused by *P. complectans* Braun was reported in Ceylon [24]. *P. deliense* Meurs was reported from India [19] and Australia [5]. *P. graminicolum* Subram was identified in Australia [25], Ceylon [26], Fiji [6], Hawai [27] and in India [26]. Lin et al. [28] studied soft rot in ginger and isolated the pathogen *P. myriotylum* Drechsler in Taiwan. It was also found in Australia [3,5], Fiji [3] and Korea [29]. The soft rot caused by *P. spinosum* Sawada in ginger have been reported in Australia [5,30] and Japan [31]. *P. ultimum* Trow affected the rhizomes of ginger in Australia, India and Japan [5,22,32]; *P. vexans* de Bary was found in India and Fiji [6,33]; and *P. zingiberis* Takahashi was observed in Japan and Korea [10,34]. Disease management strategy has been advocated for the management of the problem posed by this pathogen. Therefore, in this review an attempt has been made to provide an overview of *Pythium* soft rot in ginger with special reference to different management strategies.

2. YIELD LOSS

Loss of ginger production by soft rot varies from place to place and ranged between 4-100% [3,35]. Field losses by ginger soft rot have been reported in different countries; for example losses of 25% in Nepal [35], >50% in Fiji [3], 60% in China [21], 90% in India [36] and 100% at some cultivated areas of Australia [3]. In case of storage condition, crop loss due to *Pythium* in ginger may also be high and ranged between 4 - 90% [35,37].

3. SYMPTOMS OF *Pythium* SOFT ROT

Ginger crop infected by *Pythium* soft rot throughout the growing periods and it affect all plant parts [38]. The initiation and enlargement of brown watery lesions of pseudostem causes the stem rot/ soft rot in ginger [2]. Foliar symptoms appear as yellow to golden yellow colour on the older leaves starting from the leaf margins, finally wilting and toppling of the plants apart from rotting of the rhizomes [39]. As on older leaves progress, younger leaves start developing a similar symptom progression until the entire plant dies [40]. Through artificial inoculation, the ginger plant requires 7-10 days to show yellowing and rotting symptoms [7]. Gradually infection spreads from collar region to rhizome [41] and diseased stems can be easily pulled out from the field. Diseased plants look like brown, water soaked, soft, and it will decay gradually [2].

4. MODE OF ACTION OF *Pythium*

Pythium produces cellulolytic and pectolytic enzymes or phytotoxins, these enzymes are tissue degrading species. The action of these enzymes is the basis of pathogenesis by *Pythium* spp. [42,43]. Oospores are the major root infecting units [44], which produces germ tubes and terminate by producing a sporangium. Dissolution of the middle lamella of the host tissues results in soft rot. The high soil water deposition in the ginger plot is the main factor for production of sporangia on the host. The oomycete helps in invade and colonize the host by secreting cell wall degrading enzymes (CWDEs) like pectinase, cellulase, xylanase and protease, which breaks down the plant cell wall [45].

5. DISEASE CYCLE OF *Pythium*

5.1 Survival of Inoculums

Pythium spp. survives between crops on infected seed rhizome [46,47] and oospores takes place in scale leaves [46]. But nature of rhizome inoculum is not well understood [48]. The saprophytic survival of *Pythium* spp. on plant debris and soils produces oospores on non-host crops and weeds as well. Saprophytic survival of the fungus in soil is influenced by environmental factors, soil temperatures, moisture and presence of other microbes. Severity of *Pythium* disease is more in areas where rainfall is high or heavy clay soils where drainage is impede [49]. Oospores of *Pythium* present in the soil or infected seed rhizome would serve as the primary source of inoculums [44]. The rhizome rot infection occurs early if the infection is seed borne. Zoospores that are released from the sporangia are chemotactically attracted to the host roots where they encyst and form germ tubes which infect the host roots. Under ideal conditions, lesions appear in 72 hours around the penetration point. The zoospores released from the sporangia on the host may be carried passively or by the active movements to healthy plants where it may cause new infection resulting in the spread of the disease [50]. Infected seed rhizomes are the major sources of disease spread and serve as the primary source. Secondary spread of the disease is mainly through soil water.

5.2 Favourable Conditions

Severity of *Pythium* is influenced by different factors viz. temperature [3,5,51,52], rainfall [48], humidity [53,54], soil condition [29,48,55] etc. The optimum temperature for the germination of the oospores of *P. apanidermatum* was reported as 30°C [52]. Temperature of 20-35°C and 30-35°C were found to be conducive for causing ginger soft rot due to *P. myriotylum* and *P. aphanidermatum*, respectively [5]. The infection of *P. vexans* is maximum when the temperature is low; the maximum tolerance limit of that pathogen is being 34°C. Whereas, optimum temperature of 34°C was favourable for ginger soft rot caused by *P. aphanidermatum* and 25-30°C for *P. myriotylum* [51]. Stirling et al. [3] reported that *P. myriotylum* was capable of ruining rhizomes within 1-2 weeks in saturated condition with 26-30°C temperatures. Sarma [48] reported that high soil moisture and adequate temperature (25-30°C) prevailing during the months of July-September, coinciding with the south west monsoon is highly conducive for the disease development of rhizome rot. A warm and humid climate predisposes the plant to infection at sprouting stage, because of its tender and succulent tissues [54]. In the same way, *P. aphanidermatum* and *P. myriotylum* are reported to cause severe damage in warm humid climates [53]. Increased soil moisture may encourage disease onset and spread and wet year's confirmed more incidence of *Pythium* rhizome rot [36]. Kim et al. [29] found an optimum pH of 6.0 – 7.0 for growth of the *P. myriotylum*. Sharma et al. [55] found a significant contribution (93%) of organic carbon and soil pH for forecasting of ginger rhizome rot incidence with negative correlation. Similarly Debnath et al. [56] and Kim et al. [57] reported a negative correlation of soil pH and organic carbon with rhizome rot incidence and also found that these two factors may appear as important for occurrence. Soft rot incidence reduced in soil with low pH and organic carbon >2.25% [55]. Similarly, compost treated soil suppressed the incidence of *P. aphanidermatum* [58]. Well drained soil is suitable for less disease incidence [48]. Varying degrees of association of *Meloidogyne incognita* was noticed with root system of ginger. Interaction of this nematode with *P. aphanidermatum* neither increased the disease nor could pre dispose the plant to infection [50]. However increased rhizome rot incidence was reported in association with nematodes viz. *M. incognita* and *Pratylenchus coffeae* [59].

6. MANAGEMENT OF GINGER SOFT ROT CAUSED BY *Pythium*

6.1 Cultural Management

Different cultural practices like storage of seeds, selection of seeds, sowing time, crop rotation, drainage, area selection, land preparation, weed management, fertilizer application, soil management etc. are generally practiced in ginger field for lowering of the spread of *Pythium* spp. Treatment of seed ginger before storage and planting time by 0.3% mancozeb for a time period of 30 minutes reduced disease incidence [60]. Sharma et al. [61] found that seed rhizome treated with carbendazim (0.2%) + heat water treatment (50ºC for 10 minutes) + *T. harzianum* (0.5%) and heat water treatment (50ºC for 10 minutes) + Mancozeb (0.2%) + *T. harzianum* (0.5%) before storage recorded lower rhizome rot incidence. Similarly, Bandyopadhyay and Bhattacharya [62] reported that hot water (51°C) treatment of seed rhizome for 10 minutes gave less rhizome rot severity as compared to control. Sowing of disease free seed rhizomes is the important step to prevent the contamination of *Pythium* [54]. Size of seed rhizome affected rhizome rot incidence and Tabin et al. [63] observed that a 60 - 80 g sized seed rhizome was best for ginger cultivation in considering yield and disease incidence. Whereas, Sharma et al. [64] found an optimum rhizome size of ginger planting was 50 - 75 g. It was observed that March and April planted ginger crop recorded less disease incidence and July planted plot recorded higher disease incidence in Karnataka, India [65]. Suitable planting time is not same at different places because of variation in seasonal occurrence [48]. Crop rotations could reduce population of *Pythium* spp. to some extent [66] and it might be increased and dominant in single cropping [67]. Crop rotation with corn and other non-host crops manage soft rot disease [68] and Elliott [69] advised not to grow ginger for more than one crop on the same site. To manage soft rot of ginger, selection of well-drained soil is important and water stagnation in field may prompt plant to infection [70]. Water stagnation in field would lead to high inoculums build up and higher spread of the disease through soil water. So, better drainage could reduce the chance of infection [50]. Similarly, Smith and Abbas [71] reported that good drainage system and increase water infiltration of soil were important for *Pythium* soft rot management in ginger. Raised bed with good drainage has also been found effective to minimize rhizome rot disease in field condition [72]. Soil with higher amount of clay and low pH suppressed *P. zingiberum* [73]. Plant spacing had also effect on rhizome rot disease incidence. Tabin et al. [63] observed maximum disease incidence in a spacing of 10 x 10 cm as against minimum at 30 x 30 cm. On other hand, Sharma et al. [64] observed a plant spacing of 25 × 30 cm was better in terms of reduction in rhizome rot as well as wilt. For proper management of *Pythium*, weeding is important because weeds might play an important role in the carryover of the diseases between crop cycles [50]. Added organic matter in soil from different sources reduced incidence of soft rot [74,75]. Ayub et al. [76] conducted an experiment with the application of mustard oil cake @ 1 t/ha and poultry refuse @ 10 t/ha in soil at 21 days before sowing and another treatment with sawdust (15 t/ha) was burned one day before sowing. They found that all of above three recorded less disease (rhizome rot) severity and higher fresh rhizome yield of ginger. Singh and Tomar [77] kept 3 kg farm yard manure (FYM) for 7 days with mixing of 1 kg neem cake and 100 g *T. harzianum*, they found that application of this mixture before sowing of ginger gave maximum yield and minimum rhizome rot disease incidence. Kumar et al. [78] applied leaf mulch of *Schima wallichii* and *Datura* spp. @ 15 t/ha in two splits (first application at the time of planting followed by after earthing up) and found lowest incidence of soft rot as compared to others mulch management. Mathur et al. [79] and Kumar et al. [80] observed that solarized field recorded less rhizome rot incidence as compared to non-solarized field.

6.2 Chemical Management

Seed treatment and soil drenching are the two options for control of soft rot of ginger in respect to seed and soil borne inoculums. Avinash et al. [81] found that wherein rhizomes were treated with azoxystrobin 25%, tebuconazole 25.9%, copper oxychloride 50%, carbendazim 50%, propiconazole 25% and metalaxyl-M 4% + mancozeb 64% showed complete inhibition of *P. aphanidermatum* at different tested concentrations (0.01, 0.05 and 0.1%). Elliott [69] recommended to immerse seed pieces in metalaxyl-M 4% + mancozeb 64% (0.2%) solution for 20 minutes to reduce the incidence of disease. Based on performance after farm evaluation, metalaxyl was recommended for the seed treatment and soil drenching at the Indian Institute of Spices Research [48]. Effectiveness of metalaxyl was also reported by other investigators [82]. Seed treatment with captafol reduced rhizome rot incidence along with increased germination [82,83]. Seed treatment (0.2%) and soil drenching (0.2%) with Ridomil gold (metalaxyl-M 4% + mancozeb 64%) was found best for effective management for rhizome rot disease of ginger [76]. On the other hand, rhizomes treated with metalaxyl 8% + mancozeb

64% @ 1.25 g/litre found to be best for control of rhizome rot disease [84]. Soil drenching before sowing followed by weekly treatments with Bordeaux mixture (4:4:50) or Perenox (0.35%) and Dithane D-78 reduced the rhizome rot due to *P. aphanidermatum* and *P. myriotylum* [18]. Dohroo [85] concluded that rhizome treated with fungicide mancozeb + carbendazim (0.3 + 0.1%) to be effective against rhizome rot of ginger. Seed rhizome treated with metiram 55% + pyraclostrobin 5% followed by spraying of same chemicals at 60 days after sowing @ 3 g/litre of water exhibited least disease severity and maximum yield [86]. Jain et al. [87] conducted an experiment with seed treatment (2 g/kg seed) and soil drenching (2 g/litre water) by different fungicides. They observed that different fungicides viz. carbendazim 12% + mancozeb 63%, mancozeb 64% + metalaxyl 4%, tebuconazole 25% + trifloxystrobin 25%, carbendazim 50% and copper oxychloride 50% were found effective to manage the rhizome rot diseases as compared to control.

6.3 Biological Management

The adverse effects of fungicides pressurized us to adopt alternative strategies for control measures which are safe by the public and pose negligible risk to human health and environment. In this context, uses of biological approaches are the good alternatives to fungicides for disease control measures. Worldwide *Trichoderma* spp. are popularly used as biological control agents for control of soft rot in ginger [13,38]. Scientists revealed that the production of antifungal metabolites, extracellular enzymes, and antibiotics by *Trichoderma* are responsible for the ability to control pathogens [88]. Dohroo and Sharma [89] controlled the rhizome rot caused by *P. pleroticum* up to 80% by using *T. viride* under storage condition. *In vitro* antifungal property of *Trichoderma* spp. against the growth of *P. aphanidermatum* were established by Bharadwaj and Gupta [90]. The activity of *P. aphanidermatum* found to be inhibited by soaking in spore suspension or coated with *T. viride* and *T. hamatum* [91]. Antagonistic effect of *T. harzianum and T. aureoviride* can reduce the ginger rot caused by *P. myriotylum* [92]. Rathore et al. [93] reported that the non volatile substance produced by *T. viride* completely inhibited the growth of *P. myriotylum*. Gupta et al. [94] found that individual application of *T. harzianum* was effective and combine application of *T. harzianum*, *Glomus mosseae* and fluorescent Pseudomonads gave more effective results in terms of minimum percent rotting of ginger due to *Pythium*. Dohroo et al. [95] applied *T. harzianum* with FYM and periodic drenching of copper oxychloride @ 0.3% during rainy season in field condition and found control of soft rot disease in ginger. A study by Dohroo et al. [96] revealed that application of *T. harzianum* in soil followed by seed rhizome treated with onion as well as garlic extract were effective for reduction of soft rot in ginger. Rakesh et al. [97] found that fresh and stored cow urine at a concentration of 20% inhibits the growth of *P. aphanidermatum*.

7. CONCLUSIONS

Among the different diseases of ginger, soft rot has been considered to be most destructive disease and a major constraint of cultivation in ginger growing areas. This disease is mainly caused by the *Pythium* spp. Soft rot caused by different species of *Pythium* are distributed throughout the world. Losses of ginger due to soft rot varied from 4-100% in different countries. The disease is both seed and soil borne; and survives between crops on infected seed rhizome. The severity of *Pythium* is influenced by different factors related to environment and soil. Study shows that, different strategies like cultural, chemical and biological measures have been proven for controlling *Pythium* soft rot. But, effectiveness of single strategy was not achieved in an effective way. So, it is required to combine all approaches to reduce losses caused by *Pythium* soft rot. Among the different cultural measures, seed rhizome treatment before storage and sowing, selection of disease free seed rhizome, sowing time, application of soil amendments, good drainage of soil, soil solarization etc. are the important measures. Seed treatment and soil drenching are the two options of chemical control of soft rot. Seed rhizomes treated with azoxystrobin 25%, tebuconazole 25.9%, copper oxychloride 50%, carbendazim 50%, propiconazole 25%, metalaxyl-M 4% + mancozeb 64%, metiram 55% + pyraclostrobin 5%, carbendazim 12% + mancozeb 63%, tebuconazole 25% + trifloxystrobin 25% as well as metalaxyl 8% + mancozeb 64% resulted in effective management. Different fungicide formulations viz. carbendazim 50%, copper oxychloride 50%, metalaxyl-M 4% + mancozeb 64%, metiram 55% + pyraclostrobin 5%, carbendazim 12% + mancozeb 63%, tebuconazole 25% + trifloxystrobin 25% etc. found effecting for spraying or soil drenching. In case of biological management, scientist revealed that seed treatment and application of *Trichoderma* spp. like *T. lignorum, T. viride, T. hamatum, T. harzianum* and *T. aureoviride* were found suitable as bio agent.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Peter KV, Nybe EV, Kurien A, Ravindran PN, Nirmal BK. Yield gap and constrains in ginger. In: Ginger the genus Zingiber, 1st Ed. CRC Press, Boca Raton; 2005.
2. Dohroo NP, Ravindran PN, Nirmal BK. Diseases of ginger. In: Ginger the genus Zingiber, 1st Ed. CRC Press, Boca Raton; 2005.
3. Stirling GR, Turaganivalu U, Stirling AM, Lomavatu MF, Smith MK. Rhizome rot of ginger (*Zingiber officinale*) caused by *Pythium myriotylum* in Fiji and Australia. Australasian Plant Pathology. 2009;38: 453-460.
4. Chattopadhya SB. Disease of plants yielding drugs, dyes and spices. New Delhi: Indian Council of Agricultural Research, India; 1997.
5. Le DP, Smith MK, Aitken EAB. An assessment of *Pythium* spp. associated with soft rot disease of ginger (*Zingiber officinale*) in Queensland, Australia. Australasian Plant Pathology. 2016;45: 377-387.
6. Lomavatu MF, Conroy J, Aitken EB, Williamson P. Molecular identification of *Pythium* isolates of ginger from Fiji and Australia. In: 17th Biennial Australasian Plant Pathology Society Conference, Newcastle, NSW; 2009.
7. Philip S, Parthasarathy VA. Pathogenicity and characterization of *Pythium* species causing soft rot of ginger. In: Abstracts of M.Sc. and Ph.D Dissertations on Spice Crops, Calicut, Indian Institute of Spices Research; 2005.
8. Rath GC, Mishra MK. Fungi associated with rhizome rot of ginger in Orissa. Orissa Journal of Agricultural Research. 1993;6: 79-81.
9. Ram P, Mathur K, Lodha BC. Integrated management of rhizome rot of ginger involving biocontrol agents and fungicides. Journal of Mycology and Plant Pathology. 1999;29(3):416-420.
10. Yang KD, Kim HM, Lee WH. Studies on rhizome rot of ginger caused by *Fusarium oxysporum f. sp. Zingiberi* and *Phythium zingiberum*. Korean Journal of Plant Pathology. 1988;4(4):271-277.
11. Kulkarni S. Etiology, epidermiology and integrated management of rhizome rot of ginger in Karnataka. Indian Phytopathology. 2011;64(2):113-119.
12. Sharma ND, Jain AC. A check-list and selected bibliography of ginger diseases of the world. Tropical Pest Management. 1977;23:474-481.
13. Le DP, Smith M, Hudler GW, Aitken E. *Pythium* soft rot of ginger: Detection and identification of the causal pathogens, and their control. Crop Protection. 2014;65: 153-167.
14. Dohroo NP, Sharma SL. *Pythium pleroticum* on *Zingiber officinale*. Indian Phytopathology. 1985;38:391.
15. Butler EJ. An account of genus *Pythium* and some chytridiaceae. Memoirs of the Department of Agriculture India. 1907;1(5): 1-162.
16. Mitra M, Subramaniam LS. Fruit rot diseases of cultivated cucurbitaceous caused by *Pythium aphanidermatum* (Eds.) Fitz. Memorial Department of Agriculture India Botany. 1928;15:79-84.
17. Sarma YR, Nambiar KKN, Brahma RN. Studies on rhizome rot of ginger and its control. In: Venkataram CS (Editor). Proceedings of PLACROSYM II, Indian Society of Plantation Crops, Central Plantation Crops Research Institute, Kerala, India; 1979.
18. Shahare KC, Asthana RP. Rhizome rot of ginger and its control. Indian Phytopathology. 1962;15:77-78.
19. Haware MP, Joshi LK. Studies on soft rot of ginger from Madhya Pradesh. Indian Phytopathology. 1974;27:158-161.
20. Chowdhury EK, Hasan MM, Mustarin K, Hasan MS, Fancy R. Efficacy of different fungicides in controlling rhizome rot of ginger. Journal of Agroforestry and Environment. 2009;3(1):179-181.
21. Li Y, Mao LG, Yan DD, Liu XM, Ma TT, Shen J, Liu PF, Li Z, Wang QX, Ouyang CB, Guo MX, Cao AC. First report in China of soft rot of ginger caused by *Pythium aphanidermatum*. Plant Disease. 2014;98(7):1011.
22. Ichitani T, Shinsu T. *Pythium zingiberum* causing rhizome rot of ginger plant and its distribution. Annals of the

Phytopathological Society of Japan. 1980;46:435-441.
23. Thomas KM. Detailed administration report of the government mycologist. Madras; 1938.
24. Park M. Report of the work of the mycological division. Annual Report of Director of Agriculture Ceylon; 1934.
25. Teakle DS. Investigation on the genus pythium in Queensland; 1962. (Accessed 25 July 2020) Available:https://doi.org/10.14264/uql.2017.127
26. Park M. Report of the work of the mycological division. Annual Report of Director of Agriculture, Ceylon; 1935.
27. Trujillo EE. Disease of ginger (*Zingiber officinale*) in Hawaii. Circular Hawaii, Agricultural Experiment Station, University of Hawai; 1964.
28. Lin LT, Chang SS, Leu LS. Soft rot of ginger. Plant Protection Bulletin, Taiwan. 1971;13:54-67.
29. Kim CH, Yang SS, Hahn KD. Ecology of ginger rhizome rot development caused by *Pythium myriotylum*. Plant Pathology Journal. 1997;13:184-190.
30. Teakle DS. Species of *Pythium* in Queensland. Queensland Journal of Agricultural Science. 1960;17:15-31.
31. Ichitani T, Shinsu T. Detection of *Pythium zingiberum* causing rhizome rot disease of ginger from soils of surrounding area of continuous indoor cropping for immature rhizome production. Annals of the Phytopathological Society of Japan. 1981;47:158-165.
32. Dohroo NP. *Pythium ultimum* on *Zingiber officinale*. Indian Phytopathology. 1987; 40(2):275.
33. Ramakrishnan TS. The occurrence of *Pythium vexans* de Bary in South India. Indian Phytopatholgy. 1949;2:27-30.
34. Takahashi M. *Pythium zingiberum* causing rhizome rot of ginger plant an its distribution. Annals of the Phyto-pathological Society of Japan. 1954;18: 435-441.
35. Nepali MB, Prasad RB, Sah DN. Survey of ginger growing areas in Syanja, Palpa, Gulni and Arghaknach districts with special emphasis in rhizome rot disease. Bulletin Lumley Agricultural Research Station, Nepal; 2000.
36. Rajan KM, Agnihotri VP, Agnihotri VP, Sing N, Chaube HS, Sing VS, Dwivedi TS. *Pythium* induced rhizome rot of ginger. Problems and progress. In: Perspectives in Phytopathology, Today and Tomorrow's Printers and Publishers, New Delhi; 1989.
37. Sinha AP, Mukhopadhyay AN, Agnihotri VP, Sarbhoy AK, Kumar D. Foot rot of papaya and rhizome rot of ginger incited by *Pythium* spp. In: Perspectives in mycology and plant pathology, Malhotra Publishing House, New Delhi; 1988.
38. Gupta M, Kaushal M. Diseases infecting ginger (*Zingiber officinale* Roscoe): A review. Agricultural Reviews. 2017;38(1): 15-28.
39. Gogoi R, Nath HKD, Borah TR. Diversity of the pathogens inciting rhizome rot disease of ginger in Assam and Arunachal Pradesh. Journal of Mycology and Plant Pathology. 2008;38(2):291-294.
40. ISPS. Indo Swiss Project Sikkim, Experiences in collaboration - Ginger pests and diseases. Indo Swiss Project Sikkim Series 1; 2005.
41. Shakywar RC, Tomar KS, Pathak M. Integrated disease management of ginger rhizome rot; 2012. (Accessed 23 July 2020) Available:https://www.krishisewa.com/articles/disease-management/73-ginger-rhizome-rot.html
42. Winstead NN, McCombs CL. Pectinolytic and cellulolytic enzyme production by *Pythium aphanidermatum*. Phytopathology. 1961;51:270-273.
43. Janardhan KK, Husain A. Production of a toxic metabolite and pectolytic enzyme by *Pythium butleri*. Mycopathologia et Mycologia Applicata. 1974;52:325–330.
44. Burr TJ, Stanghellini ME. Propagule nature and density of *Pythium aphanidermatum* in field soil. Phytopathology. 1973;63:1499-1501.
45. Geethu C, Resna AK, Nair RA. Characterization of major hydrolytic enzymes secreted by *Pythium myriotylum*, causative agent for soft rot disease. Antonie van Leeuwenhoek. 2013;104:749-757.
46. Thomas KM. Detailed administration report of the government mycologist. Madras, 1938-39; 1940.
47. Park M. Report of the work of the division of plant pathology. Administration Report of Acting Director of Agriculture, Colombo: Ceylon Government Press; 1941.
48. Sarma YR, Chadha KL, Rethinam P. Rhizome rot disease of ginger and turmeric. In: Advances in Horticulture.

Malhotra Publising House, New Delhi. 1994;10.
49. Gupta M, Jebasingh T, Wang H. Diseases of ginger. In: Ginger cultivation and its antimicrobial and pharmacological potentials; 2019.
DOI: 10.5772/intechopen.88839
50. Beena N. Potentiating bioefficacy of biocontrol agents and development of integrated disease management of rhizome rot (*Pythium aphanidermatum*) of ginger (*Zingiber officinale*); 2006.
(Accessed 25 July 2020)
Available:http://hdl.handle.net/10603/42920
51. Dohroo NP. Rhizome rot of ginger (*Zingiber officinalis* Rosc.); 1979.
(Accessed 16 July 2020)
Available:https://krishikosh.egranth.ac.in/displaybitstream?handle=1/5810067320
52. Adams PB. *Pythium aphanidermatum* oospore germination as affected by time, temperature and pH. Phytopathology. 1971;61:1149-1150.
53. Dake GN, Edison S. Association of pathogens with rhizome rot of ginger in Kerala. Indian Phytopathology. 1989;42(1): 116-119.
54. Dake JN. Diseases of ginger (*Zingiber officinale* Rosc.) and their management. Journal of Spices and Aromatic Crops. 1995;4:40-48.
55. Sharma BR, Dutta S, Roy S, Debnath A, Roy MD. The effect of soil physicochemical properties on rhizome rot and wilt disease complex incidence of ginger under hill agro climatic region of West Bengal. Journal of Plant Pathology. 2010;26:198-202.
56. Debnath A, Bandyopadhyay S, Dutta S. Correlation studies including physico-chemical properties of ginger- soils from different location of Cooch Behar and rhizome rot and wilt disease severity in ginger. Journal of Mycopathological Research. 2011;49:367-368.
57. Kim GD, Lee EM, Ahn TY. Physico-chemical properties and microbial populations and diversity in soils where rhizome rot disease of ginger frequently occurs. Acta Horticulture. 2012;938:85-90.
58. Hadar Y, Mandelbaum R. Suppression of *Pythium aphanidermatum* damping off in container media containing composted liquorice roots. Crop Protection. 1986;5: 88-92.
59. Dohroo NP, Shyam KR, Bharadwaj SS. Distribution, diagnosis and incidence of rhizome rot complex of ginger in Himachal Pradesh. Indian Journal of Plant Pathology.1987;5:4-25.
60. TNAU. Soft rot or rhizome rot: *Pythium aphanidermatum*/ *P. vexans* / *P. myriotylum*; 2016.
(Accessed 16 July 2020)
Available:http://agritech.tnau.ac.in/crop_protection/ginger_diseases1.html
61. Sharma S, Dohroo NP, Veerubommu S, Phurailatpam S, Thakur N, Yadav AN. Integrated disease management of storage rot of ginger (*Zingiber officinale*) caused by *Fusarium* sp. in Himachal Pradesh, India. International Journal of Current Microbiology and Applied Sciences. 2017;6(12):3580-3592.
62. Bandyopadhyay S, Bhattacharya PM. Management of rhizome rot of ginger using physical, chemical and biological methods. Journal of Mycology and Plant Pathology. 2012;42(3):314-316.
63. Tabin T, Balasubramanian D, Arunachalam A. Influence of plant spacing, seed rhizome size and tree canopy environment on the incidence of rhizome rot in ginger. Indian Journal of Hill Farming. 2014;27(2):49-51.
64. Sharma BR, Dutta S, Ray S, Roy S. 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. 2012;4(12):105-107.
65. Rekha D, Nagaraju, Shreenivasa KR. Effect of planting time and variety on the incidence of ginger (*Zingiber officinale* rosc.) rhizome rot complex. Pest Management in Horticultural Ecosystems. 2016;22(2):195-197.
66. Harvey P, Lawrence L. Managing *Pythium* root disease complexes to improve productivity of crop rotations. Outlooks on Pest Management. 2008;19:127-129.
67. Pankhurst CE, McDonald HJ, Hawke BG. Influence of tillage and crop rotation on the epidemiology of *Pythium* infections of wheat in a red-brown earth. Soil Biology and Biochemistry. 1995;27(8): 1065-1073.
68. FAO. Ginger farming guide. Food and Agriculture Organization of the United Nations, Bangkok; 2009.
69. Elliott SM. Rhizome rot disease of ginger. Crop and Plant Protection Unit, Ministry of Agriculture, Bodles Research Station, Old Harbour, Jamaica; 2003.

70. Anandaraj M, Devasahayam S, Zachariah TJ, Eapen SJ, Sasikumar B, Thankamani CK, Rema J, Madan MS. Ginger. In: Indian Institute of Spices Research, Calicut, Kerala; 2001.
71. Smith M, Abbas R. Controlling *Pythium* and associated pests in ginger. RIRDC Publication No. 11/128, Rural Industries Research and Development Corporation. Australia Govt. Canberra; 2011.
72. Basistha A, Homan R. Evaluation and selection of appropriate management package of ginger rhizome rot disease in field condition. IOSR Journal of Agriculture and Veterinary Science. 2015;8(6):53-56.
73. Lee WH, Cheong SS, So IY. Properties of suppressive and conducive soils to ginger rhizome rot. Korean Journal of Plant Pathology. 1990;6(1):338-342.
74. Sadanandan AK, Iyer R. Effect of organic amendments on rhizome rot of ginger. Indian Cocoa, Arecanut and Spices Journal. 1986;9:94-95.
75. Thakore BBL, Mathur S, Singh RB, Chakravarti BP. Soil amendment with oil cakes in ginger field for rhizome rot control. Korean Journal of Plant Protection. 1987;26:267-268.
76. Ayub A, Sultana N, Faruk MI, Rahman MM, Mamun ANM. Control of rhizome rot disease of ginger (*Zingiber officinale* rose) by chemicals, soil amendments and soil antagonist. The Agriculturists. 2009;7:57-61.
77. Singh AK, Tomar RKS. Bio-intensive management of rhizome rot of ginger under field conditions. Journal of Biological Control. 2009;23(1):87-88.
78. Kumar A, Avasthe RK, Borah TR, Lepcha B, Pandey B. Organic mulches affecting yield, quality and diseases of ginger in mid hills of North Eastern Himalayas. Indian Journal of Horticulture. 2012;69(3):439-442.
79. Mathur K, Ram D, Poonia J, Lodha BC. Integration of soil solarization and pesticides for management of rhizome rot of ginger. Indian Phytopathology. 2002;55(3):345-347.
80. Kumar NR, Kumar KR, Babu GSK. Management of rhizome rot of ginger through soil solarization under organic cultivation; 2012.
(Accessed 24 July 2020)
Available:http://rgdoi.net/10.13140/2.1.3752.9605
81. Avinash, Bijendra K, Shivani. *In vitro* and glass house evaluation of fungicides against the pathogens associated with rhizome rot complex of ginger in Kumaon region of Uttarakhand. International Journal of Chemical Studies. 2018;6(5): 1364-1372.
82. Koshy A, Valsala PA, Marcykutty, Mathew P, Abichiran. Effect of seed treatment on soft rot disease of ginger. In: Proceedings of National Seminar on Chillies, Ginger and Turmeric, Hyderabad, Andhra Pradesh. 11-12, January; 1988.
83. Mathur S, Thakore BL, Singh RB. Effect of different fungicides on ginger rhizome rot pathogen and their effect on germination and rotting rhizome. Indian Journal of Mycology and Plant Pathology. 1984;14: 155-157.
84. Singh AK. Management of rhizome rot caused by *Pythium*, *Fusarium* and *ralstonia* spp. in ginger (*Zingiber officinale*) under natural field conditions. Indian Journal of Agricultural Sciences. 2011; 81(3):268-270.
85. Dohroo NP. Occurrence and non-chemical management of rhizome rot of ginger. Plant Disease Research. 2006;21(2):196-198.
86. Hosain MK, Hossain SMM, Abedin Z, Islam MM, Rahman MA, Rahman MS, Zafor MA. Control of rhizome rot disease of ginger through application of fungicides. Asian Research Journal of Agriculture. 2018;8(3):1-9.
87. Jain DK, Swami H, Gangwar RK. 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. 2020;9(6):903-911.
88. El-Katatny MH, Abdelzaher HMA, Shoulkamy MA. Antagonistic actions of *Pythium oligandrum* and *Trichoderma harzianum* against phytopathogenic fungi (*Fusarium oxysporum* and *Pythium ultimum var. ultimum*). Archives of Phytopathology and Plant Protection. 2006;39:289-301.
89. Dohroo NP, Sharma SL. Biological control of rhizome rot of ginger in storage with *Trichoderma viride.* Indian Journal of Plant Pathology. 1984;36(4):691-693.
90. Bharadwaj SS, Gupta PK. *In vitro* antagonism of *Trichoderma* species

against fungal pathogens associated with rhizome rot of ginger. Indian Journal of Plant Pathology. 1987;5:41-42.
91. Bhardwaj SS, Gupta PK, Dohroo NP, Shyam KR. Biological control of rhizome rot of ginger in storage. Indian Journal of Plant Pathology. 1988;6:56-58.
92. Ram P, Mathur K, Lodha BC, Webster J. Evaluation of resident biocontrol agents as seed treatments against ginger rhizome rot. Indian Phytopathology. 2000;53(4): 450-454.
93. Rathore VRS, Mathur K, Lodha BC. Activity of volatile and non-volatile substances produced by *Trichoderma viride* on ginger rhizome rot pathogens. Indian Phytopathology. 1992;45:253-254.
94. Gupta M, Dohroo NP, Gangta V, Shanmugam V. Effect of microbial inoculants on rhizome disease and growth parameters of ginger. Indian Phytopathology. 2010;63:438-441.
95. Dohroo NP, Sandeep K, Neha A. Status of soft rot of ginger. Technical Bulletin, Department of Vegetable Science, Dr. YS Parmar University of Horticulture and Forestry, Nuani, Solan; 2012.
96. Dohroo NP, Kansal S, Mehta P, Ahluwalia N. Evaluation of eco-friendly disease management practices against soft rot of ginger caused by *Pythium aphanidermatum*. Plant Disease Research. 2012;27(1):1-5.
97. Rakesh KN, Dileep N, Nawaz ASN, Junaid S. Antifungal activity of cow urine against fungal pathogens causing rhizome rot of ginger. Environment and Ecology. 2013;31:1241-1244.

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