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17. Diseases of Ginger (*Zingiber officinale* Rosc.) and Their Integrated Management

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Abstract:

Ginger (Zingiber officinale Rosc L.), a vital major spice crop, is widely cultivated for medicinal properties and culinary uses having substantial economic and export potential. However, its production is severely hampered by various fungal, bacterial, and viral diseases resulting significant economic losses. This chapter provides a comprehensive overview of the major diseases of ginger including rhizome rot, yellows, bacterial wilt, leaf spot, storage rot, mosaic, and chlorotic fleck with comprehensive discussing the economic impact, symptoms, causal organisms, pathogen survival mechanisms, and integrated disease management strategies. An integrated approach including cultural, chemical, and biological control measures is emphasized for the effective management of these diseases, thereby ensuring higher yield and quality.

Keywords:

Ginger diseases, integrated disease management, rhizome rot, symptoms.

17.1 Introduction:

Ginger (*Zingiber officinale* Rosc L.) is a valuable rhizomatous spice crop known for its distinctive aroma, flavor, and pungency. It is utilized in various products, including ginger beer, wine, cordials, carbonated beverages, confectionery, pickles, and pharmaceuticals. As a member of the Zingiberaceae family, ginger thrives in tropical and subtropical regions, making it an economically important crop (Kavitha & Thomas, 2008). Key ginger-producing countries include India, China, Nigeria, Sierra Leone, Indonesia, Bangladesh, Australia, Fiji, Jamaica, and Nepal (Dohroo *et al.*, 2012). India stands as the largest global producer of ginger, contributing approximately one-third of the world's total production (Kumar *et al.,* 2014). India is a leader in term of area and production of Ginger. In India, during 2021-2022 ginger production was 2503 thousand metric tons with an area of 210 thousand hectare. Major ginger producing states are Madhya Pradesh, Rajasthan, Gujarat, Karnataka, Telangana, Andhra Pradesh, Maharashtra, Orissa, Assam, Uttar Pradesh, West Bengal, and Kerala. In Uttar Pradesh area is 0.99 thousand ha and production 5.10 thousand metric tons during 2021-2022 (Anonymous, 2021-22).

Apart from its culinary uses, ginger is highly regarded for its medicinal properties, including anti-inflammatory, anti-cancer, and anti-diabetic effects, which help in managing conditions such as cancer, diabetes, and hypertension (Krell & Stebbing, 2012). However, ginger cultivation is frequently hampered by fungal, bacterial, and viral diseases, leading to significant yield losses (Gupta & Kaushal, 2017). These diseases impact the crop throughout its growth and storage phases, often resulting in rhizome rot. A comprehensive understanding of disease symptoms, causative pathogens, their survival mechanisms, and effective management strategies is critical for sustaining ginger production. This chapter aims to explore the economic significance of ginger diseases by addressing their symptoms, causative agents, pathogen survival, spread, and potential management approaches.

Table-17.1: List of Major Diseases of Ginger and their Causal Organism

Sr.No.	Name of diseases	Causal Organism
	Fungal diseases	
1.	Rhizome rot/soft rot	*Pythium aphanidermatum, P. myriotylum*
2.	Yellows	*Fusarium oxysporum* f.sp. *zingiberi*
3.	Leaf spot	*Phyllosticta zingiberi*
4.	Storage rot	*Fusarium oxysporium, Pythium myriotylum, Aspergillus flavus, Penicillium* sp., *Geotrichum candidum, Verticilium chlamydosporium etc.*
	Bacterial diseases	
5.	Bacterial wilt	*Ralstonia solanacearum*
	Viral diseases	
6.	Mosaic	Cucumber mosaic virus
7.	Chlorotic fleck	Ginger chlorotic fleck virus

17.2 Rhizome Rot / Soft Rot:

Economic Importance: Rhizome rot of ginger was initially reported by Butler in 1907 from Surat, Gujarat, India. It is one of the most destructive diseases of ginger, causing 50-90% losses globally (Dohroo, 2005). In the northeastern states of India, this disease has been observed both as pre-emergence and post-emergence rot of rhizomes, resulting in severe losses of up to 92% (Daiho and Upadhyay, 2004).

Symptoms: The first symptoms of soft rot appear on the above-ground parts, particularly around the collar region, as watery, brown lesions. These lesions grow, merge, and cause the stem to rot and collapse (Dohroo, 2005). The rotting rhizome produces a characteristic foul smell (Jayashree et al., 2014). Yellowing of the leaf margins, especially on the lower leaves, is one of the initial signs, which gradually spreads across the leaf blade. At the early stages, the center of the leaves remains green while the edges turn yellow. The yellowing continues, affecting all leaves, leading to the drooping, withering, and drying of pseudostems.

Causal Organism: The disease is caused by *Pythium aphanidermatum* and *Pythium myriotylum.* Butler (1907) was the first to identify *P. gracile* as the cause of ginger soft rot in India.

Taxonomic position of *Pythium aphanidermatum*

Kingdom	: Straminopila / Chromista
Phylum	: Oomycota
Class	: Oomycetes
Subclass	: Pernosporomicepidae
Order	: Pythiales
Family	: *Pythiaceae*
Genus	: *Pythium*
Species	: *aphanidermatum*

Survival and Dispersal: The pathogen is both seed-borne and soil-borne. Initially infected rhizomes, which contain oospores, serve as the primary source of infection for seeds (Thomas, 1938). Additionally, infected plant debris containing oospores left in the field is another significant source of inoculum. Low-lying fields and waterlogged conditions promote the development of rhizome rot. *Pythium* species can survive saprophytically in plant debris for an extended period.

Epidemiology: Wet soil with high moisture content and elevated soil temperatures are the key factors promoting disease development. Temperatures above 30°C, along with high soil moisture, are the critical predisposing conditions. The optimal temperature for the germination of *P. aphanidermatum* and *P. myriotylum* is around 34°C (Dake, 1995). Hossain *et al.* (2015) Rhizome rot of ginger is favored at saturated soil with moisture of 39.43 % and soil temperature between 33-34 ºC. The disease is favored by heavy rainfall during July to August (339-515 mm), 90 % relative humidity and air temperature 27-28 ºC.

Integrated Management: Smith and Abbas (2011) recommended an integrated approach focusing on cultural practices and strict quarantine procedures. Cultural measures include selecting well-drained soils and planting on raised beds of 30 cm in height and 1 m in width. It's important to choose seed rhizomes from disease-free gardens (Dohroo, 1993). Soil solarization before planting, by covering the soil with transparent polyethylene sheets for 45-50 days, is effective in reducing infections. Hot water treatment of rhizomes at 51°C for 10 minutes can also lower infection rates. The application of *Trichoderma harzianum* with neem cake at 1 kg/bed has been found effective in reducing rhizome rot incidence (Jayashree *et al*., 2014). Additionally, soil solarization and fungicide application can minimize the incidence of soft rot (Mathur *et al.*, 2002). Treating seed rhizomes with 0.3% mancozeb for 30 minutes before storage and again before planting, followed by drenching at 30- and 60-days post-planting, helps reduce the incidence of rhizome rot. Once the disease is detected in the field, affected clumps should be removed, and soil should be drenched with either 0.3% mancozeb or 0.2% copper oxychloride to prevent further spread. A single treatment of Ridomil has been found to give the highest yield by reducing the incidence of rhizome rot in ginger (Chowdhury *et al*., 2009).

Jain *et al.* (2020) conducted field experiments to evaluate the bio-efficacy of available market-ready fungicides combinations (NATIVO, SAAF, RIDOMIL) and combinations of fungicide *viz*., Copperoxychloride, Carbendazim, Mencozeb, chloropyriphos (Insecticide), Streptocycline (Bactericide) along with bio-control agents (*T. viride*) conducted at Talai village of Jhadol block of Udaipur district during the year 2016-17 and 2017- 18 to find out an effective control measure against rhizome rot (*Pythium aphanidermatum*) disease of ginger (*Zingiber officinale* Rose). The pooled results of two years show that all the treatments significantly proved superior in decreasing the incidence and severity of the diseases and increasing the germination, tiller number, and rhizome yield.

The treatment (T_8) comprising of Soil treatment with *Trichoderma viride* (3kg / 100 kg FYM) + Seed treatment (Carbendazim 50% WP, 2 gm /kg + Chloropyriphos 20 % EC 1 ml/ kg seed +Streptocyclin 6 gm/20 kg seed) + Soil drenching with Ridomil gold (Mancozeb 64 %+ Metalaxyl 4 %WP 2m per liter) and finally seed stored with treatment with (Carbendazim 50 % WP 2 gm/kg seed + Chloropyriphos 20 % EC 1 ml/kg seed fornext season) proved most effective, which gave 84.23 % mean germination, 17.73 mean number of tillers/plant, 16.28 % mean plant infected and mean yield 14.01 t/h during year 2016-17 and 2017-18.It was followed by treatment (T6), consisting of Seed treatment (Carbendazim 50 % WP 2 gm / kg + Chloropyriphos 20 % EC 1 ml /kg) + Soil drenching with SAAF (Carbendazim 12 % + Mancozeb 63 % WP) @ 2gm/lit which gave 81.79 % mean germination, 16.33 mean number of tillers/plant 20.13 % mean plant infected and mean yield 12.98 t/ha., during years 2016-17 and2017-18 The treatment (T_7) consisting of Soil treatment with *Trichoderma viride* (3kg/ 100 kg FYM) + Seed treatment (with *Trichoderma viride*(20 g / kg seed)+ Soil drenching with Bio-cure (*Trichoderma viride*10 ml/liter water) proved least effective with minimum 64.18 % mean germination, 13.26 mean number of tillers/plant, 31.68% mean plant infected and mean yield 7.78 t/ha. All the treatments were found significantly effective in managing the rhizome rot diseases and ginger yield. Patil *et al.* (2021) studied the effects of pot cultivation *on P. aphanidermatum. Trichoderma asperellum* + *Trichoderma harzianum* (88.32%) was found to have the highest percentage reduction in pre- and post-emergence rhizome rot. This was followed by *Trichoderma asperellum (*70.79%), Carbendazim 50% WP (59.27%), Carbendazim 50% WP + Metalaxyl

75 WP + *Trichoderma asperellum* (50.09%), *Trichoderma harzianum* (35.39%), and T_5 Carbendazim 50% WP + Metalaxyl 75 WP (23.71 %). With Metalaxyl 75WP, the lowest percentage of pre- and post-emergence rhizome rot was observed (11.86%).

17.3 Yellows Disease:

Economic Importance: Yellows disease was first identified by Simmonds in 1955 in Queensland. It occurs globally and has been reported in Asia (India and China), North America (Hawaii), Oceania (Australia), and Papua New Guinea.

Symptoms: The disease initially manifests as yellowing of the lower leaves, starting from the margins and gradually spreading to cover the entire leaf. Older leaves dry up first, followed by younger ones. Affected plants may exhibit premature drooping, wilting, and sometimes stunted growth. In the rhizomes, cream to brown discoloration and shriveling occur, along with root rot and central core rot, which ultimately hinders rhizome formation.

As decay progresses, only fibrous tissue remains in the rhizomes. During storage, a white cottony fungal growth may appear on the rhizome surface. In cases of dry rot, no soft rot is seen at the collar region, but the leaves turn pale, and infected plants become difficult to pull out (Dohroo, 1982).

Causal Organism: The disease is caused by *Fusarium oxysporum* Schlechtend ex Fr. f.sp. *zingiberi* (Yang *et al*., 1988). Sharma and Dohroo (1990) reported *F. oxysporum* as the primary cause of yellows in Himachal Pradesh. *F. solani* was the second most frequently isolated species (Dohroo, 1987; Chauhan and Patel, 1990), while *F. moniliforme*, *F. graminearum*, and *F. equiseti* were also associated with infected plants (Bhardwaj et al., 1988; Dohroo, 1987).

Survival and Dispersal: The fungus survives in soil as chlamydospores, which can remain viable for many years. Infected rhizomes and soil act as the primary sources for seasonal inoculum carryover. The disease spreads secondarily through irrigation water and mechanical means (Stirling, 2004). About 87% of field infections result from the use of infected seed rhizomes (Dohroo, 1989).

Epidemiology: A temperature range of 15 to 30°C, with an optimal range of 23-29°C, high humidity, and continuous presence of free water, are ideal conditions for the development of yellows in ginger (Sharma and Jain, 1978).

Integrated Management: Dohroo (1995) recommended an integrated approach to managing ginger yellows, which includes treating seed rhizomes with mancozeb and carbendazim, along with using biocontrol agents like *Trichoderma harzianum*, *T. hamatum*, and *Gliocladium virens* for seed treatment and soil application. Sharma et al. (2012) found that a plant spacing of 25×30 cm and seed rhizomes weighing 50-75 g were optimal for better crop yield and lower disease incidence. Talc-based formulations of plant growth-promoting rhizobacteria strains like XXBC-TN (*Bacillus subtilis*) and a mixture of S2BC-1 (*B. subtilis*) with TEPF-Sungal (*Burkholderia cepacia*) were developed for rhizome seed dressing and soil application in ginger fields. Systemic fungicides like Bavistin 50WP,

Ridomil Gold MZ-72, and contact fungicides like Captan, Dithane M-45, copper oxychloride, and Bordeaux mixture were found to be effective against yellows in ginger (Sagar, 2006; Hasnat *et al*., :2014).

17.4 Leaf Spot:

Economic Importance: Leaf spot disease is found worldwide and was first reported in the Godavari district of Andhra Pradesh and the Malabar region of Kerala (Rama krishnan, 1942). Sarma *et al*. (1994) observed significant yield losses ranging from 13% to 66% during wet weather conditions. Sood and Dohroo (2005) noted it as the most destructive disease in Himachal Pradesh.

Symptoms: The disease first manifests on younger leaves as small (1-10 mm x 0.5-4 mm) oval to elongated water-soaked spots, which later develop into white spots surrounded by dark brown margins with a yellow halo. As the lesions grow, adjacent spots merge, forming necrotic areas (Rama krishnan, 1942). Affected leaves become shredded and may experience extensive drying.

Causal Organism: The fungus responsible for leaf spot is *Phyllosticta zingiberi* T.S. Ramakr. It produces amphigynous, subglobose, dark brown ostiolate pycnidia on the host, measuring 78-150 µm in diameter (Rama Krishnan, 1942).

17.4.1 Survival and Dispersal:

Infected plant debris and seeds serve as the primary sources of inoculum. The pycnidia survive in leaf debris throughout the summer, where temperatures range from 30-35°C.

The disease spreads through rain splashes during intermittent showers, and the extent of fungal dispersal depends on the intensity of precipitation.

Epidemiology: According to Senapati *et al.* (2012), temperatures between 23 and 28°C, along with intermittent rain, favor disease development. Ginger plants that are six to seven months old and leaves that are two weeks old are more susceptible to the disease.

Integrated Management: Patiram *et al.* (1995) found lower disease intensity in ginger grown in partial shade compared to those grown in full sunlight in Sikkim. Growing ginger in partial shade is recommended to reduce the need for fungicidal sprays, which can also increase the number of tillers per clump and improve yield (Singh et al., 2004). One spray of carbendazim (0.15%) and two sprays of mancozeb (0.25%) provided good protection against the disease and resulted in higher yields in pot culture experiments (Verma and Vyas, 1981).

Rhizome treatment and foliar sprays with Bordeaux mixture (1%), mancozeb (0.2%), or carbendazim (0.2%) at the onset of symptoms can effectively manage the disease (Sood and Dohroo, 2005). Senapati *et al*. (2012) identified PGS-16, PGS-17, and Anamica as moderately resistant among 135 ginger cultivars tested.

17.5 Storage Rot:

Economic Importance: Storage rot leads to significant post-harvest losses in ginger rhizomes (Jadhav *et al.,* 2013; Moreira *et al.,* 2013). It impacts both the quality and quantity of seed ginger, with losses ranging from 34-50% as reported by several researchers (Sharma and Dohroo, 1982; Dohroo, 1997).

Symptoms: Fungal mycelia cause discoloration on the surface of ginger rhizomes, which leads to their decay and rot (Dohroo, 1993). This results in weight loss and shrinkage of the rhizomes during storage (Rattan *et al*., 1988).

Causal Organism: Fungi associated with ginger storage rot include *Fusarium oxysporum* Schlechtend ex Fr., *Pythium deliense* Meurs, and *P. myriotylum* Drechs. (Sharma and Jain, 1977), *Geotrichum candidum* Link (Mishra and Rath, 1989), *Aspergillus flavus* Link ex. Fr. (Geeta and Reddy, 1990), *Cladosporium lennissimum*, *Gliocladium roseum* Bainer, *Graphium album* (Corda) Sacc., *Mucor racemosus* Fresen., *Thanatephorus cucumeris* (Frenk) Donk, and *Verticillium chlamydosporium* Goddard (Dohroo and Sharma, 1992). *Penicillium brevicompactum* was the predominant species found on 85% of rhizomes with visible mold growth (Overy and Frisvad, 2005). Studies in Brazil also linked *Acremonium murorum*, *Fusarium* species, *Lasiodiplodia theobromae*, and *Sclerotium rolfsii* to storage rot (Moreira *et al.,* 2013).

Survival and Dispersal: Rhizomes infected in the field contribute to storage rot during post-harvest storage. Although storing rhizomes under cool conditions can reduce weight loss and sprouting, it may increase pathogen incidence compared to room temperature storage (Lana *et al.,* 1993).

Epidemiology: Storage rot symptoms typically begin appearing in storage pits from January, reaching peak intensity by April. This coincides with temperatures around 15.5°C and relative humidity of 67.5%, which favor disease development (Dohroo, 2001).

Integrated Management: Pre-storage treatment of ginger rhizomes with Topsin-M and Bavistin (0.2%) for one hour significantly reduces storage rot incidence (Dohroo, 2001). Dipping rhizomes in an extract of *Allium sativum* (10% w/v) or in a suspension of biocontrol agents like *Pseudomonas fluorescens* and *Trichoderma harzianum* (0.5%) for 30 minutes before storage is also effective (Ram and Thakore, 2009). Fungicides such as aureofungin (0.02%) and Benomyl (0.2%) provide good control when applied post-harvest (Haware et al., 1973). Ridomil MZ (0.3%) was found to minimize the incidence of disease during storage (Singh et al., 2004). Additionally, chitosan and oligochitosan treatments have been shown to inhibit rhizome rot, reduce water loss, and ultimately decrease post-harvest losses (Liu *et al*., 2016).

17.6 Bacterial Wilt:

Economic Importance: Bacterial wilt is a major disease affecting ginger production in several countries. First reported in the Malabar region of Madras in 1938 by Thomas, this disease can result in yield losses of up to 50% in places like Hawaii (Yu *et al*., 2003).

Symptoms: The initial symptoms include a slight yellowing and wilting of the lower leaves, which later spreads to the entire shoot, causing it to yellow, brown, and eventually die. Young shoots often become soft and rot completely, breaking off easily from the rhizome at the soil line. Water-soaked spots develop near the collar of the pseudo stem and progress both upwards and downwards. Dark streaks appear in the vascular tissues of the affected pseudo stems, which, when pressed, release a milky ooze that emits a foul odor (White *et al*., 2013). The rhizomes turn grayish-brown and eventually become soft and rot (Jayashree *et al*., 2014).

Causal Organism: The disease is caused by *Ralstonia solanacearum* (Smith) Yabuuchi *et al.*, a rod-shaped, gram-negative, aerobic bacterium with a single polar flagellum, measuring about 0.5-0.7 x 1.5-2 µm in size (Sambasivam and Girija, 2006).

Survival and Dispersal: Bacterial wilt is both soil- and seed-borne, spreading through infected planting materials or soil to new, previously disease-free areas (Moslem *et al.*, 2005). It can also spread through contaminated soil on hands, tools, boots, vehicle tires, and field equipment, as well as through water from irrigation or rainfall and infected ginger rhizomes (Janse, 1996). Additionally, alternative weed hosts and non-host plants help the bacteria survive in the absence of susceptible crops (Granada and Sequeria, 1983).

Epidemiology: Kelman (1953) observed that high rainfall and temperatures are positively correlated with the occurrence of bacterial wilt, while lower temperatures and rainfall are negatively correlated. Soil pH, temperature, and moisture significantly affect the survival and spread of the pathogen. The disease is particularly severe in hot and humid regions with temperatures ranging from 28-30°C, as well as in cooler, high-altitude areas with temperatures between 7-22°C. The presence of nematodes in the soil can also increase bacterial wilt incidence (Samuel and Mathew, 1986).

Integrated Management: Managing bacterial wilt in ginger requires an integrated approach. Seed rhizomes should be sourced from disease-free areas. Several bioagents, including *Bacillus subtilis* strain 1JN2, *Myroides odoratimimus* 3YW8, *B. amyloliquefaciens* 5YN8, and *Stenotrophomonas maltophilia* 2JW6, have shown over 50% efficacy against bacterial wilt (Yang et al., 2012).

Additionally, *Pseudomonas fluorescens*, *Trichoderma viride*, and *B. subtilis* have been identified as effective biocontrol agents against *R. solanacearum* (Singh and Jagtap, 2017). Essential oils from palmarosa and lemongrass can inhibit the race IV strain of *R. solanacearum* in both in vitro and pot experiments, reducing the disease in greenhouse tests (Paret *et al*., 2010). Soil amendments with urea and calcium oxide can decrease bacterial populations through the release of toxic ammonia and nitrate (Vudhivanich, 2002). Adding gypsum with triple super phosphate during planting helps produce bacterial wilt-free ginger rhizomes (Hepperly *et al*., 2004). Drenching the soil with copper oxychloride (0.2%) when the disease first appears can reduce bacterial wilt incidence, and treating seed rhizomes with Emisan and Plantomycin for 30 minutes is also effective (Ojha *et al*., 1986). Streptomycin and streptopenicillin have been identified as the most effective antibiotics against the pathogen in both in vitro and in vivo conditions (Sinha *et al*., 2000).

17.7 Mosaic:

Economic Importance: Mosaic disease in ginger was first reported by Nambier and Sarma in 1974 in India. They documented an infection rate of 13.3% in Gujarat and 76.11% in Poona.

Symptoms: The disease manifests as a yellowish and dark green mosaic pattern on the leaves during the early stages, leading to stunted growth in the affected plants.

Causal Organism: Mosaic disease is caused by the cucumber mosaic virus (CMV).

Survival and Dispersal: In addition to ginger, cucumber mosaic virus (CMV) can infect other plants such as *Chenopodium amaranticolor*, tobacco, cowpea, cucumber, tomato, and more, spreading through sap transmission (Su, 1980).

Integrated Management: Using disease-free rhizomes as planting material is recommended for managing the disease. Remove and destroy infected plants as soon as symptoms appear to prevent the spread of the virus to healthy plant CMV is often transmitted by aphids and other sap-feeding insects. Implement effective pest control measures to reduce the vector population using insecticides, neem oil, or other biological control agents.
Proper crop rotation and field sanitation practices should be followed. Avoid planting susceptible crops like tomato, cucumber, and cowpea near ginger fields as they can serve as alternate hosts for the virus. Planting barrier crops around ginger fields can help reduce the movement of insect vectors that spread the virus.

17.8 Chlorotic Fleck:

Economic Importance: This viral disease was first described by Thomas in 1986.

Symptoms: Symptoms manifest as chlorotic flecks on leaves, measuring 1-10 mm in length. These flecks are parallel to the veins, but occasionally centered on them. Symptoms begin to appear 3-4 weeks after artificial inoculation, primarily on young leaves.

Causal Organism: The disease is caused by the Ginger chlorotic fleck virus, which has isometric particles and single-stranded RNA (Thomas, 1986).

Survival and Dispersal: The virus is transmitted mechanically and by several species of aphids, including *Myzus persicae, Pentalonia nigronervosa*, *Rhopalosiphum maydis*, and *R. padi* (Thomas, 1986).

17.8.1 Integrated Management:

Using disease-free rhizomes as planting material and controlling the vector population can help reduce the spread of viral diseases in the field. Control the population of aphid vectors, such as *Myzus persicae*, *Pentalonia nigronervosa*, *Rhopalosiphum maydis*, and

Rhopalosiphum padi. This can be achieved through regular monitoring and the application of suitable insecticides or biological control agents to reduce aphid populations and prevent the spread of the virus. Remove and destroy any infected plants from the field to reduce the potential sources of virus transmission. Minimize mechanical damage to plants during field operations, as the virus can be transmitted through sap. Proper sterilization of tools and equipment is important to prevent the mechanical spread of the virus.

17.9 Conclusions:

Ginger is a valuable major spice crop, used for culinary, medicinal and industrial purposes having global economic value. It is highly susceptible to a variety of fungal, bacterial, and viral diseases that hampered its yield and post-harvest quality. Effective management strategies emphasize an integrated approach, combining of cultural practices, biocontrol agents, chemical treatments, and regulatory measures required to minimize losses. Among the ginger growers, awareness of these diseases, their symptoms, survival mechanisms, and appropriate control measures is essential for ensuring sustainable ginger production.

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