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Economically Imperative *Ananas comosus* Diseases, Status, and Its Control Measures Documented in Producing Countries

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ABSTRACT

Ananas comosus, commonly known as pineapple, is a fruit with a large potential market as a commodity and commercial fruit. Numerous pests and diseases affect pineapple, directly or indirectly, by lowering the quality and quantity. The fungal causative agents, namely *Fusarium ananatum* and *Thalaromyces stolii* (previously named *Penicillium funiculosum*), cause fruitlet core rot (FCR) and fusariosis by *Fusarium guttiforme*. Bacteria heart rot (BHR) is an infection by *Erwinia chrysanthemi*, newly known as *Dickeya zeae*. Nevertheless, the mealybug wilt of pineapple (MWP) is another pineapple treat to susceptible pineapple varieties caused by pineapple mealybug wilt-associated viruses (PMWaVs). Other diseases include destruction caused by pathogenic nematodes. This review discusses the status of these diseases and the control measures that greatly affect the economy of pineapple-producing countries due to the economic significance of these crops. Growers need up-to-date information on the identity of the diseases that affect pineapple crops in the various countries that produce them to effectively manage the diseases in the field.

Keywords: Economy, pineapple, plant disease, plant pathogens

INTRODUCTION

Pineapple (*Ananas comosus*), a member of the Bromeliaceae family, is an important fruit crop with over 2,000 species of pineapple. This fruit is an important source of carbohydrates, minerals, fiber, organic acids, and vitamins for humans (Chaudhary et al., 2019). In addition, pineapple has antioxidants such as flavonoids, ascorbic acid, and carotenoids. The chemical makeup of this fruit varies depending on the variety. One fresh pineapple contains 17% of the daily recommended value for vitamin C

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and is high in B-complex vitamins like pyridoxine, folate, riboflavin, and niacin. Pineapple contains bromelain, which has anti-clotting, anti-cancer, and anti-inflammatory properties (Ajayi et al., 2022; Habotta et al., 2022).

The pineapple, the second-highest tropical crop after mango, is one of the most economically significant fruits worldwide, with Asia, South Central America, and Africa being the world's top fruit producers. The negative effects of the COVID-19 pandemic in 2020 appear to have significantly influenced pineapple exports. According to the most recent data, exports totaled 3.1 million tons in 2020, representing a 7.9% decrease from 2019. Costa Rica and the Philippines, the world's two largest pineapple exporters, saw a 7.7 and 5.8% drop in their shipments, respectively (Food and Agriculture Organization of the United Nations [FAO], 2021). The most important fact about pineapple is that it is a commercial fruit grown in tropical and subtropical areas. Tropical countries such as Malaysia, Thailand, Indonesia, India, Kenya, the Philippines, and China are among the world's leading pineapple growers (Sukri et al., 2023). In 2020, Malaysia had 17,228 ha of pineapple farming, accounting for 9.5% of the nation's total fruit-growing area ("Malaysia's pineapple export," 2022). Malaysia's pineapple-producing states are Johor, Kedah, Negeri Sembilan, Pahang, Selangor, Sabah, Sarawak, and Terengganu.

Production of pineapples is expected to increase to 31 million tons globally by 2028, growing at a 1.9% annual rate with more than 100 cultivars worldwide (Muhamad et al., 2022). There are currently 6 major pineapple varieties grown in producing countries by small- and large-scale producers, including MD2, Sweet Cayenne, Española, Pernambuco, Perolera, and Queen Victoria (Alejo Jeronimo et al., 2023). The susceptibility of pineapple varieties to pathogens could vary significantly by impacting disease incidence and management. For example, the susceptibility of various pineapple cultivars to BHR disease may vary. According to Oculi et al. (2020), different pineapple cultivars respond to BHR disease differently, with some being more resistant than others. In some cases reported by Dey et al. (2018), MWP disease is more susceptible, especially on smooth Cayenne, while some pineapple cultivars may be more resistant. Plant diseases are one of many factors that could affect the number and quality of pineapple output (Sapak et al., 2021). Fungi, bacteria, viruses, and nematodes are always associated with pineapple diseases. These disease infections can potentially destroy the entire pineapple plant or significant portions of it. Pineapple-producing countries economically affected by pineapple diseases worldwide are listed in Table 1. This article reviews the prevalent and destructive pineapple diseases affecting the producing countries' crops.

MEALYBUG WILT OF PINEAPPLE (MWP)

Mealybug wilt of pineapple (MWP) is one of the most significant diseases affecting pineapple production globally (Hernández-

Table 1
List of pineapple-producing countries that were economically affected by pineapple diseases

Disease	Country	References
Mealybug wilt of pineapple (MWP)	Cuba Ghana Hawaii	Hernández-Rodrıguez et al. (2019) Asare-Bediako et al. (2020) Hernández-Rodrıguez et al. (2019)
Bacteria heart rot (BHR)	Costa Rica Malaysia Brazil Philippine Hawaii	Cano-Reinoso et al. (2021)
	Uganda	Oculi et al. (2020)
Fruitlet core rot (FCR)	Reunion Island South Africa	Vignassa et al. (2021) Chillet et al. (2020)
Fusariosis	Central America Africa Asia Brazil	Carnielli-Queiroz et al. (2019)
Causal agent by nematodes	Philippine Nigeria Brazil France	Benzonan et al. (2021) Tanimola et al. (2021) Norwegian Institute of Bioeconomy Research (2021) Soler et al. (2021)

Rodrıguez et al., 2019; Larrea-Sarmiento et al., 2021). The primary symptoms of MWP are wilting, reddish-yellow leaves beginning with the outer leaves and undersized fruit. When the symptoms are severe, the plant will likely die, the leaf tips curl and dry up, and plant growth slows down (Hutahayan et al., 2022). Although the exact cause of MWP is unknown, it is thought to be linked to specific viruses, mealybugs as vectors, ants that guard mealybugs and facilitate their spread, and environmental factors. The MWP symptoms in Hawaii, Columbia, and Cuba established the presence of a Closterovirus as the causative agent (Hernández-Rodrıguez et al., 2019; Larrea-Sarmiento et al., 2021; Moreno et al., 2023). To date, three recognized members known as pineapple mealybug wilt-associated virus-1 (PMWaV-1), -2 (PMWaV-2), and -3 (PMWaV-3), as well as one putatively postulated member known as PMWaV-5, have been identified as Ampeloviruses that infect pineapple and have been linked to MWP. It suggests that a virus previously known as PMWaV-4 is a strain of PMWaV-1 (Green et al., 2020). Recently, PMWaV-6 has been suggested as a potential new *Ampelovirus* species member (Larrea-Sarmiento et al., 2021).

In Hawaii, PMWaV-2 has been demonstrated to contribute to the etiology of MWP, whereas pineapple plants infected with PMWaV-1, PMWaV-2, or both without visible mealybug feeding do not appear to exhibit symptoms (Green et al., 2020; Larrea-Sarmiento et al., 2021).

The transmission of five pineapple mealybug-associated viruses (PMWaVs) requires using vectors rather than being physically possible. Thus, vector insects play a crucial role. Mealybugs, which can act as PMWaV vectors, also claimed that the disease's symptoms were caused by an interaction between the PMWaV virus and mealybugs' feeding behavior (Hutahayan et al., 2021). All these viruses are primarily spread semi-regularly by two *Dysmicoccus* species, the pink (*Dysmicoccus brevipes*) and grey mealybugs (*Dysmicoccus neobrevipes*). The vegetative propagation of infected pineapple materials is the primary source of viral dissemination during the establishment of new planting areas (Hernández-Rodrıguez et al., 2019).

According to our research in Malaysia (unpublished data), MWP can be common in Malaysian pineapple farms due to the widespread distribution of suckers among pineapple growers. According to the observations, the prevalence of MWP in the field area is approximately 100%. In the case of the MD2 variety, the symptoms include chlorotic patches along the lamina, necrotic leaf tips, and leaves that curled downward and dried out (Figure 1 A). In other varieties, such as Sarawak, Josephine, and Crystal Honey, the symptoms include wilting, reddening leaves starting with the outer leaves, curling down, and drying up of the leaf tips (Figure 1 B-D).

In pineapple fields, the development of MWP causes significant yield losses, which are greater in plants infected earlier by mealybugs in their life cycles. Mealybugs cause immediate damage to pineapple, resulting in chlorotic areas, and they also weaken the plant by feeding on the stem and roots, making it more vulnerable to other pests and diseases, which reduces the fruit's market value (Araya, 2019). In plants with MWP symptoms, the pineapple tips curve down, the leaves change bronze-red and lose turgidity, and the fruits are unmarketable because the flesh is fibrous and sour (Araya, 2019). MWP contributes 35 to 55% of pineapple crop yield losses in Hawaii. Yield losses in the pineapple-producing countries

Figure 1. Occurrence of mealybug wilt of pineapple (MWP) on different varieties in Melaka, Johor, and Negeri Sembilan, Malaysia: (A) MD2, (B) Sarawak, (C) Josaphine, and (D) Crystal Honey.

of Cuba were estimated to be more than 50% (Hernández-Rodrıguez et al., 2019). In other producing countries, such as Ghana, the yield loss caused by MWP is estimated to be around USD 248 per hectare (Asare-Bediako et al., 2020). When combined with abiotic stress, ampelovirus infection may also affect pineapple crop losses. In Hawaii, asymptomatic infection by PMWaV-1 causes a 6.7% output decline, with losses increasing up to 13.3% in plantations under water stress (Hernández-Rodrıguez et al., 2019).

For the management of MWP, an integrated strategy that incorporates cultural practices, biological control, and chemical control measures is required. Mealybugs and their associated ants are reduced by good soil preparation and a year-long fallow period or intercycle before planting (Araya, 2019). Pineapple growers must consider the risks of using their plants for subsequent production cycles or exchanging plants with neighbors. The continued use of infected material may encourage virus species mutations and the emergence of new virus strains and species, which could have an unpredictable effect on production (Moreno et al., 2023).

According to Gungoosingh-Bunwaree et al. (2021), despite the fact that Mauritius' pineapple growers frequently trade suckers, the failure to properly control insect vectors during the 2020 COVID-19 pandemic's forced quarantine of people may be to blame for the spread of PMWaV-1 and -2 to new pineapple-growing regions. Careful selection of disease-free suckers and the adoption of effective vector control measures must be resumed immediately to protect Mauritius' pineapple production from MWP. According to a study by Araya (2019), the control of mealybugs on pineapple stems and roots was successful when Nemacur® 40EC (fenamiphos-AMVAC) was applied to the foliage of pineapple trees, and it worked best at 10 L/ha. Synthetic insecticides are frequently applied after sowing to kill or prevent mealybugs. Since the pest likes to feed on the roots or the stem above the roots, most products used to control it are non-systemic and have limited effectiveness. A biological control method like a sugar feeder can work by managing mealybugs through ants because mealybugs and ants have a mutualistic relationship. Sugar supply can disrupt the mutualistic interaction between ants and mealybugs in citrus. Ant activity in the orange tree canopy decreased as sugar was introduced, and ant attendance at mealybug populations decreased as a result, leading to an increase in parasitism (Pérez-Rodríguez et al., 2021).

BACTERIA HEART ROT (BHR) DISEASE

BHR disease is still a major economic issue for pineapple producers in many countries, such as the Philippines, Indonesia, Costa Rica, Brazil, and Hawaii (Cano-Reinoso et al., 2021). The bacterium *Erwinia chrysanthemi*, newly known as *Dickeya zeae*, infects the plant through wounds and causes decay in the heart of the plant. The bacterial pathogen, which affects a wide range of plant species, causes soft rot diseases by attacking various plant parts at various development stages (Young et al., 2022). The bacteria with the following morphological traits were circular, convex, cream-whitish, milk-colored, and colonies with a 1–2 mm diameter were found (Aeny et al., 2020).

The disease manifests as water-soaked lesions on the interior leaves, which then coalesce into blisters as the bacteria ferment plant matter. These will eventually exude a contagious bacterial ooze. As the fruit matured, the pineapple's center crown of leaves finally collapsed, killing the apex and stopping the fruit development. Gas accumulates because of the fermented fruit. The hissing sound that the gas makes as it leaves can be heard, particularly in the stillness of the night. It was dubbed "ghost rot" because it terrified many field laborers as they went home at night (Veléz-Negrón et al., 2023; Young et al., 2022).

The symptoms of fungal heart rots can be differentiated from those of bacterial heart rots because the infection is not spread to the greener areas of older leaves (Cano-Reinoso et al., 2021). The main inoculum source for bacterial heart rot is thought to be exuded juice from previously diseased plants, and the leaves are easily detached from the plants (Figure 2). Instead, because the bacteria do not survive long on leaf surfaces, infected seed material such as suckers, slips, or crowns are not a significant source of infection. The stomata become infected, and the bacteria are primarily spread by insects, such as big-headed ants (*Pheidole megacephala*) or Argentine ants (*Linepithema humile*), as well as by wind and rain. Four- to eight-month-old plants are more susceptible to this disease. Additionally, it is believed that common pineapple plantations are more vulnerable than ratooning (Cano-Reinoso et al., 2021).

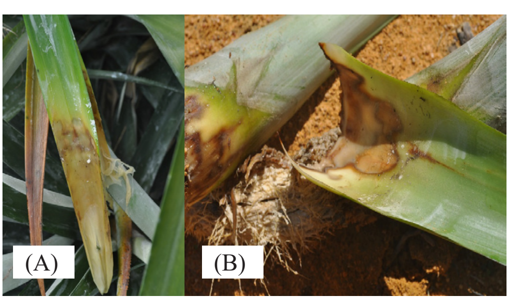

Figure 2. Signs and symptoms of bacterial heart rot (BHR) disease appear as (A) water-soaked, rotten tissue with a bad odor and (B) the leaves effortlessly detaching from the plant

BHR may reduce crop yields and quality by reducing fruit size, premature fruit drop, and reduced sugar content, resulting in economic losses for growers. In the meantime, bacterial heart rot has been reported in Malaysia, Costa Rica, Brazil, the Philippines, and Hawaii (Cano-Reinoso et al., 2021). According to Young et al. (2022), BHR disease can cause yield losses of up to 40%, which were quite significant in Malaysia in 1979. The pineapple is one of the fruits chosen for export diversification and sustainable family income growth in Uganda's fruit subsector. If not properly controlled, BHR disease can result in a 100% yield loss in Uganda (Oculi et al., 2020).

The BHR disease field study revealed an aggregated pattern of disease dissemination. The initial inoculum source site was found to be the main driver of disease onset and spread. Pineapple growers have used a variety of techniques to combat the disease, including disease monitoring, early detection, removal, and destruction of infected plants (Nor et al., 2019). Nevertheless, when disease symptoms appear, the growers tend to treat the planting materials with chemical pesticides such as benomyl (50% a.i.) and malathion (57% a.i.), which could lead to several environmental issues (Sidik & Sapak, 2021). Therefore, the disease must be controlled using alternative techniques that reduce heavy dependence on synthetic chemical pesticides. The biological control method is one of the alternative methods being investigated for controlling BHR. The potential for biological control agents (BCAs) derived from beneficial microbes isolated from healthy plants to effectively combat the disease is enormous (Sidik & Sapak, 2021). According to Sidik and Sapak (2021), *Bacillus cereus*, an isolate from asymptomatic MD2 pineapple leaves, inhibited the growth of the BHR pathogen.

Chrystal Honey, Maspine, and Sarawak types were recommended based on their BHR tolerance. However, regular disease surveillance is crucial for preventing infection for producers who plant other varieties. This discovery is crucial, particularly for plant breeders who will use it to develop new varieties, identify potential varieties, and search for resistance genes to increase varietal diversity in the future (Nor et al., 2019).

FRUITLET CORE ROT (FCR) DISEASE

FCR is one of the most common postharvest diseases of pineapples. FCR causes damage to pineapple depending on the variety. FCR is a major concern for the "Queen" cultivar but is virtually non-existent in the "MD2" cultivar. Notably, numerous pre- and postharvest diseases could also affect the MD2 cultivar. *Fusarium ananatum* and *Thalaromyces stolii* (previously known as *Penicillium funiculosum*) are the two fungal pathogens that typically cause this aggressive disease (Barral et al., 2019). For effective management, FCR disease should be managed during early postharvest stages. Typically, the appearance of the formed rot lesion can be used to distinguish between *Talaromyces* and *Fusarium* infection. *Talaromyces* typically causes dark to medium brown rot lesions with a moist, grey region in the middle. In comparison, *Fusarium* infection causes rot lesions that range in color from light to dark brown and affect the fruitlet core (Figure 3). *Fusarium* rot spots are also typical of the dry rot variety (Zakaria, 2023). According to Sapak et al. (2021), there is no proof that *F. ananatum* causes fruit rot in Malaysia. However, the authors discovered several *Fusarium* species connected to fruit rot in pineapple, including *Fusarium proliferatum*, *Fusarium sacchari*, *Fusarium verticillioides*, and *Fusarium* spp. *Fusarium proliferatum* is the most common species discovered in the infected tissues of fruit rot. In relation to the information on wind direction and the location of these crops, FCR may be caused by similar causal

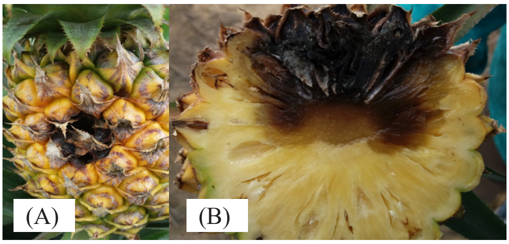

Figure 3. Fruitlet core rot (FCR) disease symptoms demonstrate (A) affected fruitlet with brown to dark brown and sunken external symptoms as the fruit ripens; (B) internal symptoms of a dark browning fruitlet from the edge to the core

pathogens as the adjacent cultivated crops (Vignassa et al., 2021).

The pathogen enters the plant through the nectary ducts and stylar canals during flowering. Once the fungus enters the floral chamber, it does not reactivate throughout fruit development. There are physiological changes after a pathogen attack, and the pineapple stimulates the phenylpropanoid pathway. Following *F. ananatum* infection, there is a buildup of free coumaroyl isocitrate and caffeoyl isocitrate in fruitless pineapples. These hydroxycinnamic acids (HCA) are involved in lignin biosynthesis and are essential in plant-pathogen interactions due to their antifungal properties (Chillet et al., 2020). The fungus is dormant during fruit development; once the fruit matures, it spreads out (Barral et al., 2019). These situations cause browning of the internal tissues (flesh), which only affects the fruitlet and has no effect on the core or exterior of the pineapple fruit. These symptoms, known as "black spots," are normal indicators of fruitlessness with the FCR infection. However, due to the lack of external symptoms, the disease incidence could not be properly assessed during or after pineapple cultivation. The complexity of the FCR pathosystem is dependent on the coexistence of healthy and diseased fruitlets within a single pineapple fruit, indicating that a particular microbiota may be responsible for pathogenesis (Vignassa et al., 2021). Because of these internal damages, determining the FCR is difficult for producers and consumers. The etiology of FCR is complicated because of the climate, fungi variety, and pineapples' physiological makeup (Barral et al., 2019).

The postharvest quality of pineapples, as well as local and international markets, are impacted when FCR occurs in tropical and subtropical regions. Brazil, Japan, China, Reunion Island, India, Hawaii, and Malaysia are the top pineapple-producing where fruitlet core rot has been reported. On Reunion Island, however, thorough investigations into the disease and its causing microbes have been carried out (Chillet et al., 2020; Vignassa et al., 2021). Disease incidence and severity have increased in the producing areas, resulting in a significant decline in fruit quality and consequent economic concerns (Vignassa et al., 2021). The output of this crop on Reunion Island is declining due to several diseases, including FCR, a postharvest disease that appears in mature pineapple. Because there are no visible external symptoms during harvest, FCR disease significantly impacts domestic and international markets (Chillet et al., 2020). In South Africa, FCR-related losses are far more severe than those caused by any other postharvest disease (Barral et al., 2019).

As a result of the economic effects of FCR, researchers and pineapple farmers started looking into ways to control FCR. Petty et al. (2005) noticed a significant decrease in black spots per fruit after spraying a mixture of two fungicides at flower induction. The application of miticide increased the frequency of black spots, contrary to expectations, in another program designed to control the mite vector (Barral et al., 2019). According to Chillet et al. (2020), essential oils and other naturally occurring antifungal substances have the potential to be an alternative control method for postharvest infections. The physiological mechanisms of fruit resistance can be stimulated by essential oils, which also have antimicrobial qualities. New alternative approaches to disease management, including the use of plant extracts with medicinal properties, have been proposed.

FUSARIOSIS DISEASE

Fusariosis, a serious disease that also affects pineapples, primarily infects the fruit but also affects all other parts of the plant. *Fusarium guttiforme*, which causes fusariosis, is the most serious fungus that affects pineapples. According to Zakaria (2023), Brazil was the world's top producer of pineapples until the discovery of fusariosis caused a serious infection. Fusariosis was later discovered in other pineapple-producing countries such as Cuba, South Africa, India, and Malaysia. Fusariosis infection typically begins in the early stages of flowering and continues through all phases of fruit growth. The first signs of fusariosis manifest in the fruitlets because the disease's pathogens penetrate the inflorescence through wounds. The lesion becomes brown discoloration and rotten fruit skin, a common disease symptom, discolored flesh (Figure 4). Contaminated planting materials could also transmit the disease. Finally, secondary infections that form on growing suckers and slips may result from an infection of the developing fruit (Zakaria, 2023).

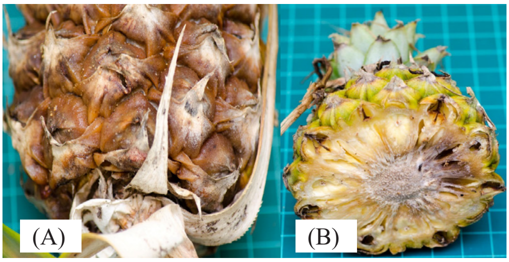

Figure 4. Fusariosis disease symptoms show (A) external brown discoloration and rotten fruit skin; (B) internal symptoms depicting discolored flesh, pinkish to brownish lesion

Zakaria (2023) also mentioned that although the symptoms of fruitlet core rot and fusariosis are identical, there are slight distinctions between the two diseases. Fruitlet core rot, which is mild, results in dry-type rotting. Contrarily, the plant-rot phase frequently connected to fruitlet core rot is absent from pineapple fusariosis.

Pathogenicity studies with susceptible pineapple varieties and morphological features have been used to identify *F. guttiforme*. The ability to identify *Fusarium* by microscopy is time-consuming and needs highly skilled personnel. Furthermore, identifying the fungus in plant cells, which may contain other *Fusarium* species, can be challenging. The *Fusarium fujikuroi* species complex (FFSC), which includes *F. guttiforme*, has a controversial taxonomy based on the genus' conventional categorization system (Carnielli-Queiroz et al., 2019). Developing novel methods for quick, accurate, and sensitive identification of this fungus is critical. In comparison to other molecular diagnostic methods and even conventional pathogen isolation techniques from infected plant tissues, real-time polymerase chain reaction represents a low-cost, high sensitivity, and high-specificity method for the diagnosis of pineapple fusariosis caused by *F. guttiforme* (Carnielli-Queiroz et al., 2019). *Fusarium semitectum* and *F. fujikuroi* were found in Malaysian pineapple plants that exhibited symptoms of fusariosis. Both species exhibited symptoms through fruit and leaf pathogenicity testing that matched those seen in the field. Unsurprisingly, both *F. semitectum* (syn. *Fusarium incarnatum*) and *F. fujikuroi* were involved in pineapple fusariosis because they are common species throughout the tropics and can infect different plant hosts. Although *F. guttiforme* and *F. ananatum* are the main species linked to pineapple fusariosis, other *Fusarium* species could also be responsible for the disease (Zakaria, 2023).

Mycotoxigenic *Fusarium* species may generate mycotoxins on pineapple plants during critical growth stages in the field, which accumulate in colonized pineapple tissues. Mycotoxin production on infected plants in the field may begin during preharvest, continue through postharvest, and begin during storage. As a result, mycotoxin contamination began in the field and continued after collection. This condition may also cause severe problems for pineapple plants when fresh pineapple fruits are consumed (Ibrahim et al., 2020). *Fusarium* species that infect cereal grains are the primary source of these mycotoxins, but mycotoxigenic species can also negatively impact tropical fruit yields; losses of up to 50% have been recorded, including pineapple (Zakaria, 2023).

Fusariosis of the pineapple is a serious fungal disease that affects both the plant and the fruit economically. There are significant phytosanitary issues with this crop, which result in financial losses and restrict pineapple exports. It is estimated that 30–40% of the fruit and up to 20% of the vegetative propagation material were lost. Fusariosis is a significant limiting factor for pineapple output in Brazil due to phytosanitary restrictions by countries in Central America, Africa, and Asia. These countries are presently free of *F. guttiforme*, but they must abide by phytosanitary laws and regulations that can be informed by quick diagnostics to streamline logistics for quarantine, prevent the introduction of the pathogen, and reduce potential economic losses (Carnielli-Queiroz et al., 2019).

Most pineapple farmers have implemented sanitation measures to reduce disease incidence on farms and treated planting materials with fungicides like benomyl or captafol. Hot water treatment at 54°C for 90 min is also recommended to reduce disease spread on planting materials, as discussed by Sapak et al. (2021). Goncalves et al. (2021) found that using garlic, neem, and ginger extracts to treat fusariosis disease in a pineapple in the state of Tocantins was ineffective, necessitating additional research for new doses and/or collaboration with chemical products intended for this purpose. In many pineapple plantations, chemical fungicides are still the primary means of disease management. For instance, various concentrations of fungicide combinations, such as azoxystrobin, cyproconazole, carboxy, thiram, tebuconazole, and methyl thiophanate, have been tried to control fusariosis in a pineapple field in Brazil (Nogueira) (Sapak et al., 2021).

According to Soler (2019), pineapple cropping methods such as mycorrhizal fungi to increase nutrient availability from the soil, bacteria for direct action on pathogens with toxins or chitinolytic enzymes, nitrogen-fixing bacteria to reduce nitrogen application, fast multiplication of disease-free planting material through *in vitro* propagation, and non-pathogenic fungi inoculation are currently integrated by utilizing biotechnologies (*Trichoderma* spp.). This presentation demonstrates the possible integration of a few of these biotechnologies and their influence on developing ecologically friendly pineapple cropping systems.

DISEASE CAUSED BY NEMATODE

Plant parasitic nematodes (PPNs) are one of the most important crop issues affecting crop production worldwide, and pineapple is one of the most economically significant crops infected by these plant pathogens. Approximately 10% of all nematode species are plant parasites, making nematodes the most diverse group of multicellular organisms on Earth. Plant parasitic nematodes are tiny organisms that reside underground (Benzonan et al., 2021). Despite reports of PPNs infecting pineapple, little research has been conducted on the fruit. Numerous species of parasitic nematodes, including root-knot (*Meloidogyne javanica* and *Meloidogyne incognita*), lesion (*Pratylenchus brachyurus*), and reniform (*Rotylenchulus reniformis*), have been observed in pineapple plants (Rabie, 2017).

In commercial pineapple plantations in Malaysia, there have been reports of the high prevalence of *Paratylenchus* sp. and a low population of *Aphelenchoides* sp. and *Pratylenchus* sp. The decrease in pineapple yield on peat soil was most likely caused by the nematode *Paratylenchus* sp. This nematode was discovered throughout the crop's development stages, with the oldest plants exhibiting the greatest population, particularly in peat soil with high acidity levels (Masdek et al., 2007). Based on a study by Tanimola et al. (2021), *Helicotylenchus* was the most prevalent nematode pest in the Obio-Akpor Local Government Area (LGA) of the five nematode pest genera discovered in both soil and pineapple roots, *Scutellonema* and *Paratylenchus* had the lowest percentage of any nematode taxa. However, the most significant nematode parasite connected to pineapple in Nigeria was the *Pratylenchus* species, with a relative importance value (RIV) of 33.8%.

In pineapple, PPNs typically feed by entering the soil through the roots. Most infections include lesions in the vascular tissues and piths that the plant relies on to transport water and nutrients. When root and vascular tissues are damaged, chlorosis on the foliage begins (Benzonan et al., 2021). As the infection progresses, the leaves will promote necrosis, and the roots will easily be removed from the infected soil. These infections can potentially spread to nearby plants and permanently harm the soil, resulting in a yearly loss of production (Benzonan et al., 2021). Due to the nature and symptoms of the disease by these nematodes, their destructive potential is often underestimated and confused with that of other plant pathogens like fungi and bacteria. Most of the time, growers lack the knowledge and awareness to address their crops (Tanimola et al., 2021).

Each year, the Philippines loses an average of 10-15% of crop yield, amounting to an estimated $78 billion in crop losses globally. Today, many farmers, particularly those in developing countries, are unaware of plant parasitic nematodes (Benzonan et al., 2021). As of 2019, Nigeria is the eighth-largest pineapple producer globally and the top producer in Africa. Pineapple production contributes significantly to household nutrition and health and improves the quality of rural life for most farmers in Nigeria. PPNs, on the other hand, have been linked to substantial yield losses in pineapple, making them one of the banes of Nigeria's pineapple industry (Tanimola et al., 2021). According to some reports, PPNs can decrease yield in Brazil by 60% for the plant crop and 40% for the second harvest (Norwegian Institute of Bioeconomy Research, 2021). The pineapple suffers significant yield losses in France due to an increasing infestation of the nematode *R. reniformis* and other "soil-borne pathogens" (Soler et al., 2021).

In their recent review article, Sapak et al. (2021) stated that cultural practices, nematicides, biological control, and the integration of all available control methods are some of the methods used by pineapple producers to handle nematode attacks. The most effective way to reduce the likelihood of subsequent sowing is to remove infected plants from the fields. According to Soler et al. (2021), the most popular short-term treatment method has remained using nematicides. Following decades of intensive monoculture, in which the natural balance between beneficial and harmful communities of soil organisms has vanished, French authorities recently prohibited using pesticides to manage "soil-borne pathogens" on pineapple. Increased infestation of the nematode *R. reniformis* and other "soil-borne pathogens" causes significant crop damage in pineapple. New cropping systems with creative ecological nematode control are needed. First, a sustainable cropping system based on pineapple and sunn hemp (*Crotalaria juncea*) rotation reduces the initial biotic stress on pineapple plants (inoculum of nematodes) (Soler et al., 2021). In addition, systemic resistance could be induced by using a chemical elicitor or pineapple endophytic bacteria to sustain low nematode populations in pineapple plants. Thus, integrated disease management could be a solution for curative and preventive measures.

CONCLUSION

This review on the predominant and destructive pineapple diseases (MWP, BHR, FCR, fusariosis, and parasitic nematode damages) affecting pineapple crops in producing countries highlights the critical importance of disease management strategies. The impact of yield losses caused by these prevalent and economically imperative pineapple diseases may vary from one producing country to another, depending on the agronomic practices, environmental factors, and farming systems that influence the pathogen populations. Strict quarantine measures are required to reduce the impact of the disease in pineapple on the international fruit trade, which affects the socioeconomic situation of some producing countries. Overall, expanding the knowledge of the diseases that affect pineapple plants will improve the effectiveness of management measures relating to causal pathogens. Since pre- and postharvest phases may alter a crop's susceptibility to pathogens, identifying pathogenic pineapple disease provides a foundation for correct handling during preharvest and postharvest storage.

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