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Epidemiology of Black Sigatoka and Its Impact on Nutrient Dynamics in Banana Plants: Addressing Climate Change Implications

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ABSTRACT

Black Sigatoka, caused by *Mycosphaerella fijiensis*, is one of the most destructive diseases affecting banana crops globally. This review focuses on the epidemiology of Black Sigatoka, exploring factors contributing to its spread, the pathogen's life cycle, and the role of environmental conditions, particularly climate change. Additionally, it delves into the nutrient dynamics of banana plants, emphasizing how nutrient deficiencies, particularly potassium, magnesium, and nitrogen, exacerbate the disease. Given the increasing unpredictability of climate patterns, this review also highlights the expected implications of climate change for Black Sigatoka's transmission and severity, and presents adaptive management strategies for sustainable banana production. By integrating climate change adaptation with nutrient management, this paper provides an updated framework for addressing Black Sigatoka in the context of modern agricultural practices.

INTRODUCTION

Banana is one of the most widely cultivated and consumed fruits globally, providing a critical source of food and income in tropical and subtropical regions. However, banana production is under constant threat from diseases, with Black Sigatoka, caused by the fungus *Mycosphaerella fijiensis*, being one of the most destructive. This disease reduces leaf area, impairs photosynthesis, and significantly decreases the yield of banana plants.

The spread and severity of Black Sigatoka are influenced by multiple environmental and biological factors. In addition to these factors, nutrient imbalances in banana plants play a crucial role in exacerbating the effects of the disease. Nutrients such as potassium (K), magnesium (Mg), and nitrogen (N) are particularly important for plant health, and deficiencies in these elements can weaken the plant's defense mechanisms, making it more susceptible to Black Sigatoka.

Climate change is increasingly recognized as a major factor influencing the epidemiology of plant diseases, including Black Sigatoka. Rising temperatures, altered rainfall patterns, and changes in humidity are expected to alter the dynamics of Black Sigatoka transmission and severity. Understanding these changes and adapting to them is crucial for managing the disease in the future. This review explores how climate change interacts with Black Sigatoka epidemiology and nutrient dynamics, highlighting the need for integrated management strategies that incorporate climate adaptation and nutrient optimization.

Figure 1: Black Sigatoka disease of banana

LITERATURE REVIEW

Epidemiology of Black Sigatoka

Black Sigatoka, caused by *Mycosphaerella fijiensis*, is one of the most destructive diseases affecting banana production. Its epidemiology focuses on how the pathogen spreads, develops, and responds to environmental conditions. The disease spreads through conidia, which are dispersed by rain splash over short distances, and ascospores, which are carried by wind over longer distances. Infection is favored by high humidity and temperatures above 20°C (Olivares *et al.*, 2022; Marin *et al.*, 2003).

Pathogen Biology and Disease Development

Mycosphaerella fijiensis is a hemibiotrophic fungus, meaning it initially feeds on living plant tissue but eventually switches to a necrotrophic phase that results in plant

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tissue death. The pathogen produces two types of spores: conidia (asexual spores) and ascospores (sexual spores). Conidia are primarily responsible for local spread, while ascospores are dispersed over long distances by wind.

The disease cycle of Black Sigatoka is closely linked to environmental conditions. When conidia land on banana leaves, they germinate and penetrate the plant tissue, initiating the infection process. Over time, these conidia multiply, producing additional spores that continue the cycle. The disease progresses rapidly under optimal conditions of temperature (20°C–30°C) and high humidity, which are common in tropical banana-growing regions (Olivares *et al.*, 2022).

Environmental Factors Favoring Disease Proliferation

Black Sigatoka thrives in humid tropical environments with frequent rainfall and warm temperatures. Rainfall supports conidial spread, while humidity promotes spore germination and infection. These environmental factors strongly influence the rapid development and persistence of the disease (Olivares *et al.*, 2022; Hillyer *et al.*, 2020).

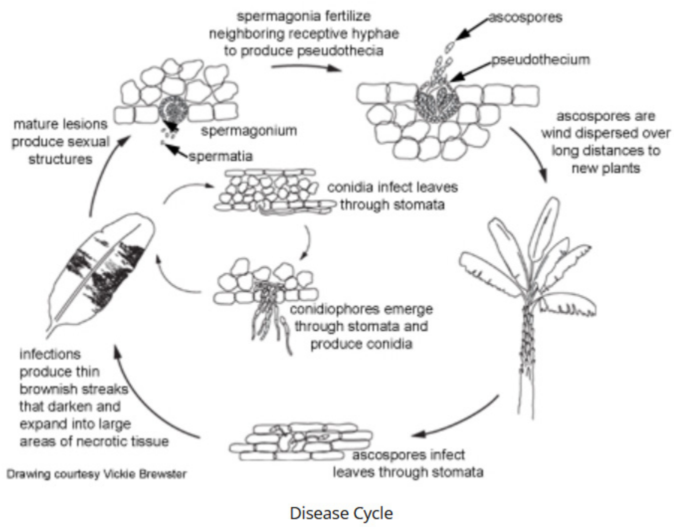

Figure 2: Disease cycle of Black Sigatoka
(Picture sourced from The Plant Health Instructor; Volume 3; Year 2003)

Transmission and Spread of Black Sigatoka

Black Sigatoka is primarily spread by wind and rain, which disperse the conidia over long distances. The spores can travel several kilometers, infecting nearby banana plants. The disease can also be transmitted through infected planting material, such as suckers and leaves, making it critical to ensure clean planting stock. In addition, farm equipment and human activity can contribute to local spread by moving infected plant material across different fields.

Esguera *et al.* (2024) emphasize the importance of proper sanitation in managing the disease. Plant debris left in the field can harbor the pathogen, contributing to the disease's persistence. Therefore, effective disease management requires controlling both local and long-distance transmission routes.

Conidia are asexual spores that primarily spread over short distances, moving between the leaves of the same plant, and contribute to the secondary spread of the disease. Ascospores, on the other hand, are sexual spores produced in pseudothecia and dispersed by the wind over long distances. They serve as the primary source of initial inoculum in the environment, leading to the establishment of the disease.

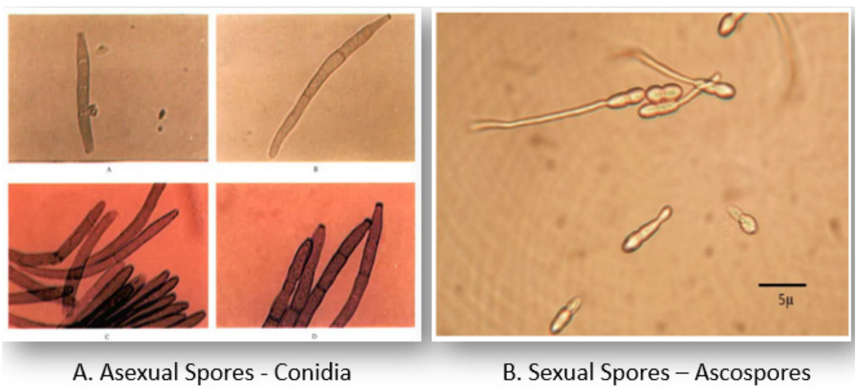

Figure 3: Asexual and sexual reproduction of Sigatoka

Impact of Climate Change on Disease Dynamics

Climate change is expected to increase the severity of Black Sigatoka by creating more favorable conditions for pathogen development. Rising temperatures, increased humidity, and altered rainfall patterns may shorten the latent period of the pathogen and increase outbreak frequency (Olivares *et al.*, 2022; Churchill, 2010; Thompson *et al.*, 2022).

Disease Management Strategies

Management of Black Sigatoka has traditionally relied on fungicides, but resistance has reduced their long-term effectiveness. Because of this, integrated disease management is recommended, including sanitation, resistant cultivars, cultural practices, biological control, and proper nutrient management (Rahman *et al.*, 2021; Patel *et al.*, 2020).

In addition, digital tools are becoming useful in banana disease management. Gerance *et al.* (2025) developed SaBaTech, a web-based pest and disease detection application for banana that uses image processing and machine learning, showing the potential of technology for early diagnosis and decision support in banana production.

Nutrient Dynamics and Impact on Black Sigatoka

Nutrient status strongly affects banana resistance to Black Sigatoka. Deficiencies in potassium and magnesium weaken plant defense and reduce plant vigor, while excessive nitrogen encourages soft growth that is more vulnerable to infection (Aguirre *et al.*, 2015; Rahman *et al.*, 2021).

Figure 4: Fungicide application through aerial spraying (*Picture sourced from Getty Images)*

Nutrient Deficiencies and Disease Severity

Potassium Deficiency and Black Sigatoka

Potassium is essential for maintaining cell wall strength, regulating water movement, and activating plant defense mechanisms. When banana plants are deficient in potassium, their tissues become weaker and less capable of resisting pathogen attack. This makes it easier for Black Sigatoka to infect the leaves, causing greater damage and reducing plant vigor (Aguirre *et al.*, 2015; Richards, 2019) .

Magnesium Deficiency and Black Sigatoka

Magnesium is a vital component of chlorophyll and is necessary for photosynthesis and energy production in banana plants. Without enough magnesium, the plant produces less energy for growth, defense, and stress recovery. As a result, magnesium-deficient plants become weaker and more susceptible to Black Sigatoka infection (Jimenez *et al.*, 2007; Rahman *et al.*, 2021).

Excess Nitrogen and Disease Severity

Nitrogen is important for plant growth, but too much nitrogen can be harmful. Excess nitrogen promotes rapid and soft tissue development, which is more easily invaded by fungal pathogens such as Black Sigatoka. This means that although nitrogen supports growth, over-application can increase disease severity by making the plant more vulnerable to infection (Silicon Uptake Studies, 2023; Rahman *et al.*, 2021).

The Importance of a Balanced Nutrient Profile

A balanced nutrient profile is essential for minimizing the effects of Black Sigatoka and maintaining healthy banana plants. Adequate potassium and magnesium strengthen plant defenses and support normal physiological functions, while proper nitrogen management prevents overly soft growth. Therefore, balanced fertilization is a key strategy in improving disease resistance and sustaining banana productivity (Aguirre *et al.*, 2015; Jimenez *et al.*, 2007; Rahman *et al.*, 2021).

Potassium and Magnesium: Critical Elements in Disease Resistance

Potassium and magnesium are essential nutrients that help banana plants resist Black Sigatoka. Potassium strengthens cell walls, regulates water balance, and supports plant defense, while magnesium is necessary for chlorophyll formation and photosynthesis. When these nutrients are available in balanced amounts, banana plants become healthier and less vulnerable to infection

(Jimenez *et al.*, 2007; Rahman *et al.*, 2021).

Nitrogen: A Double-Edged Sword

Nitrogen is important for banana growth because it supports the production of proteins, enzymes, and chlorophyll. However, too much nitrogen promotes rapid and soft tissue growth, making the plant more prone to Black Sigatoka infection. This shows that nitrogen must be managed carefully to support growth without increasing disease susceptibility (Rahman *et al.*, 2021; Silicon Uptake Studies, 2023).

Integrated Disease and Nutrient Management in the Context of Climate Change

Managing Black Sigatoka effectively requires an integrated approach that combines disease control with proper nutrient management. Balanced fertilization, sanitation, resistant varieties, and climate-adaptive practices help improve banana health and reduce disease spread. This combined strategy is more sustainable under changing environmental conditions (Patel *et al.*, 2020; Williams *et al.*, 2023).

Balanced Fertilization for Disease Resistance

Balanced fertilization is important in improving banana plant vigor and resistance to Black Sigatoka. Potassium and magnesium help strengthen plant tissues and support normal physiological functions, making infection less severe. Foliar application of these nutrients can also be effective, especially in nutrient-poor soils where plants need faster nutrient support (Aguirre *et al.*, 2015; Rahman *et al.*, 2021).

Role of Organic Practices in Disease Resistance

Organic farming practices can improve banana resistance to Black Sigatoka by enhancing soil health and nutrient availability. Composting, organic fertilizers, and biodiversity support stronger roots, better nutrient absorption, and improved plant resilience. These practices also reduce dependence on synthetic chemicals, making disease management more sustainable and environmentally friendly (Jimenez *et al.*, 2007; Nakamura *et al.*, 2018).

The Use of Biological Control Agents in Disease Management

Biological control agents, such as beneficial fungi and bacteria, offer an eco-friendly alternative to chemical fungicides in managing Black Sigatoka. These organisms suppress the pathogen by competing for nutrients and space or by producing substances that inhibit its growth. When combined with proper nutrient management, biological control can strengthen plant defense and support more sustainable banana production (Fuentes *et al.*, 2021; Rivera *et al.*, 2019).

Recent studies also support the importance of disease management in banana production. Figueroa and Hagonos Jr. (2022) found that selected commercial antifungal treatments, particularly when used in combination, effectively inhibited *Fusarium oxysporum* f. sp. *cubense* TR4 in vitro, highlighting the value of integrated approaches in controlling major banana diseases.

MATERIALS AND METHODS

This paper employed a narrative literature review approach using published journal articles, review papers, and technical sources on Black Sigatoka in banana. A total of 22 references were selected for the review. Inclusion was based on the relevance of each source to the study themes, specifically pathogen biology, disease epidemiology, environmental conditions, nutrient dynamics, climate change implications, and integrated disease management. The filtering process involved screening the collected literature for direct relevance, consistency with the objectives of the paper, and usefulness in explaining the relationship between Black Sigatoka, nutrient status, and climate-related factors; sources with limited relevance or repetitive information were excluded. The selected studies were then organized thematically, and the data were analyzed through qualitative thematic synthesis to identify recurring findings, major patterns, and practical implications for sustainable banana production and crop protection.

RESULTS AND DISCUSSION

The reviewed literature consistently shows that Black Sigatoka, caused by *Mycosphaerella fijiensis*, remains one of the most damaging diseases affecting banana production because of its strong ability to spread rapidly under favorable environmental conditions. The disease develops efficiently in humid tropical areas, particularly where rainfall is frequent and temperatures remain warm. The pathogen spreads through both conidia and ascospores, with conidia contributing to short-distance infection through rain splash and ascospores serving as the major inoculum for long-distance dispersal by wind. These findings indicate that the epidemiology of Black Sigatoka is strongly influenced by environmental exposure, spore biology, and the persistence of infected plant tissues in production areas.

The literature further reveals that the disease cycle of Black Sigatoka is closely linked to temperature and humidity, which accelerate spore germination, infection, and lesion development. Under ideal conditions, especially at temperatures above 20°C and under prolonged humidity, the pathogen is able to infect leaves quickly and complete repeated infection cycles. This explains why disease outbreaks are often more severe in tropical banana-growing regions. The findings also suggest that environmental suitability does not only favor pathogen survival but also increases the frequency of reinfection, making field-level management more difficult when preventive measures are weak or inconsistent.

Another major result from the reviewed studies is the growing role of climate change in modifying disease behavior. Rising temperatures, shifting rainfall patterns, and increased atmospheric humidity are expected to create more favorable conditions for the development and spread of *M. fijiensis*. Several sources cited in the review suggest that warmer conditions may shorten the pathogen's latent period, allowing faster disease cycles and more frequent outbreaks. This means that Black Sigatoka may become more aggressive in both currently affected areas and in locations that may become climatically suitable in the future. These findings highlight the need to view Black Sigatoka not only as a plant health issue but also as a climate-sensitive agricultural threat.

The literature also emphasizes that nutrient dynamics

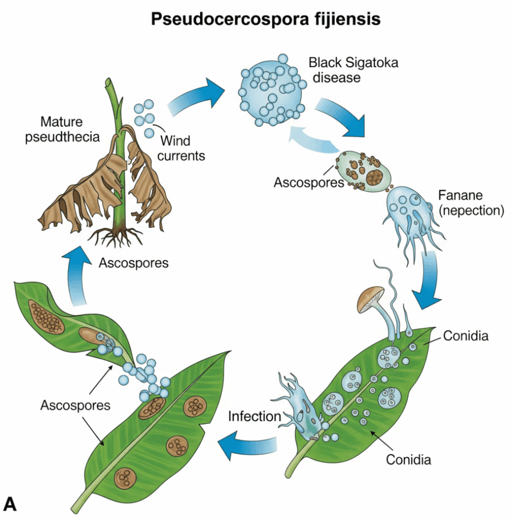

Figure 6: Life cycle of Pseudocercospora fijiensis, Black Sigatoka reproduction, banana pathogen
(Picture sourced from AgronoBlog: Agriculture Blog)

significantly influence disease severity in banana plants. Potassium and magnesium were consistently identified as critical nutrients in strengthening plant resistance. Potassium supports cell wall integrity, water regulation, and defense activation, while magnesium is essential for chlorophyll formation and photosynthesis. Deficiency in either nutrient weakens plant vigor and lowers the plant's ability to tolerate or resist infection. In contrast, excessive nitrogen application was described as a factor that promotes soft, tender plant tissues, which are more vulnerable to fungal invasion. This shows that nutrient imbalance does not merely affect growth performance but also directly alters the plant's susceptibility to Black Sigatoka.

A key point emerging from the review is that balanced fertilization is an important component of disease suppression. Studies cited in the paper indicate that adequate potassium and magnesium supply, including foliar application in nutrient-poor soils, can reduce the severity of Black Sigatoka by improving structural and physiological resistance in banana plants. On the other hand, over-fertilization with nitrogen may intensify disease pressure by stimulating lush but weak growth. These findings support the idea that nutrient management should be treated as a disease management strategy, not only as a yield-enhancement practice. Proper fertilization improves plant health, strengthens resistance, and contributes to more stable production under disease-prone conditions.

The reviewed literature likewise points to the importance of integrated disease management (IDM) in addressing Black Sigatoka. While fungicides remain widely used, their long-term effectiveness has been reduced by the development of pathogen resistance. As a result, more sustainable approaches are being emphasized, including sanitation, removal of infected debris, use of resistant cultivars, crop management practices, biological control agents, and organic soil health improvement. The literature suggests that no single intervention is sufficient on its own. Instead, combining disease monitoring, balanced nutrient supply, cultural control, and climate-adaptive practices offers a more resilient and environmentally sound approach to banana production.

Overall, the review paper synthesis demonstrates that the severity and spread of Black Sigatoka are shaped by the interaction of pathogen biology, environmental conditions, nutrient status, and farm management practices. The disease becomes more destructive when favorable weather coincides with poor nutrient balance and weak field sanitation. Conversely, banana plants are better able to withstand infection when disease control measures are integrated with proper nutrient management and climate-responsive production strategies. Therefore, the reviewed studies strongly support the need for a holistic management framework that combines epidemiological understanding, nutritional support, and sustainable agricultural practices to reduce losses caused by Black Sigatoka.

CONCLUSIONS

Black Sigatoka remains one of the most significant threats to banana production, and understanding its epidemiology is crucial for managing the disease effectively. Environmental factors, transmission dynamics, and pathogen biology all contribute to the disease's spread and severity. Moreover, nutrient imbalances, particularly deficiencies in potassium and magnesium, exacerbate the disease's impact. Therefore, effective management must incorporate both disease control strategies and balanced nutrient management practices.

Integrated Disease Management (IDM) that combines cultural practices, biological control, and proper fertilization provides a sustainable approach to mitigating the impact of Black Sigatoka. By maintaining optimal nutrient levels, banana plants can become more resilient to the disease, ensuring long-term productivity in affected regions.

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