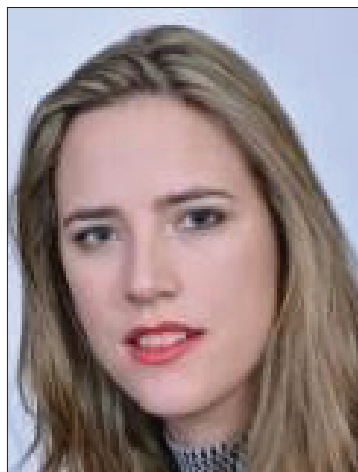


### Fusarium wilt Tropical Race 4: The banana wilt threat continues

Bananas (*Musa* spp.) are one of the most produced and consumed fruits globally and the fifth most traded agricultural product. With more than 1000 types of bananas known, a small number are grown as a staple food crop or fresh market commodity. The Cavendish variety accounts for 47% of global production, making it the most commercialised banana grown worldwide, with approximately 50 billion tons produced annually. The banana industry plays an important role both economically, employing 400 000 people in Latin America and the Caribbean alone, and socially, as a staple food in many developing countries within Africa and worldwide.

One of the most devastating constraints to banana production is Fusarium wilt, caused by the soilborne pathogen *Fusarium oxysporum* f. sp. *cubense* (Foc). The tropical race 4 (TR4) strain of Foc is particularly threatening as it infects the Cavendish banana variety and, therefore, has the potential to devastate the multibillion-dollar industry as well as impact food security and income of millions of farmers and labourers in developing countries. An outbreak of Foc race 1 in the early 1900s destroyed the well-established Gros Michel production industry with the epidemic only coming to an end upon replacement of this variety with the Cavendish variety, since it was discovered to be resistant to Foc races 1. A new race of the pathogen, Foc TR4 has caused a renewed Fusarium wilt outbreak, but this time on Cavendish bananas. Since it was first reported in Southeast Asia, Foc TR4 has continued to spread to 24 countries where, when introduced, has destroyed affected plantations.

As a soilborne pathogen, management of Fusarium wilt is challenging due to the build-up of inoculum in the soil. Factors contributing to this buildup include the survival of Foc as chlamydospores in soil, monoculture plantations of the Cavendish banana, and the perennial nature of the banana crop. Quarantine and exclusion practices, therefore, remain the most successful to restrict the spread of Foc TR4 in commercial plantations. Once the pathogen is present, the only effective strategy for sustainable production is the cultivation of Foc-resistant



varieties. To date, however, there is no resistant replacement available for the Cavendish banana. Consequently, early detection of Foc TR4 plays a crucial role in the management of

the pathogen as it allows for early identification and containment to prevent further spread, thereby attempting to minimise its impact on banana production. In this editorial we will review the status of banana Fusarium wilt TR4 in the Middle East, discuss the epidemiology, disease cycle and symptoms, and management by using a multi-component strategy to prevent the introduction of the disease into disease-free areas.

### **Fusarium wilt TR4 in the MENA region**

Fusarium wilt TR4 first moved outside Southeast Asia when it was discovered in Oman in 2009. After that it was also detected in Jordan, Lebanon and Israel. In the following section, the importance of banana production in the Middle East and North Africa (MENA) region will be introduced, and the known occurrence of Foc TR4 in MENA countries discussed.

#### **Oman**

Banana is produced on approximately 1,420 ha in the Sultanate of Oman. Cavendish is the most popular variety grown, but Fard bananas (AAB) and plantains (ABB) are also planted. Unconfirmed reports of Fusarium wilt surfaced in 2009, but the first outbreaks were confirmed in Sohar in May 2011. Since then, the disease has been discovered in four states: Al-Suwaiq, Saham, Sohar, and Nizwa. Most banana farms in Oman are small (0.5 ha), and new plantations are established with suckers from the same or neighbouring farms.

#### **Jordan**

Foc TR4 was detected in the Shooneh Janoobiyyeh district of the Jordan Valley on approximately 1,000-1,500 ha of an estimated 2,000 ha area on which Cavendish bananas were grown. Approximately 80% of the area was affected, with an incidence of 20-80%. According to local growers, Fusarium wilt has been present in the region since 2005. At the time, however, no disease was found in the neighbouring West Bank of the Palestinian Authority or in Israel.

#### **Lebanon**

Lebanon has a small Cavendish banana industry that produces fruit for local consumption and export to Syria. Fusarium wilt was first detected in the Mansouri and Berghliyyeh regions in October 2013, and the causal agent was subsequently confirmed as Foc TR4. At the time of detection, only 1 ha of bananas was affected. More recent surveillance confirmed that the

disease is widespread in banana production regions in Southern Lebanon.

#### **Israel**

Foc TR4 was isolated from plants with typical Fusarium wilt symptoms at Shfeya plantation along the southern Carmel coastal plain and Kibbutz Ein Gev on the northern banks of the Sea of Galilee in Israel in 2016. The affected plants were destroyed, and the outbreaks were contained and the area placed under strict supervision by the country's plant protection and inspection services. By early 2018, no new cases were observed, but later in the year Foc TR4 was detected in more plots in the Jordan Valley.

### **Epidemiology and disease cycle**

Foc survives as chlamydospores in the soil or banana plant debris, remaining dormant until host root exudates stimulate the spores to germinate. The pathogen spores enter the plant through the root tips and grow long hyphae that infect lateral roots before penetrating the xylem vessels, allowing the pathogen to move through the xylem and colonize the rhizome. In resistant banana varieties, the rapid release of phenolic compounds causes the formation of tyloses and gels that block and lignify the spores and pathogen structures within the xylem, preventing further spread. Active plant defence mechanisms inherent in the plant are stimulated by infection, even in susceptible varieties, although recognition of infection is not fast enough to avoid colonization. Microconidia are produced which restrict the movement of water through the banana plant by infection of the xylem. Spores germinate and continue to spread through the vascular tissue resulting in discoloration and wilting of the plant once the entire xylem system is blocked. The fungus continues to spread into nearby plant tissue and produces chlamydospores or macroconidia, which are eventually released back into the soil when the plant decomposes, thereby ensuring the survival of the pathogen.

The spread of Foc TR4 occurs mainly by passive movement of the pathogen propagules. The main cause of pathogen spread locally and via long-distance is through infected planting material. Runoff water carrying infected soil and plant parts can contaminate reservoirs, drainage canals and rivers, all of which can infect new plantations nearby. Long-distance spread through the transport and movement of inoculum within infected soil attached to farm

machinery, vehicles, the footwear of workers and domestic animals in the area also contribute to the spread of the pathogen. Non-host plants, such as weeds, are also thought to play a role as potential sources for inoculum survival and spread of the pathogen. Once in the soil, Foc TR4 can persist for several decades making it difficult to control once established and near impossible to eradicate.

### Symptomology

The development of symptoms of Fusarium wilt depends on the level of inoculum, the level of resistance or susceptibility of the host, and environmental conditions, with appearance varying between 2 months to several years. The first symptoms are chlorosis in older and then younger leaves over 1-3 weeks, followed by successive wilting and possible splitting of the pseudostem as the pathogen colonises and destroys more vascular tissue. Internally, there is dark-brown discolouration of the pseudostem and rhizome vascular tissue as it is destroyed by the pathogen. The initial (mother) plant eventually collapses, and the follower (daughter) plant begins to exhibit similar symptoms due to the connection of vascular tissue, resulting in contamination by the mother plant. The banana plant usually dies before flowering and therefore bunches are not produced, although surviving bunches contain fruit with no internal or external symptoms. Emerging leaves are stunted and short, and banana rhizomes that are younger than 4 months old will usually not show visible symptoms of the disease.



Typical banana Fusarium wilt symptoms associated with Cavendish bananas. Left: Yellowing of older leaves, with dead leaves hanging down the pseudostem. Top right: Vascular discolouration of the pseudostem. Bottom right: Discolouration of the inner rhizome.

### Management

Fusarium wilt management is challenging due to the survival of inoculum in the soil. The pathogen cannot be eradicated or treated with fungicides, and prevention of its introduction into banana fields using proper biosecurity is thus critical. Once introduced, containment can only be effective if infected plants are diagnosed early, and the infested area properly contained. If not, the disease needs to be managed,

primarily by planting disease-resistant bananas or supporting partially resistant plants using an integrated disease management strategy. The three stages of dealing with Fusarium wilt involves disease prevention, containment, and management.

### **Prevention**

Preventing the spread of Foc TR4 into disease-free areas is the most effective way to manage the disease. A series of actions are involved in prevention that can be categorized into pre-border, on-border, and on-farm measures. Pre-border interventions include certification agencies conducting a pest risk analysis to determine whether material is disease-free and can be imported and transported between and within countries. Additional measures include raising awareness about the disease, conducting training workshops, and building capacity among national and regional agencies are essential. On-border activities refer to efforts that strengthen control capacities as well as regulate the movement of plant material and farming equipment from high-risk regions to disease-free areas. Biosecurity measures can be implemented at country borders, farm gates, and different checkpoints within the farm. While molecular diagnostic tools could offer accurate detection of suspicious material when stopped by authorities, it is still unfeasible to consider its implementation in many countries. On-farm measures include implementing property fencing and establishing entrance control points for visitors and vehicles. It is also important to ensure the use of disinfectants and clean planting material, irrigation water, farming equipment, and vehicles on the plantations.

### **Early detection and containment**

When Foc is already present in soil, complete eradication is not possible. Early detection and containment strategies are therefore of utmost importance to reduce the rate of disease spread in banana plantations. Regular surveillance, a thorough diagnostics program, and collaboration among plant health authorities regionally and nationally contribute towards early detection of the pathogen. This aids in effective decision making regarding whether containment measures should be implemented. Once Foc has been detected in a plantation, this area as well as three to five rows of plants surrounding the detection site are eradicated. The plants are killed and treated with urea or burnt on site. Containment procedures in

commercial plantations involve limiting the movement of people and animals that might spread Foc-containing soil, and sanitising all shoes and farm equipment before workers leave an infected area. Additionally, fencing-off of the diseased area and putting up physical barriers can prevent water run-off to disease-free areas. These containment measures are often not possible to introduce by small-scale farmers and subsistence growers.

### **Management**

Substituting susceptible banana varieties with tolerant or resistant ones is the only way to attain sustainable banana production on Foc-infested soil. Although many active breeding programs and biotechnology laboratories are currently aiming to produce Fusarium wilt TR4-resistant plants, these are yet to be grown on a commercial level by farmers. Chemical control by using fumigants and fungicides does not eradicate the fungus from infested soils, and biocontrol products and soil amendments are often not ineffective. The only way to commercial growers to deal with the disease currently is the use of Foc TR4-tolerant Cavendish somaclones. Disadvantages of these somaclones include a longer growth cycle, compromised yield, and only partial resistance to Foc TR4. Consequently, somaclones are cultivated only in areas where Cavendish banana production is unsustainable due to the presence of Foc TR4. The use of Cavendish somaclones should be supported by integrated disease management options such early identification and eradication of disease plants, the application of biocontrol agents or soil amendments, shortening of planting cycles, planting of cover crops, and intercropping with non-host species. These approaches are expected to lower inoculum levels of the pathogen by promoting soil suppression.

### **Strategy to deal with Fusarium wilt TR4**

A multi-component, proactive strategy is needed to deal with Foc TR4. Such a strategy could consist of the following components:

#### **Awareness**

The first line of defence against Foc TR4 is to be aware of the threat posed by the pathogen, and to have knowledge on actions that can prevent introduction. This information should be shared with growers, plant protection officials and all other stakeholders of country banana industries through extension services and printed or electronic media.

## Clean planting material

The use of clean planting material to establish banana plantations is a critical step in the prevention of Foc TR4 and other destructive banana pathogens. All banana planting material imported into a country should be moved as *in vitro* plants, and not as suckers or bits. This is the primary task of a country's Plant Health authority. If the fungus is already present in a country, the infested fields and region should be placed under quarantine, and the movement of materials from such farms regulated. Banana growers in affected countries should be made aware of the risk of spread to their own farms and need to take the responsibility not to use any planting materials or plantation tools from infested farms.

## Capacity to deal with Fusarium wilt TR4 incursion

Plant health officials from national plant protection organizations (NPPOs), researchers and extension officers need to be capacitated in field and laboratory diagnosis of Foc TR4, and how to deal with the disease once a suspect case is reported. The designated inspector needs to visit the property, take samples and conduct regular surveillance in production regions. If the cause of the disease is Foc TR4, all the necessary precautions need to be taken to prevent the fungus from spreading by declaring and treating the affected site as a quarantine area. The accurate identification of the fungus is crucial, and the outcome of the test should be reported in a responsible way and in consultation with the country's NPPO.

## Biosecurity

Biosecurity measures for Foc TR4 should be introduced at country border, farm border and on-farm level. These measures involve a range of actions, including the listing of Foc TR4 as a quarantine organism, proper inspection services and diagnostic ability, control of farm access, the use of clean planting materials and the implementation of phytosanitary measures. The implementation of farm biosecurity depends on its practicality and growers' financial capacity.

## Research, development and training

Research to prevent and manage banana Fusarium wilt is required before Foc TR4 is introduced into a country, particularly considering small-grower production systems. This involves rapid and accurate detection systems that employ both in-field and remote

diagnostic technologies, the evaluation of popular banana varieties for Foc TR4 resistance and means to manage the disease in small-grower fields. Training of plant health officials, research scientists, extension officers and growers is also important in countries at risk. This should involve means for the early diagnosis of suspect plants, accurate identification of the cause of the disease, and methods to report Foc TR4 to NPPOs and the banana production community.

## Surveillance for Fusarium wilt TR4

Regular national surveys for Foc TR4 should be undertaken, especially in affected and bordering countries. The disease becomes visible once typical Fusarium wilt symptoms develop in Cavendish bananas grown in high-temperature zones, such as in the tropics. If such plants are observed, they should be treated as suspect cases and further investigated.

## Political will

It is crucial that policymakers and community leaders participate in raising awareness among stakeholders on both a national and regional scale to prevent the introduction of Foc TR4 onto banana farms. Ideally, agricultural authorities need to show commitment by carrying out actions to prevent the entry of Foc TR4. This can also include signature of agreements between affected and non-affected countries.

**Diane Mostert<sup>1</sup>**

**Altus Viljoen<sup>1</sup>**

**Maged Elkahky<sup>2</sup>**

**<sup>1</sup>Stellenbosch University, South Africa**

**<sup>2</sup>Food and Agricultural Organization of the United Nation (FAO)**