Fusarium wilt of banana

See Musapedia page on TR4

Fusarium wilt of banana, popularly known as Panama disease, is a lethal fungal disease caused by the soil-borne fungus *Fusarium oxysporum f. sp. cubense* (Foc). It is the first disease of bananas to have spread globally in the first half of the 20th century. The epidemic started in Central America on the susceptible ‘Gros Michel’ banana, which at the time dominated the global export trade. In the 1950s, 'Gros Michel' was replaced by Cavendish cultivars. At the end of the 1980s, the so-called TR4 strain, to which Cavendish cultivars are susceptible, was isolated from samples from Taiwan[1]. It has since spread through Asia and reached Africa in 2013 (see Distribution of TR4).

The fungus enters the plant through the roots and colonizes the xylem vessels thereby blocking the flow of water and nutrients. Disease progression results in the collapse of leaves at the petiole, the splitting of the pseudostem base and eventually plant death. Once established in a field, the fungus persists in soil for an indefinite period of time and cannot be managed using chemical pesticides. The solution best adapted to the continued production of bananas in infested soils is replacing susceptible cultivars by resistant ones.

The pathogenic isolates are classified into races based on the cultivars on which they cause disease. For example, the isolates that affect cultivars in the Gros Michel, Silk and Pome subgroups, among others, are classified as race 1. When Cavendish cultivars exhibiting symptoms of Fusarium wilt were first observed, the isolates were classified as race 4. They were later subdivided into subtropical race 4 (STR4) and tropical race 4 (TR4) to distinguish the strains that need predisposing factors to cause the disease from the ones that don't (see Race 4). The race concept has been criticized for being an imperfect measure of pathogenic diversity, but it is still considered useful to describe host reaction and new disease outbreaks[2].

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Distribution

Although the disease probably originated in southeast Asia, the first recording of the disease was made in 1874 in Australia, where it was observed at Eagle Farm near Brisbane. It was then reported from Panama in 1890. Within a decade the disease had spread to Costa Rica and subsequent outbreaks occurred in Surinam (1906), Cuba (1908), Trinidad (1909), Jamaica (1911), Honduras (1916) and Guatemala (1919). The disease has since been reported from most banana-producing countries.

For details on the distribution of TR4, go to the Musapedia page on TR4.

Symptoms

Main symptoms of Fusarium wilt

Fusarium wilt is a typical vascular wilt disease. The fungus invades the vascular tissue through the roots, causing discoloration and wilting, eventually killing the plant. The progress of the internal symptoms can influence the first appearance of the external symptoms. The fruit do not exhibit any symptom.

The characteristic internal symptom of Fusarium wilt is vascular discoloration, which varies from pale yellow in the early stages to dark red or almost black in later stages. Internal symptoms first develop in the feeder roots, which are the initial infection sites. The fungus spreads to the rhizome and then the pseudostem.

Externally, the first signs of disease are usually wilting and yellowing of the older leaves around the margins. The yellow leaves may remain erect or collapse at the petiole. Sometimes, the leaves remain green, except for spots on the petiole, but still snap. The collapsed leaves hang down the pseudostem like a skirt. Eventually, all the leaves fall down and dry up.

Splitting of the base of the pseudostem is another common symptom. Other symptoms include irregular, pale margins on new leaves and the wrinkling and distortion of the leaf blade.

Infected suckers do not start showing symptoms of Fusarium wilt until they are about 4 months old, a situation that has contributed to the spread of the disease through planting material. The fruit does not show any specific disease symptoms.
Reddish to dark brown discoloration of the vascular system.

Yellowing typically begins at the margin of the older leaves.

Collapsed older leaves hanging down the pseudostem.

Split pseudostem.

Farmers may spread the Fusarium fungus by transplanting symptomless but infected suckers.

**Similar diseases**

The leaf symptoms of Fusarium wilt can be confused with those of the bacterial disease *Xanthomonas wilt*. In plants affected by Fusarium, yellowing and wilting of the leaves typically progresses from the older to the younger leaves. The wilted leaves may also snap at the petiole and hang down the pseudostem. In plants affected by Xanthomonas, the wilting can begin with any leaf and the infected leaves tend to snap along the leaf blade.

In countries with Moko disease, which is caused by *Ralstonia solanacearum* race 2, and also causes vascular discoloration, it is possible to confuse the two diseases. Unlike Moko, Fusarium wilt does not cause wilting and blackening of young suckers or a dry rot in the fruit. The first symptoms of Moko on rapidly growing plants are the chlorosis, yellowing and collapse of the three youngest leaves, not the older leaves as with Fusarium wilt. Finally, with Moko the vascular discoloration is concentrated near the centre of the pseudostem and not peripherally, which is common with Fusarium wilt.

**Modes of transmission**

The fungus is commonly spread through infected planting material, infested soil and water.

**Planting material**

Symptomless but infected suckers or rhizomes can transmit the disease when planted in a new area. Infected planting material is often responsible for the local, national and international spread of the disease. Certified tissue-culture plantlets should be free of the fungus and would not contribute to the spread of the disease.

**Soil**

The fungus can persist in soil for decades, even in the absence of bananas. It can survive in infested plant debris and in the roots of alternative hosts. Staff and visitors to a banana plantation have the potential of moving the fungus in or out through infested soil attached to vehicles, tools and shoes. Untreated soil used as a potting medium can transmit the fungus and animals can also move around fungal spores present in soil.

**Water**

Spores can be carried in surface run-off water. They can also contaminate irrigation reservoirs. It is said that in China pumping water from sources contaminated with TR4 spores contributed to the
spread of the Fusarium wilt in plantations of Cavendish bananas\textsuperscript{4}.

Disease management

The fungus cannot be controlled using fungicides and cannot be eradicated from soil using fumigants. Drainage, environmental conditions and soil type influence host-pathogen interactions. Soils that suppress the disease have been reported in Central America, the Canary Islands, Australia and South Africa. However, the chemical, biological and physical factors responsible for this phenomenon are not well understood.

The solution best adapted to the continued production of bananas in infested soils is replacing susceptible cultivars with resistant ones. However, in the case of TR4, experts stress the importance of preventing the spread of the fungal strain (see Preventing the spread of TR4).

Resistant cultivars

\textbf{Gros Michel}, \textbf{Silk}, \textbf{Pome} and \textbf{Pisang awak} cultivars are generally resistant to race 2 strains but susceptible to races 1 and 4 strains. \textbf{Cavendish cultivars} are generally resistant to races 1 and 2 strains but susceptible to race 4 strains. \textbf{Plantain} and \textbf{East African highland bananas} (EAHB) cultivars are generally resistant to race 1 strains.

The \textit{FHIA} improvement programme has produced hybrids that are resistant to races 1 and 4, while the \textit{Taiwan Banana Research Institute (TBRI)} has released Giant Cavendish tissue-culture variants (GCTCV) that display varying levels of resistance to TR4\textsuperscript{5}.

In field trials conducted in China, \textit{FHIA-01}, \textit{FHIA-02}, \textit{FHIA-18}, \textit{FHIA-25}, \textit{Pisang Jari Buaya}, \textit{Rose (AA)}, and to a lesser extent \textit{GCTCV-119} and \textit{FHIA-03}, have shown resistance to TR4\textsuperscript{6}. Preliminary results from a field trial conducted in the Philippines in 2011-2012 suggest that EAHB and Plantain might be resistant to TR4. Most of the ITC accessions screened displayed little or no sign of Fusarium wilt\textsuperscript{7}. The one exception was Ibwi (ITC1465\textsuperscript{8}), whose ploidy (2x/3x)\textsuperscript{9} suggests that the accession might not be representative of the Ibwi cultivar. It is possible that the wrong accession was introduced to the ITC. In a separate field trial conducted in the Philippines, only 1\% of the GCTCV-219 plants exhibited symptoms of Fusarium wilt in the second crop cycle, whereas none of plants of the Cardava cultivar (Saba subgroup) did\textsuperscript{10}.

Two genetic engineering strategies, one involving the introduction of a resistance gene isolated from a wild relative of the banana and the other of an anti-apoptosis gene derived from a nematode\textsuperscript{11}, are being tested in Australia. Two of the evaluated lines were still free of the disease after three years of a field trial conducted in the Northern Territory\textsuperscript{12}.

Impact

Fusarium wilt is responsible for the demise of the export trade based on \textbf{Gros Michel}. By the turn of the 20th century \textbf{Gros Michel} was exported from the Caribbean and Central America, where large-scale plantations were carved out of virgin rainforest. The first losses followed soon after Fusarium wilt was reported in Panama and Costa Rica in the 1890s (the strains that cause disease on \textbf{Gros Michel} would later become known as race 1). Only the availability of vast areas of virgin land prevented an early collapse of the industry. The opening of new land to make up for the abandoned plantations (estimated at more than 40,000 ha\textsuperscript{13}) allowed production to keep ahead of the disease. But as uninfected and accessible land became increasingly rare in the the mid-1950s, production costs in Central America soared.
Even though resistant cultivars had been identified as early as 1910, the export industry did not begin to replace the susceptible Gros Michel banana until the late 1950s\[^{13}\]. The change was motivated by the entry of Ecuador as a major banana exporter in the 1950s\[^{14}\]. To compete with the cheap Gros Michel from Ecuador, the infested soils of Central America were planted with resistant Cavendish cultivars. Gros Michel has not completely disappeared, however. It is still grown by smallholder farmers, in backyard gardens and mixed crop systems.

Race 1 also had an impact on the cultivation of Silk, Pome and Pisang Awak cultivars, while race 2 reduced the cultivation of Bluggoe, especially in Latin America. African banana farmers have been less affected by Fusarium wilt given how African Plantains and East African highland bananas are largely resistant to race 1 strains.

Meanwhile, the emergence of TR4 started affecting commercial plantations of Cavendish cultivars. In the 1960s, Taiwan had about 50,000 hectares of banana plantations and was the major banana exporter to Japan. By the early 2000s, it had about 6,000 ha left in cultivation\[^{15}\]. In Indonesia and Malaysia, the arrival of TR4 in the early 1990s destroyed recently established export plantations within a few years\[^{15}\]. The fungus did the same to the banana industry in Australia's Northern Territory\[^{16}\].

In mainland China, a survey conducted in 2006 reported that about 6,700 ha had been severely affected by TR4 in Guangdong province\[^{17}\]. A report from a 2012 visit to the southwestern of Guangdong, the island of Hainan and the region around Guangxi’s capital, Nanning, hints at extensive damage\[^{18}\].

In the Philippines, the Federation of Cooperatives in Mindanao (FEDCO) called on banana farmers affected by TR4 to grow oil palm in 2014\[^{19}\], even as new banana plantations were being established\[^{20}\]. Smallholder farmers growing Cavendish bananas for the export market are also impacted\[^{21}\].

**Research**

In 1950, United Fruit (nowadays Chiquita) hired Robert H. Stover to devise management strategies for Fusarium wilt, which by then was threatening the very existence of the export trade based on Gros Michel. Stover added new insights into the taxonomy, variation, and physiology of the fungus, helped describe its interaction with banana, characterized resistance and susceptibility in banana, studied the influence of edaphic factors on the pathogen, and introduced flood fallowing as a means for cleansing contaminated soil (a practice that was later shown to contribute to the spread of the fungus). Stover’s research culminated in 1962 with the publication of "Fusarial Wilt (Panama Disease) of Bananas and other Musa species".

The publication of Stover’s monograph coincided with the substitution of the susceptible Gros Michel with resistant Cavendish cultivars. With this transition came a dramatic reduction in research on the disease as the banana export industry turned its attention to more pressing problems, such as black leaf streak\[^{22}\].

The spread of TR4 has spurred interest in research on Fusarium wilt. See efforts to address the threat of TR4.

**References**
4. New banana cultivars will help in Panama TR4 fight in the 25 July 2017 edition of farmonline.com
5. Growing Cavendish in the presence of TR4 in the 10 December 2012 issue of InfoMus@'s News and analysis
8. ITC1465 in MGIS
9. Ploidy of Ibwi in MGIS
19. Fedco urges Davao banana farmers to venture into palm oil as alternative source of income in the 10 April 2014 issue of Business Mirror.
20. Banana plantation to rise around Maguindanao massacre site in the 22 March 2014 issue of GMA news online.
See also on this website

Photos on the symptoms of Fusarium wilt in the Musarama image bank
Video on the symptoms, transmission and prevention of Fusarium wilt in the Musarama video bank

News and blogs on Fusarium wilt:
  Update on TR4 in Israel
  Zimbabwe authorizes passage of banana shipments from Mozambique
  Independent review of Biosecurity Queensland's TR4 programme
  TR4 confirmed in India
  TR4 present in the UK

More stories...
Musapedia page on an INREF-funded research project managed by Wageningen University & Research Centre (Panama disease: Multi-level solutions for a global problem)
Discussion thread on TR4 task forces in the ProMusa discussion forum

Further reading

Tropical race 4 grower kit, documents produced by Biosecurity Queensland to help Australian banana growers protect their farms
Diagnostic manual and links to presentations given at a 2014 FAO-CARDI regional workshop on the prevention and diagnostic of Fusarium wilt
Contingency plan (in Spanish) on TR4 for OIRSA countries
Fact sheet on Panama disease (8MB PDF) on the Plant Health Australia website
Fusarium wilt of banana laboratory diagnostics manual (1.8MB PDF) on the Plant Health Australia website
Datasheet on *Fusarium oxysporum* f. sp. *cubense* in CABI's Invasive Species Compendium
Panama disease: an old nemesis rears its ugly head, Part 1: The beginnings of the banana export trades Part 2: The Cavendish era and beyond

External links

Wikipedia page on Panama disease
Website for the research projects on Fusarium wilt that are managed by Wageningen University & Research Centre: fusariumwilt.org
Banana Fusarium wilt in Africa website

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