Tropical race 4 (TR4) is the name given to the strain of the fungus *Fusarium oxysporum f. sp. cubense* (*Foc*) that causes *Fusarium* wilt (aka Panama disease) in Cavendish cultivars, albeit not exclusively on Cavendish cultivars since other cultivars are also susceptible to TR4. The term TR4 was coined to distinguish this race 4 strain from the ones that affect Cavendish cultivars only in the presence of predisposing factors such as low temperatures. The latter are known as subtropical race 4 (STR4). TR4 is more specifically associated with a particular vegetative compatibility group called VCG 01213, although other VCGs have also been reported to cause *Fusarium* wilt in Cavendish cultivars in the absence of predisposing factors\(^1\). It has spread to most banana-producing countries in Asia. In 2013, it was reported in Mozambique\(^2\) and in 2019 in Colombia\(^3\).

TR4 has a wider host range than just Cavendish cultivars. In addition to hitherto unaffected cultivars, such as 'Lakatan' and 'Pisang mas', it also causes disease in groups of cultivars susceptible to races 1 and 2, such as Gros Michel, Silk, Pome and Bluggoe.

Like all other soil-dwelling *Foc* strains, TR4 cannot be controlled using fungicides and cannot be eradicated from soil using fumigants. The capacity of TR4 to survive decades in the soil, along with its lethal impact and wide host range, are among the main reasons it was ranked as the greatest threat to banana production\(^4\). To avoid further losses to the pathogen, the United Nations' Food and Agriculture Organization (FAO) has called on banana-producing countries to step up monitoring and reporting, and to contain suspected incursions to prevent the fungus from getting established\(^5\).

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Origin

There is no evidence that TR4 originated from a strain that overcame the resistance of Cavendish cultivars[6]. The strain that became known as TR4 took scientists by surprise in the early 1990s when newly established commercial Cavendish plantations where promptly destroyed by Fusarium wilt in areas of Malaysia and Indonesia with no history of Cavendish banana cultivation[7]. The theory developed by Ivan Buddenhagen is that TR4 evolved as an endophyte in a local Musa acuminata ssp. malaccensis, one of the wild ancestors of domesticated bananas, and was in the soil when the plantation was set up[8].

Distribution

In Taiwan, symptoms of Fusarium wilt on Cavendish cultivars were first observed in 1967[9]. In 1972, the results of pathogenicity tests suggested that the isolates belonged to race 1[10], but isolates tested in 1977 were designated as race 4[9]. In 1989, a previously undescribed VCG, designated VCG 01213, was identified in samples from Taiwan[11].

The vulnerability of Cavendish cultivars to what would become known as TR4 was underscored in the early 1990s, when Fusarium wilt decimated newly established plantations of Cavendish bananas in Indonesia and Malaysia[7]. The TR4 isolates introduced to Taiwan probably came from one of those places[7].

By the end of the 20th century, TR4 had been found in Taiwan, Malaysia[12], Indonesia (Java, Sumatra, Sulawesi, Halmahera, Kalimantan[13] on the island of Borneo, and Papua Province[14] on the island of New Guinea), mainland China (Guangdong[15], Hainan[16], Guangxi[17], Fujian[18][19] and
Yunnan\(^{[20]}\), and Australia (Northern Territory\(^{[21]}\)). In 2008, it was reported to be in the Philippines' island of Mindanao since at least 2005\(^{[22]}\).

Since then, the number of first reports has increased exponentially, although they have not all been formally published.

Though not formally published, TR4 is in Oman\(^{[23]}\)\(^{[24]}\)\(^{[25]}\). It seems to have been present since at least 2012.

In 2013, TR4 was reported to be in Jordan, the first official report of TR4 outside the Southeast Asia-Pacific region\(^{[26]}\). A 2014 survey revealed another infected area north of the original outbreak\(^{[27]}\).

At the end of 2013, TR4 was also reported to be in Africa, where it was confirmed to be in an export banana plantation located in northern Mozambique\(^{[2]}\). The Matanuska farm in Nampula province filed for insolvency in 2018, after which it was bought by Jacaranda Agricultura Lda and renamed Jacaranda Monapo. In 2014, TR4 was reported to be present in two other Jacaranda farms (Lúrio, in Nampula, and Ocuá, in Cabo Delgado province)\(^{[28]}\).

In 2015, TR4 was reported to be in Queensland, Australia\(^{[29]}\)\(^{[30]}\), as well as in Lebanon and Pakistan\(^{[31]}\)\(^{[32]}\). An analysis of isolates from Pakistan and the Philippines showed that they were closely related\(^{[33]}\). The incursion in Lebanon has also been shown to be associated with the one in Jordan\(^{[33]}\).

In 2017, TR4 was reported in Laos\(^{[34]}\) and Vietnam\(^{[35]}\).

In 2018, TR4 was confirmed to be in Myanmar\(^{[33]}\). The analysis of isolates from Laos, Vietnam and Myanmar provided evidence that the particular TR4 strain in these countries was likely introduced from China\(^{[33]}\).

In 2018, Israel's National Plant Protection Organization (NPPO) officially announced that TR4 had been found in two farms in Israel (the Carmel coastal plain and the eastern shores of Lake Galilee) in 2016\(^{[36]}\). After taking measures to contain the incursions, the NPPO declared that the fungal strain had been eradicated from Israel\(^{[37]}\). The declaration drew comments that TR4 had been contained rather than eradicated\(^{[38]}\). In 2019, the pest status was amended to "actionable, under eradication" following the discovery of TR4 at a number of sites close to the eastern/southern Lake Galilee area\(^{[39]}\).

In 2018, TR4 was officially reported to be in India, based on isolates collected in the state of Uttar Pradesh in 2017\(^{[40]}\). However, wilting symptoms on Cavendish cultivars had previously been observed, in 2015, by a banana grower from Barari village in the state of Bihar. Samples were collected in 2016 and TR4's presence in Bihar's Katikar and Purnea districts published in 2019\(^{[41]}\), by which time it had spread to the states of Uttar Pradesh, Madhya Pradesh and Gujarat\(^{[42]}\).

In August 2019, the Instituto Colombiano Agropecuario (ICA) confirmed the presence of TR4 in an area of 175 ha in Colombia's La Guajira department\(^{[3]}\). Symptomatic plants had been spotted earlier and the area quarantined on 11 June. It is the first report of TR4 in Latin America\(^{[43]}\).
A suspected case of TR4 in a plantation operated by a Chinese company was reported in June 2019 in the Chiang Rai province of Thailand[44].

In 2019, TR4 was confirmed to be in Turkey. According to the first report in Plant Disease, symptoms of Fusarium wilt were first observed in March 2018 during a survey of banana greenhouses along the Mediterranean coast[45].

In 2020, the NPPO of France informed the Secretariat of the European and Mediterranean Plant Protection Organization that TR4 had been detected on the island of Grande-Terre, in the French overseas department of Mayotte[46]. The fungus was found in 'Baraboufaka' (Bluggoe) and 'Kissoukari' (Silk) plants sampled from two adajacent plots in Poroani, a village in the southwestern part of the island. The symptoms were first observed in October 2019.

TR4 is also present at the Eden Project’s indoor rainforest biome in Cornwall, England[47].

Host range

In addition to Cavendish cultivars, TR4 affects cultivars susceptible to races 1 and 2 as well as hitherto unaffected cultivars such as, 'Barangan' (Lakatan subgroup, AAA genome group)[13] and 'Pisang Mas'. The often cited figure that TR4 affects cultivars that account for more than 80% of the world’s banana production[48] assumed that Plantains were also susceptible. At the time, however, the only Plantain-like material that had been evaluated against TR4 were hybrids produced by breeders[49]. The reaction of the Plantains domesticated in Africa, along with another group of locally domesticated bananas, the East African highland bananas (EAHB), was not known. The first field screening of these two subgroups was conducted in 2011-2012 in the Philippines using accessions from the ITC genebank. Most of the accessions tested were slightly to moderately susceptible[50]. Except for the 'Obubit Ntanga' Plantain accession that was still symptom-free after 10 months (a relatively short time given the perennial nature of most banana production), the disease incidence was below 5%, with the exception of 'Ibwi', for which the disease incidence was 29%. However, the ploidy of the ITC accession called Ibwi (2x/3x[51]) suggests that the material tested might not be the EAHB cultivar 'Ibwi'.

The FHIA improvement programme has produced hybrids that are resistant to races 1 and 4, while the Taiwan Banana Research Institute (TBRI) has released Giant Cavendish tissue-culture variants (GCTCV) that are partially resistant to TR4[52]. In field trials conducted in China, FHIA-01, FHIA-02, FHIA-18, FHIA-25, Pisang Jari Buaya, Rose (AA), and to a lesser extent GCTCV-119 and FHIA-03, have shown resistance to TR4[53]. In a 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[54].

Symptoms and diagnosis

The symptoms of a TR4 infection are the same as those caused by any other Foc strains (see symptoms of Fusarium wilt).

However, the wide host range of TR4 makes it difficult to diagnose TR4 on non-Cavendish bananas that are susceptible to other strains. For example, a Gros Michel infected with TR4 would not raise alarm because the
assumption would be that it is infected with a race 1 strain. The quickest way to confirm a TR4 infection is by analysing tissue samples using a TR4-specific PCR test\textsuperscript{[55]}\textsuperscript{[55]}. Fungal isolates can also be analysed to determine their vegetative compatibility group (VCG). The VCG associated with TR4 is 01213.

**Inoculating plants with *Foc***

**Extraction of *Foc* DNA**

**PCR diagnostic tests**

*Source: Prevention and diagnostic manual published by the FAO*

**Modes of transmission**

TR4 can be spread through infected planting material, infested soil and water. For more information, see the section on the modes of transmission of Fusarium wilt.

**Disease management**

Like all the other *Foc* strains, TR4 cannot be controlled using fungicides and cannot be eradicated from soil using fumigants. As a result, the spread of TR4 has led to an increase in research on biological control and the role of the soil microbial community in suppressing the pathogen\textsuperscript{[56]}.

Crop rotation with a non-banana crop that has anti-fungal activity has been used to reduce losses. In China, farmers have been growing bananas in the presence of TR4 by rotating them with Chinese leek (*Allium tuberosum*)\textsuperscript{[52]}\textsuperscript{[52]}. Chinese leeks has also been used as an intercrop\textsuperscript{[57]}\textsuperscript{[57]}.

The solution best adapted to the continued production of bananas in infested soils is replacing susceptible cultivars with resistant ones. However, given TR4's wide host range, virulence and persistence in the soil\textsuperscript{[6]}, experts stress the importance of preventing the spread of the fungus\textsuperscript{[58]}\textsuperscript{[59]}\textsuperscript{[58]}\textsuperscript{[59]} (see Preventing the spread of TR4).

**Resistant cultivars**

The FHIA improvement programme has produced hybrids that are resistant to races 1 and 4, while the Taiwan Banana Research Institute (TBRI) has released Giant Cavendish tissue-culture variants (GCTCV) that have been selected for their increased resistance to TR4\textsuperscript{[52]}.

In field trials conducted in China, FHIA-01, FHIA-02, FHIA-18, FHIA-25, Pisang Jari Buaya, Rose (AA), and to a lesser extent GCTCV-119 and FHIA-03, have shown resistance to TR4\textsuperscript{[53]}\textsuperscript{[53]}. Preliminary results from a field trial conducted in the Philippines in 2011-2012 suggest that EAHB and Plantain might be relatively resistant to TR4. The incidence of Fusarium wilt on the screened ITC accessions was generally low 75 weeks after planting\textsuperscript{[60]}\textsuperscript{[60]}. The one exception was Ibwi (ITC1465\textsuperscript{[51]}\textsuperscript{[61]}, whose ploidy (2x/3x)\textsuperscript{[51]}\textsuperscript{[51]} 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{[62]}\textsuperscript{[62]}.

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{[63]}\textsuperscript{[63]}, 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{[64]}\textsuperscript{[64]}.

**Preventing the spread of TR4**

Even though the threat posed by TR4 has been widely recognized, few TR4-free countries have taken the steps to prevent the entry of the fungal strain or to contain it when it was first detected.
By 2018, only two of the 16 countries that are known to have TR4 had taken immediate action to contain the fungal strain when it first showed up in an area: Australia in 2015 and Israel in 2016.

**Regulatory framework**

At the country level, several steps need to be taken, such as:

- Designate TR4 as a quarantine pest;
- Set up a monitoring system to promptly detect incursions;
- Enact regulations that allow the national plant protection organisation to intervene on farms, including:
  - Conduct inspections;
  - Collect samples;
  - Enforce the destruction of plants.

Contingency plans are typically developed by the authorities responsible for planning and responding to incursions of pests and diseases. They cover the technical and regulatory aspects of confirming suspected cases of and stopping the pest or pathogen from getting established.

Generic contingency plans can also be developed. OIRSA, a regional plant protection organization, whose membership includes Belize, Costa Rica, the Dominican Republic, El Salvador, Guatemala, Honduras, Mexico, Nicaragua and Panama, developed one against TR4.

**Containment**

At the farm level, containment (keeping the pathogen in) and exclusion (keeping the pathogen out) are two sides of the same coin. Except for the actions specific to isolating an infested area, the biosecurity measures aimed at preventing the fungus from escaping an infested farm are essentially the same as the ones growers can take to protect their farm. But whereas exclusion is the responsibility of the producer, containment can be legislated.

**Exclusion**

TR4 is mostly spread by infected planting material and contaminated soil and water. In Australia, the biosecurity measures banana growers have been encouraged to implement were designed to halt the movement of the pathogen along these pathways.

The primary line of defence is the exclusion of all non-essential visitors, vehicles and plant material from outside. This is part of a strategy to manage people and vehicle access that is called differential access zoning. For banana farms, three key zones are proposed:

1. The exclusion zone for vehicles that don’t need to enter the farm;
2. The separation zone for essential vehicles that are low risk (i.e. not associated with field production) and which are usually subjected to cleaning/disinfection procedures;
3. The farming zone, where farming activities take place, is physically separated from the other zones to manage the risk of cross-contamination.

Some of the actual practices put in place include physical barriers, facilities for footwear change at zone boundaries, and vehicle wash-down facilities that use disinfectants such as Farmcleanse®.
Sporekill® or Domestos®[70][71][72].

These practices also provide a barrier to the entry of other pests, diseases and weeds. Managing the movement of water and soil can also have a beneficial impact on the environment.

Putting in place measures that reduce soil erosion, such as ground covers and grassed inter-rows, would also lessen the severity of Fusarium wilt should it arrive[73].

Impact

The severity of the damage depends on interactions between the strain, its host and environmental conditions.

TR4 has devastated commercial plantations of Cavendish bananas in Taiwan, Indonesia, Malaysia and Australia’s Northern Territory[74].

In mainland China, the strategy of establishing Cavendish plantations in TR4-free areas to stay ahead of the disease has led to the spread of the fungus to all the main banana-growing provinces[75] and at least 3 countries in the Greater Mekong area[33].

In the Philippines, the extent of the damage in Cavendish plantations has not been documented. The Mindanao Banana Farmers and Exporters Association, which represents small-scale farmers growing Cavendish cultivars for the export market, has reported that about 5,900 hectares of their members’ aggregate plantation area had been infected, including 3,000 hectares that have been abandoned[76]. Some growers say their farm was infected by run-off from a nearby large commercial farm[77].

In the few instances in which losses to TR4 have been estimated, they amounted to 121 million USD in Indonesia, 253.3 million USD in Taiwan and 14.1 million USD Malaysia[78].

In Africa, where TR4 was reported for the first time in 2013 in an export plantation of northern Mozambique, the number of symptomatic plants had risen to more than 570,000 (out of a total of more than 2.5 m plants) by September 2015[79]. The disease reduced the production area from 1,500 ha in 2014 to 900 ha in 2016[28]. That same year, Formosana was planted on 200 ha. In 2018, only these 200 hectares were still in production and the number of workers had been reduced from 2,500 in 2014 to 750 in 2018[28].

For more information, see the section on the impact of Fusarium wilt.

Efforts to address the threat of TR4

Africa

Following the announcement that TR4 had been detected in Mozambique[80], the African Consortium for TR4 (AC4TR4) was launched at a workshop held at the University of Stellenbosch in April 2014[81].

Asia

The Banana Asia-Pacific Network (BAPNET) is coordinating a number of TR4-related projects and activities in various Asian countries[82].

Australia

Following the first confirmed case of TR4 in Queensland[66], Biosecurity Queensland, in partnership
with the Australian Banana Growers' Council, set up a programme of surveillance and containment. The farm was bought by the Australian Banana Growers Association in late 2016 with the objective of shutting down the farm and destroying all the banana plants.

In 2018, after TR4 had been found in two other farms, a system of certification was put in place for TR4-infested farms that meet the requirements for interstate and intrastate quarantine purposes (Inspection of bananas for freedom of soil and plant material). The system allows accredited businesses to certify their fruit consignments without putting the wider industry at risk. Accredited farms will be visited by biosecurity officers to audit the fruit inspection process and ensure that biosecurity requirements are being met.

In 2018, the Queensland Department of Agriculture and Fisheries released the review of Biosecurity Queensland's TR4 programme. It had commissioned the independent review to establish on what basis the programme should continue.

**Latin America and the Caribbean**

OIRSA, a regional organization for plant and animal health, has produced a contingency plan specific to TR4 for its nine member countries (Belize, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Mexico, Nicaragua and Panama), the plan is available in Spanish only.

The banana research network for Latin America and the Caribbean, MUSALAC, has been organizing training on quarantine pests, with a special emphasis on TR4.

In 2014, the Caribbean Agricultural Research and Development Institute (CARDI) organized a seminar and a training workshop to raise awareness of the potential threat of TR4 as a key step to prevent its introduction to the Caribbean.

**Global**

In December 2013, a task force on TR4 was set up within the framework of the World Banana Forum. In December 2014, the FAO held a consultation with a group of international experts to agree on the framework for a global programme. The plan would work on three main fronts: preventing future outbreaks, managing existing cases, and strengthening international collaboration and coordination among institutions, researchers, governments and producers.

The Wageningen university & research centre in the Netherlands is leading three projects on TR4: INREF, KNAW-SPIN and PromoBanana.

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92. FAO-funded awareness raising and training activities in the Caribbean
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See also on this website

News and blogs on TR4:
   TR4 in Mayotte
   TR4 in Turkey
   TR4 in Colombia
   'Goldfinger' given a second chance in Australia
   Update on TR4 in Israel
More stories...
References on TR4 in Musalit
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
Musapedia page on an INREF-funded research project managed by Wageningen University & Research Centre (Panama disease: Multi-level solutions for a global problem)

Further reading
Tropical race 4 grower kit, series of documents produced by Biosecurity Queensland to help Australian banana growers protect their farms
Contingency plan (in Spanish) on TR4 for OIRSA countries
Diagnostic manual and links to presentations given at a 2014 FAO-CARDI regional workshop on the prevention and diagnostic of Fusarium wilt
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

Research projects on Fusarium wilt that are managed by Wageningen University & Research Centre: fusariumwilt.org
Website of the World Banana Forum task force on tropical race 4
Video on Observations on on-farm biosecurity practices in the Philippines
Response to TR4 on the website of the Australian Banana Growers' Council
Response to TR4 on the website of Biosecurity Queensland
Banana Production at the Crossroads, video of a scientific session on the impact of TR4 at the American Phytopathological Society's 2015 Annual Meeting in Pasadena, California, USA.

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