Xanthomonas wilt of banana

Xanthomonas wilt of banana - better known as BXW, and to a lesser extent as BBW (for banana bacterial wilt) - is a bacterial disease caused by the bacterium *Xanthomonas campestris pv. musacearum* (*Xcm*). Before 2001, it was found only in Ethiopia, where it affects bananas and its close relative enset (*Ensete ventricosum*)[1]. It has since spread to the Great Lakes region of East Africa, where it has caused considerable losses when left uncontrolled. Although no resistant cultivars have been identified, the disease can be controlled by using cultural practices.

Removing the male bud (debudding) as soon as the fruits have set will prevent transmission of the disease by insects carrying the bacteria-laden exudates produced by infected plants. Debudding coupled with sanitation measures to ensure that cutting tools are not infected, will go a long way to prevent the disease from getting established. Should the disease show up, removing the diseased stem, a practice made possible by the atypical behaviour of the bacteria[2], has been shown to reduce the incidence of new infections to negligible levels when used in combination with the practices that prevent transmission of the bacteria[3]. However, it should not be used with other diseases like Bunchy top and Fusarium wilt[2].

### Contents

- Distribution and spread of the disease
  - Symptoms
  - Similar diseases
- Modes of transmission
  - Transmission through insects
  - Transmission through contaminated tools
  - Transmission through infected planting materials
- How to prevent BXW
  - Debudding
  - Disinfecting tools
- How to control BXW
  - Removing infected plants
    - Single diseased stem removal
  - Genetic engineering
- Host reaction
- Alternative hosts
- Efforts to address the outbreak
Distribution and spread of the disease

Xanthomonas wilt is currently found only in eastern Africa and the northeastern corner of the Democratic Republic of Congo. It was first reported on enset and banana in Ethiopia in 1968[^4], although earlier records report a disease consistent with these symptoms as present in the 1930s[^5]. Spread beyond Ethiopia was not reported until the disease was found in Uganda in 2001[^6]. Subsequent spread to other countries in eastern Africa has proceeded rapidly. In many instances, however, the exact time of introduction is not known.

Although it is said to have been first observed in 2001 by farmers in the North Kivu Province, the disease was not confirmed in the Democratic Republic of Congo until 2004[^7]. In Rwanda, Xanthomonas wilt was first identified in 2005, in the north-western part of the country, around Rubavu, where local farmers have mentioned seeing symptoms around 2002-2003[^8]. The disease most likely spread for DR Congo's Kivu region.

The disease was reported to have spread to Tanzania in 2005, and to Kenya[^9] and Burundi in 2006[^10][^11].

An analysis of data collected between 2001 and 2006 in Uganda and in six countries of the Great Lakes region in 2007 suggest that the number of newly affected areas declined between 2004 and 2005, and that the spread of the disease was changing from being more or less continuous to more isolated outbreaks[^12].

Symptoms

The disease causes loss both through death of the plant and rotting of the fruit. The leaves gradually turn yellow and start looking lifeless as if they were melting under intense heat. They eventually turn brown and die.

In flowering plants, the first symptoms of insect transmission are a drying rot and blackening of the male bud that start with the outer bracts and eventually extend to the rachis. The fruits ripen unevenly and prematurely, turning from green to yellow and black rapidly. The pulp of the rotting fruits shows rusty brown stains.

Internal symptoms revealed by doing a cross-section of an infected pseudostem are yellow-orange streaking of the vascular tissues and the presence of a yellow bacterial ooze, which can also be seen from any other infected plant part.
Similar diseases

In the absence of other symptoms, the leaf symptoms of Xanthomonas wilt can be confused with those of Fusarium 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.

The flower and fruit symptoms are similar to those observed in other bacterial wilts, but no other bacterial wilt of bananas are known to occur in Africa.

Modes of transmission

Insects, farm tools and infected planting material are the main agents of transmission. Their relative importance in spreading the disease depends on the management practices being applied, the type of cultivar and agroecological conditions.

Leaf wetness has also been implicated in disease establishment. Inoculated leaves of 3-month-old tissue-culture plants that were kept wet for 72 hours developed symptoms within 14 days, contrary to the control plants whose leaves were allowed to dry\textsuperscript{[13]}. The results may explain why a higher percentage of non-flowering 'Pisang Awak' was infected the high altitude region of Masisi in DR Congo (26\%) than in the mid-altitude region of Central Uganda (6.1 to 9.3\%)\textsuperscript{[13]}. In the high altitudes, rainfall is evenly distributed throughout the year, as opposed to two rainy seasons interspersed with a dry season at mid-altitudes. High plant densities could also contribute to disease spread when inoculum splashes down from the taller infected plants to the suckers growing below.
Goats and other livestock can carry the bacteria in their mouth and as such spread the disease to healthy plants. Pests such as weevils and nematodes can also help the bacteria in the soil gain entry into the plant through the injuries they make on the root system.

**Transmission through insects**

Fresh wounds offer bacteria a point through which they can enter or leave the plant. Bacteria have been isolated from the sap and ooze collected from the cushions to which the male flowers were attached and the scars made by the fallen bracts, and to a lesser extent from the nectar of flowers[14].

An insect visiting the male bud of an infected plant can get bacteria on its body through a wound that exudes bacteria-laden ooze. The bacteria on the insect's body can then infect healthy plants when the insect visits healthy plants that have similar wounds.

Even though female flowers are more visited than male flowers and the loss of their bract also leaves a scar, experiments suggest that infection only occurs through the cushions of male flowers as no flower infection occurs when the male bud is removed[15]. It could be because the female bract scars are less numerous and less accessible than the male bract scars.

In Uganda, the bacterium was isolated from stingless bees (*Plebeina denoiti* and undetermined species of the Apidae family), honeybees (*Apis mellifera*), fruit flies (Drosophilidae family) and grass flies (Chloropidae family)[14].

Cultivars that have persistent bracts and flowers are less likely to contract the disease from flying insects visiting the male bud, although some cultivars whose bracts and flowers do fall off also seem to escape infection. In general, *East African highland bananas* (EAHB) seem less prone to insect transmission, maybe because their inflorescence is less attractive to insects. The cultivar 'Kayinja', on the other hand, is very prone to floral infection[16].

Insect transmission is also less frequent at high altitudes, probably because the lower temperatures are not favourable to insect vectors. Male bud infections were rare at altitudes of 1,700m and above in Ethiopia[17] and the Masisi district (1700 m) of DR Congo, where the disease was first observed[7].

In 2012, a survey of the insect species visiting male buds in fields located at low, medium and high altitudes was conducted during each of Rwanda's cropping season (short dry, short rainy, long dry and long rainy)[18]. Seventeen insect species belonging to 12 families were collected and the *Xcm* bacterium was isolated from the external body parts of representatives of each species. The highest number of insects was recorded in low altitude areas during the long rainy season. The incidence of floral infections declined with increasing altitude, in parallel with insect activity. Insect activity also varied with the type of cultivar, with dessert and beer types attracting more insects than the cooking and multipurpose cultivars. 'Kayinja' (a beer cultivar), 'Kamarasenge' (an AAB dessert cultivar) and 'Injagi' (an EAHB cooking cultivar) attracted the largest number of insects in their respective use group, regardless of altitude. At the other end of the spectrum, not only did 'Nkazikamwe' (an EAHB cooking cultivar), 'Impura' (an EAHB beer cultivar) and 'Ikinyangurube' (an AAA dessert cultivar) attract less insects, they also possess persistent bracts and neutral flowers.
that interfere with insect transmission.

**Transmission through contaminated tools**
Cutting tools, such as machetes, pangas, knives, leaf removers and hoes, are one of the main mechanisms by which the disease is spread. Transmission occurs when a cutting tool is used on an infected plant, where it comes in contact with the bacteria in the sap or ooze, and then on a healthy plant. Sharing tools between farms and contracting out farm work increase the risk of spreading the bacteria through contaminated tools.

**Transmission through infected planting materials**
The spread, over short and long distances, has been associated with the movement of symptomless but infected suckers for replanting. Latent infections could explain the spread of Xanthomonas wilt in previously disease-free areas by farmers who unwittingly exchanged what they thought were healthy suckers[19]. Banana plant residues can also spread the disease[20].

**How to prevent BXW**
Even though no resistant cultivars have been identified, removing the male bud after the last hand has set will prevent insect transmission of the bacteria and keeping cutting tools clean will avoid transmission through contaminated tools. Should the disease show up, removing the diseased stem has been shown to reduce the incidence of new infections to negligible levels when used in combination with the practices that prevent transmission of the bacteria. Growing cultivars that have persistent bracts has also been proposed to protect the male bud from insect-transmitted infections[18].

**Debudding**
Insect transmission of the bacteria through the inflorescence can be prevented by removing — using a forked stick instead of a knife — the male bud as soon as the last hand has formed[15]. Using a forked stick not only avoids the risk of moving bacteria around on knives, should the plant be already infected, but also enables farmers to remove out-of-reach male buds.

**Disinfecting tools**
Only clean tools should be used on healthy plants. Cutting tools can be sterilized by putting the blade in a fire. The blade should be left in the fire for a short time (about 20-30 seconds). It should not get red hot.

Farmers should not let people from outside their farm use their cutting tools without sterilizing them first.

**How to control BXW**
**Removing infected plants**
From the early days of the epidemics, farmers were advised to uproot diseased mats, and to dispose of the plant debris, before replanting using clean planting material. (Studies on the survival of bacteria in the soil suggest that it should be safe to replant bananas after six months[21]). The practice, however, was not widely adopted[22]. A 2010 household survey targeting Uganda’s main production systems — the intensively managed EAHB production systems and the less intensively managed ‘Kayinja’ ones — showed that 53% of EAHB farmers and 30% of ‘Kayinja’ farmers uprooted
the entire mat\textsuperscript{[23]}.

Mats can also be destroyed by injecting an herbicide into the pseudostem of the mother plant\textsuperscript{[24]}. Notwithstanding health and environmental issues (the most effective herbicide turns out to be more persistent in the environment\textsuperscript{[25]}), adoption by farmers has also been poor. Some of the possible reasons that have been cited are: inaccessibility of herbicides in rural areas, perceived high cost of herbicides and reluctance to inject infected mother plants as asymptomatic suckers will also die\textsuperscript{[26]}.

Cutting down all the plants at soil level, destroying emerging suckers and leaving the rhizome to rot, which can take up to 24 months if no measure is taken to accelerate decomposition, has been used by Ugandan farmers to clear heavily infested banana plots for planting annual crops\textsuperscript{[26]}.

**Single diseased stem removal**

*p* Single diseased stem removal (SDSR), which consists in cutting off the infected plant at soil level, is an alternative to uprooting the entire mat that is made possible by the atypical behaviour of the bacteria\textsuperscript{[27]}. Long-term studies have shown that the bacteria do not go on to systematically colonize all the suckers attached to the rhizome. Moreover, even when the bacteria are present in a sucker, the disease may not develop or develop much later (latent infections)\textsuperscript{[28][26]}. The SDSR technique has been shown to reduce the incidence of new infections to negligible levels when used in combination with the practices that prevent transmission of the bacteria\textsuperscript{[3]}. However, it should not be used with other diseases like *Bunchy top* and *Fusarium wilt*\textsuperscript{[2]}.

**Genetic engineering**

Cultivars genetically modified to be resistant to the *Xanthomonas* bacterium using a gene from sweet pepper have been developed\textsuperscript{[29]} and tested in field trials\textsuperscript{[30]}.

**Host reaction**

So far, no resistant cultivars have yet been identified and field observations in areas where the bacterium is present suggest that all commonly grown cultivars succumb to the disease. Laboratory experiments on 7 cultivars and a wild species observed differences in susceptibility, with the cultivar 'Kayinja' being the most susceptible, whereas 10% of the potted *Musa balbisiana* plants that had showed early signs of necrosis, eventually recovered and did not wilt\textsuperscript{[31]}. Similarly, all the three-month plants from 42 genotypes tested in a pot trial eventually developed the disease, except for the *Musa balbisiana* plants, from which no bacterial cells were recovered\textsuperscript{[32]}. In later screenhouse and field trials, *Musa balbisiana* plants were symptom-free 6 weeks after a single inoculation at dosages that caused disease on the Pisang Awak controls\textsuperscript{[33]}. Disease symptoms were observed six weeks after a second inoculation, but only at the highest dosages.

Some cultivars, however, possess characteristics (such as persistent male bracts and flowers or no male bud) that make it harder for the bacteria to infect the plants under natural conditions. While these cultivars escape transmission by insect vectors, they are still vulnerable to transmission through cutting tools.

**Alternative hosts**

Cereals, especially maize, may serve as a reservoir to the bacteria\textsuperscript{[34]}.

The pathogenicity of three *Xcm* isolates extracted from naturally infected plants growing in Ethiopia(a cultivated enset, a wild enset and a banana cultivar) was tested in a pot experiment. All the isolates were shown to be pathogenic to a banana cultivar (Pisang Awak), ten enset cultivars,
ten wild enset, two maize cultivars, four sorghum cultivars, wild sorghum (*Sorghum halepense*), two finger millet cultivars, *Canna indica* and *Canna orchoides*.[35]

**Efforts to address the outbreak**

Beyond what individual farmers can do on their plots, a number of measures, such as intensive surveillance and reporting of new outbreaks (with prompt action to investigate them and take action) and strict control of the movement of plant material from infected areas to unaffected ones, have been proposed.[36] However, in plots of 'Kayinja', which are frequently neglected and for which ownership and responsibility for maintenance is often obscure, the likelihood of stopping the progress of the disease through coordinated actions is judged low.[36]

Early on in the outbreak, affected and threatened countries were urged to develop national and regional strategies.[37] In Uganda, the Ministry of Agriculture Animal Industry and Fisheries (MAAIF) and the National Agricultural Research Organization (NARO) embarked on an intensive programme to raise awareness of the problem and enable farmers to identify the symptoms of the disease and to implement control measures.[38] The country was divided into endemic areas (where the disease was present), frontline (bordering the endemic areas) and threatened (disease-free) in the hope of isolating, and eventually eradicating, the disease from the endemic areas.

A number of approaches were used to reach out to farmers: the extension system, media (local radio, television, newspapers and brochures) civic, cultural and local leaders, and a participatory development communication approach which consisted in organizing, at the local level, farmers, local leaders, extension staff, researchers and communication specialists.[39][40][41] An analysis of different approaches used in Uganda to mobilise farmers suggests that farmer field schools have been more effective in reducing the incidence of Xanthomonas wilt than the traditional approach of using extension services and mass media.[42]

In 2006, a regional Crop Crisis Control project (C3P) was initiated to reduce the spread and impact of the disease through education and training in East and Central Africa.[43] The project adopted a cascade training model, that is those who participated in a regional training were expected to conduct further training in their country. The people trained in-country would then take the training to the community level. In less than a year, the regional trainings had reached more than 1,000 extension and research staff while more than 30,000 farmers had been trained at the community level. However, considerable differences in capacities and institutional structures between countries affected implementation.

Coupling data on the incidence of the disease with other types of information, such as the share of bananas in daily food intake and the level food insecurity, was suggested to identify areas that should be targeted in priority.[44]

Scientists have also mentioned the lack of incentive for farmers living in threatened, but not yet affected, areas to adopt preventive measures.[43][45]
Field trials of the SDSR technique show that it can keep the disease in check. In Uganda, Kenya and the Democratic Republic of Congo (DR Congo) the proportion of diseased plants declined to between 3% and 20% 9 months after the start of a field trial[48]. One year after the start of separate field trials in the North and South Kivu provinces of DR Congo, the proportion of diseased plants was reduced to less than 0.5%[3].

References

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News and blogs on Xanthomonas wilt:
- Incomplete systemicity: a helping hand in the fight against Xanthomonas wilt of banana
- Project on the uptake of a technique to manage Xanthomonas wilt
- First results of a field trial of Xanthomonas wilt-resistant GM bananas
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Special issue on Xanthomonas wilt in Uganda in the African Crop Science Journal

External links

Simon Eden-Green, slide show on Xanthomonas wilt

Contributors to this page: Anne Vézina.

Page last modified on Friday, 01 March 2019 13:41:42 CET by Anne Vézina.
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