A fungicide is a specific type of pesticide used in controlling fungal diseases by inhibiting or killing the causal agent. Fungicides are routinely used in commercial plantations to control black leaf streak (BLSD) and Sigatoka leaf spot, as well as post-harvest diseases. However, not all diseases caused by fungi can be controlled by fungicides. Fusarium wilt, for example, cannot be controlled by fungicides, one of the reasons that led to the demise of Gros Michel as the export banana when race 1 strains of the Fusarium fungus entered Latin America.

Fungicides are used as a formulated product consisting of an active ingredient plus inert ingredients that improve the performance of the product. Against leaf diseases, fungicides are mixed with water, oil or an oil-water emulsion and then applied using equipment ranging from small hand-held and back-pack sprayers to large spray units carried by tractors or aircraft.

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Contact fungicides

Contact fungicides (also called protectants) are used against foliar diseases. They remain on the surface of plants and act by preventing spore germination. However, they are only effective on the leaves present at the moment of application and can be easily washed away by rain. Their main
drawback is the need for repeated applications to protect the new leaves. In the case of BLSD, since most infections start on the underside of the leaf during the unfurling of the cigar leaf, the effectiveness of contact fungicides depends on the quality of the coverage during the unfurling and on the interval between applications. On the other hand, they do not induce the selection of resistant fungal strains.

There are only a few types of contact fungicides. The main chemical classes of contact fungicides used in banana plantations are benzene derivatives and carbamates.

**Benzene derivatives**

*Cortotonalin*

Cortotonalin is a broad spectrum contact fungicide used in banana plantations to control BLSD. It can only be mixed with water as it becomes toxic to the plant when mixed with oil\(^1\). It's unlikely to present acute hazard in normal use. According to the banana working group of the Fungicide Resistance Action Committee (FRAC)\(^2\), Cortotonalin can be used solo or in mixtures with partners at manufacturers’ recommended effective rates. There are no limitations or restrictions concerning the number of applications, the timing or the sequence as long as it is within the limits of the manufacturers' labels\(^3\).

**Carbamates**

*Mancozeb*

Mancozeb is a fungicide in a subclass of carbamate pesticides called dithiocarbamates. As a cholinesterase inhibitor, it can have effects on the nervous system. It's unlikely to present acute hazard in normal use. According to FRAC banana working group, Mancozeb can be used solo or in mixtures with partners at manufacturers’ recommended effective rates. There are no limitations or restrictions concerning the number of applications, the timing or the sequence as long as it is within the limits of the manufacturers' labels\(^3\).

**Systemic fungicides**

Systemics (also called penetrants) are absorbed into plants. Some only penetrate the leaf, while others can be distributed to the entire banana plant. They also have a more or less pronounced curative effect. Against BLSD, the curative effect is more pronounced on stages 1 and 2. They don’t have any effect on the necrotic stages (5 and 6), although sporulation may be temporarily decreased\(^4\).

Since the mode of action of these systemic fungicides is very specific, small genetic changes in the fungus can overcome their effectiveness. Disease management strategies that rely heavily upon these fungicides often lead to pathogen populations becoming less sensitive or resistant to them. In their biennial review of fungicide sensitivity and use, the FRAC banana working group focuses exclusively on the control BLSD and makes recommendations on eight main classes of fungicides used against the fungal disease\(^3\).

**Benzimidazoles**

Benzimidazoles (BCMs) are broad-spectrum fungicides that interfere with cellular division. The following fungicides are used in banana cropping to control BLSD: benomyl, carbendazim, thiophanate, thiophanate-methyl\(^5\).

BMCs were introduced the late 1960s. At the time, they represented a ground-breaking class of
fungicides with high systemic and curative activity that allowed long intervals between applications. However, within a few years loss of disease control was beginning to be recorded in many crops. *Mycosphaerella fijiensis* began to show resistance to this class of fungicides within 2 to 3 years of their first use\(^6\).

The FRAC banana working group recommends that they should be used only in mixtures and only in full alternation with other, non-cross resistant modes of action. No consecutive BCM-applications (blocks) should be applied. To reduce selection pressure, the total number of applications a year should not exceed 3 and should not represent more than 33% of total number of sprays. They are preferably used at lower disease pressure and the sprays must be separated by at least 3 months of a BCM-free period\(^7\).

**Quinone outside inhibitors**

Quinone outside inhibitors (QoIs) in the Strobulirin chemical class of fungicides that inhibit mitochondrial respiration by binding to the cytochrome B enzyme complex. The following QoI fungicides are used in banana cropping to control BLSD: azoxystrobin, pyraclostrobin, trifloxystrobin\(^5\).

Resistance to QoIs in *Mycosphaerella fijiensis* and some other fungi is conferred by a point mutation in the mitochondrial cytochrome B gene\(^7\). Resistance to QoIs has been observed in Ecuador, Colombia, Guatemala, Costa Rica and the Philippines. QoIs should be used only in mixtures and only in full alternation. To reduce selection pressure, the total number of applications a year should not exceed 3 and should not represent more than 33% of total number of sprays. They are preferably used at lower disease pressure and the sprays must be separated by at least 3 months of a QoI-free period\(^3\).

**Demethylation inhibitors**

Demethylation inhibitors (DMIs) hinder the biosynthesis of ergosterol, a major component of the plasma membrane of certain fungi and needed for fungal growth. The following DMI fungicides are used in banana cropping to control BLSD: bitertanol, difenoconazole, epoxiconazole, fenbuconazole, myclobutanil, propiconazole, tebuconazole, tetcraconazole, triadimenol\(^5\). Shifting of DMI sensitivity over the baseline sensitivity has been observed up to 2009. Sensitivity has since stabilized at a higher level compared to pre 2009 in Belize, Ecuador, Colombia, Guatemala, Costa Rica, Honduras, Panama and the Philippines\(^5\). Mechanism of resistance to DMIs has been elucidated to be based on mutations in the cyp 51 gene of M. fijiensis. Additional reduction of sensitivity may come from overexpression of the cyp 51 gene\(^5\). All the active ingredients belonging to the DMI class of fungicides are considered to be a single product group, amongst which there is in general some degree of cross resistance. Mixtures of two or more DMIs can be applied to provide good biological efficacy; however, they do not provide an anti resistance strategy and must be treated as a solo DMI for resistance management\(^3\). The FRAC banana working group recommends that they should be used only in mixtures and only in full alternation with other, non-cross resistant modes of action. To reduce selection pressure, the total number of applications a year should not exceed 8 and should not represent more than 50% of total number of sprays. Applications should preferably start at the onset of the annual disease progress curve\(^3\).

**Amines**

Amines are another group of ergosterols synthesis. The following amine fungicides are used in banana cropping to control BLSD: spiroxamine, fenpropimorph, fenpropidin and tridemorph\(^5\). The
sensitivity to amines is at high levels and did not change significantly between 2010 and 2014[5]. The FRAC banana working group says that Amines can be used solo or in mixtures, but recommends applications in mixtures. A maximum of 2 consecutive sprays (block) containing amines can be used. Full alternation is preferred. Amines should be used at a maximum of 15 applications, but not more than 50% of the total number of sprays[3].

**Anilinopyrimidines**
Pyrimethanil is the only active ingredient from the group of anilinopyrimidines, which is currently used in banana cropping to control BLSD[5]. The FRAC banana working group recommends that Pyrimethanil should be used only in mixtures and only in full alternation with other, non-cross-resistant modes of action. Consecutive or so-called “block” applications are not recommended. To reduce selection pressure, the total number of applications a year should not exceed 8 and should not represent more than 50% of total number of sprays[3].

**Succinate dehydrogenase inhibitors (SDHIs)**
The following SDHI fungicides are used in banana cropping to control BLSD: boscalid, fluopyram, fluxapyroxad and isopyrazam[5]. The FRAC banana working group recommends that SDHIs should be used only in mixtures and only in full alternation with other, non-cross resistant modes of action. No consecutive SDHI-applications (blocks) should be applied. To reduce selection pressure, the total number of applications a year should not exceed 3 and should not represent more than 33% of total number of sprays. Applications should preferably start at the onset of the annual disease progress curve and be applied at times of lower disease pressure. Applications should be separated by at least 3 months of a SDHI-free period[3].

Where an SDHI is used as a soil drench for nematode control then, as a precautionary measure, it should be counted as one of the permitted SDHI applications. Another mode of action should be used for the first foliar fungicide application providing satisfactory disease control against *Mycosphaerella fijiensis* within the first 7 days after the soil drench application. Foliar applications with alternating mode of actions should be continued for the remaining growing period[3].

**Guanidines**
To control BLSD, the FRAC banana working group recommends that Guadinines should be used only in mixtures and only in full alternation with other, non-cross-resistant modes of action. To reduce selection pressure, the total number of applications a year should not exceed 6 and should not represent more than 33% of total number of sprays. Applications have to be separated by at least 6 weeks of a Guanidine-free period[3].

**N-Phenylcarbamates**
To control BLSD, the FRAC banana working group recommends that N-Phenylcarbamates should be used only in mixtures and only in full alternation with other, non-cross-resistant modes of action. To reduce selection pressure, the total number of applications a year should not exceed 3 and should not represent more than 33% of total number of sprays. Applications should preferably start at the onset of the annual disease progress curve and be applied at times of lower disease pressure. Applications have to be separated by at least 3 months of a N-Phenylcarbamates-free period[3].

**References**

2. FRAC banana working group
3. General use recommendations for fungicides used in bananas made by the FRAC banana working group
5. PDF of 2014 Banana FRAC Meeting Minutes

Further reading