Geographical distribution of the two species *Mycosphaerella musicola* Leach (*Cercospora musae*) and *M. fijiensis* Morelet (*C. fijiensis*), respectively agents of Sigatoka Disease and Black Leaf Streak Disease in bananas and plantains.

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GEOGRAPHICAL DISTRIBUTION OF THE TWO SPECIES *MYCOSPHAERELLA MUSICOLA* LEACH *(CERCOSPORA MUSAE)* AND *M. FIJIENSIS* MORELET *(C. FIJIENSIS)*, RESPECTIVELY AGENTS OF SIGATOKA DISEASE AND BLACK LEAF STREAK DISEASE IN BANANAS AND PLANTAINS.

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ABSTRACT - This article reviews the current geographical distribution of the two species *Mycosphaerella musicola* Leach and *M. fijiensis* Morelet in the main banana production areas throughout the world. The very high pathogenic activity of *M. fijiensis* and its wide distribution in Africa, Latin America, SE Asia and the Pacific is one of the main limiting factors in banana and plantain growing.

REPARTITION GEOGRAPHIQUE DES DEUX ESPECES *MYCOSPHAERELLA MUSICOLA* LEACH *(CERCOSPORA MUSAE)* ET *M. FIJIENSIS* MORELET *(C. FIJIENSIS)*, RESPECTIVEMENT AGENTS DE LA MALADIE DE SIGATOKA ET DE LA MALADIE DES RAIES NOIRES DES BANANIERS ET PLANTAINS

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RESUME - Ce document fait le point actuel sur la répartition géographique des deux espèces *Mycosphaerella musicola* et *M. fijiensis* dans les principales zones de production du monde. L'activité parasitaire très supérieure de *M. fijiensis* et son extension en Afrique, en Amérique latine, dans le Sud est asiatique et dans le Pacifique constituent l'un des principaux facteurs limitant de la culture des bananiers et plantains.

Production of bananas (sweet or «table» bananas), plantains and other cooking bananas is subject to considerable pressure from parasites including the very serious Sigatoka leaf spot diseases. It is recalled that they include two species :

Mycosphaerella musicola Leach [perfect form of *Paracercospora musae* (Zimm.)] Deighton which is responsible for Sigatoka leaf spot disease, also known as yellow Sigatoka. This species is pathogenic in particular for triploid AAA (Cavendish subgroup, Gros Michel, etc.) bananas and a limited number of diploid AA and triploid AAB varieties.

Mycosphaerella fijiensis Morelet [perfect form of *Pseudocercospora fijiensis* (Morelet) Deighton] causes black leaf streak disease, also called black Sigatoka. This species differs from the former in its anamorphic (conidial) state and by its stronger pathogenic activity on broad range of host. *M. fijiensis* is particulary damaging to all table bananas and also for numerous cultivars belonging to different genomic groups (AA, AAB, and ABB). The high susceptibility of the «plantain» subgroup (AAB) is having consequences in yield reductions or, in extreme cases, elimination of a subsistence production. This is serious when plantains are a major component of the diet as is the case in many tropical countries. In addition, the chemical control strategies (which are frequently expensive) applicable to industrial plantations of table bananas cannot be used in the cropping system concerned. A third species, *M. fijiensis* var. *diffornis*, which has characters common to both species described above, has been described from musa (Mulder and Stover, 1976). It was first observed in Honduras and has been frequently mentioned by different Latin American authors. However, Pons (1987), on the basis of mycological analysis, and then Stover (1987), have proposed synonymy of this species with *M. fijiensis*.

M. musicola was the first species to be described in banana (by Zimmermann in Java in 1902) and subsequently reached epidemic proportions in most of the banana growing countries of the world. *M. fijiensis* was not observed until 1963 (Rhodes, 1964) in Fiji.

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The characteristics common to both species are :

- they both display high aerial dispertion capability principally by ascospores and locally by conidia. This form of dispersal is probably responsible for a majority of intra continental spread. Movements between continents is more likely to be the result of transfer of plant material ;

- development is limited to intertropical production zones ;

- when both species are present simultaneously in the same region (e.g. when *M. fijiensis* is introduced in a zone already attacked by *M. musicola*), the competitive advantage lies with *M. fijiensis*, wich is much more pathogenic and progressively replaces *M. musicola*. This generally leads to the total disappearance of *M. musicola*.

Between 1962 and 1978, the geographical distribution of the two species was reviewed by several authors (Meredith, 1970 ; Meredith and Lawrence, 1969 ; Stover, 1962, 1976, 1978). Since then, *M. fijiensis* has continued to spread to new zones where it has replaced *M. musicola*. The area affected by the latter species, long considered as the cause of the most important fungal disease in bananas, has dwindled steadily over a period of about 20 years as *M. fijiensis* has spread. However, this is not a systematic trend. It would seem that certain abiotic conditions which control the spread of *M. fijiensis* sometimes permit the survival of *M. musicola* populations. This is particularly the case in highland populations in various regions described below.

The presence of host which are susceptible to *M. musicola* but resistant to *M. fijiensis* (very few of these exist) is another possibility for the continuing presence of *M. musicola* disease at a given site. For example, we have observed several cases of strong development of *M. musicola* on «Pisang mas» in spite of high pressure from inoculum of *M. fijiensis* from adjacent plants.

The bibliographical base mentioned above has been updated using the various data gathered in recent years on the presence of the two species in five large regions: Africa, Latin America and the Caribbean, Asia, Australia and Oceania.

PRELIMINARY REMARKS

Study of the morphology of the conidial state characteristics of the two species, which has been described at length in the literature (Meredith and Lawrence, 1969, 1970), is the only method by which the species can be differentiated with certainty (table 1). Simple observation of symptoms - which are nevertheless quite different - can be used as a guide but is not sufficient for accurate diagnosis.

Determination is carried out directly on leaf samples after bleaching and staining to observe the typical stages of the two *Cercospora* stages (conidiophores and conidia). Epidermal strips excised from lesions with a sharp scalpel and heated in lactophenol offer a clear view of stromat, conidiophore and conidial morphologies. Conidia of *M. fijiensis* are to be found almost exclusively on the adaxial surfaces. Conidia of *M. musicola* may be found on both surface often farming in abundance on the abaxial surface.

Evaluation of the distribution of the species reported here is based on different sources of information. Our own observations of material received at our respective laboratories or collected during various evaluation operations were used, together with information provided by various specialists, generally based in production regions.

DISTRIBUTION OF *MYCOSPHAERELLA FIJIENSIS*

Asia, Australia and Oceania

Black leaf streak was first observed as serious disease of bananas in plantations on the South-eastern coast of Viti Levu in the Fiji Islands (Rhodes, 1964). It is of historical interest to note that this outbreak occurred approximately 100 km from the Sigatoka valley, the area from which Sigatoka disease took its name following serious damage to plantations and the description of *M. musicola* by Massee 50 years earlier (Massee, 1914).

Subsequently, black leaf streak disease was reported by Graham (1969) in Tonga and Western Samoa and then on an epidemic scale in the Pacific: Solomon Islands, New Britain, New Caledonia, Hawaii, Papua New Guinea, New Hebrides, the Philippines, Singapore, Tahiti, Taiwan, U.S. Pacific Territories and Western Malaysia (Meredith and Fitman, 1970). *M. fijiensis* (referred to as *M. fijiensis* var. *difformis* at the time) was also described in the Cook Islands and Niue (Stover, 1976).

The disease was also observed on Hainan Island in China in 1980 (Stover, 1987). We isolated *M. fijiensis* from samples (of Bluggoe) collected in the Canton region, which would appear to indicate more extensive spread of this species in Southern China. The most recent record of spread within the region is Australia. Black leaf streak was first described on the islands in the Torres Strait (Badu, Bamaga, Thursday, Moa, Murray) in 1981 and then in the far north of Australia (Cape York) in 1982 (Jones, 1983). A programme to eradicate the disease from mainland Australia is in progress (Jones, 1989). Stover (1978) placed the centre of origin of *M. fijiensis* in the Papua New Guinea - Solomon Islands area and suggested that populations first moved at a very early date to Taiwan (before 1927) and only afterwards to Fiji, Hawaii, the Philippines and Southern Malaysia.

Latin America

Black leaf streak disease was observed for the first time in Latin America in 1972 in Honduras near La Lima (Stover, 1980). The disease rapidly reached epidemic proportions throughout Latin America (Figure 1). It was observed in Belize in 1975, in Guatemala and in the San Carlos plantain growing zone in Costa Rica in 1977, in Salvador and Nicaragua (Chinandega) in 1979 and in the Guapiles production zone in Costa Rica, in Panama and in Southern Mexico (Villa Hermosa) in 1980. The disease was detected in October 1981 in Colombia in the Uraba banana production region and subsequently throughout the northern part of the country. It then developed southwards to the various Pacific coast regions.

TABLE 1 - Morphological features of the two Sigatoka pathogens (from Stover, 1980).

Pathogen	Conidiophores				Conidia
	First appearance	Form	Distribution on lesions	Morphology	
Mycosphaerella musicola	spot stage	dense fascicles on dark stroma (sporodochium)	abundant on both surfaces	straight, hyaline, mostly without septation, geniculation, or branching; no spore scars	mostly cylindric, occasionally obclavate, 1-5 septate; same thickness throughout length; no distinct basal hilum
Mycosphaerella fijiensis	early streak stage	emerge singly or in small groups 2-5 stalks); no sporodochia	mainly on lower surface	straight or bent geniculate, pale to light brown, 0-3 septate, occasionally branched, slightly thickened spore scars	obclavate to cylindro-clavate 1-6 septate; tapering from hilum end to apex; distinct basal hilum (scar)

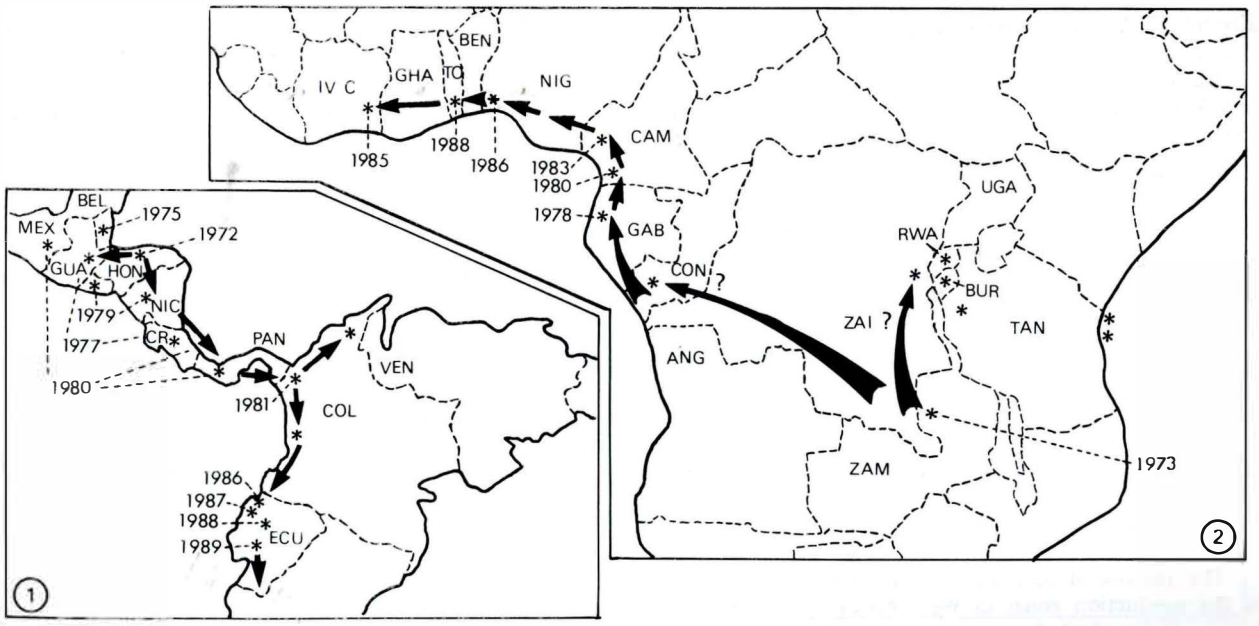
Ecuador is the most recent country to be affected by black leaf streak disease in Latin America. The disease was reported in 1986 in the northern part of the country, as would be expected. The *M. fijiensis* front currently moving southward is monitored within the framework of an agreement between IRFA-CIRAD and PNB (Programa Nacional del Banano). *M. fijiensis* was observed in the Esmeraldas region in 1986 and then 100 km further south at Quininde in 1987. In 1988, the disease was reported near La Concordia and in March 1989 in the central Babahoyo region at 100 km from Guayaquil. Today this population threatens the large Machala banana growing zone in the south of the country.

Black leaf streak is not present in Venezuela, but the southward-moving limit of the pathogen population is only a few kilometres from the northern frontier. It is also absent in the Caribbean islands.

Africa.

Observed in 1973, black leaf streak disease was described for the first time in Africa in 1975 by Raemaekers in Zambia at a site 800 km north of Lusaka. It was then reported in Gabon in 1978 (Frossard, 1980) and since then, has spread rapidly in West Africa (Figure 2). It was observed in Cameroon in 1980, in the Kribi region near the Equatorial Guinea and Gabon frontiers (Tézénas du Montcel, 1982), and in the Mungo and then the Fako regions in 1983. Today, the disease is present in all industrial banana plantations (Fouré and Lescot, 1988).

Presence of the disease was confirmed (by microscopic observation) in Nigeria in June 1986 and in Togo in 1988. We have no information on the presence of *M. fijiensis* in Benin and Ghana. However, typical *M. fijiensis* structures were observed in leaf samples collected in eastern Côte



DISTRIBUTION (CHRONOLOGY OF FIRST REPORTS) OF BLACK LEAF STREAK DISEASE (*M. FIJIENSIS*).
Figure 1 - IN THE LATIN AMERICAN AREA. Figure 2 - IN THE AFRICAN AREA.

TABLE 2 - Distribution by countries of Sigatoka disease (*M. musicola*) and approximate dates of first reported appearance (after R.H. Stover, 1962).

Africa		**North America**	
Br. Cameroons	1941	Mexico	1936
Fr. Cameroons	1946	Florida, U.S.A.	1955
Congo Rep. (former Belgian)	1948		
Fr. Guinea	1952	**South America**	
Ghana	1955	Brazil	1944
Madagascar	1957	Br. Guiana	1935
Mauritius	1960	Colombia	1937
Mozambique	1948	Ecuador	1952
Nigeria	?	Peru	1946
Nyasaland	1955	Surinam	1934
Sierra Leone	1956	Venezuela	1937-41
Tanganyika	1939		
Uganda	1938	**Central America and West Indies**	
Zanzibar	1939 ?	Br. Honduras	1936
		Costa Rica	1937
Asia		Cuba	1938
Assam	1946	Dominica	1938
Ceylon	1928	Dominican Rep.	1937
China	1936	Grenada	1936
Formosa	1959	Guadeloupe	1932 ?
Java	1902	Guatemala	1937
Malaya	1933	Haiti	1937
Philippines	1947 ?	Honduras	1935
		Jamaica	1936
Australia and Oceania		Martinique	1936
Fiji	1913	Montserrat	1955
Hawaii	1959	Nicaragua	1937
New Caledonia	1951	Panama	1937
Netherlands New Guinea	1953	Puerto Rico	1938-39
New Guinea	1954	El Salvador	1944
New South Wales	1927	St Lucia	1938
Norfolk Is.	1954	St Vincent	1937
Queensland	1924	Trinidad	1934
Solomon Is.	1946		
Wallis Is.	1954		

d'Ivoire (Dibi, Aboisso, Abengourou) in 1985.

Black leaf streak disease was also reported in the Boko and Kinkala regions in the Congo in 1985 (Mourichon, 1986). The seriousness of the damage and the extent of the disease in this region appeared to indicate that *M. fijiensis* had been present in the Congo for several years.

Symptoms similar to those of black leaf streak were observed during an evaluation mission in several countries in East Africa in 1987 (Sebasigari and Stover, 1987): eastern Zaïre, Rwanda, Burundi, Tanzania (on only a few plants at Maruka experimental station) and Pemba and Zanzibar islands. The disease was not reported in Uganda. The above distribution in based on symptoms alone and awaits confirmation by microscopic analysis. However, we examined several samples collected in Rwanda in 1989 and confirmed the presence of black leaf streak in Imbo plain on the cultivars Intuntu and Inyamumyn.

The pattern of movement of *M. fijiensis* from Gabon to the production zones in West Africa appears to have been well described. In contrast, previous events are much less clear. It was suggested that Gabon might have been an introduction zone (Frossard, 1980). In the light of the levels of infection recorded further south, it may well be possible that black leaf streak developed over the whole of Africa from a much more central area such as southern Zaïre/Zambia.

Distribution of *Mycosphaerella musicola*.

The pattern of global distribution of *M. musicola* has been described in detail by Stover (1962). At that time the species was present in all banana production regions, making Sigatoka disease one of the most important epidemic plant disease (Table 2). Black leaf streak disease (*M. fijiensis*) has progressively replaced *M. musicola* in many localities.

Although it is widely recognized that *M. musicola* is displaced by *M. fijiensis* soon after the arrival of the latter in a new locality it is perhaps simplistic to assume this displacement is complete, or that it is a universal phenomenon. There are a growing number of examples to the contrary, the most compelling in the region where both diseases were first recorded.

M. musicola was first described from Java in 1902 as *Cercospora musae* (Zimmermann, 1902). It was subsequently identified as the cause of serious damage to plantations in the Sigatoka valley of Viti Levu, Fiji (Pacific Islands, independently redescribed as *Cercospora musae*) by Massee (1914). Despite its subsequent global spread, *M. musicola* has never been recorded from Papua New Guinea. Given the geographical location of Papua New Guinea (between the sites of the original recordings of the disease), it is inconceivable that at some stage the disease was not present there. However, in recent IBPGR germplasm collecting expeditions, only *M. fijiensis* wad found on diseased leaf samples forwarded to the DSIR laboratories in New Zealand. Conversely, in East Java, Indonesia, an area relatively near to and contiguous with the Papua New Guinea/Irian Jaya land mass [and near the presumed centre of origin of *M. fijiensis* (Stover, 1978)] only *M. musicola* was found in samples forwarded to New Zealand in 1989. *M. musicola* was also confirmed in samples from Malaysia and Thailand and Philippines in 1989. In the Philippines, the species appear to co-exist (Natural, 1989). Further examples are found in the highland banana production areas of Cameroon or Colombia (coffee growing zone) where only *M. musicola* develops; in particular, infection rates are very high on plantains. In these countries, development of *M. fijiensis* is limited to lowland areas (Fouré and Lescot, 1988; Pefoura and Mourichon, 1990).

Northern Argentina (Victoria region) must be included to this list of zones affected by *M. musicola* alone.

General observations.

It seems timely to review the distribution of the species *M. fijiensis* and *M. musicola* in the various production zones so that epidemiological aspects of the two diseases can be better evaluated. The above revised geographical distribution is as complete as available information allows. Given the present distribution (Figure 3), the importance of *M. fijiensis* is probably underestimated. Because of data accumulated in commercial plantations the situation in Latin America may be easy to assess. The same does not apply to the other banana regions in the world. The possibility of the presence of black leaf streak disease in others countries in Africa (Angola, Zaïre, Namibia, Botswana, Zimbabwe, Mozambique and Kenya) and Asia (India and Burma) deserves closer examination. The rate of spread of *M. fijiensis* observed and studied in different regions will probably lead to its presence in all banana growing zones during the next decade.

Analysis of the various data on movements of the different diseases has led to suggestions concerning the geographical origins of the different species. Studies in the different production zones of *M. fijiensis* alone (presumed old introduction) or in combination with *M. musicola* (recent introduction) suggests that the centre of origin of the species is in the Papua New Guinea - Solomon Islands area (Stover, 1978). This information is extremely important since this area is one of longstanding domestication of different primitive diploid types which, studied using classic taxonomic methods (Tézenas du Montcel, 1988) or chemotaxonomy (Horry, 1989), express many genetic similarities to various cooking bananas including plantains. Thus the Papua New Guinea - Solomon Islands area may be the main site of host-parasite coevolution. It is generally accepted that under these circumstances that the potential variability of pathogenic capability is expressed, and in the present case, *M. fijiensis* may have acquired certain characteristics in this region which made it pathogenic for plantains before it moved to other production regions (SE Asia, Pacific, Africa, Latin America). Likewise, it is generally conceded coevolution areas generally house potential sources of resistance (Harlan, 1976). The Papua New Guinea region should be placed at the top of the list of areas to be evaluated in a programme of genetic improvement with search for wild diploids with good resistance to

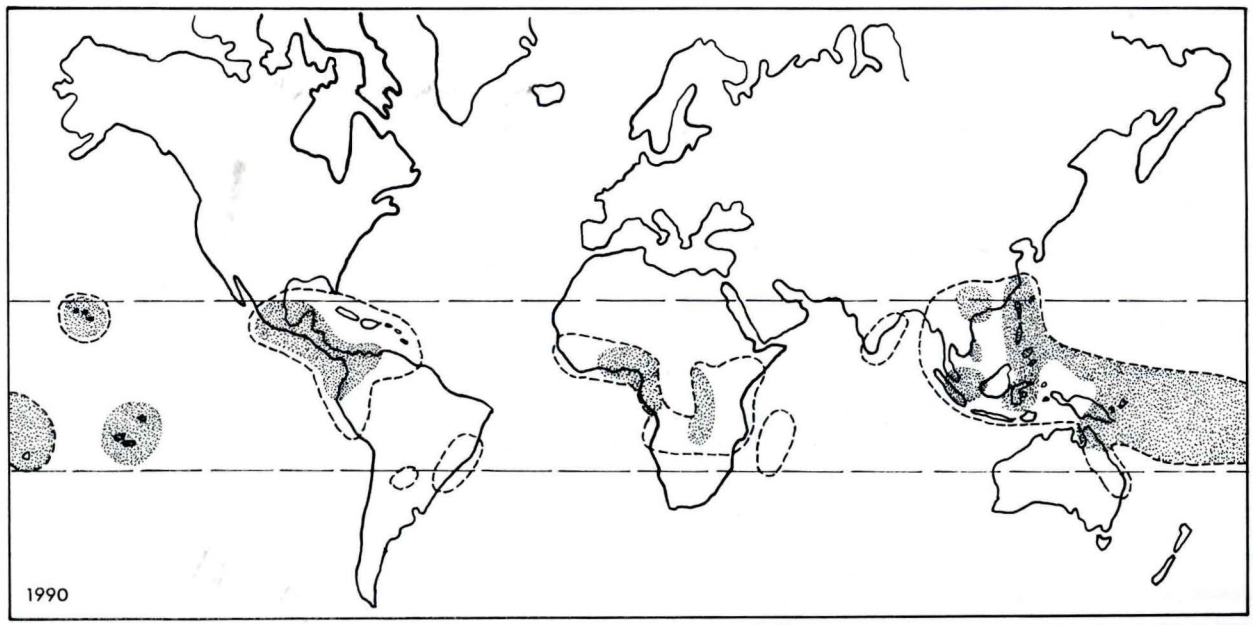


Figure 3 • WORLD SPREAD OF SIGATOKA DISEASE *(M. MUSICOLA)* [---] AND BLACK LEAF STREAK DISEASE *(M. FIJIENSIS* ▨.

black leaf streak disease. Similarly collections of the pathogen should reveal the scope of pathogenic variability within the organism. Furthermore, the possibility of inter relationships between *M. fijiensis* and *M. musicola* developed during the common periods of colonisation in various regions must be considered. The possibility of exchange of genetic information by interspecific crosses is being evaluated in the laboratory today. Likewise, studies are in progress to examine the existence of polymorphism in these parasite populations.

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REPARTICION GEOGRAFICA DE LAS DOS ESPECIES *MYCOSPHAERELLA MUSICOLA* LEACH *(CERCOSPORA MUSAE)* Y *M. FIJIENSIS* MORELET *(C. FIJIENSIS)*, AGENTES RESPECTIVAMENTE DE LA ENFERMEDAD DE SIGATOKA Y DE LA ENFERMEDAD DE LAS RAYAS NEGRAS DE LOS BANANOS Y PLATANOS.

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RESUMEN - Este documento describe cuál es la situación actual sobre la repartición geográfica de las dos especies *Mycosphaerella musicola* y *M. fijiensis* en las principales zonas de producción del mundo. La actividad parasitaria muy superior de *M. fijiensis* y su extensión en Africa, en América latina, en el Sudeste asiático y en el Pacífico constituyen uno de los principales factores limitadores del cultivo del banano y del plátano.