Integrated management of *Fusarium* wilt or Panama disease of banana: perspectives of cultural, biological, chemical and genetic control.

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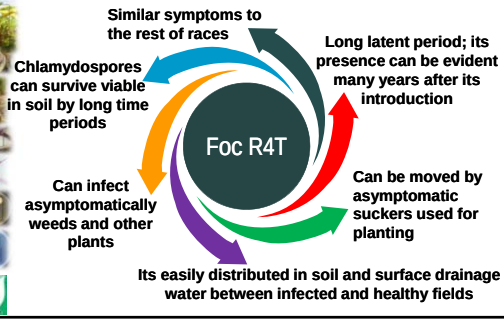
Regional Workshop on the prevention and diagnostic of *Fusarium* Wilt (Panama disease) of bananas and plantains caused by *Fusarium oxysporum cubensis* – Tropical Race 4 (TR4)
Port Spain, Trinidad and Tobago April 28th-May 9th, 2014

Content:

- Panama disease causal agent and its cycle
- Integrated management: epidemiological bases
- Genetic management
- Cultural management
- Chemical control
- Biological control
- Discussion and conclusions

Biological and epidemiological characteristics of Foc TR4 to consider for its management



Epidemic progress models

Function	Ecuation	Transformation of growth
Logistic	$X_1 = X_{max}/1+be^{-rt}$	$X_1 = \ln X_1/ 1- X_1$
Mitscherlich n=1	$X_1 = K X_{max} (1- e^{-kt})$	$X_1 = \ln [(1- X_1/X_{max})]$
Bertalanffy n=1	$X_1 = K_{max} (1-be^{-kt})$	$X_1 = \ln[(1-X_1/X_{max})]$
Gompertz	$Xi = X_{max} . e^{(- be)-kt}$	$Xi = -\ln -\ln(X_i/X_{max})$
Weibull	$Xi = 1-e \{ -[(t-a)/b]^c\}$	$Xi = 1/ 1+e\{-\ln[Xo/1-Xo]+rt\}$

r, k, b = epidem speedometers;
X_1, X_0 = initial inoculum

Management measures impact on epidemiological parameters

Final disease amount	Initial inoculum	Infection increment rate	Time
X_n =	X_0 +	r ·	t_n

	Principal effect on:	
A-. Avoiding pathogen		
Geographic area selection	X_0	r
Plantation area selection	X_0	r
Planting date selection	X_0	r y t
Healthy planting material use	X_0	r
Cultural practices modification	r	
B-. Pathogen exclusion		
Seed or planting material treatment	X_0	
Inspection and certification	X_0	
Quarantine	X_0	
Vectors elimination	X_0	r

Management measures impact on epidemiological parameters

Final disease amount	Initial inoculum	Infection increment rate	Time
X_n =	X_0 +	r ·	t_n

	Principal effect on:	
E. Resistance host development.		
Selection and resistance breeding		
a) Vertical resistance	X_0	
b) Horizontal resistance		r
c) Bi-dimensional resistance	X_0	r
d) Population resistance (multiline)		r
Resistance by chemotherapy		r
Resistance through nutrition		r
F. Therapy applied to diseased plants		
– Chemoterapy		r
– Heat treatment	X_0	
– Surgery	X_0	

Prevention and fight against Foc TR4

- ✓ Preventive measures of exclusion
- ✓ Outbreaks monitoring
- ✓ Early diagnostic
- ✓ Contention and eradication:
  - – Quarantine measures to limit access and dissemination
  - – Dig channels around plants and infected fields
  - – Elimination of diseased plants
  - – Pathogen eradication
- ✓ Suppression = Management: Integrated management
  - – Use of resistant varieties
  - – Production of healthy planting material
  - – Cultural management
  - – Fungicides, sterilizants and chemical induction of resistance
  - – Biological control

Integrated management of Fusarium wilt

INTRODUCTION

Genetic resistance
- ✓ Natural resistance
- ✓ Genetic breeding
- ✓ Mutations
- ✓ Genetic engeneering

Biocontrol
- ✓ Suppresive soils
- ✓ Fungi
- ✓ Bacteria
- ✓ Actinomycetes

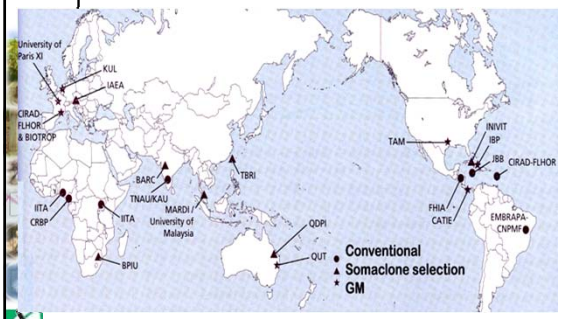
Cultural control
- ✓ Quaratine and sanitation
- ✓ Tissue culture
- ✓ Annual cropping
- ✓ Crop rotation
- ✓ Soil amendments and fertilizers
- ✓ Flooding

Chemical control
- ✓ Fungicides
- ✓ Sterilizers
- ✓ Soil fumigants
- ✓ Chemical activators

Resistencia genética

Principales programas de mejoramiento

Main banana breeding programs



Genetic resistance

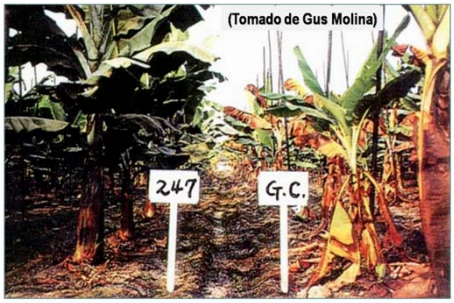
International Transit Center (ITC)


Leuven, Bélgica

- ✓ 1050 accessions stored in vitro
- ✓ Distribution of indexed material
- ✓ Genetic transformation program

Genetic resistance

Recurrent selection of tissue culture mutants (Taiwan)



Clon TBRI-247 Altamente resistente a *Foc* RT 4

Genetic resistance

Resistant cultivars to Fusarium wilt identified in the screening program

H.C. Hwang (2005)

Highly resistant cultivars	Moderately resistant cultivars
GCTCV- 40	GCTCV- 46
GCTCV- 44	GCTCV- 53
GCTCV-104	GCTCV- 62
GCTCV-105 (1995)	GCTCV-201
GCTCV-119	GCTCV-215 (1991)
GCTCV-217 (1998)	GCTCV-216
GCTCV-218 (2002)	

Genetic resistance and annual cropping in Taiwan

- ✓ To minimize typhoon impacts
- ✓ Allow crop rotation with rice
- ✓ Allow recurrent selection for resistance
- ✓ Disease management tactic

Genetic resistance and annual cropping in Taiwan

Use of tissue culture plants in anual cropping (Pix by S.C. Hwang)

(Adaptado de Gus Molina)

Giant Cavendish

Formosana

Nusantra Tropical Fruit:

- 1999: 4,500 ha de Valery
- 2001: 80% de infección; el área disminuyó a 200 ha
- Cultivo anual con GCTCV 119: selección
- Area actual: 900 ha; < del 10% infección
- Para mercado local

Genetic resistance

IMTP in China

Genetic resistance

Foc TR4 Cultivar Reaction in Guangzhou China.

Cultivars	(% of diseased plants)
FHIA 01	0
FHIA 02	0
FHIA 18	0
FHIA 25	0
Aacv Rose	0
P. Jari Buaya	0
GCTV -119	9
FHIA 17	100
FHIA 23	100
Williams	100
Yangambi km 5	100
Cachaco	100
SH3640	100
Gros Michel	100
SH 3436-9	100
Baxi (control; Cavendish)	100

Genetic resistance

Foc TR4 Cultivar Reaction in Panyou China

Cultivars	Number of assessed plants	Plants with exetrnal symptoms (%)	Internal coloration index
FHIA 02	18	22.2	2.8 ± 1.7
FHIA 03	18	38.9	1.0
Williams	18	72.2	2.5 ± 2.1
Aacv Rose	18	0	1.8 ± 1.1
Gros Michel	18	100	3.7
Yangambi km 5	12	33.4	1.0
FHIA 17	18	25	4.8
FHIA 23	18	38.9	1.5
GCTCV -119	18	27.8	1.1 ± 0.2
SH 3436-9	18	5.6	1.6 ± 1.0
SH 3640	18	11.1	2.7 ± 2.1
FHIA 18	18	38.9	1.0
FHIA 21	18	27.8	2.6 ± 1.4
CRBP39	18	16.7	2.8 ± 1.1
Baxi (control)	18	44.4	2.8 ± 1.1

Cultural control

Quarantine measures and sanitation

Puestos de desinfección en accesos

Cultural control

Quarantine measures and sanitation

Fences to limit access

Quarantine measures and sanitation

Elimination of infected plants

Ditches around infected plant

Cultural Control

Quarantine measures and sanitation

Eradication

Containers with disinfectants based on sodium hypochlorite or quaternary ammonia for machete disinfection during elimination of each plant

Quarantine measures and sanitation

MeBr use

Quarantine measures and sanitation

Disinfection with Dazomet (Basamid Granules)

SPECIMEN LABEL. Database and format copyrigl

BASF

Basamid® Granular

soil fumigant

For pre-planting control of most weeds, nematodes, and soil diseases

Active Ingredient:
Tetrahydro-3,5,-dimethyl-2H-1,3,5-thiadiazine-2-thione 99%
Inert ingredients 1%

Total 100%

EPA Reg. No. 7969-99 EPA Est. No. 39578-TX-1

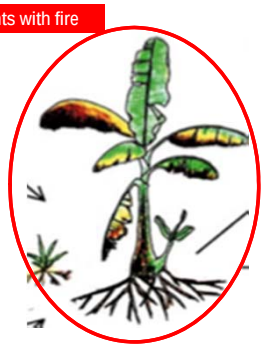
Quarantine measures and sanitation

Glyphosate injection: plant elimination, NO pathogen eradication in soil

Plant elimination in zones A and/ or B

Elimination of infected plants with fire

Consist in plant isolation with aluminum or galvanic zinc foils and to proceed to burn the plant until rhizome



Eradication of infected banana plant in Australia [Australian Bananas – 19p]

Quarantine measures and sanitation

To keep area free of weeds

Maintenance the field free of weeds and access limitation

Cultural control

Certified material free of Panama disease
✓ Prevent Panama disease spread.

Tissue culture plants

✓ Are more vulnerable to disease if planted in infected soils (Smith, 1999)

Nurseries certified free *Foc*

Cultural control

Previous research

Flooding and fallows

- ✓ Promising results in the 1960's
- ✓ Is not obtained a complet eradication
- ✓ Is speculated that flooding with fallow destroy natural soil suppression
- ✓ Pearl river flooding in China have spread TR4
- ✓ Floodings caused by Sagua river in Cuba, spread R1 and R2 in fields.

Cultural control

Previous research

Crop rotation
✓ Can not be obtained long term control with crop rotation (Stover, 1962)

Sequeira (1958)
Velvet bean
Sorghum
Sugarcane
↓
Insufficient diminution of pathogen inoculum

Sequeira (1962)
Sugarcane + follow by a year
↓
Incidence diminution by 42%

Hwang (1985)
Sugarcane
Paddy rice
↓
Without disease diminution
↘
Short lasting control

Meng *et al*., (1999)
Intercropping with oil palm
↓
Lower disease incidence

Cultural control

Crop rotation in China

Dr. Yi Ganjun in the 7th BAPNET SC Meeting, Hanoi, Vietnam

Cultural control

Previous research

Soil ammendments and fertilizers

- ✓ Experimental serie with fertilizers (Knudson, 1923-27; Butler, 1960)
- ✓ Sodium nitrate (Meredith, 1941)
- ✓ Inorganic fertilizers, green manure, lime, compost, bagasse (Risbeth & Naylor, 1957)
- ✓ Ca and organic matter (Ploetz, 1990)
- ✓ $CaCO_3$; $Ca(OH)_2$; Ca SO_4; Fe EDDHa; bagazo (Peng *et al.*, 1990)

Cultural control

Effect of several nutrients on Fusarium wilts

NUTRIENT	EFFECT	REFERENCE
NO_3^-	NO_3^- increment reduce disease development	Huber y Watson, 1974 Jones *et al.*, 1989 Wolf & Jones, 1981
NH_4^+	NH_4^+ increment favor disease development	Dominguez *et al.*, 1996 Wolf & Jones, 1981
pH of soil	pH close to 7 is less optimal for *Fusarium* wilt; pH below 6.5 favor disease development. Higher pH in suppressive soils reduce infections	Wolf & Jones, 1981 Dominguez *et al.*, 2001 Dushkova & Prokinova,1989
Liming and Ca++	Increase soil uppresiveness and reduce chlamydospores germination	Höper *et al.*, 1995 Peng *et al.*, 1999.

Cultural control

Effect of several nutrients on Fusarium wilts

NUTRIENT	EFFECT	REFERENCE
K+	Higher in suppresive soils K addition reduce disease	Peng *et al.*, 1999 Tharp y Wardleigh, 1939
P +	Reduce disease incidence	Wolf & Jones, 1981
Mg+	Higher in suppressive soils	Peng *et al.*, 1999
Mn y Zn	Defficience reduce disease	Jones & Wolf 1967, 1969
Fe	A reduction of availability increase soil suppresiveness and chlamydospore germination	Scher y Baker, 1982 Peng *et al.*, 1999
Na	Higher in suppressive soils	Dominguez *et al.*, 1996, Peng *et al.*, 1999

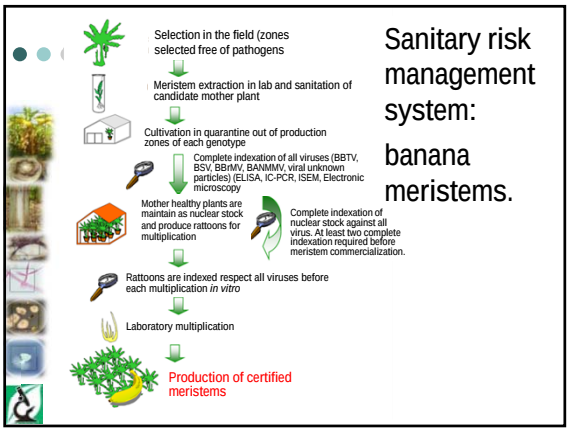
Cultural control

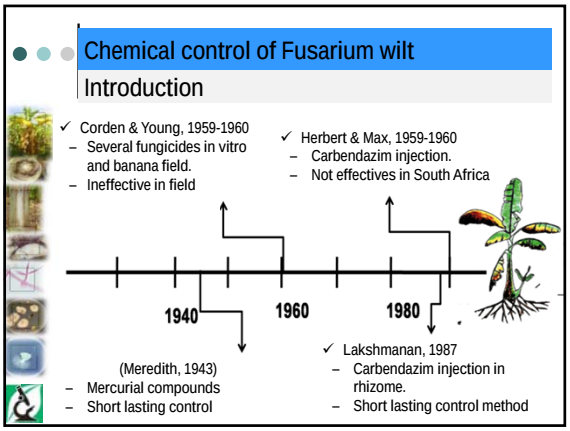
Manejo de *Foc* R4T en Lampung Sumatra, Indonesia:

- **Cultivo anual usando plantas de cultivo de tejidos**
- **Variedad resistente a Foc TR4: GCTCV 119**
- **Detección temprana, erradicación, fertilización orgánica**
- **Rotaciones con yuca (Cassava).**

Cultural control

Philippines. Physical control with heat

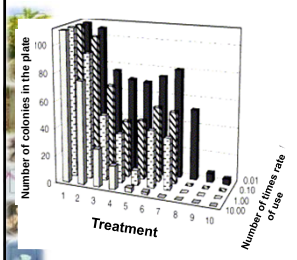

Selection in the field (zones selected free of pathogens
Meristem extraction in lab and sanitation of candidate mother plant
Cultivation in quarantine out of production zones of each genotype
Complete indexation of all viruses (BBTV, BSV, BBMV, BANMMV, viral unknown particles) (ELISA, IC-PCR, ISEM, Electronic microscopy
Mother healthy plants are maintain as nuclear stock and produce rattoons for multiplication
Complete indexation of nuclear stock against all virus. At least two complete indexation required before meristem commercialization.
Rattoons are indexed respect all viruses before each multiplication *in vitro*
Laboratory multiplication
Production of certified meristems
Sanitary risk management system:
banana meristems.


Chemical control of Fusarium wilt
Introduction
✓ Corden & Young, 1959-1960
– Several fungicides in vitro and banana field.
– Ineffective in field
✓ Herbert & Max, 1959-1960
– Carbendazim injection.
– Not effectives in South Africa
1940
1960
1980
(Meredith, 1943)
– Mercurial compounds
– Short lasting control
✓ Lakshmanan, 1987
– Carbendazim injection in rhizome.
– Short lasting control method


Chemical control of Fusarium wilt
Surface disinfectants
1919
✓ Copper sulphate
✓ Formaldehide
INEFFECTIVE
1957
✓ Disulphate charcoal
✓ Formaline
INEFFECTIVE
1999 +
Copper oxychloride
Australia: 'Farmcleanse (quaternary ammonia)
Replace:
– Chloride bleach
– Methylate alcohol

Chemical control of *Fusarium* wilt

Sterilizers (Nel *et. al*., 2007)



Commercial name	Active ingredients
1. Chloride	Chloride–Ca
2. Cupravit	Copper oxychloride
3. Desogem	Biguanidine and quaternary ammonia
4. Farm cleanse	Quaternary ammonia
5. Jik	Sodium hypochlorite
6. Prazin Agri	Hydrochloride biguanidine polymeric and quaternary ammonia
7. Omega	Prochloraz
8. Sporekill	Polydimetilchloride of ammonia

Systemic fungicide mobility used in banana with regard to octanol /water partition coefficient (log P_{ow})

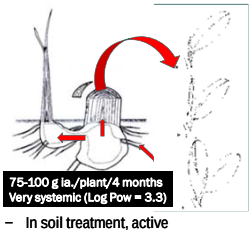
Producto	Log P_{ow}
benomyl	1.4
Methyl thiophanate	1.5
spiroketalamine	2.8
pyrimethanil	2.8
azoxystrobin	2.5
cyproconazole	2.9
flutriafol	2.9
triadimenol	3.3
epoxiconazole	3.4
tebuconazole	3.7
propiconazole	3.7
flusilazole	3.7
hexaconazole	3.9
bitertanole	4.1
difenoconazole	4.3
trifloxystrobin	4.5

Mobile

Low mobility

Efficacy of EBI fungicides on the control of Sigatoka disease of bananas caused by *Mycosphaerella musicola* Leach ex Mulder in Cuba

Triadimenol at soil.

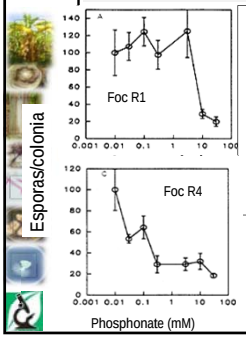


75-100 g ia./plant/4 months
Very systemic (Log Pow = 3.3)

- In soil treatment, active ingredient (triadimenol) is absorbed during 16 weeks.

Chemical control of Fusarium wilt

Fungicides and resistance activators



Australasian Plant Pathology (1996) 25: 31-35

The effect of phosphonate on the sporulation of *Fusarium oxysporum* f.sp. *cubense*

Amanda J. Davis and Bruce R. Grant

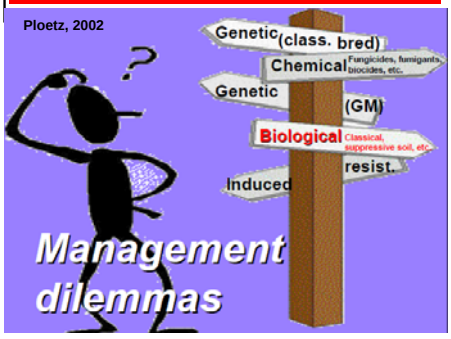
Russell Grimwade School of Biochemistry, The University of Melbourne, Parkville, Victoria 3052 Australia

Abstract

Potassium phosphonate (0.3 mM) inhibited the production of microconidia by *Fusarium oxysporum* f.sp. *cubense* (*Foc*) in vitro. Sporulation of another isolate of *Foc*, and two isolates of *F. oxysporum* f.sp. *dianthi* was less sensitive to phosphonate. The fungicide did not reduce the viability of spores of *Foc* produced in its presence and inhibited the germination of microconidia of *Foc* only at high concentrations (ED_{50} 30 mM).

- ✓ Reduce mycelia development and hence, microconidia production
- ✓ Effect on germination at concentrations higher than 30mM

Biocontrol



Biocontrol

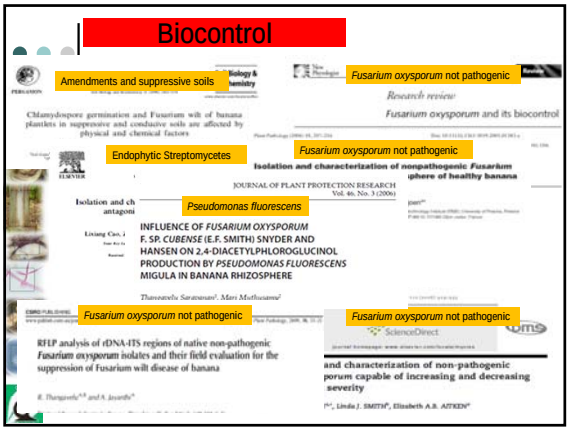
Amendments and suppressive soils

Fusarium oxysporum not pathogenic

Endophytic Streptomycetes

Fusarium oxysporum not pathogenic

Pseudomonas fluorescens



Chlamydospore germination and Fusarium wilt of banana plantlets in suppressive and conducive soils are affected by physical and chemical factors

Research review

Fusarium oxysporum and its biocontrol

Isolation and characterization of nonpathogenic *Fusarium* ...sphere of healthy banana

JOURNAL OF PLANT PROTECTION RESEARCH Vol. 46, No. 3 (2006)

INFLUENCE OF *FUSARIUM OXYSPORUM* F. SP. *CUBENSE* (E.F. SMITH) SNYDER AND HANSEN ON 2,4-DIACETYLPHLOROGLUCINOL PRODUCTION BY *PSEUDOMONAS FLUORESCENS* MIGULA IN BANANA RHIZOSPHERE

Fusarium oxysporum not pathogenic

RFLP analysis of rDNA-ITS regions of native non-pathogenic *Fusarium oxysporum* isolates and their field evaluation for the suppression of Fusarium wilt disease of banana

Fusarium oxysporum not pathogenic

and characterization of non-pathogenic ...porum capable of increasing and decreasing ...severity

Biocontrol


Research review

Fusarium oxysporum and its biocontrol

- ✓ 30 articles in Annual Reports
- ✓ Only 3 related to perenne plants
- ✓ 2 in banana related to suppressive soils
- ✓ 1 on classic biological control

Biocontrol

Difficulties or limitations of *Foc-Musa* pathosystem

- ✓ Fusarium wilt is a difficult target for biocontrol
- ✓ Banana are usually cropped by many cycles; biocontrol should be long lasting in perennial production systems.
- ✓ Soil environment where pathogen reside complicate infections site protection.
- ✓ Vascular localization protect pathogen from many potential biocontrol agents.

Biocontrol

Studies carried out until present

- ✓ Unfortunately have been few field studies and few efficacy control data reported in scientific reviews. More commonly:
  - → In vitro pathogen inhibition studies
  - → Reduction of disease in pots or trays trials in greenhouses and laboratory
  - → Biochemical characteristics of antagonists and pathogens
  - → Other interaction types between microbe and antagonists

... And when field studies has been carried out results has been disappointed

Biocontrol

However…

FITOSANIDAD vol. 13, no. 4, diciembre 2009

Control biológico

EFICACIA DE *TRICHODERMA HARZIANUM* A34 EN EL BIOCONTROL DE *FUSARIUM OXYSPORUM F. SP. CUBENSE*, AGENTE CAUSAL DE LA MARCHITEZ POR *FUSARIUM* O MAL DE PANAMÁ DE LOS BANANOS EN CUBA

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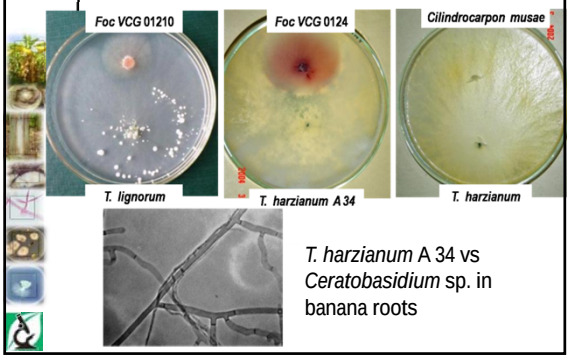
Trichoderma harzianum & T. lignorum vs *Foc, Cilindrocarpon musae and Ceratobasidium sp. (Rhizoctonia fragarie).*



T. harzianum A 34 vs *Ceratobasidium* sp. in banana roots

Results of *T. harzianum* applications in *Foc* conducible soils in a 170 ha farm in Caney del Sitio, Palma Soriano, Santiago de Cuba.

Treatment	Cultivar	% infected plants	Comments
Untreated	Burro CEMSA	> 60%	Field destroyed.
20 g/ plant with $8x10^9$ conidia/gr	Burro CEMSA	< 1%	In production for more of 5 years
Untreated	FHIA 03 and FHIA 23,	> 30%	Field destroyed.
20 g/ plant with $8x10^9$ conidia/gr	FHIA 03 and FHIA 23	< 1 %	In production for more of 5 years

Contingency Plan for Foc TR4

Elaborado por:
Miguel Ángel Dita Rodríguez
Plutarco Elías Echegoyén Ramos
y
Luis Fernando Pérez Vicente

OBJECTIVE:
Bring scientific, organizational and reglamentary bases of actions to implement by National Plant Protection Services, for opportune management (identification, diagnostic, eradication-confining, contetion- management) of an eventual outbreak of FocTR4 in region.

http://www.oirsa.org/aplicaciones/subidoarchivos/BibliotecaVirtual/PlandecontingenciacontraFocR4TOIRSA.pdf

Content:

1. General information
2. Identification procedures
3. Technical and economic feasibility
4. Reglamentary procedures
5. Organization for execution
6. Communication and Advertising
7. Cooperation and Coordination Relationships
8. Surveys procedures
9. Control procedures
10. Assessment of Emergency Program
11. Financing
12. Bibliography
Annexes

- ✓ 155 pages
- ✓ 7 tables
- ✓ 18 figures

ANNEXES CONTAIN:

1. Foc TR4 data sheet
2. Foc TR4 diagnostic protocols
3. Contacts in case of Foc TR4 outbreaks or incursions
4. Amplify list of hosts of Foc TR4
5. Glossary
6. Emergency declaration Form for a Foc TR4 outbreak
7. Template to inform to the public the presence of a Foc TR4 outbreak
8. Capacity building program
9. Actions for eradication-confinement of a Foc TR4 outbreak
10. Design and assessment of Foc TR4 surveys
11. Formularies (examples)
12. Research advances
13. International financial sources

I. General Information

1.1 Plan Objective
1.2 Clarifications
1.3 Main Contact.
1.4 Security Program
1.5 Definitions

II. Identification procedures

2.1 Initial finding of a suspect event (can be done by a vigilance program of an NPPO or an unofficial entity)
2.2 Preliminary diagnostic
2.3 Diagnostic confirmation

III. Economical and Technical Feasibility

JUSTIFICATION.

3.1 Technical feasibility of Eradication-Confinement

III. Economical and Technical Feasibility

3.2 Economic feasibility of Eradication-Confining

- Primary benefits
- Secondary benefits

IV. Reglamentary Procedures

4.1 Legal Framework on Phytosanitary Emergences

4.2 Actions to Reglamentation

V. Organization for execution

5.1 Emergence activation

5.2 Procedures for preliminary assessment

5.3 Operational answers according the situation

Potential scenaries of an Foc TR4 outbreak, regarding adoption of eradication confinement or suppression - contention strategies.

Factors in favor of eradication – confining	Factor in favor of suppression-contention
Small and natural isolated outbreak area and exist certainty that the disease has not spread (disease is confined) .	The outbreak area even when small are not completely isolated. There is a probability of disease scape to other areas.
Available measures for eradication and confinement can be applied in Foc TR4 outbreak area.	Successful application of eradication - confinement measures, not feasible in outbreak area, but feasible for disease suppression.
Was detected a single outbreak and there is certainty (through antecedents) that this outbreak is the result of a single introduction in the country (secondary dispersion do not occur).	Several outbreaks detected in distant sites and it is probable a secondary dispersion occurrence after disease establishment in the country. It was not possible to establish a route or precedence of the pest.
The outbreak site is of easy access and allow an adequate and successful application of control measures of contention, eradication and surveillance to verify occurrence of re-emergences	Outbreak site is inaccessible or do not allow eradication/suppression measures of the pest. However, can be implemented contention measures.

VI. Communication and Advertising

6.1 Politic and Communication and Advertising Strategies

(The FIMN N° 17, *Pest Notification,* indicate responsibilities of NPFO and requisites to notify the pest outbreak presence and dispersal)

VII. Cooperation and Coordination Relationships

7.1 Collaboration with stakeholders

7.2 Possible Cooperation Areas

7.3 Recommendation for Cooperation Relationships.

VIII. Procedures for surveys

8.1 Types of surveys
(In Appendix 10 are details of these surveys)

8.1.1 Surveys of detection.
(To determine if *Foc* TR4 is present in a determined area, after a first disease detection.)

8.1.2 Delimitation surveys
(Establishment of infested area frontiers)

8.1.3 Surveys for monitoring
(Characterize Foc TR4 evolution in areas considered with presence of the disease inside reglammented area)

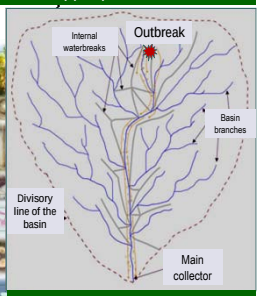
8.2 Parameters to calculate sample Size

IX. Control procedures

To define control strategy it is important consider that eradication and Foc TR4 confining depend on:

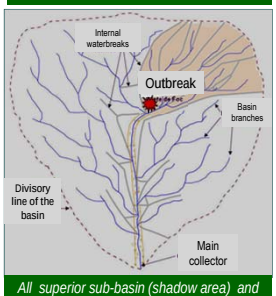
- Early pest detection;
- Elimination of *Musa* spp. and other infected (or with probability of being infected) host plants (check elimination procedures in 9.1.1 and host list in Appendix 4);
- Prevention of mobilization by any way of infected plant parts, soil and any other article that could transport the pest outside of outbreak site (see Appendix 1);
- Elimination of volunteer plants in the outbreak site to avoid the permanence of the pest in them;
- Restriction of access to unauthorized persons and equipment that could carry soil particles to outside outbreak site; and
- Limitation of soil surface water movement between infected and healthy plants.

Hypothetical outbreak of Foc TR4 in the upper part of a river basin



Downstream areas (between orange arrows) with higher probability to present pest outbreaks

Hypothetical outbreak of Foc TR4 close to a river basin



All superior sub-basin (shadow area) and downstream areas (between orange arrows) with higher probability to present pest outbreaks

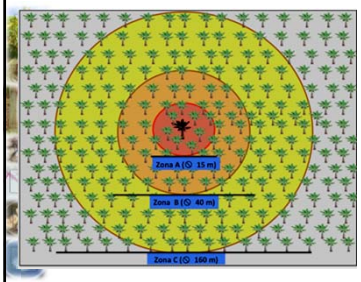
Eradication confinement actions in an outbreak of *Fusarium oxysporum* f. sp. *cubense* TR4 tropical according zones

CHARACTERISTICS/ ACTIONS	Infected zone		Safeguard zone	
	Diseased plant	Zone A	Zone B	Zone C
	Quarantined area			
	Controlled area			
Diameter in m from infected(s) plant(s)	*	15	40	160
Sampling and analysis	Yes	Yes	Yes	No
Destruction of plants	Yes	Yes	Desirable	No
Soil fumigation	Yes	Yes	No	No
Weed elimination	Yes	Yes	Yes	Yes
Building of ditches of 15-20 x 20 cm around infected plants with symptoms or with positive diagnostic	Yes	Yes	NA	NA
Building of ditches of 15-30 x 30 cm around area to fumigate (area under quarantaine)	Yes	Yes	NA	NA
Personal, equipment and animal movement restriction to the area	Yes	Yes	Yes	Yes

Eradication confinement actions in an outbreak of *Fusarium oxysporum* f. sp. *cubense* TR4 tropical according zones (cont.)

CHARACTERISTICS/ ACTIONS (cont.)	Infected zone		Safeguard zone	
	Diseased plant	Zone A	Zone B	Zone C
	Quarantined area			
	Controlled area			
Restriction of plant or soil movement from or to the area	Yes	Yes	Yes	Yes
Elimination of infected plants at laboratory diagnostic confirmation, according control actions	Yes	Yes		
Establishing of quarantine period during at least 1 ½ year (see 9.1.1)	Yes	Yes	Very desirable	No
Clean fallow	Yes	Yes	Very desirable	No
Continuous actions	Yes	Yes		
Surveillance for symptom detection	Yes	Yes	Yes	Yes
Sampling for diagnostic	Yes	Yes	Samples at random	No
Eradication- confining measures establishing for new outbreaks. Re-establishing of areas A, B and C	Yes	Yes	Yes	Yes

Representative diagram of treatment zones of an outbreak of *Fusarium oxysporum* f. sp. *cubense* TR4 in a banana monoculture



- ✓ Red circle (zone A) represent quarantine area and eradication zone where exist more probability of symptomatic and asymptomatic infected plants (Plant in black in the center indicates the diseased plant)
- ✓ Zone B (orange) and zone C (yellow) represent the area under control.

Integrated management of Fusarium wilt

Remarks

- ✓ Foc TR4 exclusion by quarantine measures and monitoring surveys are the main measure to adopt in LA&C.
- ✓ Fast sensible and specific diagnostic methods are essential point to aspire to eradication of an eventual disease outbreak
- ✓ The most effective and sustainable fight against Fusarium wilt is the use of resistant varieties.
- ✓ Cultivar obtained by mutagenesis and somaclonal variation with recurrent selection allow sustainable disease management for short time, if supported by cropping practices directed to disease supression.

Integrated management of Fusarium wilt

Remarks

- ✓ Partial resistant cultivars cropping should be companioned of strict quarantine measures. These cultivars can carry out the pathogen asymptomatically and become a way of disease spread.
- ✓ Main disease dissemination way is infected planting material. Tissue culture and agamic certified healthy planting material production program have to be implemented.
- ✓ Personnel, equipment, tools and animals can carry out the soil and inoculum between infected and free areas.
- ✓ Monitoring and sanitation of infected plants allows reduce inoculum production

Integrated management of Fusarium wilt

Remarks

- ✓ Product based on quaternary ammonia have proved being efficient to equipment and tool disinfection.
- ✓ Fungicide use is not economically viable to control Fusarium wilt. However exist options that can be use to produce healthy plant material in nurseries.
- ✓ Use antagonist for disease management are controversial and field studies are scarce.
- ✓ Organic matter applications improve microbial balance and suppressive capacity of soil.

Integrated management of Fusarium wilt

Remarks

- ✓ Low pH increase disease incidence meanwhile high pH reduce disease frequency.
- ✓ Calcium amendments reduce disease incidence whereas urea increase disease incidence.
- ✓ Combine use of healthy planting material and *Trichoderma harzianum*, allows banana cropping in infected soils for some years.