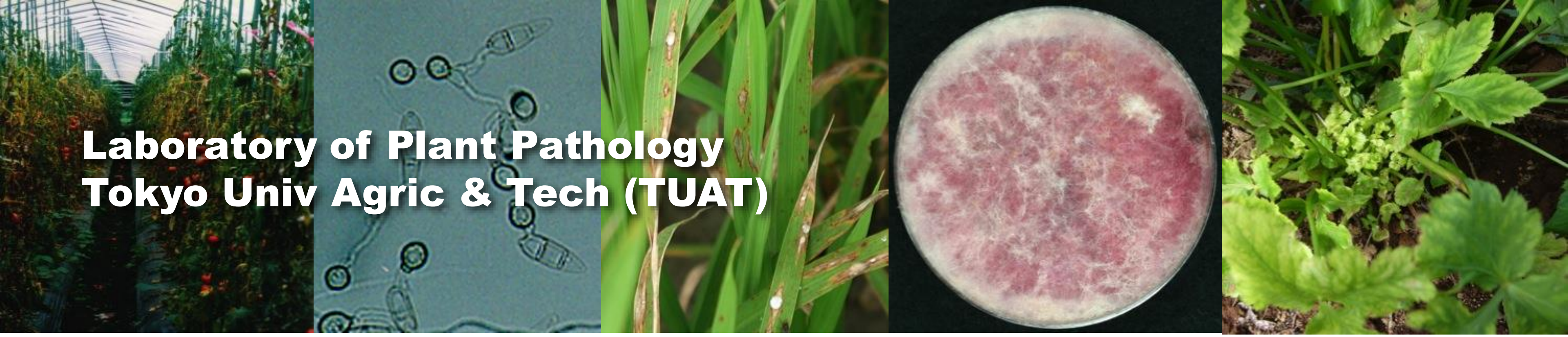
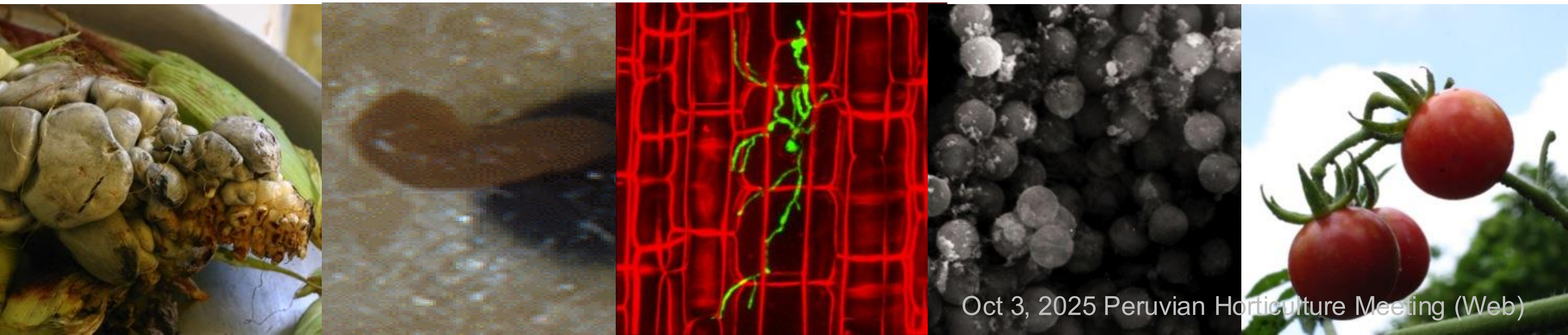


Plant Soilborne Fusarium Diseases
-Banana and Tomato Wilt Diseases-

Tsutomu Arie
Tokyo University of Agriculture and Technology (TUAT)
www.tuat.ac.jp/~plantp



TUAT

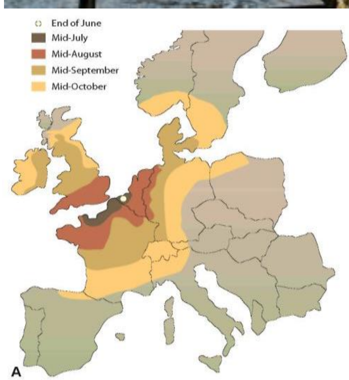
Invasive plant diseases threaten human lives indirectly

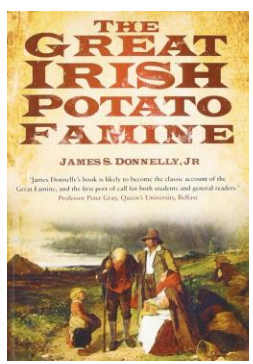
Potato famine

1845–1846

Population : ~1.25 billion

1 million people dead



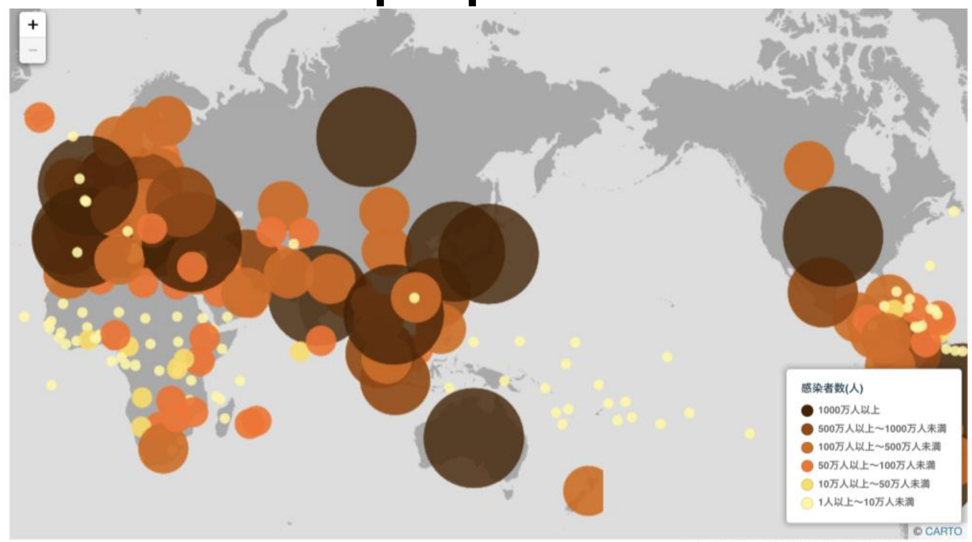


COVID-19

Jan 2020–Mar 2023（NIH）

Population : ~8 billion

6.9 million people dead



※米 ジョンズ・ホプキンス大学の発表をもとに作成
※地図「Natural Earth」から作成

Impact of plant disease in human history

Table 1.5 Some examples of the impact of plant diseases.

Type of impact	Disease	Agent	Country/region affected
Famine	Late blight of potato	*Phytophthora infestans*	Europe 1845–1846
	Brown spot of rice	*Helminthosporium oryzae*	India 1942–1943
	Cassava bacterial blight	*Xanthomonas campestris* pv. *manihotis*	Zaire 1970–1975
	Failure of maize crop	Maize mosaic virus?	Guatemala, 9th-century Mayan civilization
Economic	Coffee rust	*Hemiliea vastatrix*	Sri Lanka 1870; now worldwide
	Cocoa swollen shoot	CSSV (virus)	Ghana/Nigeria 1930–
	Panama disease of banana	*Fusarium oxysporum* f.sp. *cubense*	Central America 1930–1955
Agricultural	Southern corn leaf blight	*Bipolaris maydis*	USA 1970
	Citrus canker	*Xanthomonas campestris* pv. *citri*	USA 1910– ; South America
Ecological	Dutch elm disease	*Ophiostoma novo-ulmi*	Northern hemisphere 1930, 1970–
	Jarrah die-back	*Phytophthora cinnamomi*	Western Australia 1920–

Lucas (1998)

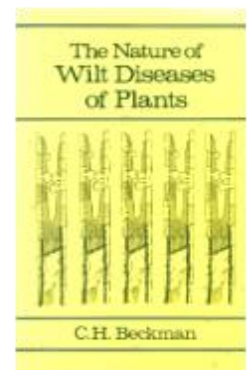
Fusarium diseases

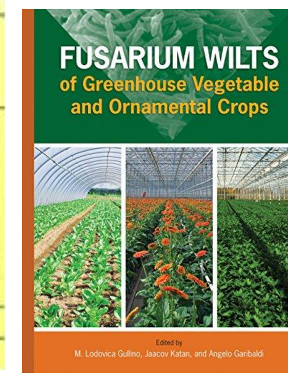
The Genus ***Fusarium***

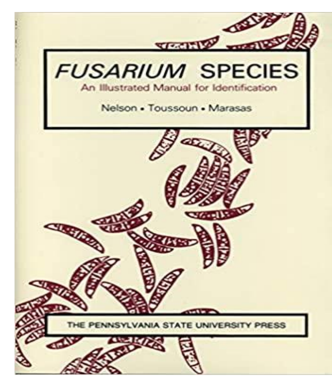
Fungi/Ascomycota/Sordariomycetes/Hypocreales/Nectriaceae

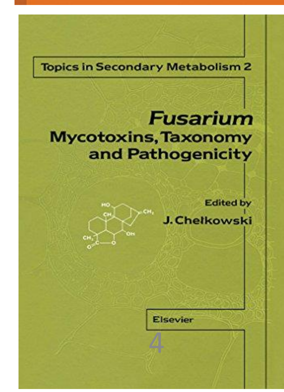
Ascomycota
Perfect stage: *Nectria*、*Gibberella*等
More than 100 species
Classification is currently undergoing
(*F. oxysporum* species complex, etc.)

Mycoprotein（*F. venenatum*）
Biocontrol agent（NPF)
Animal and human pathogen
Plant pathogens
F. oxysporum
F. solani
F. fujikuroi
F. graminearum→mycotoxin









Fusarium oxysporum

Fusarium oxysporum (species) Classification is currently undergoing

forma specialis (f. sp., forms)

taxonomy based on host plant species

f. sp. *cubense* (Banana wilt, or, Panama disease)

f. sp. *lycopersici* (Tomato wilt)

f. sp. *conglutinans* (Cabbage yellows)

、、、 (more than 120 forms)

Race

taxonomy based on host plant varieties

race 1 (Incompatible with cv. Cavendish)

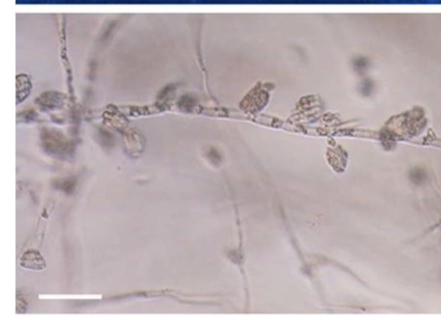
race 4 (Compatible with cv. Cavendish)

race SR4 (Sub-tropical race 4, weak pathogenicity)

race TR4 (Tropical race 4, strong pathogenicity)

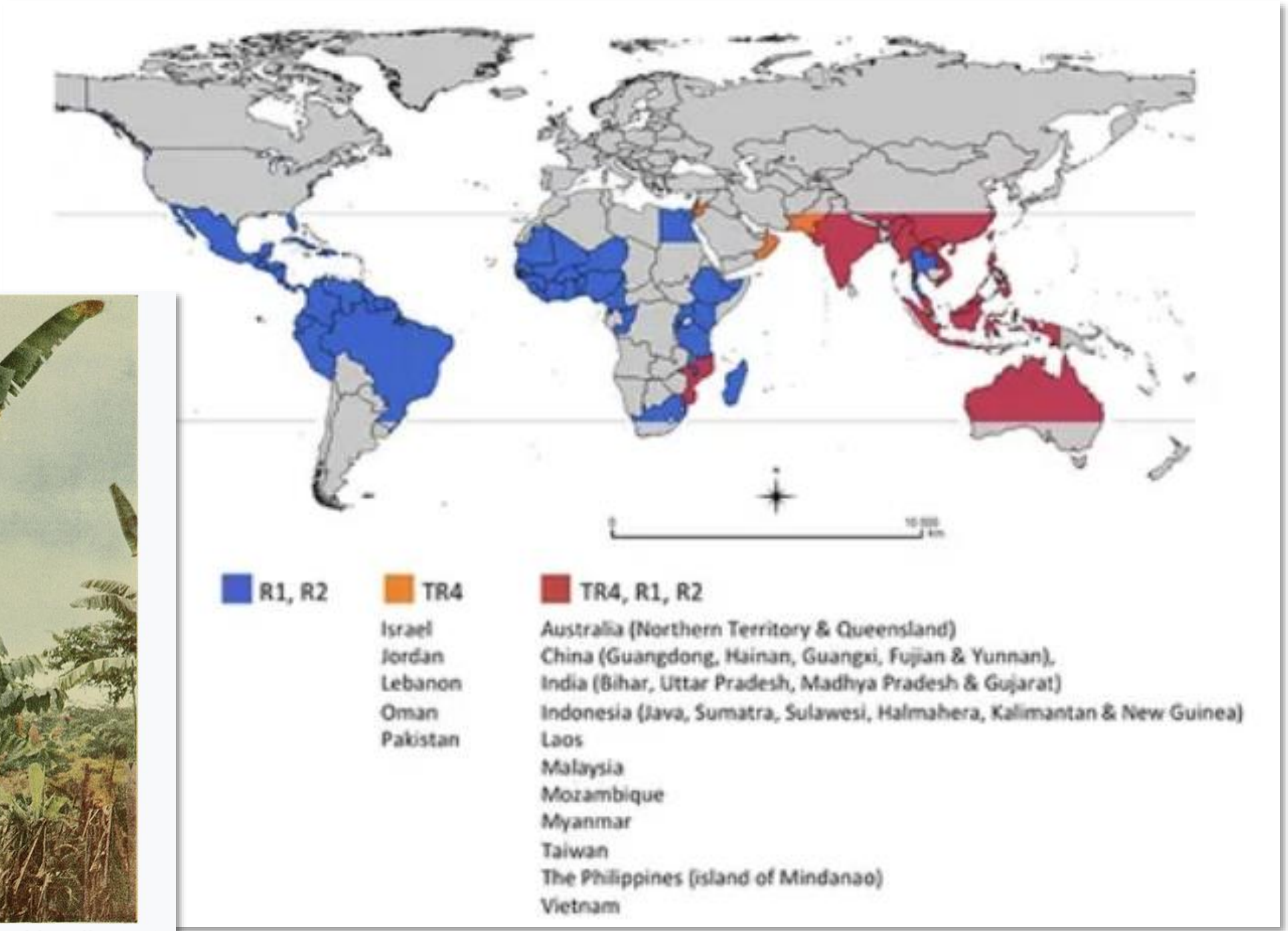
***F. oxysporum* f. sp. *cubense* race TR4:New FWB fungus**

Fusarium oxysporum f. sp. *cubense* (*Foc*) the pathogen of Fuasrium wilt (FWB)



Soilborne pathogen
Difficult to control

The pandemic history of FWB



Gros Michel banana affected by disease, Costa Rica, 1919 Wiki

Dita M et al. (2018) Front Plant Sci 9:1468

Switching to resistant variety Cavendish

cv. Gros Michel

Race 1

Race SR4

Race TR4

cv. Cavendish

(resistant to race 1)

Ohho Express

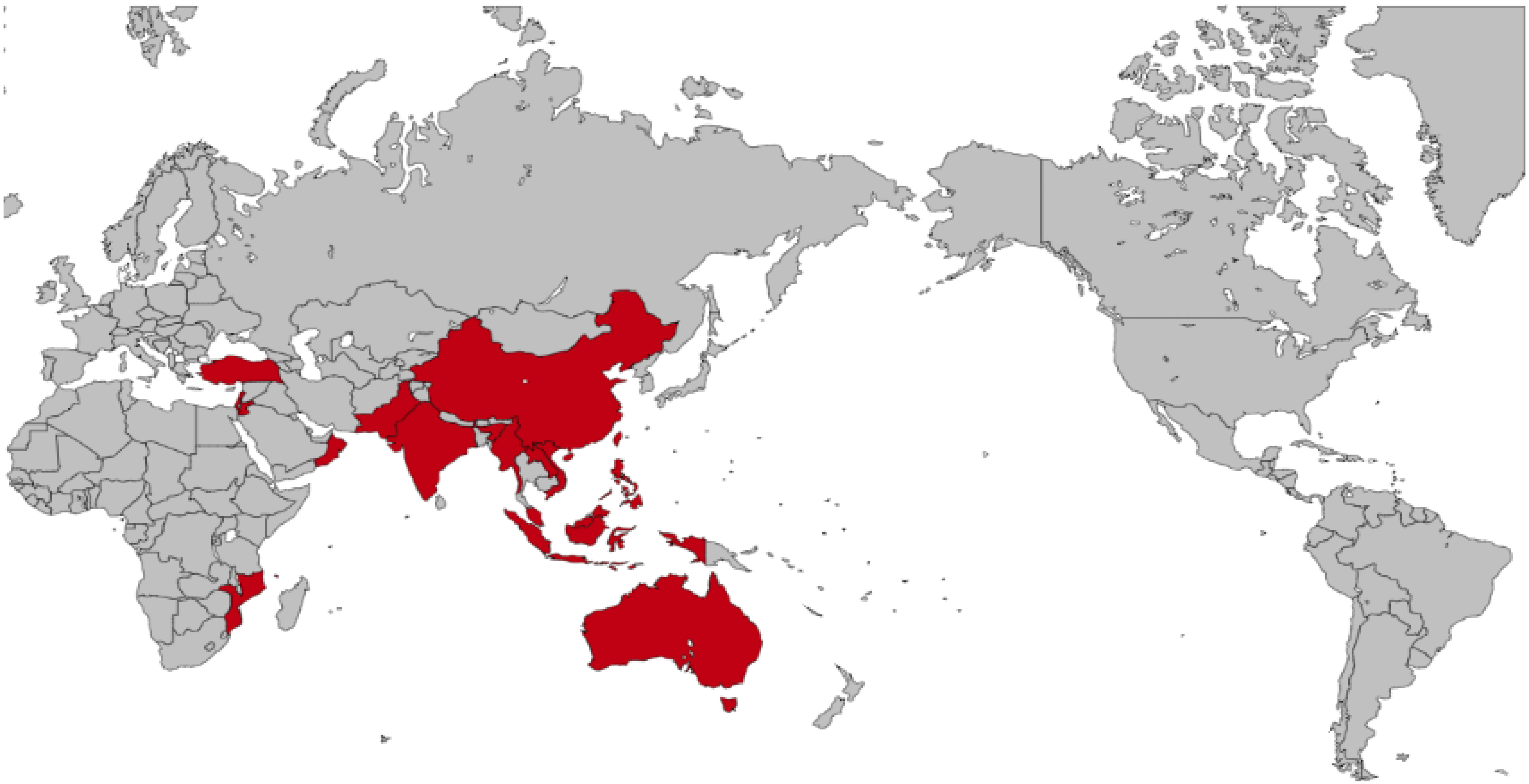
Race 1

Race SR4 (weak pathogenicity)

Race TR4 (strong pathogenicity)

The Pandemic of New FWB

Fusarium oxysporum f. sp. *cubense* race TR4



How is *Foc* transmitted?

Transmission through

- Soil
- Air
- Water (Flood, irrigation)
- Human foot and equipment
- Seedling plants

Countermeasures

- Isolation of fields
- Hygiene management (Shoes, Equipment)
- Prohibition of movement of Seedlings, Fruits, Residues
- Pathogen-free seedlings
- Soil disinfection, etc.

New FWB has arrived in South America (Colombia)

2019

Science Contents News Careers Journals

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Monocultures of the Cavendish banana variety are highly susceptible to *Fusarium*. ISTOCK.COM/MG81

Devastating banana disease may have reached Latin America, could drive up global prices

By Erik Stokstad | Jul. 17, 2019 , 2:20 PM

https://www.sciencemag.org/news/2019/07/devastating-banana-disease-may-have-reached-latin-america-could-drive-global-prices

NATIONAL GEOGRAPHIC

The banana is one step closer to disappearing

A fungus that devastates banana plants has now arrived in Latin America, the Colombian government confirms.

Science AAAS

Colombia confirms that dreaded fungus has hit its banana plantations

By Sabine Galvis | Aug. 12, 2019 , 4:25 PM

New FWB has arrived in South America (Piura, Peru)

2021/4/14 SENASA confirms outbreak of Tropical Fusarium Race 4 in Piura | Government of Peru

gob.pe

MIDAGRI (/midagri) News (/busquedas?contenido%5B%5D=noticias&institucion=senasa)

National Agrarian Health Service of Peru (/senasa)
Ministry of Agrarian Development and Irrigation (/midagri)

SENASA confirms outbreak of Tropical Fusarium Race 4 in Piura

Press release

Photos: Senasa

April 12, 2021 - 8:47 am

After the SENASA phytosanitary surveillance system detected a suspected case of Tropical Fusarium Raza 4, the Ministry of Agrarian Development and Irrigation began the immediate execution of phytosanitary measures to control the outbreak and thus protect the national production of bananas and plantains that spreads in the national territory, with an area of 170,000 hectares.

The results of the samples evaluated at the SENASA Plant Health Diagnosis Center confirm the presence of *Fusarium oxysporum* f. sp. *cubense* Race 4 Tropical (Foc R4T) on a 0.5 hectare plot, located in the district of Querecotillo, in the province of Sullana, department of Piura.

Through Chief Resolution No. 0048-2021-MIDAGRI-SENASA, published in the Official Gazette El Peruano, the entire national territory has been declared a state of

https://www.gob.pe/institucion/senasa/noticias/429832-senasa-confirma-brote-de-fusarium-raza-4-tropical-en-piura 1/3

COMUNICADO Nº02

2021

El Servicio Nacional de Sanidad Agraria – SENASA, pone en conocimiento lo siguiente:

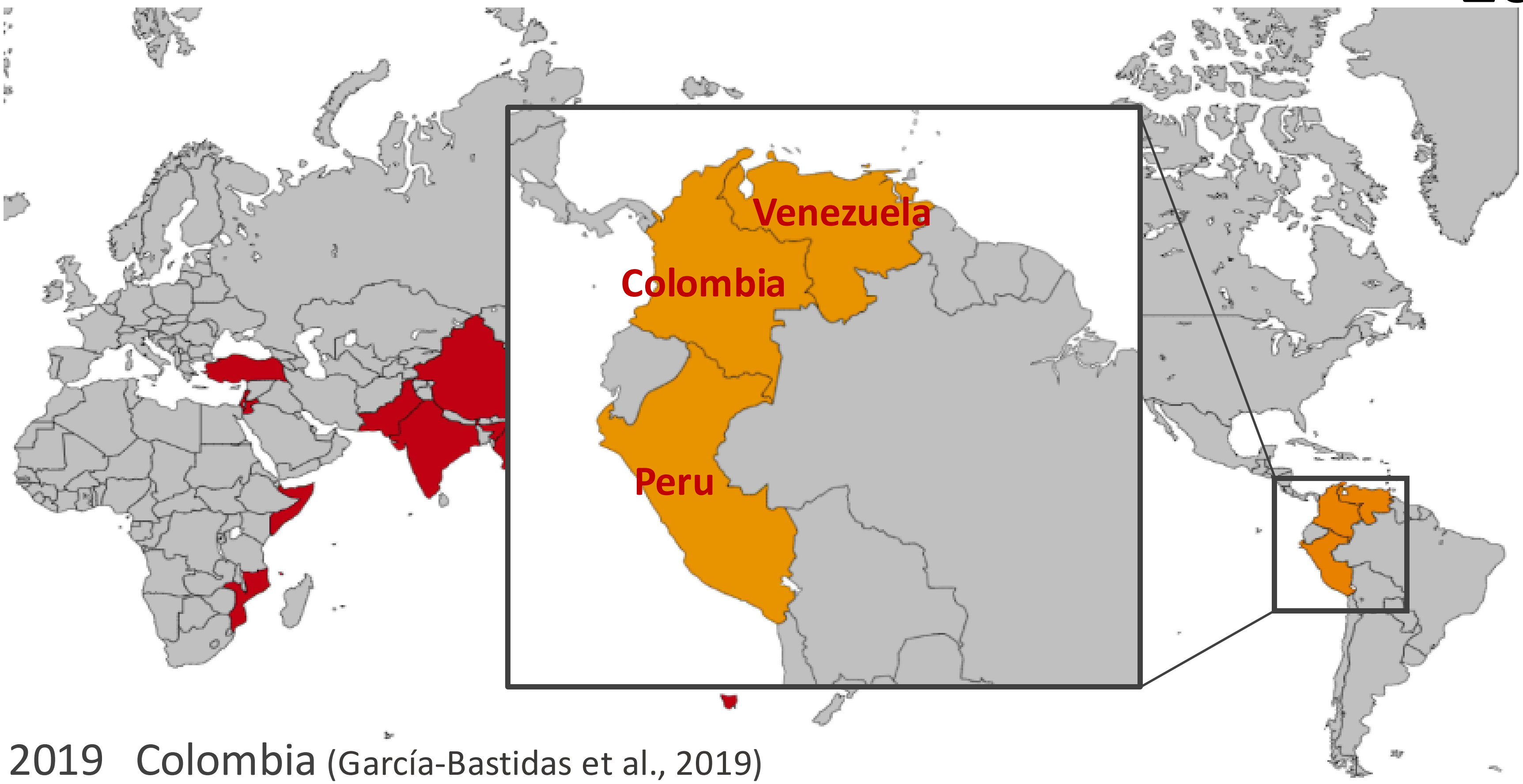
1. Mediante comunicado de fecha 08 de abril de 2021, el SENASA hizo de conocimiento de la posible presencia de *Fusarium oxysporum* f. sp. *cubense* Raza 4 Tropical (Foc R4T) en una parcela de 0.5 ha en el distrito de Querecotillo, provincia de Sullana, departamento de Piura.
2. La Unidad del Centro de Diagnóstico de Sanidad Vegetal del SENASA, ha emitido resultado POSITIVO a las pruebas de PCR y Secuenciamiento para esta plaga FocR4T.
3. Mediante Resolución Jefatural Nº 048-2021-MIDAGRI-SENASA, se ha dispuesto la emergencia fitosanitaria nacional para la ejecución de acciones de vigilancia, control y erradicación de la mencionada plaga, poniendo mayor énfasis en las principales regiones productoras de banano y plátano.
4. El hongo Foc R4T no afecta a la salud humana, por lo que el consumo de plátano y banano es seguro e inocuo para la población.
5. El hongo Foc R4T no se viabiliza a través de la fruta del banano o plátano; por lo que no debería haber impactos negativos a las exportaciones de esta fruta.
6. El SENASA cuenta con un adecuado sistema de vigilancia, diagnóstico de laboratorio y un plan de control que permita atender en forma eficaz y eficiente este foco.
7. Finalmente, se recomienda a los productores de plátano/banano, evitar llevar material vegetal (plantones o hijuelos) a sus parcelas e implementar medidas fitosanitarias con énfasis en bioseguridad, acorde a las recomendaciones del SENASA.

Lima, 12 de abril de 2021

PERÚ Ministerio de Desarrollo Agrario y Riego | SENASA PERU | BICENTENARIO PERÚ 2021

New FWB has arrived in South America (Venezuela)

2023



2019 Colombia (García-Bastidas et al., 2019)

2021 Peru (Acuña et al., 2020)

2023 Venezuela (Herrera et al., 2023)

Countermeasures in Peru

¿Qué es Fusarium Raza 4 Tropical – Foc R4T?

- ✓ Hongo del suelo que sobrevive por décadas.
- ✓ No tiene control químico eficaz.
- ✓ Afecta todas las variedades de banano y plátano.
- ✓ Causa marchitez hasta la muerte de la planta.
- ✓ No existen variedades comerciales resistentes ni tolerantes.
- ✓ No afecta la fruta ni a las exportaciones.
- ✓ No afecta la salud humana.

PERÚ Ministerio de Desarrollo Agrario y Riego

SENASA PERU

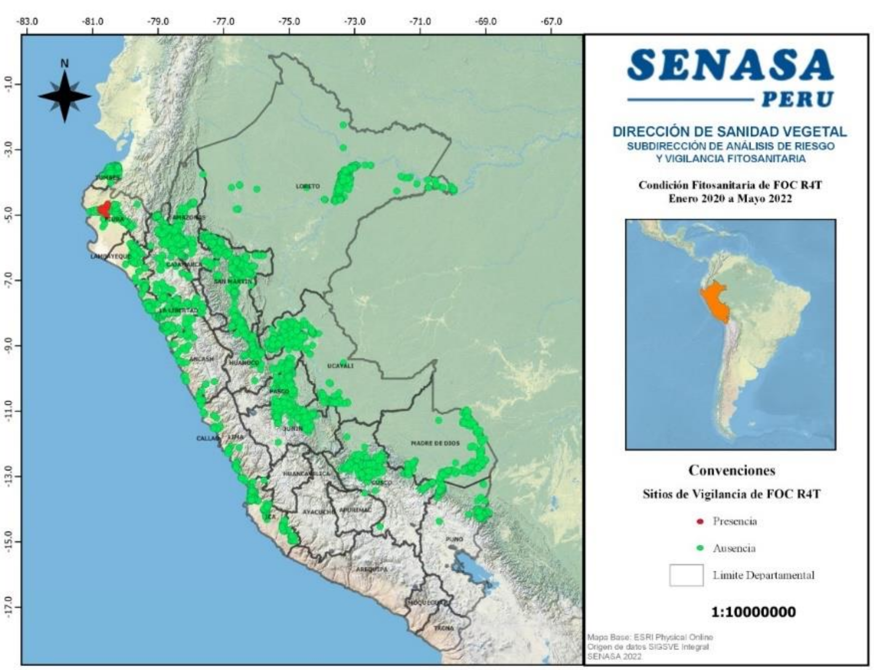
BICENTENARIO PERÚ 2021

TUAT

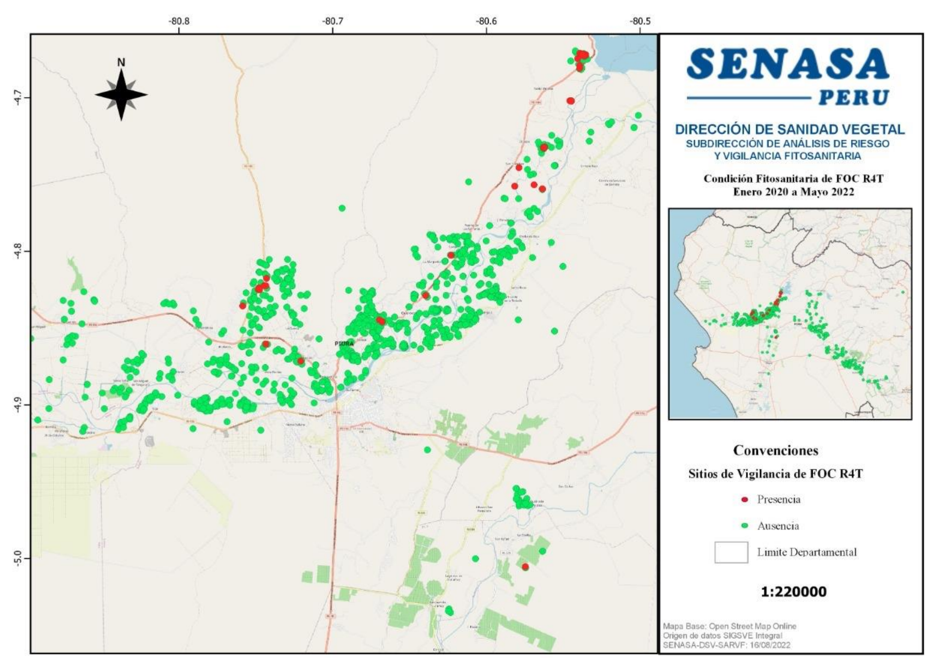
Countermeasures in Peru

Foc R4T - Piura - Perú - 2022

Mapa de sitios de prospección y positivos a Foc R4T a nivel nacional (2021 – 2022)



Ubicación de reportes positivos a Foc R4T (Sullana – Piura) (Abril 2021 – Agosto 2022)



PERÚ Ministerio de Desarrollo Agrario y Riego

SENASA PERU

BICENTENARIO PERÚ 2021

Countermeasures in Peru

Contención – manejo de Foc R4T en Piura

PERÚ Ministerio de Desarrollo Agrario y Riego

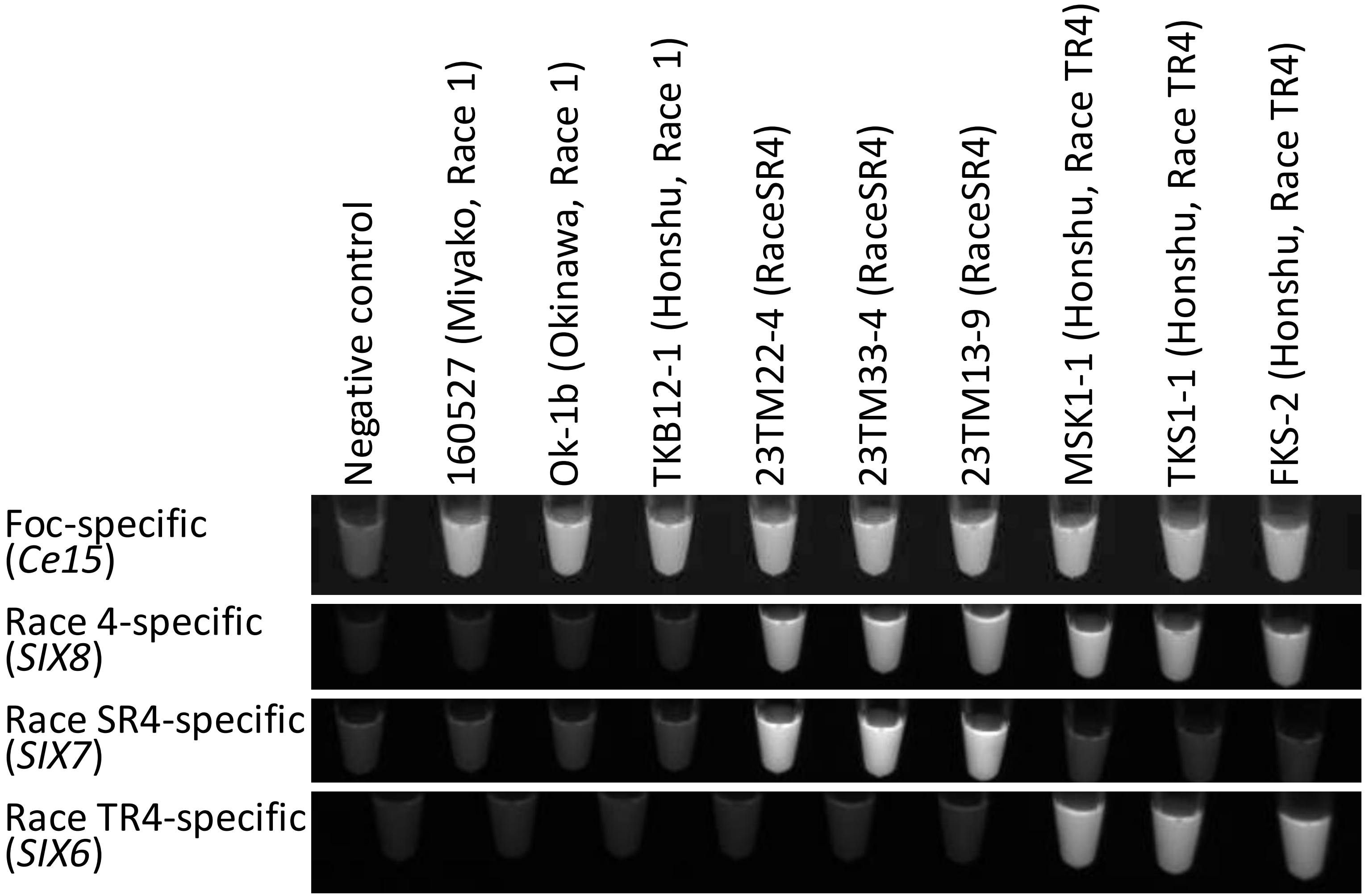
SENASA PERU

BICENTENARIO PERÚ 2021

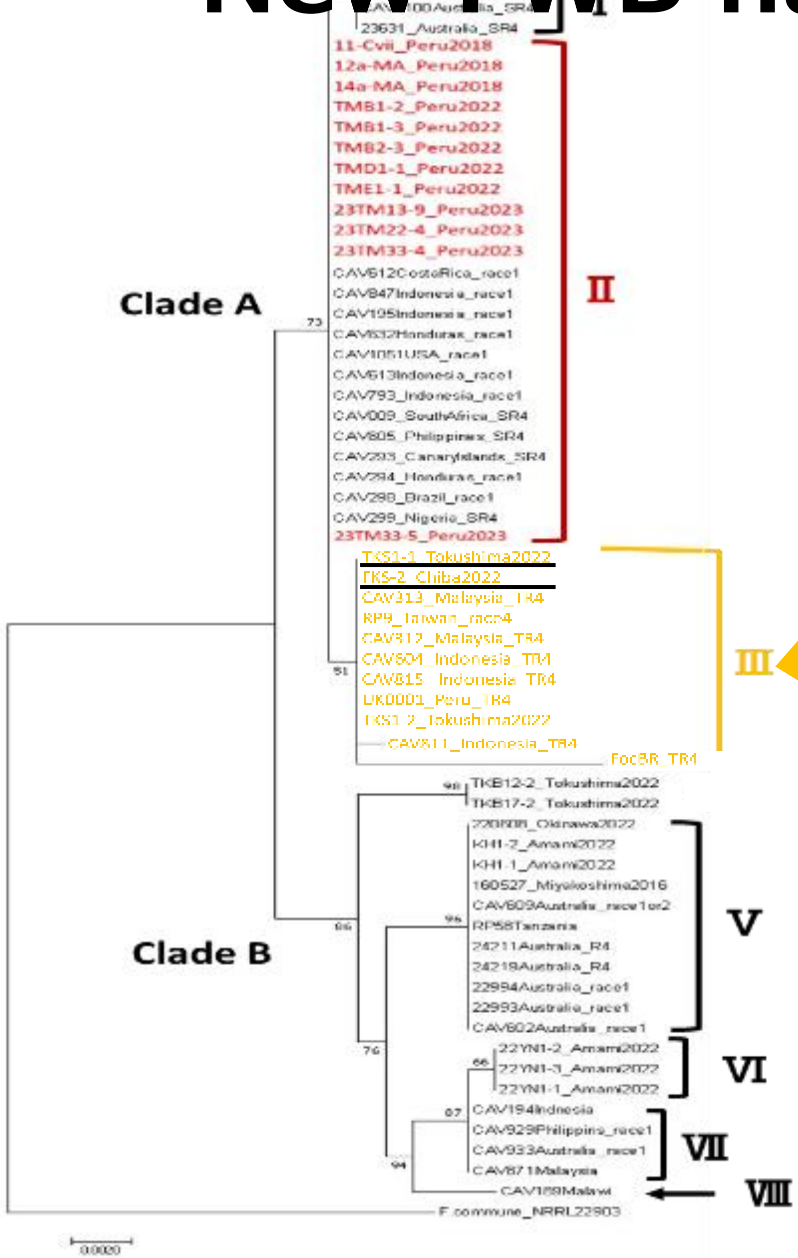
New FWB has arrived Japan

New FWB has arrived Japan

Diagnose by LAMP using TR4-specific primer set



New FWB has arrived Japan



The pathogen of the FWB found in Honshu, Japan, is in the same cluster III as race TR4 (the new FWB pathogen) reported overseas

New FWB has arrived Japan

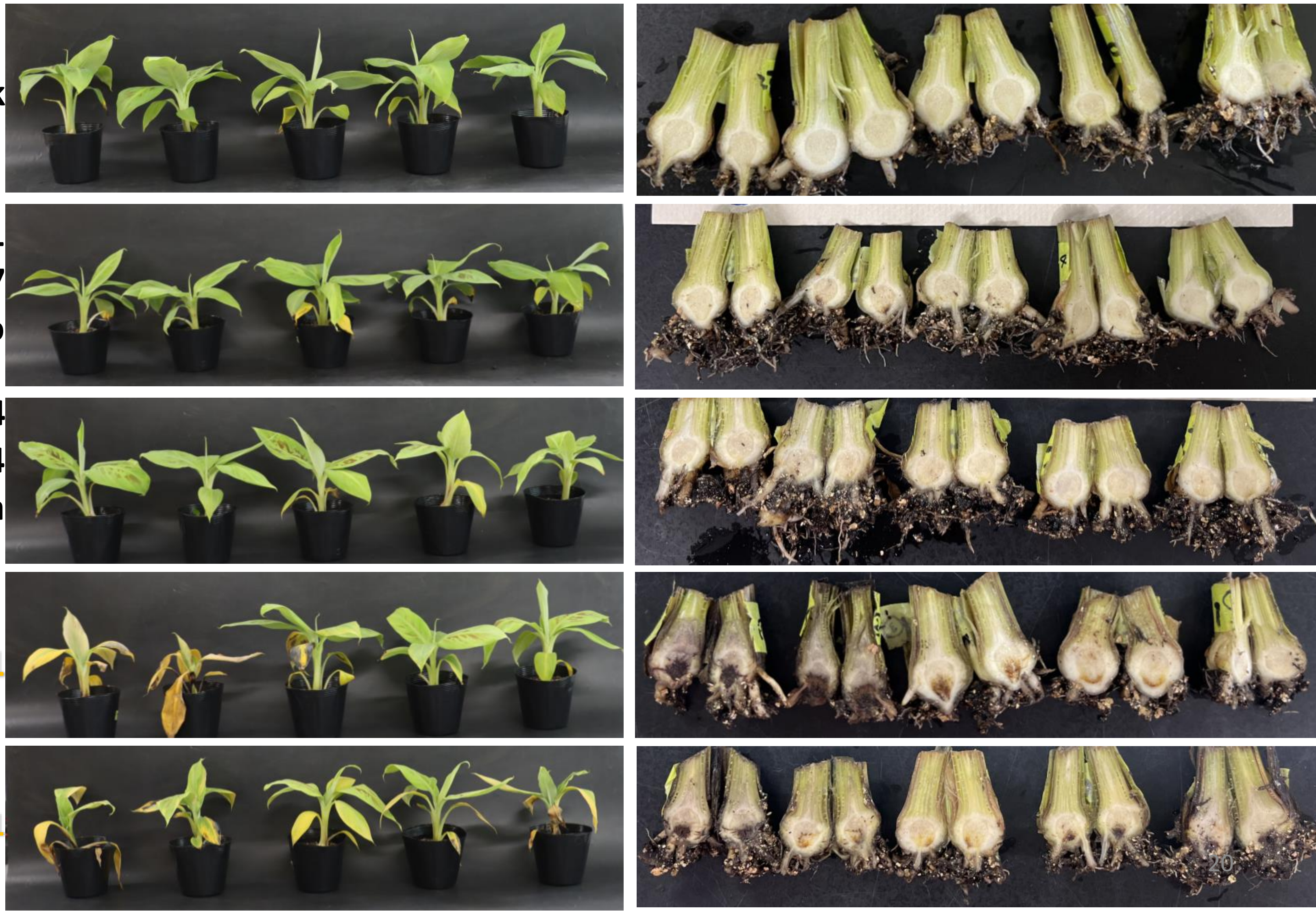
cv. Cavendish

Mock

Race 1
160527
Miyako

Race SR4
23TM22-4
Tingo Maria

Race TR4
TKS1-1
MAS1-1



The Pandemic of New FWB

https://www.cabidigitallibrary.org/doi/full/10.1079/cabicompendium.59074053#REF-DDB-206236

nature

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NEWS · 19 AUGUST 2019

Alarm as devastating banana fungus reaches the Americas

The region produces most of the world's banana exports – and the fungus affects the most popular commercial variety.

Jonathan Lambert

Bananas are one of Colombia's most important exports. Credit: Luis Acosta/AFP/Getty

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https://www.nationalgeographic.com/environment/2019/08/banana-fungus-latin-america-threatening-future.html

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ENVIRONMENT

The banana is one step closer to disappearing

A fungus that devastates banana plants has now arrived in Latin America, the Colombian government confirms.

BY MYLES KARP

PUBLISHED AUGUST 12, 2019

A fungus that has wreaked havoc on banana plantations in the Eastern Hemisphere has, despite years of preventative efforts, arrived in the Americas.

ICA, the Colombian agriculture and livestock authority, confirmed on Thursday that laboratory tests have positively identified the presence of so-called Panama disease Tropical Race 4 on banana farms in the Caribbean coastal region. The announcement was accompanied by a declaration of a national state of emergency.

The discovery of the fungus represents a potential impending disaster for bananas as both a food source and an export commodity. Panama disease Tropical Race 4—or TR4—is an infection of the banana plant by a fungus of the genus *Fusarium*. Although bananas produced in infected soil are not unsafe for humans, infected plants eventually stop bearing fruit.

AGRICULTURE

Banana growers fight renewed extinction risk as lethal fungus spreads

Resurgence of Panama disease threatens one of world's most valuable crops

Bananas are displayed at a shop in Halle, Belgium. Eaten across the world, the fruit is grown in the tropics, from Southeast Asia to Latin America. © Reuters

KOJI KATO, Nikkei science editor

August 8, 2022 00:27 JST

TOKYO -- Decades after decimating banana plants worldwide, Panama disease once again threatens to wipe out the crop key to economies across Asia, Latin America and beyond.

Establishment of an Alert System for *Fusarium oxysporum* f. sp. *cubense*, the Banana and Plantain Wilt Pathogen, and Mitigation of the Disease

A JST/JICA SATREPS Project

Japan

Tokyo University of Agriculture and Technology (TUAT)

Japan International Research Center for Agricultural Science (JIRCAS)

Tottori University (TU)

Peru

Universidad Nacional Agraria La Molina (UNALM)

Instituto Nacional de Innovación Agraria (INIA)

Universidad Nacional Agraria de La Selva (UNAS)

1 NO POVERTY

Cooperative institution

Institute of Physical and Chemical Research (RIKEN)

Funding institutions

Japan Science and Technology Agency (JST)

Japan International Cooperation Agency (JICA)

Tomato wilt

One of the most devastating soilborne diseases of tomato caused by *F. oxysporum* f. sp. *Lycopersici* (*Fol*)

How and when did *Fol* emerge?

wild tomato → domestication & breeding → modern tomato

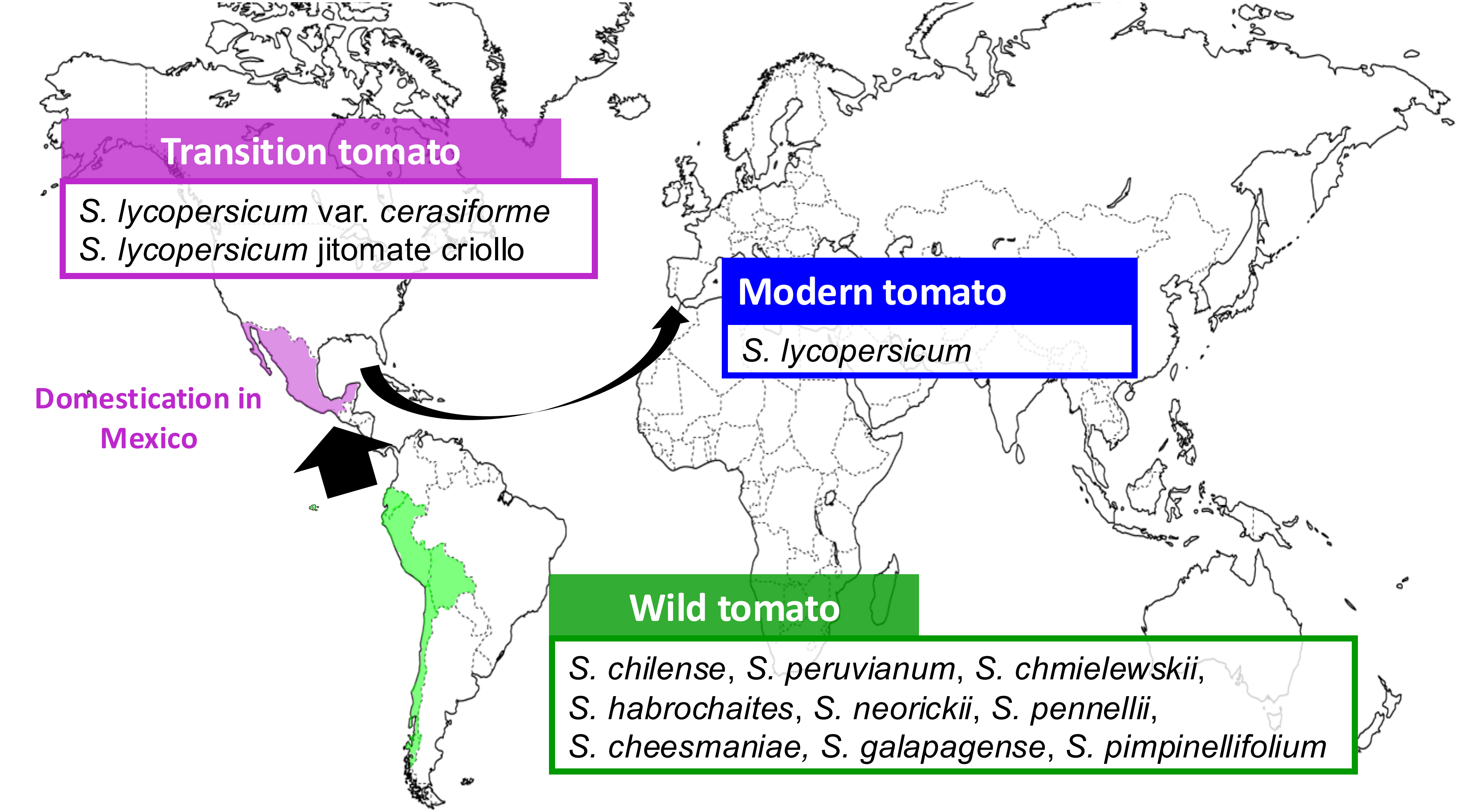
coevolution in agriculture

non-pathogen → acquisition of pathogenicity → pathogen

Hypothesis: *Fol* emerged from a mutualistic non-pathogenic *F. oxysporum* on tomato, during domestication and breeding of tomato

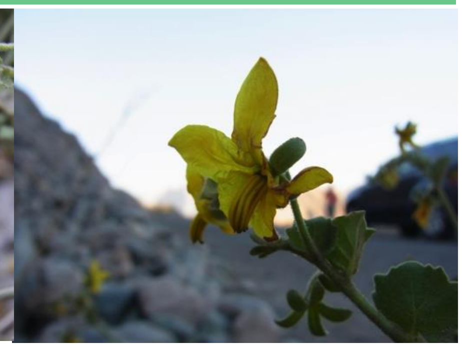
To verify the hypothesis, we tried to make a collection of *F. oxysporum* from tissues and rhizosphere of wild, transition, and modern tomatoes for phylogenetic analysis

History of tomato domestication and breeding



Sampling wild tomatoes in Peru, 2010–2018

S. pennellii



S. pimpinellifolium

S. peruvianum

Collection of tomatoes

Wild tomatoes

S. chilense	Chile, Peru
S. Peruvianum	Chile, Peru
S. habrochaites	Peru
S. pennellii	Peru
S. pimpinellifolium	Ecuador, Peru

Transition tomatoes

S. lycopersicum var. *cerasiforme*	Mexico
S. lycopersicum (jitomate criollo)	Mexico

Modern tomatoes

S. lycopersicum	Chile, Mexico, Italy, Afganestan, Japan

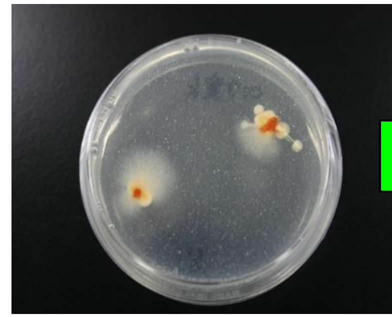
None of the wild and transition tomatoes presented wilt disease symptoms

Isolation of *F. oxysporum*

from tomato tissues

Place the piece of tissues on Potato sucrose agar medium and Fusarium selective medium

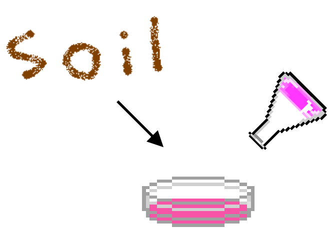
incubate for
3 to 5 days



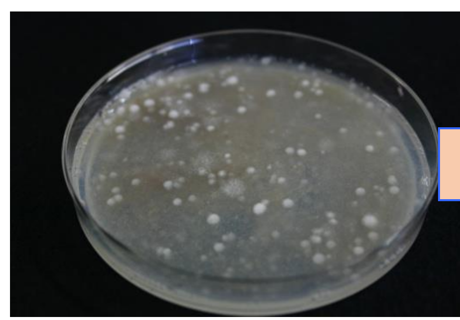
isolation

from rhizosphere soil

isolated by soil-plate method (Warcup, 1950) using *Fusarium* selective medium (Komada 1975)



incubate for
3 to 5 days



isolation

All the isolates collected were non-pathogenic to tomato

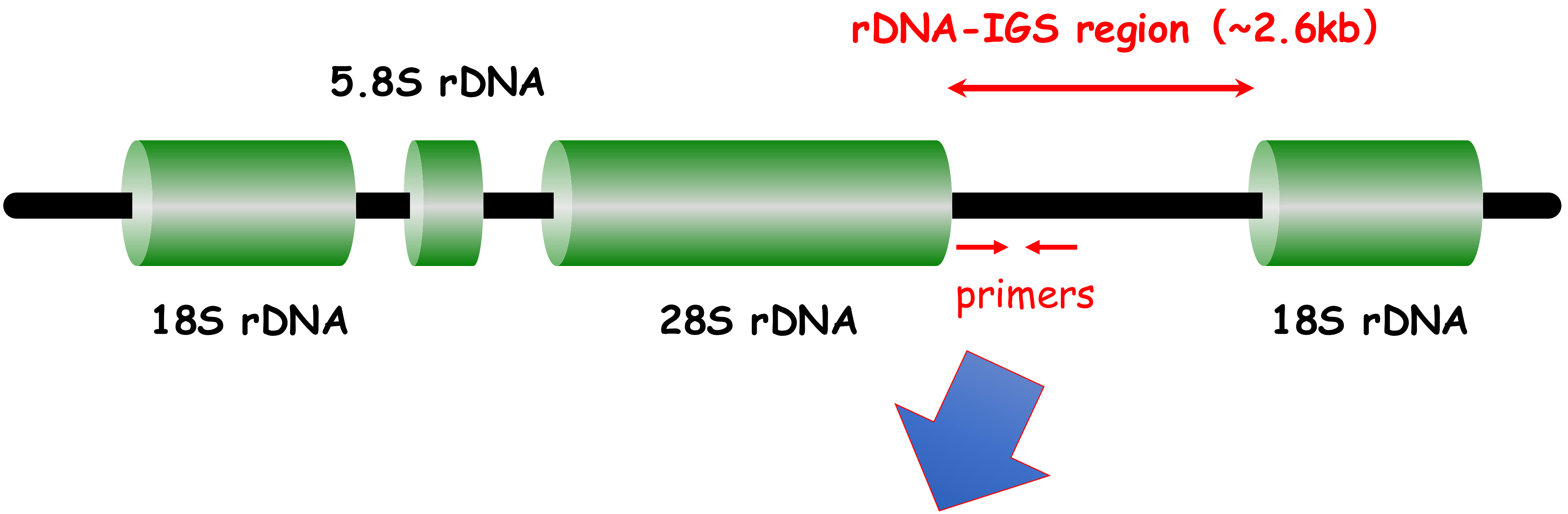





	Plant tissues	Rhizosphere
Wild tomato（Chile, Ecuador, Peru）		
S. chilense	0	30
S. peruvianum	12	134
S. habrochaites	0	44
S. pennellii	0	13
S. pimpinellifolium	2	55
Transition tomato（Mexico）		
S. Lycopersicum var. *cerasiforme*	1	16
jitomate criollo	1	23
Modern tomato（Chile, Mexico, Italy, Afghānestān, Japan）		
S. lycopersicum	26	77
	42	**392**

Phylogenetic analysis

- Many polymorphisms are conserved in ribosomal DNA-intergenic spacer (rDNA-IGS) region of *F. oxysporum* (Appel and Gordon 1996)



construction of the phylogenetic tree of *F. oxysporum* isolates

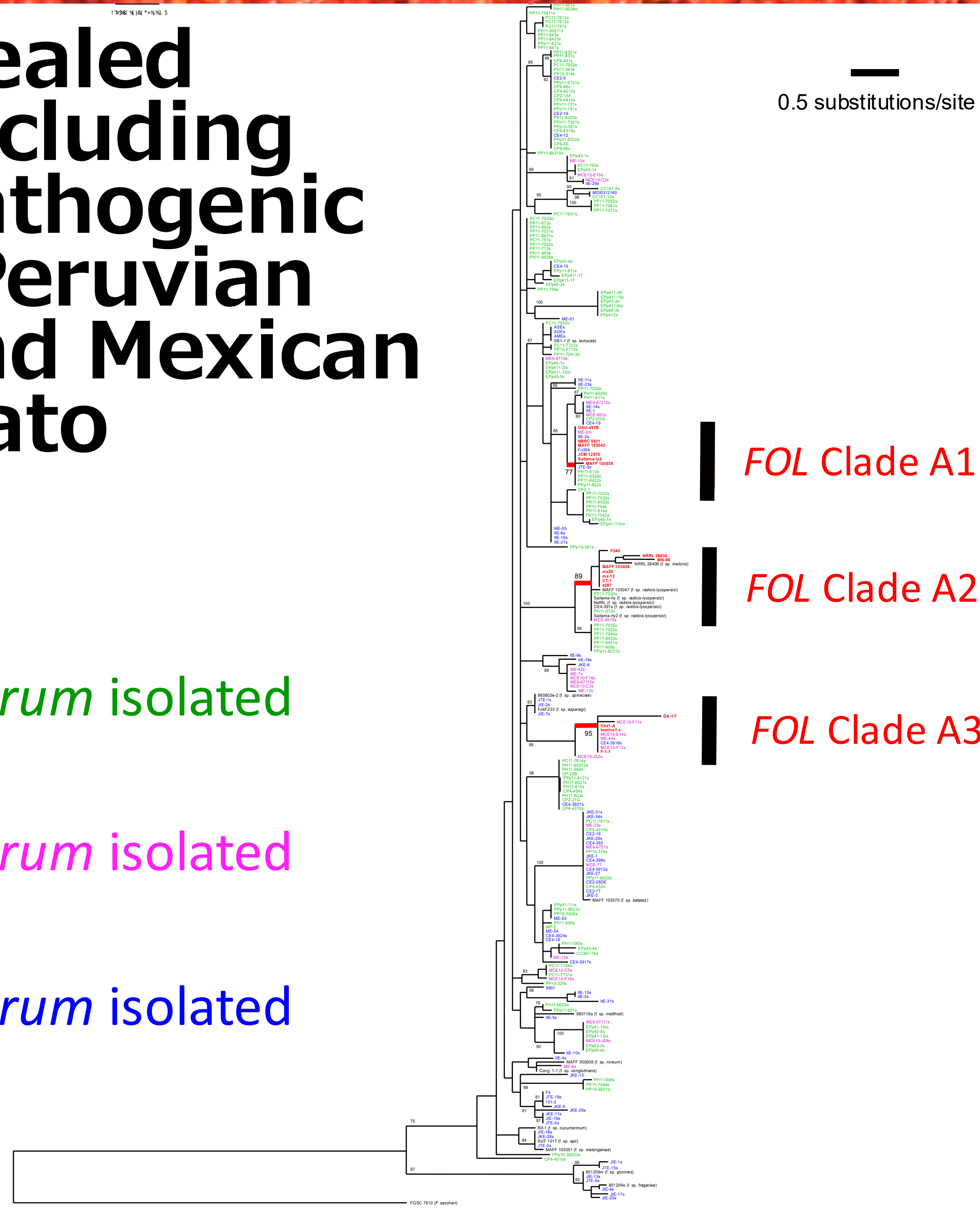
Phylogeny revealed three clades including *Fol* and non-pathogenic isolates from Peruvian wild tomato and Mexican transition tomato

FOL

Non-pathogenic *F. oxysporum* isolated from wild tomato

Non-pathogenic *F. oxysporum* isolated from transition tomato

Non-pathogenic *F. oxysporum* isolated from modern tomatoes



Clade A1

OSU-451B
NBRC 6531
MAFF 103043
JCM 12575
Saitama-ly2
MAFF 103038
PH11-613s
PP11-8328s
PP11-8422s
PPp11-802s
CP2-1
ME-2m
ItE-2s
Fo304
JTE-3s

Clade A2

F240
NRRL 26034
MN-66
MAFF 103036
mx20
mx-13
CT-1
4287
PP11-7035s
PH11-572s
MCE-9515s

Clade A3

DA-1/7
Chz1-A
tomino1-c
F-1-1
MCE10-F11s
MCE10-E14s
ME-44s
MCE10-F12s
CE4-3916s

FOL

Non-pathogenic *F. oxysporum* isolated from wild tomato

Non-pathogenic *F. oxysporum* isolated from transition tomato

Non-pathogenic *F. oxysporum* isolated from modern tomatoes

Non-pathogenic *F. oxysporum* isolated from wild tomato in Peru, from transition tomato, and from modern tomato were grouped together with *Fol*

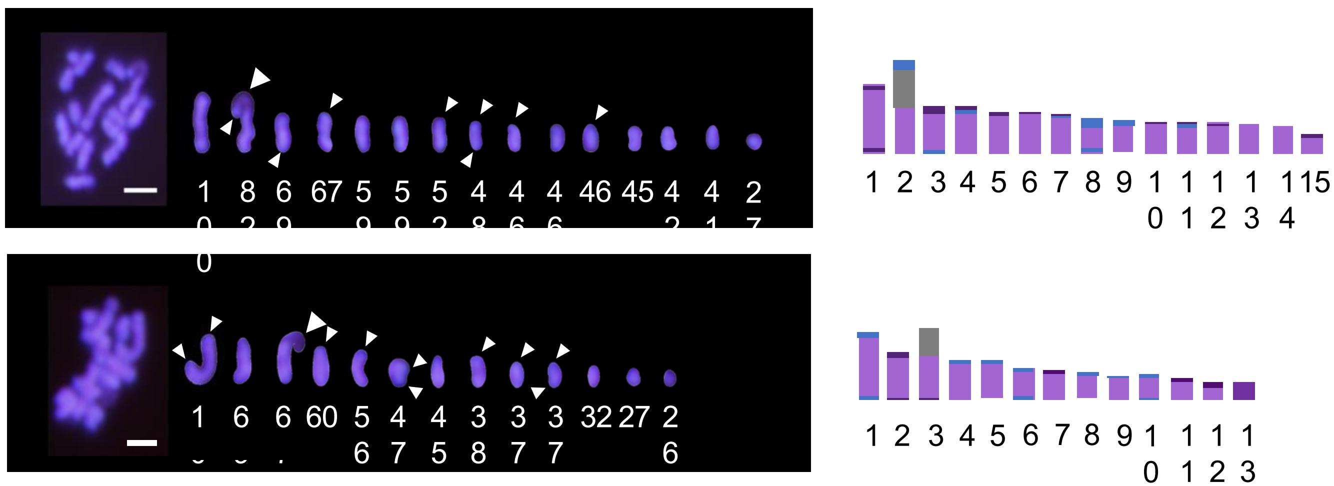
The origins of *Fol* could be non-pathogenic mutualistic *F. oxysporum* isolates on wild tomatoes in Peru

Pathogenic *Fol* has additional chromosomes than non-pathogenic *Fusarium* sp. (NPF)

Germ tube burst method

Fol

NPF
(tomato)



Ayukawa *et al.*, (2018)

Fol carries a dispensable and mobile small pathogenicity chromosome ch14

Vol 464 | 18 March 2010 | doi:10.1038/nature08850 nature

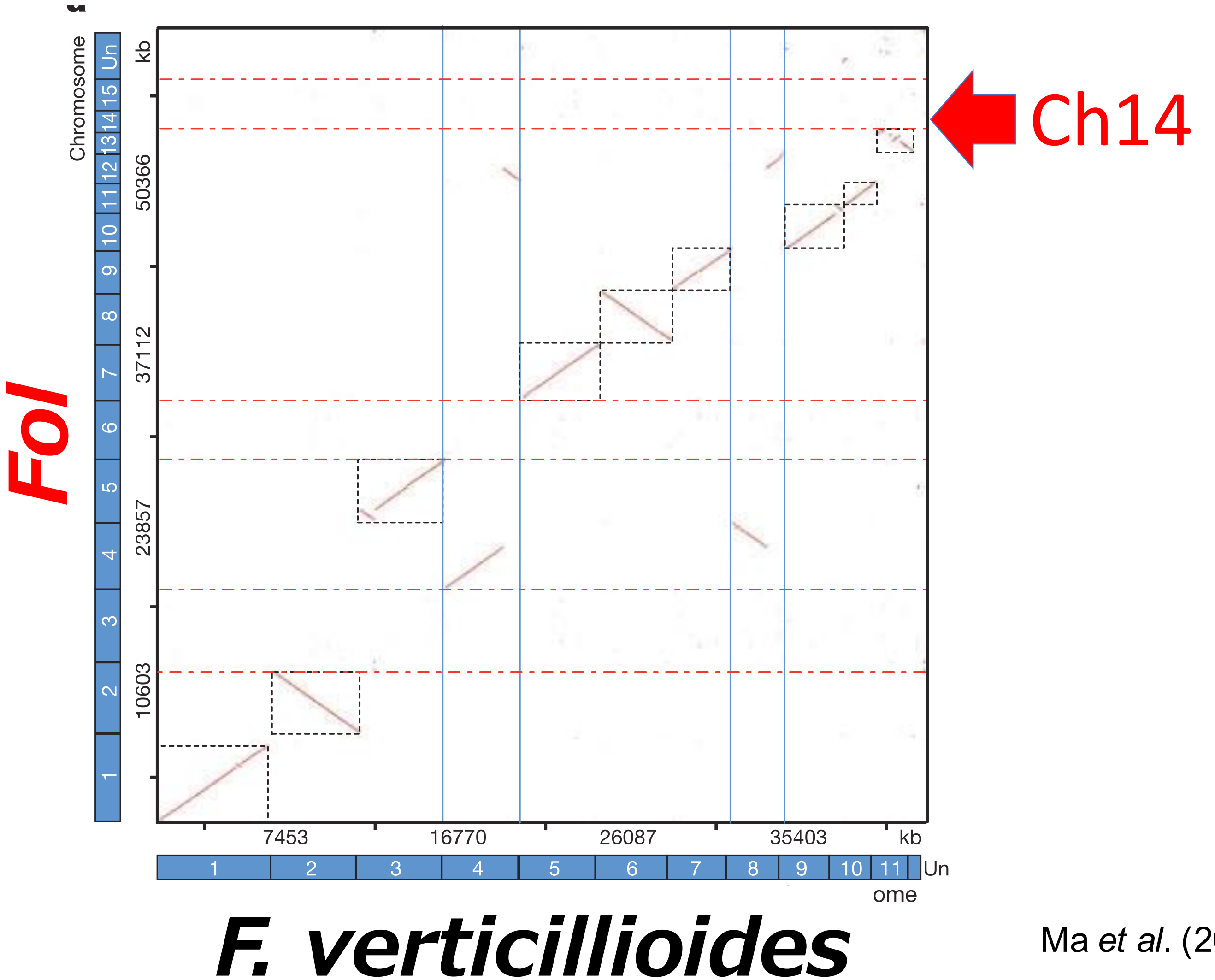
ARTICLES

Comparative genomics reveals mobile pathogenicity chromosomes in *Fusarium*

Li-Jun Ma[1]*, H. Charlotte van der Does[2]*, Katherine A. Borkovich[3], Jeffrey J. Coleman[4], Marie-Josée Daboussi[5], Antonio Di Pietro[6], Marie Dufresne[5], Michael Freitag[7], Manfred Grabherr[1], Bernard Henrissat[8], Petra M. Houterman[2], Seogchan Kang[9], Won-Bo Shim[10], Charles Woloshuk[11], Xiaohui Xie[12], Jin-Rong Xu[11], John Antoniw[13], Scott E. Baker[14], Burton H. Bluhm[11], Andrew Breakspear[15], Daren W. Brown[16], Robert A. E. Butchko[16], Sinead Chapman[1], Richard Coulson[17], Pedro M. Coutinho[8], Etienne G. J. Danchin[8]†, Andrew Diener[18], Liane R. Gale[15], Donald M. Gardiner[19], Stephen Goff[20], Kim E. Hammond-Kosack[13], Karen Hilburn[15], Aurélie Hua-Van[5], Wilfried Jonkers[2], Kemal Kazan[19], Chinnappa D. Kodira[1]†, Michael Koehrsen[1], Lokesh Kumar[1], Yong-Hwan Lee[21], Liande Li[3], John M. Manners[19], Diego Miranda-Saavedra[22], Mala Mukherjee[10], Gyungsoon Park[3], Jongsun Park[21], Sook-Young Park[9]†, Robert H. Proctor[16], Aviv Regev[1], M. Carmen Ruiz-Roldan[6], Divya Sain[3], Sharadha Sakthikumar[1], Sean Sykes[1], David C. Schwartz[23], B. Gillian Turgeon[24], Ilan Wapinski[1], Olen Yoder[25], Sarah Young[1], Qiandong Zeng[1], Shiguo Zhou[23], James Galagan[1], Christina A. Cuomo[1], H. Corby Kistler[15] & Martijn Rep[2]

Ma et al. (2010) Nature 464: 367-373

Small chromosome ch14 is unique in *Fol*

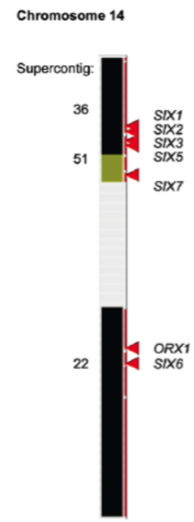


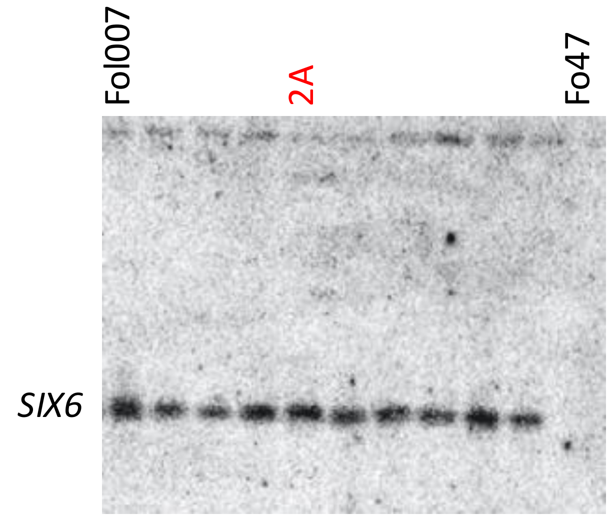
Ma *et al*. (2010) *Nature* 464: 367-373

Small chromosome ch14 determines pathogenicity of *Fol*

Ma *et al*. (2010) *Nature* 464: 367-373

Non-pathogenic *F. oxysporum* (Fo47) gained pathogenicity to tomato (2A) by obtaining ch14 by protoplast fusion with *Fol* (Fol007)

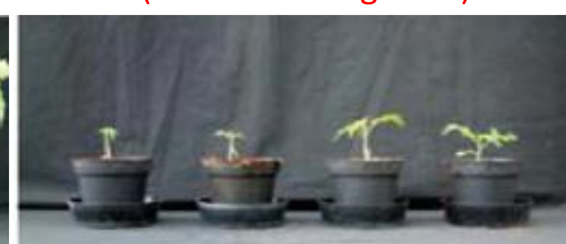




Fol007
（*Fol* race 2）

Fo47
（Non-pathogenic*F. oxysporum*）

2A
(Fo47 obtaining ch14)



Non-pathogenic *F. oxysporum* from wild, transition, and modern tomato does not have ch14; *Fol* carries ch14, Suggesting horizontal transfer of ch14

Clade	Strain	*SIX3* □	*SIX1* □
Clade A1	OSU-451B	+	+
	NBRC 6531	+	+
	MAFF 103043	+	+
	JCM 12575	+	+
	Saitama-ly2	+	+
	MAFF 103038	+	+
	PH11-613s	−	−
	PP11-8328s	−	−
	PP11-8422s	−	−
	PPp11-802s	−	−
	CP2-1	−	−
	ME-2m	−	−
	ItE-2s	−	−
	Fo304	−	−
	JTE-3s	−	−
Clade A2	F240	+	+
	NRRL 26034	+	+
	MN-66	+	+
	MAFF 103036	+	+
	mx20	+	+
	mx-13	+	+
	CT-1	+	+
	4287	+	+
	PP11-7035s	−	−
	PH11-572s	−	−
	MCE-9515s	−	−
Clade A3	DA-1/7	+	+
	Chz1-A	+	+
	tomino1-c	+	+
	F-1-1	+	+
	MCE10-F11s	−	−
	MCE10-E14s	−	−
	ME-44s	−	−
	MCE10-F12s	−	−
	CE4-3916s	−	−

Non-pathogenic *F. oxysporum* gained pathogenicity to tomato by obtaining the small chromosome maybe by horizontal chromosomal transfer (HCT)

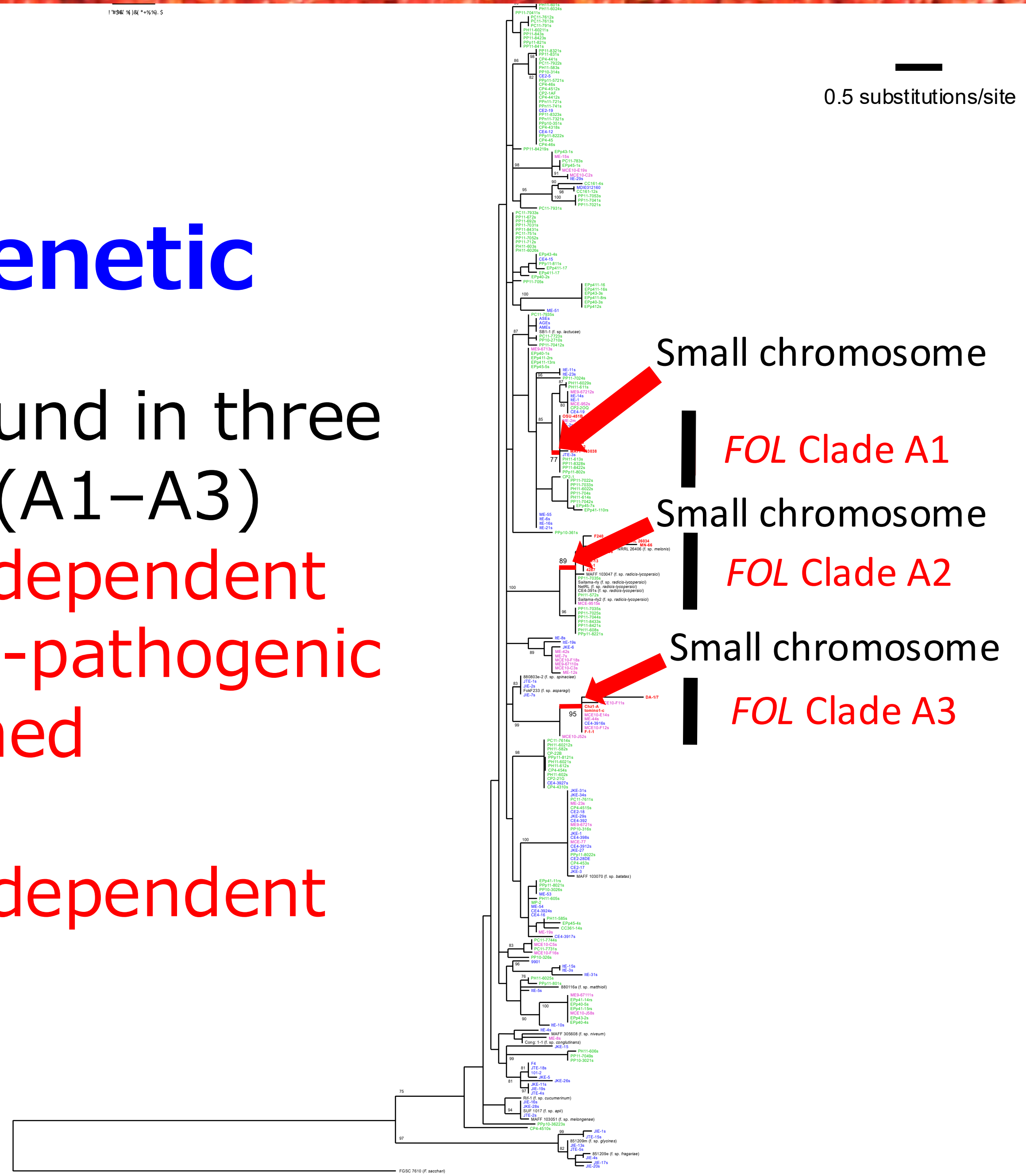
Non-pathogenic *F. oxysporum*

↓ ← Small chromosome

F. oxysporum f. sp. *lycopersici*,
The tomato wilt fungus (*Fol*)

Fol is not monophylogenetic

Fol isolates are found in three distinctive clades (A1–A3)
=at least three independent events where non-pathogenic *F. oxysporum* gained pathogenicity
=at least three independent HCT



Kawabe (2005) JGPP 71:263

How and when did *Fol* emerge?

Peru | Mexico | Worldwide

Wild tomato

Transition tomato

Modern tomato

F. oxysporum

Ancient *Fol*
(non-pathogenic mutualistic *F. oxysporum*)

Fol

Small chromosome ch14 by horizontal transfer

How and when did *Fol* emerge?

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MICROBES AND ENVIRONMENTS

The Tomato Wilt Fungus *Fusarium oxysporum* f. sp. *lycopersici* shares Common Ancestors with Nonpathogenic *F. oxysporum* isolated from Wild Tomatoes in the Peruvian Andes

KEIGO INAMI[1], TAKESHI KASHIWA[1], MASATO KAWABE[2], AKIKO ONOKUBO-OKABE[1], NOBUKO ISHIKAWA[1], ENRIQUE RODRÍGUEZ PÉREZ[3], TAKUO HOZUMI[4], LILIANA ARAGÓN CABALLERO[5], FATIMA CÁCERES DE BALDARRAGO[6], MAURICIO JIMÉNEZ ROCO[7], KHALID A. MADADI[8], TOBIN L. PEEVER[9], TOHRU TERAOKA[1], MOTOICHIRO KODAMA[10], and TSUTOMU ARIE[1]*

[1]*Graduate school of Agriculture, Tokyo University of Agriculture and Technology, Fuchu, Tokyo, 183–8509, Japan;* [2]*National Agricultural Research Center (NARC), Tsukuba, Ibaraki, 305–8666, Japan;* [3]*Department of Plant Breeding, Chapingo Autonomous University, Texcoco, CP 56230, Mexico;* [4]*Interdisciplinary Research Center for Environment and Rural Service, Chapingo Autonomous University, Texcoco, CP 56230, Mexico;* [5]*Department of Phytopathology, National Agrarian University—La Molina, Lima, Peru;* [6]*Department of Biology, National University of San Augustín, Arequipa, Peru;* [7]*Tarapacá University, a la Casilla 6-D, Arica, Chile;* [8]*Kabul University, Jamal Mina, Afghanistan;* [9]*Department of Plant Pathology, Washington State University, Pullman, Washington 99164–6430, USA; and* [10]*Department of Agriculture, Tottori University, Tottori, Tottori, 680–8553, Japan*

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Fusarium oxysporum is an ascomycetous fungus that is well-known as a soilborne plant pathogen. In addition, a large population of nonpathogenic *F. oxysporum* (NPF) inhabits various environmental niches, including the phytosphere. To obtain an insight into the origin of plant pathogenic *F. oxysporum*, we focused on the tomato (*Solanum lycopersicum*) and its pathogenic *F. oxysporum* f. sp. *lycopersici* (*FOL*). We collected *F. oxysporum* from wild and transition *Solanum* spp. and modern cultivars of tomato in Chile, Ecuador, Peru, Mexico, Afghanistan, Italy, and Japan, evaluated the fungal isolates for pathogenicity, VCG, mating type, and distribution of *SIX* genes related to the pathogenicity of *FOL*, and constructed phylogenies based on ribosomal DNA intergenic spacer sequences. All *F. oxysporum* isolates sampled were genetically more diverse than *FOL*. They were not pathogenic to the tomato and did not carry *SIX* genes. Certain NPF isolates including those from wild *Solanum* spp. in Peru were grouped in *FOL* clades, whereas most of the NPF isolates were not. Our results suggested that the population of NPF isolates in *FOL* clades gave rise to *FOL* by gaining pathogenicity.

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Dr. Casas Andres
Dr. Razuri Vicente
Ms. Heidi Huarhua Zaquinaula
Prof. Paomo Angel Alfonso
Ms. Cecilia Ono Morikawa
Mr. Yuichi Nishida

San Agustín University

Dr. Cáceres de Baldarrago Fatima

Universidad Nacional Agraria de la Selva (UNAS)

Prof. Oscar Cabezas H.

INIA (Peru)

Prof. Oscar Cabezas H.