Monograph
On
The Genus Fusarium

By

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Preface

This Monograph is dedicated to the eminent pathologist Prof. Abdul-Rahman Khater, who was the first to direct my attention in 1966 that the nervous manifestations of donkeys were most probably caused by intoxication, rather than virus infection as propagated at that time. It is also dedicated to Prof. Nabil Hassan, the first veterinarian who studied Fusarium during his PhD mission in Moscow in the late sixty and who gave an excellent talk on fusraiotoxicosis at the International mycotoxicosis conference held in Nairobi, 1978, where I was working as FAO Consultant.


Prof. Khater


Prof. Nabil in Nairobi


Mai Hamed

This and other monographs I have uploaded before are intended to be sources for information for the students without any restriction, particularly for those in the developing countries, who are not able to buy expensive books or subscribe in journals or pay to read an article, because of shortage of the hard currency.

When I started planning this monograph on the genus Fusarium, I have not imagined that I will find such enormous amounts of data on a single organism, so that I feel now after ending the monograph that I have actually written a synopsis as a guide to the postgraduate students to have an idea about the past history of the genus Fusarium, which was mainly concerned with its discovery and nomenclature , and the recent history of the main discoveries, which are concerned mainly with the molecular characteristics of the organism. The data provided by the assistant lecturer Mai Hamed obliged me to involve her for the first time as a co-author in one of my manuals

Prof. Dr. Mohamed Refai, Cairo 22.6.2015

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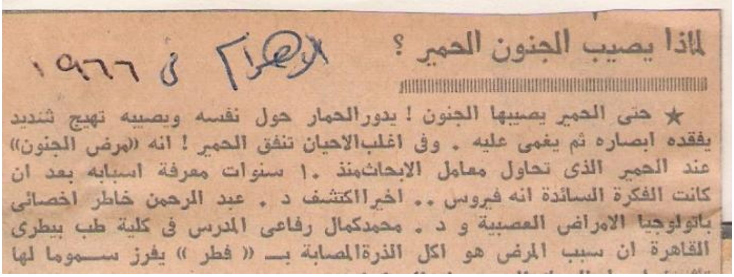
1. Introduction

The Fusarium was always in the back mind of the author since the mid sixties, when several donkeys died in the Sharkia Govornorate at that time with nervous manifestations as the main symptoms. The pathologists diagnosed the cases as encephalomalacia and the virologists failed to isolate a virus. The author had the chance to visit the places, where the donkeys died and noticed that donkeys were eating the corn stumps, which were covered with pink fungal growth, which was identified as *Fusarium species*. Regrettably, the author had no facilities at that time to continue studying the problem and resorted to education of the farmers to prevent their animals from consuming such mouldy stumbs through lectures and announcement in the daily news paper Al-Ahram. The farmers responded positively, so that in a short time the problem was solved.



لماذا يصيب الجنون الحمير ؟

الأهرام في ١٩٦٦

★ حتى الحمير يصيبها الجنون ! يدورالحمار حول نفسه ويصيبه تهيج شديد يفقده ابصاره ثم يغمى عليه . وفى اغلب‌الاحيان تنفق الحمير ! انه «مرض الجنون» عند الحمير الذى تحاول معامل الابحاث‌منذ ١٠ سنوات معرفة اسبابه بعد ان كانت الفكرة السائدة انه فيروس .. اخيراكتشف د . عبد الرحمن خاطر اخصائى باتولوجيا الامراض العصبية و د . محمدكمال رفاعى المدرس فى كلية طب بيطرى القاهرة ان سبب المرض هو اكل الذرةالمصابة بـــ « فطر » يفرز ســموما لها

Al Ahram, 1966

<u>Why madness affects donkeys?</u>

Even donkeys are affected by madness! The donkey goes around himself and falls, then becomes severely irritated, loses his vision and then fainted, and most often dies. Its madness disease of donkeys, where research labs ten years ago tried to detect its viral cause, as it was believed. Finally it was discovered by Dr. Abdul Rahman Khater, specialist in pathology of neurological diseases and Dr. Mohamed Kamal Refai, teacher in the College of Veterinary Medicine, Cairo University, that the cause of the disease is related to consumption of corn contaminated with a fungus that secretes toxins that affects the brain.

وزاره الزراعه
مصلحة الطب البيطرى
« نداء »
للفلاحين وحائزى الحيوانات

تلاحظ للمصلحة البيطرية بوزارة الزراعة فى الآونة الأخيرة نفوق عدد من الحيوانات وبصفة خاصة الحمير والجمال وذلك بظهور أعراض عصبية مرضية على هذه الحيوانات تنتهى غالبا بنفوقها وذلك نتيجة لتغذيتها على الأذرة التالفة والمتعفنة.

لذا تهيب المصلحة بجميع أصحاب هذه الحيوانات بعدم تقديم مثل هذه الأذرة التالفة لحيواناتهم حتى لا تتعرض للإصابة بهذا المرض وذلك حفظا على حيواناتهم.

ونرجو عند ظهور مثل هذه الحالات إخطار أقرب طبيب بيطرى للقيام فورا لعمل الإسعافات اللازمة.

المراقبة العامة للإرشاد البيطرى

Ministry of Agriculture
Department of Veterinary Medicine
Call for
Farmers and holders of animals

The Department of Veterinary Medicine in the Ministry of Agriculture has been informed recently about the death of a number of animals, particularly donkeys and camels with the manifestations of neurological symptoms that end often with their death as a result of feeding on mouldy and damaged maize

Therefore calls upon all owners of such animals not to provide such damaged maize to their animals so as not expose them to the disease so as to preserve their animals

We hope in such cases to notify the nearest veterinarian to do immediately the necessary first aid

Veterinary extension

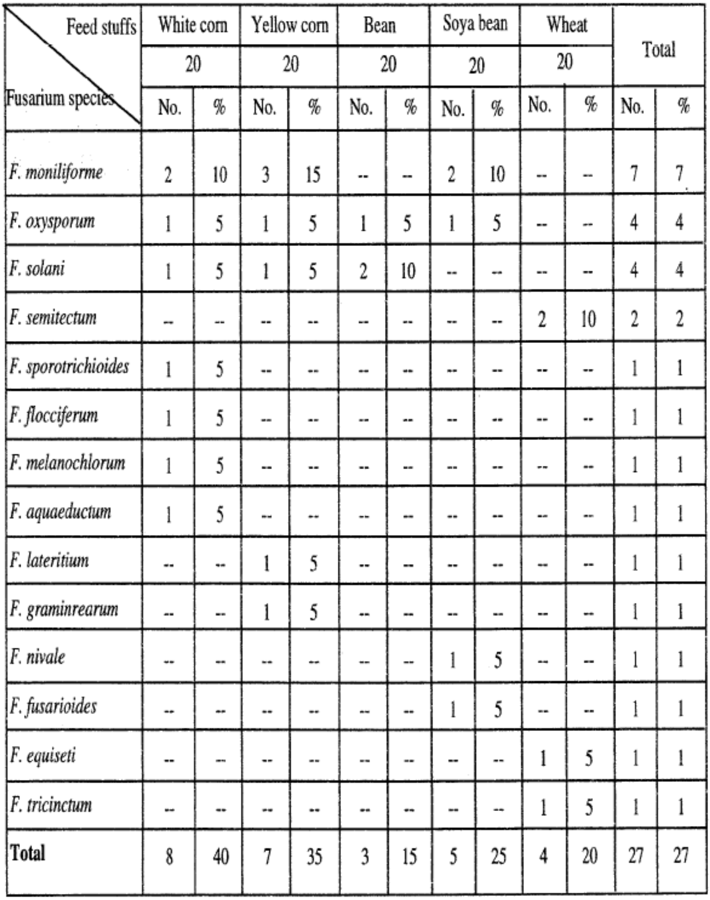
The authors had the chance to consider *Fusarium* in the studies done later on feeds, which are mentioned above. The evaluation of 160 samples of feed (80 of each of yellow corn and mixed feed) at different seasons of the year for fungal contamination indicated that the *Fusarium* species were isolated only during winter in tested samples (5, 15%) of yellow corn and mixed feeds respectively.[47]

Moreover, two studies were done on *Fusarium*. The first study was concerned with the incidence of *Fusarium* in equine feeds. In this study 100 equine feeds (48 barley, 16 pelleted feeds,14 Soya bean, 12 yellow corn and 10 hay samples) were collected from different farms and clubs and subjected to mycological examination for isolation and identification of *Fusarium* species. All samples examined were contaminated with moulds.

The highest total *Fusarium* count/g was obtained from the Soya bean samples, however, the *Fusarium* colony counts constituted the highest percentage of total fungal count in barley, which reached to 71.43% in one sample, 50.0% in one samples, 10-18% in 6 samples and 5.55% in one sample. In Soya bean, the highest contribution of *Fusarium* in total fungal count was 33.33% in one sample and 18.75% in another sample, while the rest of the samples the contribution varied from 1.52-3.57%. The lowest *Fusarium* count was observed in corn and hay where it varied from 0.88-11.90% and 2% respectively of the total fungal count only. The incidence of *Fusarium* was the highest in samples of yellow corn 58.33%, followed by soya, in which the incidence of *Fusarium* was 42.85%; in barley it was 18.75% and in hay it was 10%. Samples of pelleted feeds were all negative for *Fusarium*. 44 isolates of *Fusarium* were recovered from equine feeds. The isolates were identified into 9 *Fusarium* species. The most common *Fusarium* species was *F. verticillioides* (21 isolates), followed by *F. anthophilum* (9 isolates), *F. proliferatum* and *F. solani* (4each), *F. dimerum* (2 isolates) and one isolate of each of *F. nygamai, F. oxysporum*, *F. poae* and *F. sporotrichoides.* Only one isolate was recovered from hay, which was identified as *F. verticillioides.*[35]

The results of the second study were published in the year 2001, where 14 *Fusarium species* were isolated feedstuffs and identified **.**

Prevalence of Fusarium species in feedstuffs



Feed stuffs	White corn		Yellow corn		Bean		Soya bean		Wheat		Total	
	20		20		20		20		20			
Fusarium species	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
F. moniliforme	2	10	3	15	--	--	2	10	--	--	7	7
F. oxysporum	1	5	1	5	1	5	1	5	--	--	4	4
F. solani	1	5	1	5	2	10	--	--	--	--	4	4
F. semitectum	--	--	--	--	--	--	--	--	2	10	2	2
F. sporotrichioides	1	5	--	--	--	--	--	--	--	--	1	1
F. flocciferum	1	5	--	--	--	--	--	--	--	--	1	1
F. melanochlorum	1	5	--	--	--	--	--	--	--	--	1	1
F. aquaeductum	1	5	--	--	--	--	--	--	--	--	1	1
F. lateritium	--	--	1	5	--	--	--	--	--	--	1	1
F. graminrearum	--	--	1	5	--	--	--	--	--	--	1	1
F. nivale	--	--	--	--	--	--	1	5	--	--	1	1
F. fusarioides	--	--	--	--	--	--	1	5	--	--	1	1
F. equiseti	--	--	--	--	--	--	--	--	1	5	1	1
F. tricinctum	--	--	--	--	--	--	--	--	1	5	1	1
Total	8	40	7	35	3	15	5	25	4	20	27	27

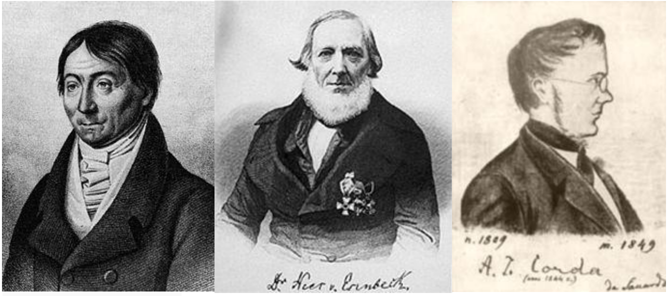
2. History and nomenclature of the Genus Fusarium

1809: Link

Fusarium roseum Link (1809),

1825: Link

Fusarium ciliatum Link (1825);
Fusarium ciliatum var. ciliatum Link (1825),
Fusarium stilbaster (Link) Link (1825)
Fusarium roseum f. roseum Link (1832),
Fusarium roseum var. roseum Link (1832),



Heinrich F. Link, Christian G. D. Nees von Esenbeck A.C.J. Corda

1816-1818: Nees

Fusarium lateritium Nees (1816),
Fusarium lateritium f. lateritium Nees (1816),
Fusarium lateritium subsp. lateritium Nees (1816),
Fusarium lateritium var. lateritium Nees (1816
Fusarium heterosporum Nees (1817),
Fusarium heterosporum f. heterosporum Nees & T. Nees (1818),
Fusarium heterosporum var. heterosporum Nees & T. Nees (1818),

1823-1824: Schlechtendahl

Fusarium tremelloides Grev. (1823),
Fusarium oxysporum Schltdl. (1824);
Fusarium oxysporum f. oxysporum Schltdl. (1824),
Fusarium oxysporum subsp. oxysporum Schltdl. (1824),
Fusarium oxysporum var. oxysporum Schltdl. (1824
Fusarium sulphureum Schltdl. (1824);
Fusarium expansum Schltdl. (1824);

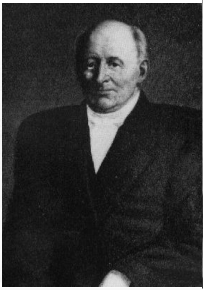
1828-1842:Corda

Fusarium flocciferum Corda (1828);
Fusarium flocciferum f. flocciferum Corda (1828),
Fusarium aurantiacum Corda (1829),
Fusarium roseum f. roseum Link (1832),
Fusarium roseum var. roseum Link (1832),
Fusarium strobilinum Corda (1837),
Fusarium merismoides Corda (1838),
Fusarium merismoides f. merismoides Corda (1838)
Fusarium merismoides var. merismoides Corda (1838)
Fusarium cinctum Corda (1842),

1832-1849:Frees

Fusarium fructigenum Fr. (1832);
Fusarium fructigenum var. fructigenum Fr. (1832),
Fusarium herbarum (Corda) Fr. (1849),
Fusarium herbarum var. herbarum (Corda) Fr. (1849),

Elias M.Fries



Samuel H. Schwabe

Jean Pierre F. Montagne

1839: Schwabe

Fusarium graminearum Schwabe (1839),
Fusarium graminearum var. graminearum Schwabe (1839)

1843: Montagne

Fusarium reticulatum Mont. (1843);
Fusarium reticulatum f. reticulatum Mont. (1843),
Fusarium reticulatum var. reticulatum Mont. (1843),
Fusarium platani Mont. (1849),

1843-1869: Wellman, Bérenger, Rabenh., Roberge, Westend. Lacroix, Kalchbr.

Fusarium retusum Wellman (1943)
Fusarium maculans Bérenger (1844),
Fusarium oxysporum var. aurantiacum (Corda) **Rabenh.**

(1844),

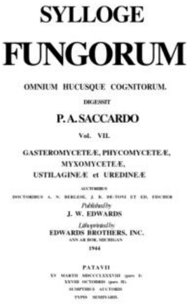
Fusarium subtectum Roberge ex Desm. (1846),
Fusarium peltigerae Westend. (1849);
Fusarium amentorum Lacroix (1854)
Fusarium pteridis Kalchbr. (1861)

1870: Fuckel

Fusarium sambucinum Fuckel (1863)
Fusarium nervisequum Fuckel (1870)
Fusarium nervisequum f. nervisequum Fuckel (1870)
Fusarium nervisequum f. platani (Lév.) Fuckel (1870)
Fusarium larvarum Fuckel (1870)
Fusarium larvarum var. larvarum Fuckel (1870)
Fusarium sambucinum f. sambucinum Fuckel (1870)
Fusarium sambucinum var. sambucinum Fuckel (1870)
Fusarium sphaeriae Fuckel (1870)
Fusarium sphaeriae var. sphaeriae Fuckel (1870)
Fusarium violaceum Fuckel (1870)

1875: Berk. & Broome & Ravenel (1875)

Fusarium heteronemum Berk. & Broome (1865)
Fusarium semitectum Berk. & Ravenel (1875)
Fusarium semitectum f. semitectum Berk. & Ravenel (1875)
Fusarium semitectum var. semitectum Berk. & Ravenel (1875)
Fusarium cucumerinum Berk. & Broome (1876),



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DIGESSIT
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PATAVII
XV MARTII MDCCCLXXXVIII (pars I)
XXVIII OCTOBRIS (pars II)
SUMPTIBUS AUCTORIS
TYPIS SEMINARII.

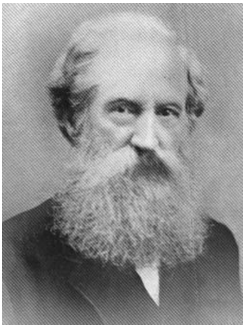
Pier Andrea Saccardo

1877-1955: Saccardo

Fusarium miniatum Sacc. (1877),
Fusarium pyrochroum (Desm.) Sacc. (1879),

Fusarium pyrochroum var. pyrochroum (Desm.) Sacc. (1879)
Fusarium album Sacc. (1880)
Fusarium album f. album Sacc. (1880)
Fusarium album var. album Sacc. (1880)
Fusarium album f. piceae-vulgaris Sacc. (1880)
Fusarium betae (Desm.) Sacc. (1880),
Fusarium roseum var. buxi Sacc. (1881),
Fusarium roseum var. calystegiae Sacc. (1881),
Fusarium roseum var. cucubali-bacciferi Sacc. (1881),
Fusarium roseum var. dulcamarae Sacc. (1881),
Fusarium roseum var. filicis Sacc. (1881),
Fusarium roseum var. helianti Sacc. (1881)
Fusarium roseum var. lupini-albi Sacc. (1881),
Fusarium roseum var. maydis Sacc. (1881),
Fusarium roseum var. phytolaccae Sacc. (1881),
Fusarium roseum var. rosae Sacc. (1881),
Fusarium roseum var. rusci Sacc. (1881)
Fusarium roseum var. vitalbae Sacc. (1881)
Fusarium lycopersici Sacc. (1881),
Fusarium obtusiusculum Sacc. (1881),
Fusarium solani (Mart.) Sacc. (1881),
Fusarium solani f. solani (Mart.) Sacc. (1881),
Fusarium solani var. solani (Mart.) Sacc. (1881),
Fusarium roseum var. helianti Sacc. (1881)
Fusarium roseum var. lupini-albi Sacc. (1881),
Fusarium roseum var. maydis Sacc. (1881),
Fusarium roseum var. phytolaccae Sacc. (1881),
Fusarium roseum var. rosae Sacc. (1881),
Fusarium roseum var. rusci Sacc. (1881)
Fusarium roseum var. vitalbae Sacc. (1881)
Fusarium lycopersici Sacc. (1881),
Fusarium obtusiusculum Sacc. (1881),
Fusarium solani (Mart.) Sacc. (1881),
Fusarium solani f. solani (Mart.) Sacc. (1881),
Fusarium solani var. solani (Mart.) Sacc. (1881),
Fusarium lateritium f. mori (Desm.) Sacc. (1884),
Fusarium oxysporum subsp. lycopersici Sacc. (1886),
Fusarium oxysporum var. lycopersici Sacc. (1886),
Fusarium pallidoroseum var. pallidoroseum (Cooke) Sacc. (1886),
Fusarium rimosum (Peck) Sacc. (1886),
Fusarium roseolum (Stephens) Sacc. (1886),
Fusarium argillaceum (Fr.) Sacc. (1886)
Fusarium avenaceum (Fr.) Sacc. (1886)

Fusarium avenaceum f. avenaceum (Fr.) Sacc. (1886),
Fusarium avenaceum subsp. avenaceum (Fr.) Sacc. (1886),
Fusarium avenaceum var. avenaceum (Fr.) Sacc. (1886),
Fusarium bacilligerum (Berk. & Broome) Sacc. (1886),
Fusarium berenice (Berk. & M.A. Curtis) Sacc. (1886),
Fusarium detonianum Sacc. (1886);
Fusarium candidum (Link) Sacc. (1886),
Fusarium cerealis (Cooke) Sacc. (1886),
Fusarium chilense (Mont.) Sacc. (1886),
Fusarium episphaericum (Cooke & Ellis) Sacc. (1886),
Fusarium equiseti (Corda) Sacc. (1886),
Fusarium equiseti f. equiseti (Corda) Sacc. (1886),
Fusarium equiseti subsp. equiseti (Corda) Sacc. (1886),
Fusarium equiseti var. equiseti (Corda) Sacc. (1886),
Fusarium fuckelii Sacc. (1886),
Fusarium incarnatum (Desm.) Sacc. (1886);
Fusarium lagenariae (Schwein.) Sacc. (1886),
Fusarium tricinctum (Corda) Sacc. (1886),
Fusarium tricinctum f. tricinctum (Corda) Sacc. (1886),
Fusarium tricinctum var. tricinctum (Corda) Sacc. (1886)
Fusarium urticearum (Corda) Sacc. (1886)
Fusarium obtusum (Cooke) Sacc. (1886),
Fusarium ossicola (Berk. & M.A. Curtis) Sacc. (1886),
Fusarium pallidoroseum (Cooke) Sacc. (1886)
Fusarium minutissimum (Desm.) Sacc. (1886)
Fusarium succisae (J. Schröt.) Sacc., Sylloge Fungorum (1892)
Fusarium culmorum (Wm.G. Sm.) Sacc. (1895);
Fusarium culmorum f. culmorum (Wm.G. Sm.) Sacc. (1892),
Fusarium culmorum var. culmorum (Wm.G. Sm.) Sacc. (1892)
Fusarium lolii (Wm.G. Sm.) Sacc. (1895),
Fusarium longissimum Sacc. & P. Syd. (1899)
Fusarium orthosporum Sacc. (1902),
Fusarium spicariae-colorantis Sacc. & Trotter ex De Jonge (1909),
Fusarium micropus Sacc. (1921),
Fusarium moniliforme var. oryzae Sacc. (1951)
Fusarium heterosporum f. aleuritis Saccas & Drouillon (1951),
Fusarium equiseti var. intermedium Saccas (1955),



Mordecai Cubitt Cooke

1878: Cooke & W.R. Gerard, Thüm. & Pass

Fusarium glandicola Cooke & W.R. Gerard (1878),
Fusarium tortuosum Thüm. & Pass. (1878),

1879: Pirotta & Riboni

Fusarium lactis Pirotta (1879);

1881: Cooke & Harkn

Fusarium eucalypti Cooke & Harkn. (1881),
Fusarium eucalypti Cooke & Harkn. (1881),

1882: Penzig and Ruan, Y.M. Jiang, W. Luo & J.H. Wan

Fusarium dimerum Penzig., Michelia 2 (8): 484 (1882)
Fusarium dimerum Penz. (1882),
Fusarium dimerum var. dimerum Penz. (1882)
Fusarium roseum var. dracaenae Roum. (1882),
Fusarium avenaceum f. fabalis X.Y. Ruan, Y.M. Jiang, W. Luo & J.H. Wang (1982),
Fusarium avenaceum f. fabarum X.Y. Ruan, Y.M. Jiang, W. Luo & J.H. Wang (1982),

1883: J. Schröt., Cooke & Harkn.

Fusarium deformans J. Schröt. (1883),
Fusarium obtusisporum Cooke & Harkn. (1884),

1886-1895: Berl. & Voglino and Ellis & Everh

Fusarium nivale Ces. ex Berl. & Voglino (1886),
Fusarium nivale f. nivale Ces. ex Berl. & Voglino (1886),
Fusarium nivale var. nivale Ces. ex Berl. & Voglino (1886),

Fusarium caeruleum Lib. ex Sacc. (1886);
Fusarium caeruleum var. caeruleum Lib. ex Sacc. (1886)
Fusarium heterosporum f. paspali Ellis & Everh. (1886),
Fusarium barbatum Ellis & Everh. (1888),
Fusarium acuminatum Ellis & Everh. (1895)
Fusarium acuminatum subsp. acuminatum Ellis & Everh. (1895)
Fusarium blasticola Rostr. (1895),

1887-1890: Cooke & Massee, Briard, Oudem.,
Fusarium bulbigenum Cooke & Massee (1887)
Fusarium bulbigenum f. bulbigenum Cooke & Massee (1887),
Fusarium bulbigenum var. bulbigenum Cooke & Massee (1887)
Fusarium hypocreoideum Cooke & Massee (1888),
Fusarium bugnicourtii Brayford (1987)
Fusarium elongatum Cooke (1890);
Fusarium asparagi Briard (1890)
Fusarium caricis Oudem. (1890),

1891: Lagerh. & Rabenh, Erikss., Allesch.,
Fusarium aquaeductuum (Radlk. & Rabenh.) Lagerh. & Rabenh. (1891),
Fusarium aquaeductuum subsp. aquaeductuum (Radlk. & Rabenh.) Lagerh. & Rabenh. (1891)
Fusarium aquaeductuum var. aquaeductuum (Radlk. & Rabenh.) Lagerh. & Rabenh. (1891)
Fusarium tritici Erikss. (1891)
Fusarium robiniae Pass. (1891),

1892: G.F. Atk, Pass., J. Schröt.
Fusarium persicae (Sacc.) G.F. Atk. (1892)
Fusarium vasinfectum var. vasinfectum G.F. Atk. (1892),
Fusarium vasinfectum G.F. Atk. (1892)
Fusarium vasinfectum f. vasinfectum G.F. Atk. (1892)
Fusarium cerasi Rolland & Ferry (1892),
Fusarium mali Allesch. (1892),
Fusarium succisae J. Schröt. (1892);

1893: Pound & Clem, Syd., E.F. Sm
Fusarium rhizogenum Pound & Clem. (1893),
Fusarium pyrochroum var. diatrypellicola Syd. (1893),

1894: Lambotte & Fautrey
Fusarium scirpi Lambotte & Fautrey (1894),
Fusarium scirpi f. scirpi Lambotte & Fautrey (1894)

Fusarium scirpi subsp. scirpi Lambotte & Fautrey (1894),
Fusarium scirpi var. scirpi Lambotte & Fautrey (1894)
Fusarium niveum E.F. Sm. (1894),

1895- 1908: Henn

Fusarium camerunense Henn. (1895),
Fusarium speiranthis Henn. (1896)
Fusarium sarcochroum f. polygalae-myrtifoliae Henn. (1898)
Fusarium paspalicola Henn. (1899),

Paul Christoph Hennings

Fusarium stromaticola Henn. (1900);
Fusarium vogelii Henn. (1902);
Fusarium eucalypticola Henn. (1901);
Fusarium euonymi-japonici Henn. (1902);
Fusarium derridis Henn. (1902)
Fusarium coccidicola Henn. (1904),
Fusarium juruanum Henn. (1904);
Fusarium paspali Henn. (1905);
Fusarium pentaclethrae Henn. (1905);
Fusarium sorghi Henn. (1907);
Fusarium coniosporiicola Henn. (1907),
Fusarium coniosporiicola Henn. (1907)
Fusarium coniosporiicola Henn. (1907),
Fusarium phyllachorae Henn. (1907);
Fusarium lucumae Henn. (1908)

1997-1900: Allesch., Brunaud., Speg., Prill. & Delacr, E.F. Sm., Syd. & P. Syd., Mussat

Fusarium roseum var. lonicerae Allesch. (1897),

Fusarium roseum f. visci Brunaud (1898)
Fusarium sapindophilum Speg. (1898),
Fusarium dianthi Prill. & Delacr. (1899),
Fusarium tracheiphilum E.F. Sm. (1899),
Fusarium euonymi Syd. & P. Syd. (1900);
Fusarium atrovirens (Berk.) Mussat (1900),

1901-1903: Bolley, Sorauer, Oudem., J.V. Almeida & Sousa da Câmara, Bres., C. Massal., C.J.J. Hall

Fusarium lini Bolley (1901),
Fusarium nivale (Fr.) Sorauer (1901),
Fusarium nicotianae Oudem. (1902),
Fusarium dimorphum J.V. Almeida & Sousa da Câmara (1903);
Fusarium eichleri Bres. (1903);
Fusarium lichenicola C. Massal. (1903),
Fusarium vasinfectum var. pisi C.J.J. Hall (1903),

1904-1910: J. Sheld, Schikora, **Koord., M.L. Lutz,Brick, Lindau, Peck, E.F. Sm, E.J. Butler**

Fusarium moniliforme J. Sheld. (1904),
Fusarium moniliforme f. moniliforme J. Sheld. (1904)
Fusarium moniliforme subsp. moniliforme J. Sheld. (1904),
Fusarium moniliforme var. moniliforme J. Sheld. (1904)
Fusarium vasinfectum var. pisi Schikora (1906),
Fusarium veratri (Allesch.) Höhn. (1906),
Fusarium javanicum Koord. (1907),
Fusarium theobromae M.L. Lutz (1907),
Fusarium decemcellulare Brick (1908),
Fusarium didymum (Harting) Lindau (1909),
Fusarium hibernans Lindau (1909);
Fusarium willkommii Lindau (1909),
Fusarium bartholomaei Peck (1909),
Fusarium juglandinum Peck (1909);
Fusarium cubense E.F. Sm. (1910),
Fusarium cubense var. cubense E.F. Sm. (1910),
Fusarium udum E.J. Butler (1910),

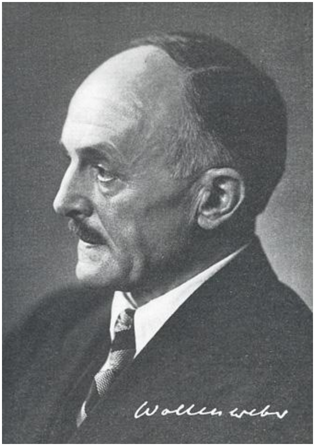
1910: Appel & Wollenweber

Fusarium discolor Appel & Wollenw. (1910
Fusarium discolor var. sulphureum (Schltdl.) Appel & Wollenw. (1910
Fusarium elegans Appel & Wollenw. (1910)
Fusarium falcatum Appel & Wollenw. (1910),
Fusarium falcatum var. falcatum Appel & Wollenw. (1910),

Fusarium gibbosum Appel & Wollenw. (1910),
Fusarium gibbosum var. gibbosum Appel & Wollenw. (1910),
Fusarium martii Appel & Wollenw. (1910),
Fusarium martii f. martii Appel & Wollenw. (1910),
Fusarium martii var. martii Appel & Wollenw. (1910),
Fusarium metachroum Appel & Wollenw. (1910);
Fusarium orthoceras Appel & Wollenw. (1910),
Fusarium orthoceras var. orthoceras Appel & Wollenw. (1910),
Fusarium rostratum Appel & Wollenw. (1910);
Fusarium rubiginosum Appel & Wollenw. (1910);
Fusarium sarcochroum f. mali (Allesch.) Ferraris (1910)
Fusarium subulatum Appel & Wollenw. (1910)
Fusarium ventricosum Appel & Wollenw. (1913

1912: Jacz., Bruschi, Dasz., Kabát & Bubák

Fusarium trifolii Jacz. (1912),
Fusarium lycopersici Bruschi (1912),
Fusarium albidoviolaceum Dasz. (1912)
Fusarium fraxini Kabát & Bubák (1912),



Die Fusarien
ihre Beschreibung, Schadwirkung
und Bekämpfung

Von

Dr. H. W. Wollenweber und Dr. O. A. Reinking
Oberregierungsrat und Mitglied der Biologischen Reichsanstalt für Land- und Forstwirtschaft Berlin-Dahlem
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Mit 95 Textabbildungen

BERLIN
VERLAGSBUCHHANDLUNG PAUL PAREY

Dr.H. W. Wollenweber

1912-1935: Wollenweber

Fusarium trichothecioides Wollenw. (1912)
Fusarium conglutinans Wollenw. (1913),
Fusarium conglutinans f. conglutinans Wollenw. (1913),
Fusarium conglutinans var. conglutinans Wollenw. (1913),
Fusarium lycopersici (Sacc.) Wollenw. (1913),
Fusarium poae (Peck) Wollenw. (1914);

Fusarium poae f. poae (Peck) Wollenw. (1913),
Fusarium redolens var. redolens Wollenw. (1913)
Fusarium redolens Wollenw. (1913)
Fusarium redolens f. redolens Wollenw. (1913
Fusarium udum (Berk.) Wollenw. (1913),
Fusarium udum var. pusillum Wollenw. (1913)
Fusarium udum var. udum (Berk.) Wollenw. (1913),
Fusarium vasinfectum var. inodoratum Wollenw. (1913),
Fusarium orthoceras var. triseptatum Wollenw. (1914
Fusarium batatas Wollenw. (1914),
Fusarium batatas var. batatas Wollenw. (1914),
Fusarium caudatum Wollenw. (1914)
Fusarium orthoceras var. albidoviolaceum (Dasz.) Wollenw. (1916),
Fusarium orthoceras var. longius (Sherb.) Wollenw. (1916),
Fusarium zonatum (Sherb.) Wollenw. (1916),
Fusarium zonatum f. zonatum (Sherb.) Wollenw. (1916)
Fusarium zonatum (Sherb.) Wollenw. (1916),
Fusarium zonatum f. zonatum (Sherb.) Wollenw. (1916),);
Fusarium scirpi var. filiferum (Preuss) Wollenw. (1916),
Fusarium scirpi var. longipes (Wollenw. & Reinking) Wollenw. (1916),
Fusarium zonatum (Sherb.) Wollenw. (1916),
Fusarium zonatum f. zonatum (Sherb.) Wollenw. (1916),);
Fusarium filiferum (Preuss) Wollenw. (1916);;
Fusarium dimerum var. majusculum Wollenw. (1916),
Fusarium asclerotium (Sherb.) Wollenw. (1916),
Fusarium anthophilum (A. Braun) Wollenw. (1916)
Fusarium anthophilum f. anthophilum (A. Braun) Wollenw. (1916),
Fusarium congoense Wollenw. (1916),
Fusarium lateritium var. longum Wollenw. (1916),
Fusarium moniliforme var. anthophilum (A. Braun) Wollenw. (1916),
Fusarium uncinatum Wollenw. (1917),
Fusarium uncinatum Wollenw. (1917),
Fusarium uncinatum Wollenw. (1917),
Fusarium fructigenum var. majus Wollenw. (1917),
Fusarium aquaeductuum var. pusillum Wollenw. (1917),
Fusarium aquaeductuum var. volutum Wollenw. (1917
Fusarium sambucinum var. coeruleum Wollenw. (1917),
Fusarium culmorum var. majus Wollenw. (1924),
Fusarium avenaceum var. pallens Wollenw. (1924),
Fusarium pusillum Wollenw. (1924)
Fusarium stilboides var. stilboides Wollenw. (1924),
Fusarium stilboides Wollenw. (1924)
Fusarium salicis var. minus Wollenw. (1924),

Fusarium fructigenum var. minus Wollenw. (1925),
Fusarium oxysporum var. gladioli Massey (1926),
Fusarium orthoconium Wollenw. (1926),
Fusarium dimerum var. pusillum (Wollenw.) Wollenw. (1930),
Fusarium ciliatum var. episphaericum (Cooke & Ellis) Wollenw. (1930),
Fusarium ciliatum var. majus Wollenw. (1930)
Fusarium conglutinans var. majus Wollenw. (1930),
Fusarium cavispermum var. minus Wollenw. (1930),
Fusarium culmorum var. cereale (Cooke) Wollenw. (1930),
Fusarium dimerum var. violaceum Wollenw. (1930
Fusarium equiseti var. bullatum (Sherb.) Wollenw. (1930),
Fusarium equiseti var. crassum Wollenw. (1930),
Fusarium herbarum var. avenaceum (Fr.) Wollenw. (1930),
Fusarium herbarum var. volutum Wollenw. (1930),
Fusarium graminum var. herbarum (Corda) Wollenw. (1930),
Fusarium lateritium var. fructigenum (Fr.) Wollenw. (1930),
Fusarium lateritium var. majus (Wollenw.) Wollenw. (1930),
Fusarium lateritium var. minus (Wollenw.) Wollenw. (1930),
Fusarium lateritium var. tenue Wollenw. (1930),
Fusarium lateritium var. uncinatum (Wollenw.) Wollenw. (1930),
Fusarium herbarum var. graminum (Corda) Wollenw. (1930),
Fusarium herbarum var. detonianum (Sacc.) Wollenw. (1930
Fusarium moniliforme var. minus Wollenw. (1930),
Fusarium sambucinum var. minus Wollenw. (1930),
Fusarium scirpi var. acuminatum (Ellis & Everh.) Wollenw. (1930),
Fusarium scirpi var. caudatum (Wollenw.) Wollenw. (1930),
Fusarium scirpi var. comma Wollenw. (1930),
Fusarium scirpi var. compactum Wollenw. (1930),
Fusarium semitectum var. majus Wollenw. (1930)
Fusarium solani var. aduncisporum (Weimer & Harter) Wollenw. (1930),
Fusarium solani var. martii (Appel & Wollenw.) Wollenw. (1930),
Fusarium solani var. medium Wollenw. (1930),
Fusarium sphaeriae var. majus Wollenw. (1930)
Fusarium sporotrichioides var. minus Wollenw. (1930),
Fusarium vasinfectum var. lutulatum (Sherb.) Wollenw. (1930),
Fusarium vasinfectum var. zonatum (Sherb.) Wollenw. (1930),
Fusarium poae f. pallens Wollenw. (1930),
Fusarium solani var. eumartii (C.W. Carp.) Wollenw. (1931),);
Fusarium reticulatum var. medium Wollenw. (1931),
Fusarium reticulatum var. negundinis (Sherb.) Wollenw. (1931),
Fusarium sambucinum var. medium Wollenw. (1931),
Fusarium sarcochroum var. robiniae (Pass.) Wollenw. (1931),

Fusarium scirpi var. copactum Wollenw. (1931),
Fusarium merismoides var. chlamydosporale Wollenw. (1931),
Fusarium merismoides var. crassum Wollenw. (1931),
Fusarium graminearum var. caricis (Oudem.) Wollenw. (1931),
Fusarium heterosporum var. congoense (Wollenw.) Wollenw. (1931
Fusarium heterosporum var. lolii (Wm.G. Sm.) Wollenw. (1931),
Fusarium heterosporum var. paspalicola (Henn.) Wollenw. (1931),
Fusarium javanicum var. radicicola Wollenw. (1931),
Fusarium dimerum var. nectrioides Wollenw. (1931),
Fusarium bulbigenum var. batatas Wollenw. (1931),
Fusarium bulbigenum var. blasticola (Rostr.) Wollenw. (1931),
Fusarium bulbigenum var. niveum (E.F. Sm.) Wollenw. (1931),
Fusarium bulbigenum var. tracheiphilum (E.F. Sm.) Wollenw. (1931),
Fusarium conglutinans var. citrinum Wollenw. (1931),
Fusarium flavum (Fr.) Wollenw. (1931);
Fusarium nivale var. majus Wollenw. (1931),
Fusarium solani var. striatum (Sherb.) Wollenw. (1931)
Fusarium stilboides var. minus (Wollenw.) Wollenw. (1931),
Fusarium solani var. eumartii (C.W. Carp.) Wollenw. (1931),);
Fusarium solani var. striatum (Sherb.) Wollenw. (1931)
Fusarium bactridioides Wollenw. (1934);
Fusarium solani var. minus Wollenw. (1935)
Fusarium oxysporum var. cubense (E.F. Sm.) Wollenw. (1935),

1915-1928 : Sherbakoff

Fusarium anguioides Sherb. (1915)
Fusarium anguioides f. anguioides Sherb. (1915)
Fusarium anguioides var. anguioides Sherb. (1915)
Fusarium anguioides var. caudatum Sherb. (1915)
Fusarium angustum Sherb. (1915)
Fusarium arthrosporioides Sherb. (1915)
Fusarium arthrosporioides var. arthrosporioides Sherb. (1915),
Fusarium arthrosporioides var. asporotrichum Sherb. (1915
Fusarium bullatum Sherb. (1915),
Fusarium culmorum var. leteius Sherb. (1915),
Fusarium cuneiforme Sherb. (1915),
Fusarium diversisporum Sherb. (1915)
Fusarium falcatum var. fuscum Sherb. (1915)
Fusarium oxysporum var. asclerotium Sherb. (1915),
Fusarium oxysporum var. longius Sherb. (1915),
Fusarium oxysporum var. resupinatum Sherb. (1915),
Fusarium lutulatum Sherb. (1915),
Fusarium lutulatum var. zonatum Sherb. (1915),

Fusarium martii var. minus Sherb. (1915),
Fusarium martii var. viride Sherb. (1915),
Fusarium redolens var. solani Sherb. (1915),
Fusarium sporotrichioides Sherb. (1915);
Fusarium sporotrichioides subsp. sporotrichioides Sherb. (1915),
Fusarium sporotrichioides var. sporotrichioides Sherb. (1915),
Fusarium striatum Sherb. (1915),
Fusarium udum var. solani Sherb. (1915),
Fusarium redolens var. solani Sherb. (1915),
Fusarium sporotrichioides Sherb. (1915);
Fusarium sporotrichioides subsp. sporotrichioides Sherb. (1915),
Fusarium sporotrichioides var. sporotrichioides Sherb. (1915),
Fusarium striatum Sherb. (1915),
Fusarium udum var. solani Sherb. (1915),
Fusarium solani var. cyanum Sherb. (1915),
Fusarium solani var. subfuscum Sherb. (1915
Fusarium sporotrichioides Sherb. (1915);
Fusarium sporotrichioides subsp. sporotrichioides Sherb. (1915),
Fusarium sporotrichioides var. sporotrichioides Sherb. (1915),
Fusarium striatum Sherb. (1915),
Fusarium udum var. solani Sherb. (1915),
Fusarium negundinis Sherb. (1923)
Fusarium spinaciae Sherb. (1923),
Fusarium tumidum Sherb. (1928),

1915-1924 : C.W. Carp., Gonz. Frag. Lindf., Beach, E.W. Brandes, Davis, J. Johnson, Cif.m Loubière

Fusarium eumartii C.W. Carp. (1915),
Fusarium roseum var. phaseoli Gonz. Frag. (1916),
Fusarium gymnosporangii Jaap (1916)
Fusarium redolens var. angustius Lindf. (1917),
Fusarium redolens var. angustius Lindf. (1917),
Fusarium conglutinans var. callistephi Beach (1918),
Fusarium cubense var. inodoratum E.W. Brandes (1919),
Fusarium martii f. phaseoli Burkh. (1919),
Fusarium sphaeriae var. robustum Davis (1919),
Fusarium oxysporum var. nicotianae J. Johnson (1921),
Fusarium roseum var. zeae Cif. (1921),
Fusarium sampaioi Gonz. Frag. (1924);
Fusarium sarcochroum var. casei Loubière (1924),
Fusarium oxysporum var. obtusiusculum (Sacc.) Cif. (1924),

1925-1935: Wollenweber & Reinking

Fusarium longipes Wollenw. & Reinking, (1925)
Fusarium moniliforme var. majus Wollenw. & Reinking (1925),
Fusarium moniliforme var. minus Wollenw. & Reinking (1925),
Fusarium moniliforme var. subglutinans Wollenw. & Reinking (1925),
Fusarium camptoceras Wollenw. & Reinking (1925);
Fusarium chlamydosporum Wollenw. & Reinking (1925);
Fusarium chlamydosporum var. chlamydosporum Wollenw. & Reinking (1925),
Fusarium moniliforme var. erumpens Wollenw. & Reinking (1925),
Fusarium neoceras Wollenw. & Reinking (1925);
Fusarium neoceras var. neoceras Wollenw. & Reinking (1925)
Fusarium coccophilum (Desm.) Wollenw. & Reinking (1935),
Fusarium oxysporum var. gladioli Massey (1926),
Fusarium orthoconium Wollenw. (1926),
Fusarium avenaceum var. volutum (Wollenw.) Wollenw. & Reinking (1935),
Fusarium orthoceras var. apii (P.E. Nelson & Sherb.) Wollenw. & Reinking (1935),

1926-1934: Weimer & Harter, Tucker, Caldis, Curzi, Linford, Jacz., Letov, Beeli, D. Stewart, . Benn, Fahmy, Kulk.

Fusarium aduncisporum Weimer & Harter (1926)
Fusarium batatas var. vanillae Tucker (1927),
Fusarium moniliforme var. fici Caldis (1927),
Fusarium moronei Curzi (1928);
Fusarium oxysporum var. medicaginis Weimer (1928),
Fusarium orthoceras var. pisi Linford (1928),
Fusarium buharicum Jacz. ex Babajan & Teterevn.-Babajan (1929);
Fusarium caucasicum Letov (1929);
Fusarium album var. abietinum Beeli (1930)
Fusarium conglutinans var. betae D. Stewart (1931),
Fusarium vasinfectum var. sesami Zaprom. (1926),
Fusarium scirpi var. nigrantum F.T. Benn. (1932),
Fusarium scirpi var. pallens F.T. Benn. (1932),
Fusarium vasinfectum var. egyptiacum Fahmy (1927),
Fusarium albedinis (Kill. & Maire) Malençon (1934)
Fusarium vasinfectum var. crotalariae Kulk. (1934),

1934-1936: Reinking , Sartory, R. Sartory, J. Mey. & Bamuli, Kirschst.

Fusarium concolor Reinking (1934);
Fusarium elongatum Reinking (1934)
Fusarium tumidum var. humi Reinking (1934),
Fusarium sublunatum Reinking (1934);

Fusarium sublunatum var. sublunatum Reinking (1934),
Fusarium sublunatum var. elongatum Reinking (1935),
Fusarium caeruleum var. cellulosae R. Sartory, J. Mey. & Bamuli (1935)
Fusarium phragmiticola Kirschst. (1936);

937-1939: P.E. Nelson & Sherb, Syd., Bugnic., Hepting,

Fusarium apii P.E. Nelson & Sherb. (1937)
Fusarium apii var. apii P.E. Nelson & Sherb. (1937),
Fusarium apii var. pallidum P.E. Nelson & Sherb. (1937)
Fusarium andinum Syd. (1939)
Fusarium oxysporum var. meniscoideum Bugnic. (1939
Fusarium perniciosum Hepting (1939),
Fusarium tumidum var. coeruleum Bugnic. (1939),

1940-1845: Wollenw., Dearn. & House, Toole, Rodigin, T.F. Yu, L. McCulloch, Weimer, Padwick..

Fusarium orthoceras var. ricini Wollenw. (1940),
Fusarium orthoceras var. betae Padwick (1940),
Fusarium orthoceras var. callistephi Padwick (1940),
Fusarium orthoceras var. ciceris Padwick (1940),
Fusarium orthoceras var. conglutinans Padwick (1940),
Fusarium ulmicola Dearn. & House (1940)
Fusarium oxysporum f. perniciosum Toole (1941),
Fusarium wolgense Rodigin (1942);
Fusarium citriforme Jamal. (1943),
Fusarium avenaceum var. fabae T.F. Yu (1944),
Fusarium orthoceras var. gladioli L. McCulloch (1944),
Fusarium udum var. cajani Padwick (1940),
Fusarium udum var. crotalariae Padwick (1940),
Fusarium solani f. lupini Weimer (1944)
Fusarium oxysporum f. radicis-lupini Weimer (1944)
Fusarium brachygibbosum Padwick (1945);

W. (Bill) C. Snyder and H. N. Hansen

1940-1949: W.C. Snyder & H.N. Hansen

Fusarium oxysporum f. apii (P.E. Nelson & Sherb.) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. batatas (Wollenw.) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. betae (D. Stewart) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. callistephi (Beach) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. cepae (Hanzawa) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. conglutinans (Wollenw.) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. cubense (E.F. Sm.) W.C. Snyder & H.N. Hansen (1940
Fusarium oxysporum f. gladioli (Massey) W.C. Snyder & H.N. Hansen (1940)
Fusarium oxysporum f. lini (Bolley) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. lupini W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. lycopersici (Sacc.) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. melonis W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. medicaginis (Weimer) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. narcissi W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. dianthi (Prill. & Delacr.) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. pini (Hartig) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. pisi (Linford) W.C. Snyder & H.N. Hansen (1940),);
Fusarium oxysporum f. tuberosi W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. udum (E.J. Butler) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. vasinfectum (G.F. Atk.) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. nicotianae (J. Johnson) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. niveum (E.F. Sm.) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. spinaciae (Sherb.) W.C. Snyder & H.N. Hansen (1940),
Fusarium oxysporum f. tracheiphilum (E.F. Sm.) W.C. Snyder & H.N. Hansen (1940)
Fusarium oxysporum f. barbati W.C. Snyder (1941),

Fusarium solani f. cucurbitae W.C. Snyder & H.N. Hansen (1941),
Fusarium solani f. eumartii (C.W. Carp.) W.C. Snyder & H.N. Hansen (1941)
Fusarium solani f. phaseoli (Burkh.) W.C. Snyder & H.N. Hansen (1941)
Fusarium solani f. pisi (F.R. Jones) W.C. Snyder & H.N. Hansen (1941)
Fusarium solani f. radicicola (Wollenw.) W.C. Snyder & H.N. Hansen (1941),
Fusarium oxysporum f. phaseoli J.B. Kendr. & W.C. Snyder (1942),
Fusarium oxysporum f. raphani J.B. Kendr. & W.C. Snyder (1942),
Fusarium episphaeria (Tode) W.C. Snyder & H.N. Hansen (1945)
Fusarium episphaeria f. coccophilum (Desm.) W.C. Snyder & H.N. Hansen (1945),
Fusarium episphaeria f. episphaeria (Tode) W.C. Snyder & H.N. Hansen (1945),
Fusarium nivale f. graminicola (Berk. & Broome) W.C. Snyder & H.N. Hansen (1945),
Fusarium roseum f. cereale (Cooke) W.C. Snyder & H.N. Hansen (1945
Fusarium rigidiusculum W.C. Snyder & H.N. Hansen (1945)
Fusarium tricinctum f. poae (Peck) W.C. Snyder & H.N. Hansen (1945),
Fusarium oxysporum f. rhois W.C. Snyder & Hepting (1949),

1948-1949: Steyaer, V.P. Bhide & Uppal, K.F. Baker, T.F. Yu & C.T. Fang, Laskaris, Toovey, Hepting

Fusarium xylarioides Steyaert (1948),
Fusarium orthoceras var. lathyri V.P. Bhide & Uppal (1948),
Fusarium oxysporum f. matthioli K.F. Baker (1948),
Fusarium oxysporum f. fabae T.F. Yu & C.T. Fang (1948
Fusarium oxysporum var. lathyri V.P. Bhide & Uppal (1948),
Fusarium oxysporum f. delphinii Laskaris (1949),
Fusarium oxysporum f. gladioli Toovey (1949),
Fusarium lateritium f. pini Hepting (1949),

1950: Raillo. Sawada, Zambett.. (Kill. & Maire) Malençon, Petr.,

Fusarium aquaeductuum subsp. medium (Wollenw.) Raillo (1950)
Fusarium aquaeductuum var. cavispermum (Corda) Raillo (1950)
Fusarium aquaeductuum var. flavum (Fr.) Raillo (1950),
Fusarium aquaeductuum var. dimerum (Penz.) Raillo (1950),
Fusarium avenaceum subsp. volutum (Wollenw.) Raillo (1950),
Fusarium avenaceum var. detonianum (Sacc.) Raillo (1950),
Fusarium avenaceum var. graminum (Corda) Raillo (1950)
Fusarium bulbigenum var. apii (P.E. Nelson & Sherb.) Raillo (1950),
Fusarium bulbigenum var. cucumis Raillo (1950
Fusarium bulbigenum var. pisi (Linford) Raillo (1950),
Fusarium compactum (Wollenw.) Raillo (1950);

Fusarium equiseti subsp. ossicola (Berk. & M.A. Curtis) Raillo (1950),
Fusarium heterosporum var. negundinis (Sherb.) Raillo (1950),
Fusarium lateritium subsp. majus (Wollenw.) Raillo (1950),
Fusarium oxysporum var. callistephi Raillo (1950),
Fusarium oxysporum var. cepae (Hanzawa) Raillo (1950),
Fusarium oxysporum var. dianthi (Prill. & Delacr.) Raillo (1950)
Fusarium oxysporum var. pisi (C.J.J. Hall) Raillo (1950),
Fusarium oxysporum var. solani Raillo (1950),
Fusarium oxysporum var. trifolii (Jacz.) Raillo (1950),
Fusarium martii var. caucasicum Raillo (1950),
Fusarium neoceras var. subglutinans (Wollenw. & Reinking) Raillo (1950),
Fusarium moniliforme subsp. majus (Wollenw. & Reinking) Raillo (1950),
Fusarium sambucinum var. cereale (Cooke) Raillo (1950),
Fusarium wollenweberi Raillo (1950);
Fusarium wollenweberi f. wollenweberi Raillo (1950),
Fusarium scirpi subsp. acuminatum (Ellis & Everh.) Raillo (1950),
Fusarium sporotrichioides subsp. minus (Wollenw.) Raillo (1950),
Fusarium sporotrichioides var. tricinctum (Corda) Raillo (1950),
Fusarium laricis Sawada (1950);
Fusarium nivale var. oryzae Zambett. (1950),
Fusarium oxysporum var. albedinis (Kill. & Maire) Malençon (1950),
Fusarium mindoanum Petr. (1950);

1951-1954:T.T. McClure, Pettinari, Prasad, P.R. Mehta & Lal, (Luc) C. Moreau, W.L. Gordon, Prasad & Patel (1952.

Fusarium solani f. batatas T.T. McClure (1951),
Fusarium oxysporum var. opuntiarum Pettinari (1951),
Fusarium oxysporum f. psidii Prasad, P.R. Mehta & Lal (1952),
Fusarium annulatum Bugnic. (1952)
Fusarium moniliforme f. subglutinans (Luc) C. Moreau (1952),
Fusarium oxysporum var. redolens (Wollenw.) W.L. Gordon (1952)
Fusarium lateritium f. cajani (Padwick) W.L. Gordon (1952),
Fusarium lateritium f. crotalariae (Padwick) W.L. Gordon (1952),
Fusarium oxysporum f. passiflorae W.L. Gordon (1954),
Fusarium solani f. nicotianae Prasad & Patel (1952),

1953- Y. Nisik. & Kyoto Watan, Vasudeva & Sriniv., Bagchee , (Steyaert) Delassus, Tochetto, (T.F. Yu) W. Yamam., Cif.

Fusarium bulbigenum var. nelumbicola Y. Nisik. & Kyoto Watan. (1953),
Fusarium orthoceras var. lentis Vasudeva & Sriniv. (1953),
Fusarium solani f. albiziae Bagchee (1954)
Fusarium oxysporum f. xylarioides (Steyaert) Delassus (1954),
Fusarium oxysporum var. herbemontis Tochetto (1954)
Fusarium avenaceum f. fabae (T.F. Yu) W. Yamam. (1955),

Fusarium dominicanum Cif. (1955)

1953-1987: Bilaĭ

Fusarium sporotrichiella Bilaĭ (1953),
Fusarium sporotrichiella var. poae (Peck) Bilaĭ (1953),
Fusarium sporotrichiella var. sporotrichiella Bilaĭ (1953),
Fusarium sporotrichiella var. sporotrichioides (Sherb.) Bilaĭ (1953),
Fusarium sporotrichiella var. tricinctum (Corda) Bilaĭ (1953),
Fusarium avenaceum var. herbarum (Corda) Bilaĭ (1955),
Fusarium microcera Bilaĭ (1955);
Fusarium microcera var. microcera Bilaĭ (1955),
Fusarium nivale var. larvarum (Fuckel) Bilaĭ (1955),
Fusarium solani var. caeruleum (Lib. ex Sacc.) Bilaĭ (1955),
Fusarium solani var. redolens (Wollenw.) Bilaĭ (1955),
Fusarium tricinctum var. anthophilum (A. Braun) Bilaĭ (1955),
Fusarium sambucinum var. trichothecioides (Wollenw.) Bilaĭ (1955),
Fusarium gibbosum var. bullatum (Sherb.) Bilaĭ (1987),
Fusarium avenaceum var. anguioides (Sherb.) Bilaĭ (1987),
Fusarium moniliforme var. lactis (Pirotta) Bilaĭ (1987),
Fusarium sambucinum var. ossicola (Berk. & M.A. Curtis) Bilaĭ (1987),
Fusarium sambucinum var. sublunatum (Reinking) Bilaĭ (1987),
Fusarium solani var. argillaceum (Fr.) Bilaĭ (1987),
Fusarium sporotrichiella var. poae (Peck) Bilaĭ (1987),
Fusarium sporotrichiella var. tricinctum (Corda) Bilaĭ (1987),
Fusarium oxysporum var. orthoceras (Appel & Wollenw.) Bilaĭ (1987),
Fusarium lateritium var. stilboides (Wollenw.) Bilaĭ (1987),
Fusarium microcera var. orthoconium (Wollenw.) Bilaĭ (1987),
Fusarium microcera var. cerasi (Rolland & Ferry) Bilaĭ (1987),
Fusarium gibbosum var. acuminatum (Ellis & Everh.) Bilaĭ (1987),
Fusarium sporotrichiella var. anthophilum (A. Braun) Bilaĭ (1987),

1954-1958: Gerlach, (Hepting) Carrera , Sauthoff, J.H. Owen, R.D. Raabe. (Ellis & Everh.) Arx, (Padwick) Erwin, Matus & K. Ishig.

Fusarium oxysporum f. cyclaminis Gerlach (1954),
Fusarium bulbigenum f. aechmeae Sauthoff & Gerlach (1957),
Fusarium vasinfectum var. perniciosum (Hepting) Carrera (1955),
Fusarium oxysporum f. cucumerinum J.H. Owen (1956),
Fusarium oxysporum f. aechmeae Sauthoff (1957),
Fusarium oxysporum f. hebes R.D. Raabe (1957),
Fusarium lunatum (Ellis & Everh.) Arx (1957),
Fusarium lateritium f. ciceris (Padwick) Erwin (1958),
Fusarium oxysporum f. melongenae Matus & K. Ishig. (1958),

1959-1962: Sawada, Petr., W.L. Gordon ex B.K. Bakshi & S. Singh ter , (Desm.) **Matuo & K. Satô, (Cooke & Harkn.) Arya & G.L. Jain, W. Yamam.**

Fusarium biseptatum Sawada (1959);
Fusarium ramulicola Sawada (1959);
Fusarium solani f. mori Sawada (1959),
Fusarium kurdicum Petr. (1959);
Fusarium solani f. dalbergiae W.L. Gordon ex B.K. Bakshi & S. Singh ter (1959),
Fusarium splendens Matuo & Takah. Kobay. (1960);
Fusarium solani f. piperis F.C. Albuq. (1961),
Fusarium solani f. xanthoxyli Y. Sakurai & Matuo (1961),
Fusarium lateritium f. mori (Desm.) Matuo & K. Satô (1962),
Fusarium oxysporum f. ciceris Matuo & K. Satô (1962),
Fusarium oxysporum f. eucalypti (Cooke & Harkn.) Arya & G.L. Jain (1962
Fusarium phyllostachydicola W. Yamam. (1962);

1964-1965:Y.N. Ming & T.F. Yu, G.M. Armstr. & J.K. Armstr., N. Barros

Fusarium otomycosis Y.N. Ming & T.F. Yu (1966);
Fusarium oxysporum f. cassiae G.M. Armstr. & J.K. Armstr. (1966),
Fusarium roseum f. phaseoli N. Barros (1966),
Fusarium solani f. keratitis Y.N. Ming & T.F. Yu (1966),
Fusarium solani f. viridiflavum Y.N. Ming & T.F. Yu (1964),
Fusarium solani f. robiniae Matuo & Y. Sakurai (1965),

1968-1969: Messiaen & R. Cass, Batikyan & Abramyan

Fusarium roseum var. arthrosporioides (Sherb.) Messiaen & R. Cass. (1968),
Fusarium roseum var. gibbosum (Appel & Wollenw.) Messiaen & R. Cass. (1968),
Fusarium semitectum var. violaceum Batikyan & Abramyan (1969),
Fusarium buxicola var. chlamydosporum Batikyan (1969),
Fusarium lateritium var. microconidium Batikyan & Abramyan (1969),
Fusarium martiellae-discolorioides Batikyan (1969);

1971: C. Booth, (E.J. Butler) W. Gams, (Padwick) Subram.

Fusarium epistroma (Höhn.) C. Booth (1971),
Fusarium fusarioides (Gonz. Frag. & Cif.) C. Booth (1971
Fusarium illudens C. Booth (1971)
Fusarium stoveri C. Booth (1971),
Fusarium lateritium var. buxi C. Booth (1971),
Fusarium solani var. caeruleum (Lib. ex Sacc.) C. Booth (1971),
Fusarium redolens f. spinaciae (Sherb.) Subram. (1971)
Fusarium solani f. hibisci Ribeiro et al. (1971),

Fusarium sacchari (E.J. Butler) W. Gams, Cephalosporium-artige Schimmelpilze: 218 (1971)
Fusarium merismoides f. ciceris (Padwick) Subram. (1971),

1973-1976: Joffe, P.K.S. Gupta, Tubaki, C. Booth & T. Harada
Fusarium equiseti var. compactum (Wollenw.) Joffe (1973),
Fusarium solani var. ventricosum (Appel & Wollenw.) Joffe (1973),
Fusarium equiseti var. caudatum (Wollenw.) Joffe (1974),
Fusarium equiseti var. longipes (Wollenw. & Reinking) Joffe (1974),
Fusarium sporotrichioides var. chlamydosporum (Wollenw. & Reinking) Joffe (1974),
Fusarium psidii P.K.S. Gupta (1974);
Fusarium enterolobii P.K.S. Gupta (1974);
Fusarium merismoides var. acetilereum Tubaki, C. Booth & T. Harada (1976),
Fusarium merismoides var. ecetilereum Tubaki, C. Booth & T. Harada (1976)

1976-1977: Nirenberg, T. Aoki & Samuels, Gerlach
Fusarium fijikuroi Nirenberg (1976);
Fusarium proliferatum (Matsush.) Nirenberg (1976);
Fusarium proliferatum var. minus Nirenberg (1976),
Fusarium sacchari var. elongatum Nirenberg (1976),
Fusarium sacchari var. subglutinans (Wollenw. & Reinking) Nirenberg (1976),
Fusarium verticillioides (Sacc.) Nirenberg (1976),
Fusarium proliferatum (Matsush.) Nirenberg ex Gerlach & Nirenberg (1982);
Fusarium proliferatum var. proliferatum (Matsush.) Nirenberg ex Gerlach & Nirenberg (1982),
Fusarium setosum Nirenberg & Samuels (1989);
Fusarium setosum Nirenberg & Samuels (1989);
Fusarium torulosum (Berk. & M.A. Curtis) Nirenberg (1995);
Fusarium venenatum Nirenberg (1995);
Fusarium nisikadoi T. Aoki & Nirenberg (1997);
Fusarium zealandicum Nirenberg & Samuels (2000),
Fusarium robustum Gerlach (1977);
Fusarium larvarum var. rubrum Gerlach (1977),
Fusarium lunulosporum Gerlach (1977)
Fusarium merismoides var. violaceum Gerlach (1977),
Fusarium chlamydosporum var. fuscum Gerlach (1977)

Wally F. O. Marasas

1982-1983: L.W. Burgess, P.E. Nelson & Toussoun, Marasas

Fusarium crookwellense L.W. Burgess, P.E. Nelson & Toussoun (1982);
Fusarium subglutinans (Wollenw. & Reinking) P.E. Nelson, Toussoun & Marasas (1983),
Fusarium subglutinans var. subglutinans (Wollenw. & Reinking) P.E. Nelson, Toussoun & Marasas (1983),

1983-1984: Subrahm, Rossman, Samuels & Rogerson

Fusarium lacertarum Subrahm. (1983);
Fusarium tasmanicum (McAlpine) Rossman (1983); ,
Fusarium staphyleae Samuels & Rogerson (1984),

1986-1987: L.W. Burgess & Trimboli, Marasas, P.E. Nelson, Toussoun & P.S. van Wyk

Fusarium nygamai L.W. Burgess & Trimboli (1986),
Fusarium polyphialidicum Marasas, P.E. Nelson, Toussoun & P.S. van Wyk (1986);
Fusarium dlaminii Marasas, P.E. Nelson & Toussoun (1986)
Fusarium beomiforme P.E. Nelson, Toussoun & L.W. Burgess, Mycologia 79: 884-889 (1987)

1987-1991: Chen

Fusarium solani var. petroliphilum Q.T. Chen & X.H. Fu (1987),
Fusarium sphaerosporum Q.T. Chen & X.H. Fu (1987);
Fusarium merismoides var. artocarpi X.H. Fu & Q.T. Chen (1989),
Fusarium merismoides var. persicicola X.H. Fu & Q.T. Chen (1989),
Fusarium moniliforme var. annulatum (Bugnic.) F.J. Chen (1991),
Fusarium subglutinans var. succisae (J. Schröt.) F.J. Chen (1991),

1988-1989: Tivoli, P.E. Nelson & Rabie, R.F. Castañeda, P. Oliva, Fresneda & N. Rodr.,

Fusarium roseum f. compactum Tivoli (1988),
Fusarium napiforme Marasas, P.E. Nelson & Rabie (1988);
Fusarium pallidoroseum var. majus (Wollenw.) R.F. Castañeda, P. Oliva, Fresneda & N. Rodr. (1989)
Fusarium setosum Nirenberg & Samuels (1989);

1990-1993:Agnihothr. & Nirenberg, A. Pande & V.G. Rao , Gruyter & J.H.M. Schneid,

Fusarium ambrosium (Gadd & Loos) Agnihothr. & Nirenberg (1990)
Fusarium oxysporum f. tabernaemontanae A. Pande & V.G. Rao (1990
Fusarium cereale (P. Karst.) Gruyter & J.H.M. Schneid. (1991),
Fusarium torulosum (Berk. & M.A. Curtis) Gruyter & J.H.M. Schneid. (1991);
Fusarium moniliforme var. hangzhouense Gong C. Wang & Q.M. Ye (1992),

1993-1998: G.A. Forbes, Windels & L.W. Burgess, Sangal., Summerell, Marasas & Logrieco, Klittich, J.F. Leslie, P.E. Nelson

Fusarium acuminatum subsp. armeniacum G.A. Forbes, Windels & L.W. Burgess (1993)
Fusarium avenaceum subsp. aywerte Sangal. & L.W. Burgess (1995)
Fusarium avenaceum subsp. nurragi Summerell & L.W. Burgess (1995),
Fusarium babinda Summerell, C.A. Rugg & L.W. Burgess (1995);
Fusarium globosum Rheeder, Marasas & P.E. Nelson (1996);
Fusarium thapsinum Klittich, J.F. Leslie, P.E. Nelson & Marasas (1997),
Fusarium musarum Logrieco & Marasas (1998);
Fusarium nelsonii Marasas & Logrieco (1998);

Kerry O'Donnell

1998: Nirenberg & O'Donnell, T. Aoki,

Fusarium acutatum Nirenberg & O'Donnell (1998)
Fusarium begoniae Nirenberg & O'Donnell (1998)
Fusarium brevicatenulatum Nirenberg & O'Donnell (1998)
Fusarium bulbicola Nirenberg & O'Donnell (1998);
Fusarium circinatum Nirenberg & O'Donnell (1998),
Fusarium concentricum Nirenberg & O'Donnell (1998);
Fusarium denticulatum Nirenberg & O'Donnell (1998);
Fusarium guttiforme Nirenberg & O'Donnell (1998);
Fusarium pseudocircinatum O'Donnell & Nirenberg (1998);
Fusarium pseudonygamai O'Donnell & Nirenberg (1998);
Fusarium pseudoanthophilum Nirenberg, O'Donnell & Mubat. (1998);
Fusarium ramigenum O'Donnell & Nirenberg (1998);
Fusarium kyushuense O'Donnell & T. Aoki (1998);
Fusarium phyllophilum Nirenberg & O'Donnell (1998);

1999-2000: O'Donnell & T. Aoki, W. Gams, Klamer, Benyon, Summerell & L.W. Burgess,

Fusarium pseudograminearum O'Donnell & T. Aoki (1999),
Fusarium miscanthi W. Gams, Klamer & O'Donnell (1999);
Fusarium aywerte (Sangal. & L.W. Burgess) Benyon & L.W. Burgess (2000)
Fusarium nurragi (Summerell & L.W. Burgess) Benyon, Summerell & L.W. Burgess (2000);
Fusarium armeniacum (G.A. Forbes, Windels & L.W. Burgess) L.W. Burgess & Summerell (2000);

2000-2002: Koord.) Q.M. Ye, Geiser & Juba, Palacios-Prü & V. Marcano, Marasas, Rheeder, Lampr., K.A. Zeller & J.F. Leslie, T. Aoki, O'Donnell & K. Ichik.

Fusarium solani var. javanicum (Koord.) Q.M. Ye (2000),
Fusarium hostae Geiser & Juba (2001);
Fusarium alkanophilum Palacios-Prü & V. Marcano (2001)
Fusarium andiyazi Marasas, Rheeder, Lampr., K.A. Zeller & J.F. Leslie (2001)
Fusarium fractiflexum T. Aoki, O'Donnell & K. Ichik. (2001);
Fusarium falciforme (G. Carrión) Summerb. & Schroers (2002

2003: T. Aoki, O'Donnell, K. Ichik, Britz, Marasas, M.J. Wingf., Summerell, J.F. Leslie, Yosh. Homma, Lattanzi

Fusarium sterilihyphosum Britz, Marasas & M.J. Wingf. (2002);
Fusarium mangiferae Britz, M.J. Wingf. & Marasas (2002);
Fusarium konzum Zeller, Summerell & J.F. Leslie (2003),

Fusarium tucumaniae T. Aoki, O'Donnell, Yosh. Homma & Lattanzi (2003);
Fusarium virguliforme O'Donnell & T. Aoki (2003);
Fusarium phaseoli (Burkh.) T. Aoki & O'Donnell (2003),


B. A. Summerell,


John F. Leslie


H Corby. Kistler

2004:Torp, Nirenberg, L.W. Burgess, Summerell, O'Donnell, T. Aoki, Kistler & Geiser, Baayen & Hooftman

Fusarium langsethiae Torp & Nirenberg (2004);
Fusarium gaditjirrii Phan, L.W. Burgess & Summerell (2004),
Fusarium acaciae-mearnsii O'Donnell, T. Aoki, Kistler & Geiser (2004)
Fusarium asiaticum O'Donnell, T. Aoki, Kistler & Geiser (2004)
Fusarium austroamericanum T. Aoki, Kistler, Geiser & O'Donnell (2004)
Fusarium boothii O'Donnell, T. Aoki, Kistler & Geiser (2004);
Fusarium brasilicum T. Aoki, Kistler, Geiser & O'Donnell (2004);
Fusarium meridionale T. Aoki, Kistler, Geiser & O'Donnell (2004);
Fusarium mesoamericanum T. Aoki, Kistler, Geiser & O'Donnell (2004);
Fusarium foetens Schroers, O'Donnell, Baayen & Hooftman (2004);
Fusarium matuoi Hosoya & Tubaki (2004),
Fusarium cortaderiae O'Donnell, T. Aoki, Kistler & Geiser (2004);


H.P. Bachmann

2005-2008: H.P. Bachm., T. Aoki & O'Donnell, Starkey, L.R. Gale, Kistler, Aberra, Z.H. Zhao & G.Z. Lu Fusarium brasiliense T. Aoki & O'Donnell (2005);
Fusarium cuneirostrum O'Donnell & T. Aoki (2005);
Fusarium gerlachii T. Aoki, Starkey, L.R. Gale, Kistler & O'Donnell (2007);

Fusarium vorosii B. Tóth, Varga, Starkey, O'Donnell, H. Suga & T. Aoki (2007);
Fusarium aethiopicum O'Donnell, Aberra, Kistler & T. Aoki (2008)
Fusarium delphinoides Schroers, Summerb., O'Donnell & Lampr. (2009),
Fusarium sinensis Z.H. Zhao & G.Z. Lu (2008);

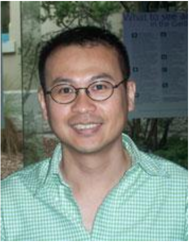



Yli-Mattila Tapani **R.C. Ploetz** Gabriel Otero-Colina S. Freeman

2009-2010: Schroers, Summerb. & O'Donnell, T. Aoki, Gagkaeva, Yli-Mattila, Kistler, , S. Freeman, Otero-Colina, Rodr.-Alv., Fern.-Pav., R.C. Ploetz, A. Jacobs, Marasas & P.S. van Wyk

Fusarium biseptatum Schroers, Summerb. & O'Donnell (2009),
Fusarium nectrioides (Wollenw.) Schroers, Summerb. & O'Donnell (2009),
Fusarium penzigii Schroers, Summerb. & O'Donnell (2009),
Fusarium ussurianum T. Aoki, Gagkaeva, Yli-Mattila, Kistler & O'Donnell (2009);
Fusarium mexicanum T. Aoki, S. Freeman, Otero-Colina, Rodr.-Alv., Fern.-Pav., R.C. Ploetz & O'Donnell (2010);
Fusarium ananatum A. Jacobs, Marasas & P.S. van Wyk (2010)





F. Ameena Nalim Antonio Moretti **E.C.Y. Liew**

2011: Samuels, Nalim & Geiser, Summerell & E.C.Y. Liew, T. Aoki & O'Donnell, P. Nicholson, Gagkaeva, Burkin, Kononenko, Gavrilova, Yli-Mattila, Van Hove, Waalwijk, Munaut, Logrieco & Ant. Moretti, Scaufl. & Munaut

Fusarium pseudensiforme Samuels, Nalim & Geiser (2011);
Fusarium rectiphorum Samuels, Nalim & Geiser (2011)
Fusarium kelerajum Samuels, Nalim & Geiser (2011);

Fusarium haematococcum Nalim, Samuels & Geiser (2011
Fusarium kurunegalense Samuels, Nalim & Geiser (2011)
Fusarium mahasenii Samuels, Nalim & Geiser (2011);
Fusarium burgessii M.H. Laurence, Summerell & E.C.Y. Liew (2011);
Fusarium crassistipitatum Scandiani, T. Aoki & O'Donnell (2011);
Fusarium louisianense L.R. Gale, Kistler, O'Donnell & T. Aoki (2011);
Fusarium nepalense T. Aoki, Jon Carter, P. Nicholson, Kistler & O'Donnell (2011);
Fusarium sibiricum Gagkaeva, Burkin, Kononenko, Gavrilova, O'Donnell, T. Aoki & Yli-Mattila (2011);
Fusarium musae Van Hove, Waalwijk, Munaut, Logrieco & Ant. Moretti (2011);
Fusarium temperatum Scaufl. & Munaut (2011);


Takayuki Aoki


David M. Geise


Ning Zhang


Cristiano S. Lima

2012-2013: T. Aoki, H. Suga, F. Tanaka, Scandiani & O'Donnell, C.S. Lima, Pfenning & J.F. Leslie, Geiser, Short & Ning Zhang

Fusarium cicatricum (Berk.) O'Donnell & Geiser (2013);
Fusarium azukiicola T. Aoki, H. Suga, F. Tanaka, Scandiani & O'Donnell (2012);
Fusarium tupiense C.S. Lima, Pfenning & J.F. Leslie (2012);
Fusarium cyanostomum (Sacc. & Flageolet) O'Donnell & Geiser (2013);
Fusarium cicatricum (Berk.) O'Donnell & Geiser (2013);
Fusarium keratoplasticum D. Geiser, O’Donnell, Short & Ning Zhang (2013);
Fusarium neocosmosporiellum O'Donnell & Geiser (2013)
Fusarium torreyae T. Aoki, J.A. Sm., L. Mount, Geiser & O’Donnell (2013);
Fusarium petroliphilum (Q.T. Chen & X.H. Fu) D. Geiser, O’Donnell, Short & Ning Zhang (2013),

3. Fusarium nomenclature

3.1. The name

- The genus Fusarium was first described and named by Link (1809), based on the classical shape of its fusiform macroconidia, then it was sanctioned under Fries 1821.
- The anamorphs within this clade have consistently been described as Fusarium, with occasional isolates or species classified in other genera including Acremonium, Cylindrocarpon, Pycnofusarium,Trichofusarium, Cephalosporium, and others particularly when the macroconidia are not observed.
- A number of lineages basal to the terminal Fusarium clade that produce Fusarium-like anamorphs were recently moved to new, revised, or existing genera based on morphological and phylogenetic considerations, such as Microcera, Macroconia, Fusicolla, and Stylonectria
- With the abandonment of dual nomenclature, a broad consensus within the global community of Fusarium researchers has strongly supported the unitary use of the name Fusarium instead of several teleomorph names linked to it.

3.2. One Fungus, One Name

- In a letter to the editor, Geiser et al., 2013, advocated recognizing the genus Fusarium as the sole name for a group that includes virtually all Fusarium species causing infection or mycotoxicosis in plants, man and animals.
- This circumscription will free scientists from any obligation to use other genus names, including teleomorphs, for species nested within this clade, and

preserve the application of the name Fusarium in the way it has been used for almost a century.

- Due to recent changes in the International Code of Nomenclature for algae, fungi, and plants, this is an urgent matter that requires community attention. The alternative is to break the longstanding concept of Fusarium into nine or more genera, and remove important taxa such as those in the F. solani species complex from the genus, a move they believe is unnecessary.

3.3. Species concepts and phylogenetic classification:

- **Morpho-species concept (MSC):**

  Current classifications schemes are based exclusively on a morphological species concept (MSC), typically Fusarium species are defined on the basis of a few distinctive morphological features:

  - curved, transversely septate conidia ("macroconidia") produced from sporodochia or pionnotes,
  - generally smaller conidia of various shapes and septation ("microconidia" and/or "mesoconidia") produced from unbranched or branched mycelial conidiophores, producing conidiogenous cells with one (monophialidic) or more (polyphialidic) openings, and
  - thick-walled, generally globose thallospores (chlamydospores) produced in or on hyphae or conidia, singly or in chains or bunches.
  - Sexual spores, when observed, produced in flaskshaped fruiting bodies (perithecia) that are usually in shades of red, orange, blue or purple, with little or no stromatal tissue. Asci produced from distinct hymenia, single-

walled (unitunicate) containing eight ascospores, which usually possess one or more septa, but can be aseptate.

- **Biological species concept (BSC):**
  - The biological species concept defines a species as members of populations that actually or potentially interbreed in nature, i.e. they produce sexual spores (teleomorph).
  - The biological species concept is verified by mating experiments
  - The biological species concept has been used to identify species in the Gibberella fujikuroi F. solani species complexes, that are known to produce teleomorph spores
  - This approach cannot be used for species that do not produce a teleomorph, such as F. oxysporum.
  - Thus, the concept has been developed for only a few species and mating experiments take about one month to complete, many strain fail to mate with standard testers, and negative data are equivocal.

- **Phylogenetic species concept (PSC)** :

  These species are defined as the smallest group of populations for which a unique profile of character states, including autapomorphies
  - **An same (<u>autapomorphy</u>) is a derived trait that is unique to one group**,
  - **A same (<u>synapomorphy</u>) is a derived trait shared by two or more groups.** and synapomorphies, are fixed within the populations

- Such species defining derived characters (**apomorphies)** form the basis of a cladistic analysis that are extending to all species of Fusarium.

3.4. Clades/Complexes

The genus Fusarium encompasses at least 20 genealogically exclusive clades, lineages or complexes:

1. F. sambucinum,
2. F. chlamydosporum,
3. F. incarnatum-equiseti
4. F. tricinctum
5. F. heterosporum
6. F. fujikuroi
7. F. nisikadoi
8. F. oxysporum
9. F. redolens
10. F. babinda
11. F. concolor
12. F. lateritium
13. F. buharicum
14. F. buxicola
15. F. staphyleae
16. F. solani
17. F. decemcellulare
18. F. albidum
19. F. dimerum
20. F. ventricosum species complexes or clades.

Each clade or complex comprises several species, e.g. 5 phylogenetically distinct species were identified within Fusarium oxysporum and approximately 50 species within Fusarium solani.

3.5. Formae speciales

Pathogenic strains of F. oxysporum cause wilt diseases on a number of agronomically important crops. Isolates that attack the same crop are included in the same forma specialis. Most formae speciales are pathogenic to a single crop e.g.

- F. oxysporum f. sp. cubense on banana,
- F. oxysporum f. sp. dianthi on carnation,
- F. oxysporum f. sp. vasinfectum on cotton.
- Some attack more than one crop, e.g. F. oxysporum f. sp. cucumerinum affects both cucumber and melon.
- Within F. oxysporum species, there is a high level of host specificity with over 120 described *formae speciales.*

3.6. Races

Most formae speciales of F. oxysporum are comprised of two or more races, whereas a small proportion are monotypic (e.g. F. oxysporum f. sp. radicis-lycopersici). Races in F. oxysporum are defined by their impact on differential host cultivars.

- F. oxysporum can be distinguished into physiological races on the basis of the capacity of the pathogen to attack differential carnation cultivars. To date, ten races have been described worldwide.

    - **Races 1 and 8** apparently originated in the Italian Riviera, where they are associated with Mediterranean carnation ecotypes found in Italy, France, and Spain. It attacks, mostly Gros Michel, Silk, Pome and Latundan cultivars
    - **Race 2** is widespread in all areas of carnation cultivation in the world. It attacks Bluggoe and other plantain (ABB genome) bananas
    - **Race 4** is found in carnation cultivars in the United States, Italy, Israel, Spain, and Colombia. It is pathogenic to Cavendish bananas

        - **Race 3** was initially classified as a Fod race, but DNA-based methods recently reclassified it as **F. redolens**, revealing that F. redolens and F. oxysporum not only are different species but also lack a sister group relationship.

Isolates in race 4 are further subdivided into Foc ‘tropical’ and Foc ‘subtropical’, based on whether or not they cause disease on Cavendish bananas under tropical environmental conditions.

3.7. Characterization of formae speciales based on pathogenicity

This can be problematic , because:

- complete sets of differentials may no longer be available
- pathogenicity tests can be influenced by temperature, host age, method of inoculation and other variables, those conducted in different laboratories may generate incongruent results.
- field testing is time-consuming, expensive, and appropriate test sites may not be available for a given race or for the needed length of time.
- F. oxysporum cannot be morphologically distinguished from other formae speciales that cause wilting in other hosts and other non-pathogenic F. oxysporum endophytes, saprophytes and antagonists.

3.8. Characterization of formae speciales into vegetative compatibility groups (VCG):

- Vegetative compatibility is controlled in Fusarium spp. by several vegetative (vic) or heterokaryon (het) incompatibility loci.
- For two individuals to be vegetatively compatible and form a stable heterokaryon, they need to share a common allele at each vic locus.

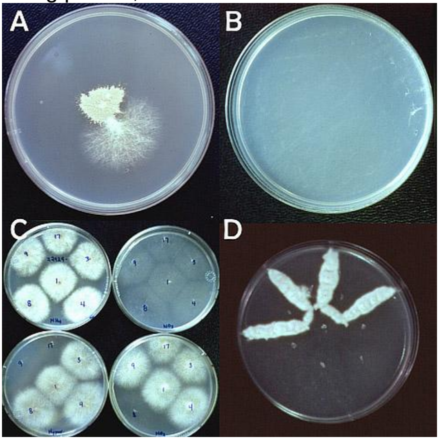
- VCGs represent good phenotypic characters for assessing diversity within populations.
- Vegetative compatibility may be determined with complementation assays between auxotrophic nutritional mutants.
- Puhalla (1985) developed an efficient technique for determining compatibility.
- **Vegetative compatibility test** in FOC has been assessed with nitrate-nonutilizing, *nit*, mutants.

  (A) Wildtype isolates are cultured on a chlorate containing medium on which mutant sectors eventually form (lower righthand corner).

  (B) Mutant sectors that develop usually grow diffusely on a medium that contains nitrate as the sole source of N. These *nit* mutants are phenotyped for utilization of different nitrogen sources to determine the portion of the nitrate utilization pathway that has been affected.

  (C) *nit* mutants have been plated on a basal medium that contains either ammonium (upper left), nitrate (upper right), hypoxanthine (lower left) or nitrite (lower right). The mutant at the top of each of these plates is a NitM mutant since it utilizes neither nitrate nor hypoxanthine. All that remain, except that on the lower left, utilize all but nitrate and are *nit*1 mutants.

  (**D**) **Wild-type growth** at the intersection of complementary mutants, as seen in the following picture,



(**Ploetz, R.C. 2005. Panama Disease: An Old Nemesis Rears its Ugly Head Part 2**)

VCGs of Fusarium oxysporum

To date, more than 20 VCGs of Fusarium oxysporum have been reported.

- Some are distributed worldwide,
- others have narrow distributions.
- Some of the VCGs have been recovered from a wide array of cultivars and genomes,
- some have come from specific banana genomes, and
- others have been found on a single cultivar.

3.9. Chemotypes of the Fusarium graminearum Complex (*Fg* complex)

Every species within the *Fg* complex is capable of producing type B trichothecenes in plants. Based on the chemical structure, including the acetylation position, 5 type B trichothecene chemotypes have been identified within the *Fg* complex:

1. **3-acetyldeoxy-nivalenol (3-AcDON):** *F. ussurianum* strains
2. **15-acetyldeoxynivalenol (15-AcDON)**: *F. aethiopicum*, *F. boothii* and *F.vorosii* strains
3. **4-acetylnivalenol (NIV):**
   F. meridionale and *F. gerlachii* strains
4. **3-AcDON, 15-AcDON and NIV:**
   F. graminearum s.s. and *F. asiaticum*.
5. **AcDON and NIV:**
   F. mesoamericanum, *F. austroamericanum*, *F. cortaderiae*, *F. brasilicum*can *and F. acaciae-mearnsii*.

4. Classification of the genusFusarium

4.1. Historical:

- The genus Fusarium was erected by Link in 1809 for fungi with canoe- or banana-shaped conidia
- Approximately 1000 species had been described in the period 1809-1935
- Wollenweber & Reinking , Germany (1935)- organized the genus in 16 sections,65 species, 55 varieties, 22 forms
- Snyder& Hansen (1940s), U SA- compressed the 16 sections into nine species, and the species in section Elegans into a single species, F. oxysporum.
- Railo (1950), Russia –mentioned 55 species
- Gordon (1952), Canada- mentioned 26 species
- Bilai (1955), Russia –mentioned 9 sections, 26 species, 29 varieties
- Messiaen & Cassi (1968), France-mentioned 9 species
- Booth (1971), England- 48 species and 104 forms and varieties
- Mato(1972), Japan- 10 species
- Joffe (1974), Isael-13 sections,33 species,14 varieties
- Gerlach (1982) , Germany-78 species
- Nelson, Toussoun & Massas (1983), USA -30 species
- Leslie and Summerell (2006) summarized information for 70 species of Fusarium, and this monographic publication was the first for the genus to integrate morphological and phylogenetic information.

4.2.Wollenbecher and Reinking classification of Fusarium genus (1935)

4.2.1. Fusarium species

I. Section: Eupionnotes (Nectria)

1. F. aquaeductuum (Radlk. et Rabh.) Lagh (N. episphaeriae v. coronate)
2. F. cavispermum, Corda
3. F. melanochlorum (Casp.) Sacc . (N. flavor-viridis)
4. F. merismoides Corda
5. F. dimerum Penzig
6. F. flavum (Fr.) Wr.

II. Section:Macroconia (Nectria)

7. F. coccophilum n.c. (N. coccophila)
8. F. buxicola Sacc, (N. Desmazierii)
9. F. expansum Schlechtendahl (N. stilbosporae)
10. F. sphaeriae Fuckel: (N. leptosphaeriae)
11. F. gigas Spegazzini

III. Section:Spicarioides (Calonectria)

12. F. decemcellulare Brick(Calonectria rigidinscula)

IV. Section: Submicrocera (Calonectria)

13. F. ciliatum Link (Calonectria decora)
14. F. cerasi Roll. et Ferry

V. Section:Pseudomicrocera (Calonectria)

15. F. juruanum P. Henn (Calonectria diploa)
16. F. orthoconium Wr.

VI. Section:Arachnites (Calonectria)

17. F. nivale (Fr.) Ces (Calonectria graminicola)
18. F. kühnii (Fuck.) Sacc.
19. F. larvarum Fuck

VII. Section:Sporotrichiella

20. F. poae (Peck) Wr.
21. F. chlamydosporum Wr. et RG.
22. F. tricinctum (Cda.) Sacc.
23. F. sporotrichioides Sherb.

VIII. Section:Roseum

24. F. avenaceum (Fr.) Sacc.
25. F. graminum Corda
26. F. arthrosporioides Sherb.
27. F. De Tonianum Sacc.

IX. Section:Arthrosporiella

28. F. semitectum Berk. et Rav.
29. F. camptoceras Wr. et Rg.
30. F. anguioides Sherb.
31. F. concolor Rh.
32. F. diversisporum Sherb.

X. Section:Gibbosum (Gibberella)

33. F. scirpi Lamb. et Fautr. with var. acuminatum (G. acuminate)
34. F. equiseti (Cda.) Sacc. with var. bullatum (G. intricans)

XI. Section:Discolor (Gibberella)

Subsection Neesiola

35. F. heterosporum Nees
36. F. reticulatum Mont. (Gibberella cyanea ?)

Subsection Saubinetii (gibberella)

37. F. graminearum Schwabe: (G. saubinetii)
38. F. sambucinum Fuckel (G. pulicaris)
39. F. culmorum (W.G.Sm.) Sacc.
40. F. flocciferum Corda (G. heterochroma)
41. F. sublunatum Rg.
42. F. macroceras Wr. et Rg.
43. F. tumidum Sherb.

Subsection Trichthecioides

44. F. trichothecioides Wr.
45. F. bacteridioides Wr.

XII. Section:Laterituim (Gibberella)

46. F. lateritium Nees (Gibberella baccata)
47. F. sacrochroum (Desm.) Sacc (G. pseudopulicaris)
48. F. stilboides Wr.

XIII. Section:Liseola (Gibberella)

49. F. moniliforme Sheld. (Gibberella fujikuroi)
50. F. lactis Pir. et Rib.
51. F. neoceras Wr. et Rg

XIV. Section:Elegans

Subsection Ortocera

52. F. orthoceras App et Wr.
53. F. conglutinans Wr
54. F. lini Bolley
55. F. bostrycoides Wr. et Rg.
56. F. angustum Sherb

Subsection Constrictum

57. F. bulbigenum Cke. et Mass

Subsection Oxysporum

58. F. oxysporum Schl.
59. F. dianthi Prill. et Del.
60. F. vasinfectum Atk.
61. F. redolens Wr.

XV. Section:Martiella (Hypomyces)

62. F. javanicum Koord. (Hypomyces)
63. F. solani (Mart. Pr. P.) App. et Wr.
64. F. coeruleum (Lib.) Sacc

XVI. Section:Ventrocosum (Hypomyces)

65. F. argillaceum Fr.) Sacc.: (Hypomyces solani)

4.2.2. Fusarium varieties

1. F. aquaeductuum (Radlk. et Rabh.) Lagh. v. medium
2. F. avenaceum (Fr.) Sacc. v. volutum n.c.
3. F. bulbigenum Cke. et Mass v. batatas Wr.
4. F. bulbigenum Cke. et Mass v. blasticola (Rostr.) Wr.
5. F. bulbigenum Cke. et Mass v. lycopersici (Brushi)Wr.
6. F. bulbigenum Cke. et Mass v. niveum (E.F.S,.) Wr.
7. F. bulbigenum Cke. et Mass v. tracheiphilum (E.F.S,.) Wr.
8. F. conglutinans Wr. v. betae Stewart
9. F. conglutinans Wr. v. citrinum Wr.
10. F. conglutinans Wr. v. callistephi Beach
11. F. culmorum (W.G.Sm.) Sacc. v. cereal (Cke.) Wr.
12. F. dimerum Penzig v. nectrioides Wr.
13. F. dimerum Penzig v. pusillum Wr.
14. F. dimerum Penzig v. violaceum Wr.
15. F. equiseti (Cda.) Sacc. v. bullatum (Sherb.)Wr.: Gibberella intricans Wr.
16. F. heterpsporum Nees v. congoense Wr.

17. F. javanicum Koord. v. ensiforme (wr. et Rg.) Wr.:Hypomyces ipomoeae (Hals.) v. major Wr,
18. F. javanicum Koord. v. radicicola Wr.: : Hypomyces ipomoeae (Hals.) f. 1 Wr.
19. F. lateritium Nees v. longum Wr.
20. F. lateritium Nees v.majus Wr.: Gibberella baccata (Wallr.) Sacc. v. major Wr.
21. F. lateritium Nees v. minus Wr.
22. F. lateritium Nees v. mori Desm.: Gibberella baccata (Wallr.) Sacc. v. moricola (DNtrs.) Wr.
23. F. lateritium Nees v. uncinatum Wr.
24. F. merismoides Corda v. chlamydosporale Wr.
25. F. merismoides Corda v. crassum Wr.
26. F. moniliforme Sheldon: Gibberella Fujikuroi (Saw.) Wr.
27. F. moniliforme Sheldon v. anthophilum (A.Br.) Wr.
28. F. moniliforme Sheldon v. minus Wr.
29. F. moniliforme Sheldon v. subglutinans Wr. et Rg.: Gibberella Fujikuroi (Saw) Wr. v. subglutinans Edw.
30. F. nivale (Fr.) Ces.: v. majus Wr.: Calonectria graminicola (Berk. et Brme.) Wr. v. neglecta Krpe
31. F. orthoceras App et Wr. v. apii (Nels. et Cochr.) n.c.
32. F. orthoceras App et Wr. v. pisi Linford
33. F. oxysporum Schl. v. aurantiacum (Lk.) Wr.
34. F. oxysporum Schl. v. cubense (F.F.Sm.) n.c.
35. F. oxysporum Schl. v. Gladioli Mass.
36. F. oxysporum Schl. v. medicaginis Weimer
37. F. oxysporum Schl. v. nicotianae Johns.
38. F. reticulatum Mont. v. negundinis (Sherb.) Wr.
39. F. sambucinum Fuck. v. minus Wr.
40. F. scirpi Lamb. et Fautr. v. acuminatum (Ell. et Ev.) Wr.: Gibberella accuminata Wr.
41. F. scirpi Lamb. et Fautr. v. caudatum Wr.
42. F. scirpi Lamb. et Fautr. v. compactum Wr.
43. F. scirpi Lamb. et Fautr. v. filiferum (Presuu) Wr.
44. F. semitectum Berk. et Rav. v. majus Wr.
45. F. solani (Mart. Pr. P.) App. et Wr. v. aduncisporum (Weim et Hart) Wr.
46. F. solani (Mart. Pr. P.) App. et Wr. v. eumartii (Carp.) Wr. Hypomyces haematococcus (Berk et Brme.) Wr.

47. F. solani (Mart..) v. Martii (App. et Wr.) Wr.
48. F. solani (Mart.) App. et Wr. v. minus Wr. hypomyces haematococcus (Berk. et Brme.) v. breviconus Wr.
49. F. solani (Mart.) App. et Wr. v. striatum (Sherb.) Wr.: hypomyces haematococcus (Berk. et Brme.) v. cancri (Rutg.) Wr.
50. F. sporotrichioides Sherb. v. minus Wr.
51. F. sublunatum v. elongatum Rg.
52. F. tumidum Sherb. v. humi Rg.
53. F. vasinfectum Atk. v. lutulatum (Sherb.) Wr.
54. F. vasinfectum Atk. v. zonatum (Sherb.) Wr.
55. F. aquaeductuum (Radlk. et Rabh.) Lagh. v. medium Wr.: Necteria episphaeria (Tode) Fr.

4.2.3. Fusarium formae

1. F. avenaceum (Fr.) Sacc. f.1 n.c.
2. F. orthoceras App et Wr. v. apii (Nels. et Cochr.) f. 1. n.c.
3. F. oxysporum Schl. f. 1 Wr
4. F. oxysporum Schl. f. 2 Wr
5. F. oxysporum Schl. f. 6 Wr
6. F. oxysporum Schl. f. 7 Wr
7. F. oxysporum Schl. f. 8 Snyder
8. F. oxysporum Schl. v. aurantiacum (Lk.) f. 1 Wr.
9. F. redolens f. 1 Wr.
10. F. reticulatum Mont. f. 1 Wr.
11. F. sambucinum Fuck. f. 1 Wr.
12. F. sambucinum Fuck. f. 2 Wr.
13. F. sambucinum Fuck. f. 4 Wr.
14. F. sambucinum Fuck. f. 5 Wr.
15. F. sambucinum Fuck. f, 6 Wr.
16. F. solani (Mart..) v. Martii (App. et Wr.) f. 1 Wr.
17. F. solani (Mart..) v. Martii (App. et Wr.) Wr. f. 2 Snyder
18. F. solani (Mart..) v. Martii (App. et Wr.) Wr. f. 3 Snyder
19. F. vasinfectum Atk. f; 1 Wr.
20. F. vasinfectum Atk. f; 2 n.c.
21. F. vasinfectum Atk. v. zonatum (Sherb.) f. 1 (Lk.) et Bail.) Wr.
22. F. vasinfectum Atk. v. zonatum (Sherb.) f. 2 (Lk.) et Bail.) Wr.

4.3. Snyder and Hansen classification, 1940

1. Fusarium episphaeria
2. Fusarium rigidiuscula
3. Fusarium nivale
4. Fusarium tricinctum
5. Fusarium roseum
6. Fusarium lateritium
7. Fusarium moniliforme
8. Fusarium oxysporum
9. Fusarium solani

4.4. A. Raillo classification, 1950

1. Fusarium anguioides f. 1 Raillo
2. Fusarium anguioides f. 2 Raillo
3. Fusarium anthophilum f. 1 Raillo
4. Fusarium anthophilum f. 2 Raillo
5. Fusarium aquaeductuum subsp. medium (Wollenw.) Raillo,
6. Fusarium aquaeductuum var. cavispermum (Corda) Raillo,
7. Fusarium aquaeductuum var. dimerum (Penz.) Raillo
8. Fusarium aquaeductuum var. flavum (Fr.) Raillo
9. Fusarium avenaceum subsp. volutum (Wollenw.) Raillo
10. Fusarium avenaceum var. detonianum (Sacc.) Raillo
11. Fusarium avenaceum var. graminum (Corda) Raillo
12. Fusarium bulbigenum var. apii (R. Nelson & Sherb.) Raillo
13. Fusarium bulbigenum var. cucumis Raillo
14. Fusarium bulbigenum var. pisi (Linford) Raill
15. Fusarium caudatum f. 1 Raillo
16. Fusarium caudatum var. filiferum Raillo
17. Fusarium compactum (Wollenw.) Raillo
18. Fusarium conglutinans f. 1 Raillo
19. Fusarium equiseti f. 1 Raillo
20. Fusarium equiseti f. 1 Raillo
21. Fusarium equiseti f. 2 Raillo
22. Fusarium equiseti subsp. ossicola (Berk. & M.A. Curtis) Raillo

23. Fusarium flocciferum f. 1 Raillo
24. Fusarium heterosporum f. 1 Raillo
25. Fusarium heterosporum f. 2 Raillo
26. Fusarium heterosporum var. negundinis (Sherb.) Raillo
27. Fusarium javanicum subsp. ensiforme (Wollenw. & Reinking) Raillo
28. Fusarium lateritium subsp. majus (Wollenw.) Raillo
29. Fusarium martii var. caucasicum Raillo
30. Fusarium moniliforme subsp. majus (Wollenw. & Reinking) Raillo
31. Fusarium neoceras var. subglutinans (Wollenw. & Reinking) Raillo
32. Fusarium oxysporum var. callistephi Raillo
33. Fusarium oxysporum var. cepae (Hanzawa) Raillo
34. Fusarium oxysporum var. dianthi (Prill. & Delacr.) Raillo,
35. Fusarium oxysporum var. pisi (C.J.J. Hall) Raillo
36. Fusarium oxysporum var. solani Raillo
37. Fusarium oxysporum var. trifolii (Jacz.) Raillo
38. Fusarium poae f. 1 Raillo
39. Fusarium sambucinum f. 1 Raillo
40. Fusarium sambucinum f. 2 Raillo
41. Fusarium sambucinum var. cereale (Cooke) Raillo
42. Fusarium sarcochroum f. 1 Raillo
43. Fusarium scirpi subsp. acuminatum (Ellis & Everh.) Raillo
44. Fusarium semitectum f. 1 Raillo
45. Fusarium sporotrichioides subsp. minus (Wollenw.) Raillo
46. Fusarium sporotrichioides var. tricinctum (Corda) Raillo
47. Fusarium wollenweberi Raillo
48. Fusarium wollenweberi f. 1 Raillo

4.5. W. Gerlach & H.I. Nierenberg classification, 1982

1. Fusarium acuminatum Ell. & Kellerm.
2. Fusarium anguioides Sherb.
3. Fusarium annulatum Bugnicourt
4. Fusarium anthophilum (A. Braun) Wollenw.
5. Fusarium aquaeductuum (Radlk. & Rabenh.) Lagerh. var. aquaeductuum
6. Fusarium aquaeductuum (Radlk. & Rabenh.) Lagerh. var. medium Wollenw.
7. Fusarium arthrosporioides Sherb.

8. Fusarium avenaceum (Fr.) Sacc. var. avenaceum
9. Fusarium avenaceum (Fr.) Sacc. var. volutum Wollenw. & Reinking
10. Fusarium bactridioides Wollenw.
11. Fusarium buharicum Jaczewski ex Babayan & Temereyenkoyea
12. Fusarium buxicola Sacc
13. Fusarium camtoceras Wollenw. & Reinking
14. Fusarium caucasicum Letov
15. Fusarium cavispermum Corda
16. Fusarium chlamydosporum Wollenw. & Reinking var. chlamydosporum
17. Fusarium chlamydosporum Wollenw. & Reinking var. fuscum Gerlach
18. Fusarium ciliatum Link
19. Fusarium coccidicola P. Henn
20. Fusarium coccophilum (Desm.) Wollenw. & Reinking
21. Fusarium coeruleum (Libert) ex Sacc.
22. Fusarium compactum (Wollenw.) Gordon
23. Fusarium concolor Reinking
24. Fusarium culmorum (W. G. Smith) Sacc.
25. Fusarium decemcellulare Brick.
26. Fusarium detonianum Sacc.
27. Fusarium dimerum Penzig in Sacc.
28. Fusarium diversisporum Sherb.
29. Fusarium epistroma (Höhnel) C. Booth
30. Fusarium equiseti (Corda) Sacc. var. equiseti
31. Fusarium eumartii Carpenter
32. Fusarium expansum Schlecht.
33. Fusarium flavum (Fr.) Wollenw.
34. Fusarium flocciferum Corda
35. Fusarium fujikuroi Nirenberg
36. Fusarium gigas Speg.
37. Fusarium graminearum Schwabe
38. Fusarium graminum Corda

39. Fusarium heterosporum Nees ex Fr. var. congoense (Wollenw.) Wollenw.
40. Fusarium heterosporum Nees ex Fr. var. heterosporum
41. Fusarium illudens C. Booth
42. Fusarium inflexum R. Schneider in Schneider & Dalchow
43. Fusarium javanicum Koorders
44. Fusarium kuehnii (Fuckel) Sacc.
45. Fusarium lactis Pirotta & Riboni
46. Fusarium larvarum Fuckel
47. Fusarium larvarum Fuckel var. rubrum Gerlach
48. Fusarium lateritium Nees ex Link. var. lateritium
49. Fusarium lateritium Nees ex Link. var. longum Wollenw.
50. Fusarium lateritium Nees ex Link. var. majus (Wollenw.) Wollenw.
51. Fusarium longipes Wollenw. & Reinking
52. Fusarium lunulosporum Gerlach
53. Fusarium macroceras Wollenw. & Reinking
54. Fusarium melanochlorum (Casp.) Sacc.
55. Fusarium merismoides (Corda) var. merismoides
56. Fusarium merismoides Corda var. acetilereum Tubakai, C. Booth & Harada
57. Fusarium merismoides Corda var. chlamydosporale Wollenw.
58. Fusarium merismoides Corda var. crassum Wollenw.
59. Fusarium merismoides Corda var. violaceum Gerlach
60. Fusarium neoceras Wollenw. & Reinking
61. Fusarium nivale Ces. Ex Sacc. var majus Wollenw.
62. Fusarium nivale Ces. Ex Sacc. var. nivale
63. Fusarium orthoconium Wollenw.
64. Fusarium oxysporum Schlecht. var. meniscoideum Bugnicourt
65. Fusarium oxysporum Schlecht. var. Oxysporum
66. Fusarium poae (Peck) Wollenw. in Lewis
67. Fusarium proliferatum (Matsushima) Nirenberg
68. Fusarium proliferatum (Matsushima) Nirenberg var. minus Nirenberg
69. Fusarium redolens Wollenw.
70. Fusarium reticulatum Montagne var. reticulatum

71. Fusarium robustum Gerlach
72. Fusarium sacchari (Butler) W. Gams
73. Fusarium sacchari (Butler) W. Gams var. elongatum Nirenberg
74. Fusarium sacchari (Butler) W. Gams var. subglutinans (Wollenw. & Reinking) Nirenberg
75. Fusarium sambucinum Fuckel var. coeruleum Wollenw.
76. Fusarium sambucinum Fuckel var. sambucinum
77. Fusarium sarcochroum (Desm.) Sacc.
78. Fusarium semitectum Berk. & Rav. in Berkeley var. majus Wollenw.
79. Fusarium semitectum Berk. & Rav. in Berkeley var. semitectum
80. Fusarium solani (Mart.) Sacc. var. solani
81. Fusarium sphaeriae Fuckel
82. Fusarium sporotrichioides Sherb. var. minus Wollenw.
83. Fusarium sporotrichioides Sherb. var. sporotrichioides
84. Fusarium stilboides Wollenw. var. stilboides
85. Fusarium stoveri
86. Fusarium sublunatum Reinking var. elongatum (Reinking) Reinking in Wollenweber & Reinking
87. Fusarium sublunatum Reinking var. sublunatum
88. Fusarium succisae (Schröter) Sacc.
89. Fusarium sulphureum Schlecht.
90. Fusarium tabacinum (Beyma) W. Gams in Gams & Gerlagh
91. Fusarium trichothecioides Wollenw. in Jamieson & Wollenweber
92. Fusarium tricinctum (Corda) Sacc.
93. Fusarium tumidum Sherb. var. coeruleum Bugnicourt
94. Fusarium tumidum Sherb. var. humi Reinking
95. Fusarium tumidum Sherb. var. tumidum
96. Fusarium udum Butler
97. Fusarium ventricosum Appel & Wollenw.
98. Fusarium verticillioides (Sacc.) Nirenberg
99. Fusarium xylarioides Steyaert

4.6. C. Booth classification, 1971.

4.6.1. Fusarium species

1. Section:Arachnites

1. F. stoveri Booth
2. F. tabacinum (Beyma) W. Gams
3. F. dimerum Penzig
4. F. nivale (Fr.) Ces. Rabenh.

[Submicrocera]

2. Section:Martiella

[Ventricosum]

5. F. solani (Mart.) Sacc.
6. F. illudens Booth
7. F. ventricosum Appel & Wollenweber
8. F. tumidum Sherb

3. Section:Epispheria

[**Eupionnotes and Macroconia**]

9. F. aquaeductuum Lagh.
10. F. buxicola Sacc.
11. F. epistromum (Höhn.) Sacc.
12. F. melanochlorum (Casp.) Sacc.
13. F. merismoides Corda
14. F. sphaeriae Fockel
15. F. gigas Speg.

4. Section:Spicarioides

16. F. decemcellulare Brick.

5. Section: Sporotrichiella

17. F. poae (Peck) Wrollenweber
18. F. tricinctum (Corda.) Sacc

6. Section: Arthrosporiella

19. F. sporotrichioides Sherb.
20. F. fusarioides (Frag. & Cif,) Booth

[**Roseum**]

21. F. avenaceum (Corda ex Fr.) Sacc.
22. F. camptoceras Wollenw. & Reink.
23. F. semitectum Berk. & Berkeley

7. Section: Coccophilum

24. F. larvarum Fuckel.
    [**Pseudomicrocera and Macroconia**]
25. F. coccophilum (Desm.) Wollenw.
26. F. juruanum P. Henn.

8. Section: Lateritium

27. F. lateritium Nees
28. F. lateritium var. buxi
29. F. udum Butler
30. F. stilboides Wollenw.
31. F. xylarioidesSteyaert

9. Section: Liseola

32. F. moniliforme Sheldon.

10. Section: Elegens

33. F. oxysporum Schlech.
34. F. oxysporum var. redolens

11. Section: Gibbosum

35. F. concolor Reinking
36. F. equiseti (Corda) Sacc.
37. F. acuminatum Ellis & Everhart
38. F. arthrosporioides Sherb.

12 . Section: Discolor

39. F. trichothecioides Wollenw
40. F. bubaricum Jaczewski
41. F. sambucinum Fuckel
42. F. sambucinum Fuckel var. corruleum Wollenw.
43. F. culmorum (W. G. Smith) Sacc.
44. F. heterosporum Nees
45. Gibberella gordonia spec. nov.
46. F. graminearum Schwabe
47. F. flocciferum Corda
48. F. sulphureum Sclechtendahl

4.6.2.Fusarium varieties

1. F. solani (Mart.) Sacc. f. sp. **albizziae**
2. F. solani (Mart.) Sacc. f. sp. **aurantifoliae**
3. F. solani (Mart.) Sacc. f. sp. **batatas**
4. F. solani (Mart.) Sacc. f. sp. **cucurbitae**

5. F. solani (Mart.) Sacc. f. sp. **dalbergiae**
6. F. solani (Mart.) Sacc. f. sp. **cumartii**
7. F. solani (Mart.) Sacc. f. sp. **fabae**
8. F. solani (Mart.) Sacc. f. sp. **keratitis**
9. F. solani (Mart.) Sacc. f. sp. **lupini**
10. F. solani (Mart.) Sacc. f. sp. **mori**
11. F. solani (Mart.) Sacc. f. sp. **otomycosis**
12. F. solani (Mart.) Sacc. f. sp. **phaseoli**
13. F. solani (Mart.) Sacc. f. sp. **piperis**
14. F. solani (Mart.) Sacc. f. sp. **pisi**
15. F. solani (Mart.) Sacc. f. sp. **radicicola**
16. F. solani (Mart.) Sacc. f. sp. **robiniae**
17. F. solani (Mart.) Sacc. f. sp. **viridiflavum**
18. F. solani (Mart.) Sacc. f. sp. **Xanthoxyli**
19. F. solani (Mart.) Sacc. f. sp. **Coeruleum**
20. F. aquaeductuum var. **medium**
21. F. avenaceum (Corda ex Fr.) Sacc. **fabae**
22. F. semitectum var**. majus**
23. F. lateritium (Nees) emend. Snyd & Hansen f. sp. **cerealis**
24. F. lateritium (Nees) emend. Snyd & Hansen f. sp.**ciceri**
25. F. lateritium (Nees) emend. Snyd & Hansen f. sp. **mori**
26. F. lateritium (Nees) emend. Snyd & Hansen f. sp. **pini**
27. F. lateritium (Nees) emend. Snyd & Hansen f. sp. **buxi** var. nov.
28. F. lateritium var. **buxi** Booth var. nov.
29. F. udum Butler f. sp. **crotalariae**
30. F. moniliforme var. **subglutinans**
31. Fusarium oxysporum f.sp. **aechmeae**
32. Fusarium oxysporum f.sp. **albedinis**
33. Fusarium oxysporum f.sp. **anethi**
34. Fusarium oxysporum f.sp. **asparagi**
35. Fusarium oxysporum f.sp. **batatas**
36. Fusarium oxysporum f.sp. **betae**
37. Fusarium oxysporum f.sp. **callisephi**
38. Fusarium oxysporum f.sp. **cannabis**
39. Fusarium oxysporum f.sp. **carthami**
40. Fusarium oxysporum f.sp. **cassia**
41. Fusarium oxysporum f.sp. **cattleyae**
42. Fusarium oxysporum f.sp. **cepae**
43. Fusarium oxysporum f.sp. **ciceris**

44. Fusarium oxysporum f.sp. **chrysanthemi**
45. Fusarium oxysporum f.sp. **coffea**e
46. Fusarium oxysporum f.sp. **conglutinans**
47. Fusarium oxysporum f.sp. **coriandrii**
48. Fusarium oxysporum f.sp. **cubense**
49. Fusarium oxysporum f.sp. **cucumerinum**
50. Fusarium oxysporum f.sp. **cumini**
51. Fusarium oxysporum f.sp. **cyclaminis**
52. Fusarium oxysporum f.sp. **delphinii**
53. Fusarium oxysporum f.sp. **dianthi**
54. Fusarium oxysporum f.sp. **elacagni**
55. Fusarium oxysporum f.sp. **elacidis**
56. Fusarium oxysporum f.sp. **eucalypti**
57. Fusarium oxysporum f.sp. **fabae**
58. Fusarium oxysporum f.sp.fragariae
59. Fusarium oxysporum f.sp. gerberae
60. Fusarium oxysporum f.sp. gladioli
61. Fusarium oxysporum f.sp. glycines
62. Fusarium oxysporum f.sp. hebae
63. Fusarium oxysporum f.sp. herbemontis
64. Fusarium oxysporum f.sp. gladioli
65. Fusarium oxysporum f.sp. langenariae
66. Fusarium oxysporum f.sp. lathyri
67. Fusarium oxysporum f.sp. lentis
68. Fusarium oxysporum f.sp. lini
69. Fusarium oxysporum f.sp. luffae
70. Fusarium oxysporum f.sp.lupini
71. Fusarium oxysporum f.sp. lycopersici
72. Fusarium oxysporum f.sp. mathioli
73. Fusarium oxysporum f.sp. medicaginis
74. Fusarium oxysporum f.sp. melonis
75. Fusarium oxysporum f.sp. narcissi
76. Fusarium oxysporum f.sp. nicotianae
77. Fusarium oxysporum f.sp. niveum
78. Fusarium oxysporum f.sp. opuntiarum
79. Fusarium oxysporum f.sp. passiflorae
80. Fusarium oxysporum f.sp. passiflorae
81. Fusarium oxysporum f.sp. perniciosum
82. Fusarium oxysporum f.sp. phaseoli

83. Fusarium oxysporum f.sp. pini
84. Fusarium oxysporum f.sp. pisi
85. Fusarium oxysporum f.sp. psidii
86. Fusarium oxysporum f.sp. querci
87. Fusarium oxysporum f.sp. radici-lupini
88. Fusarium oxysporum f.sp.raphani
89. Fusarium oxysporum f.sp. rauvoltiae
90. Fusarium oxysporum f.sp. rhois
91. Fusarium oxysporum f.sp. ricini
92. Fusarium oxysporum f.sp. stedi
93. Fusarium oxysporum f.sp. sesame
94. Fusarium oxysporum f.sp. sesbaniae
95. Fusarium oxysporum f.sp. spinaciae
96. Fusarium oxysporum f.sp. stachydis
97. Fusarium oxysporum f.sp. tracheiphilum
98. Fusarium oxysporum f.sp. trifolii
99. Fusarium oxysporum f.sp. tuberosi
100. Fusarium oxysporum f.sp. **tulipae**
101. Fusarium oxysporum f.sp. **vanillae**
102. Fusarium oxysporum f.sp. **vasinfectum**
103. Fusarium oxysporum f.sp**. zingiberi**
104. F. heterosporum Nees Ex Fr. f. sp**. aleuritidis**

4.7. John F. Leslie, Brett A. Summerell. The Fusarium Laboratory Manual, 2006

1. Fusarium acuminatum Ellis & Everhart
2. Fusarium acutatum Nirenberg & O’Donnell
3. Fusarium andiyazi Marasas, Rheeder, Lampr., K.A. Zeller & J.F. Leslie,
4. Fusarium anthophilum (A. Braun) Wollenweber
5. Fusarium armeniacum (Forbes, Windels & Burgess) Burgess & Summerell
6. Fusarium avenaceum (Fries) Saccardo

7. Fusarium aywerte (Sangalng & L.W. Burgess) Benyon & L.W. Burgess
8. Fusarium babinda Summerell, C.A. Rugg & L.W. Burgess
9. Fusarium begoniae Nirenberg and O’ Donnell
10. Fusarium beomiforme P.E. Nelson, Toussoun & L.W. Burgess
11. Fusarium brevicatenulatum Nirenberg , O’Donnell, Kroschel & Andrianaivo
12. Fusarium bulbicola Nirenberg & O’Donnell,
13. Fusarium camptoceras Wollenweber & Reinking,emend. Marasas & Logrieco
14. Fusarium chlamydosporum Wollenw. & Reinking
15. Fusarium circinatum Nirenberg & O’Donnell, emend Britz, Coutinho, Wingfield and Marasas
16. Fusarium compactum (Wollenweber) Gordon
17. Fusarium concentricum Nirenberg & O’Donnell
18. Fusarium crookwellense L.W. Burgess, P.E. Nelson & Toussoun
19. Fusarium culmorum (W.G. Smith) Saccardo
20. Fusarium decemcellulare Brick
21. Fusarium denticulatum Nirenberg & O’Donnell
22. Fusarium dimerum Penzig
23. Fusarium dlaminii Marasas, P.E. Nelson & Toussoun
24. Fusarium equiseti (Corda) Saccardo
25. Fusarium foetens Schroers, O’Donnell, Baayen & Hooftman
26. Fusarium fujikuroi Nirenberg
27. Fusarium globosum Rheeder, Marasas & P.E. Nelson
28. Fusarium graminearum Schwabe
29. Fusarium guttiforme Nirenberg & O’Donnell
30. Fusarium heterosporum Nees ex Fries
31. Fusarium hostae Geiser & Juba
32. Fusarium konzum Zeller, Summerell & J.F. Leslie
33. Fusarium lactis Pirotta & Riboni
34. Fusarium lateritium Nees
35. Fusarium longipes Wollenw. & Reinking
36. Fusarium mangiferae Britz, M.J. Wingf. & Marasas

37. Fusarium merismoides Corda
38. Fusarium miscanthi W. Gams, Klamer & O’Donnell
39. Fusarium musarum Logrieco & Marasas
40. Fusarium napiforme Marasas, P.E. Nelson & Rabie
41. Fusarium nelsonii Marasas & Logrieco
42. Fusarium nisikadoi T. Aoki & Nirenberg
43. Fusarium nurragi (Summerell & L.W. Burgess) Benyon, Summerell & L.W. Burgess
44. Fusarium nygamai L.W. Burgess & Trimboli
45. Fusarium oxysporum Schlchtendahl
46. Fusarium phyllophilum Nirenberg & O’Donnell
47. Fusarium poae (Peck) Wolleweber
48. Fusarium polyphialidicum Marasas, P.E. Nelson, Toussoun & P.S. van Wyk
49. Fusarium proliferatum (Matsush.) Nirenberg
50. Fusarium pseudoanthophilum Nirenberg & O'Donnell
51. Fusarium pseudocircinatum Nirenberg & O'Donnell
52. Fusarium pseudograminearum O'Donnell & T. Aoki
53. Fusarium pseudonygamai Nirenberg & O'Donnell
54. Fusarium ramigenum Nirenberg & O'Donnell
55. Fusarium redolens Wollenweber
56. Fusarium sacchari (E.J. Butler) W. Gams
57. . Fusarium sambucinum Fuckel
58. Fusarium scirpi Lambotte & Fautrey
59. Fusarium semitectum Berkeley & Ravenel
60. Fusarium solani (Martius) Appel & Wollenweber, emend, Snyder & Hansen
61. Fusarium sporotrichioides Sherbakoff
62. Fusarium sterilihyphosum Britz, Marasas & M.J. Wingfield
63. Fusarium subglutinans (Wollenweber & Reinking) P.E. Nelson, Toussoun & Marasas
64. Fusarium succisae (J. Schröter) Saccardo
65. Fusarium thapsinum Klittich, J.F. Leslie, P.E. Nelson & Marasas
66. Fusarium torulosum (Berkeley & M.A. Curtis) Nirenberg

67. Fusarium tricinctum (Corda) Saccardo
68. Fusarium udum E.J. Butler
69. Fusarium venenatum Nirenberg
70. Fusarium verticillioides (Saccardo) Nirenberg

4.8. Toxigenic Fusarium species

1. **Fusarium acaceae-mearnsii**: nivalenol, 3A- Deoxynivalenol
2. **Fusarium acuminatum**: trichothecenes, enniatin B, moniliformin
3. **Fusarium acutatum**: beauvericin, fumonisin
4. **Fusarium aethiopicum** : 15A- Deoxynivalenol
5. **Fusarium anantum**: fumonisins
6. **Fusarium andiyazi**: moniliformin, fumonisins
7. **Fusarium anthophilum**: moniliformin, fumonisins
8. **Fusarium armeniacum:** T-2. HT-2, neosolaniol
9. **Fusarium asiaticum**: trichothecines
10. **Fusarium astroamericanum**: nivalenol, 3A- Deoxynivalenol
11. **Fusarium avenaceum**: beauvericin, fusarin C, moniliformin, enniatins A,B,C
12. **Fusarium begonia**: moniliformin, fumonisin B1
13. **Fusarium beomiforme**: moniliformin, beauvericin
14. **Fusarium boothii** : 15A- Deoxynivalenol
15. **Fusarium brasilicum**: nivalenol, 3A- Deoxynivalenol
16. **Fusarium brevicatenulatum**: fumonisin B1
17. **Fusarium chlamydosporum**: moniliformin
18. **Fusarium circinatum**: beauvericin, fusaric acid
19. **Fusarium compactum** trichothecenes
20. **Fusarium concentricum**: fumonisins
21. **Fusarium crookwellense**: nivalenol, zearalenone, fusaric acid, fusarin C
22. **Fusarium culmorum**: moniliformin,deoxynivalenol, fusarin C, zearalenone, trichothecines

23. **Fusarium dactylidis**: nivalenol , zearalenone
24. **Fusarium delphinoides**: indole-3-acetic acid
25. **Fusarium denticulatum**: moniliformin
26. **Fusarium dlaminii**: beauvericin, moniliformin, fumonisins
27. **Fusarium equiseti**: butenolidem, beauvericin, trichothecenes, nivalenol, T-2 toxin, fusarochromanon, zearalenone, equisetin,
28. **Fusarium fujikuroi**: moniliformin, beauvericin, fusaric acid
29. **Fusarium gerlachii**: nivalenol
30. **Fusarium globosum**: fumonisin, beauvericin, fusaproliferin
31. **Fusarium graminearum**: zearalenon, nivalenol, 3A-Deoxynivalenol, 15A-Deoxynivalenol
32. **Fusarium guttiforme**: beauvericin, fusaproliferin
33. **Fusarium heterosporum**: fusaric acid
34. **Fusarium konzum**: fumonisins, beauvericin, fusaproliferin
35. **Fusarium kyushuense**: trichothecenes
36. **Fusarium lactis**: moniliformin
37. **Fusarium lateritium**: enniatins, lateropyrone
38. **Fusarium longipes**: beauvericin
39. **Fusarium langsethiae**: diacetoxyscirpenol, T-2 toxin , HT-2 toxin, neosolaniol culmorins, chrysogine, aurofusarin, and enniatins
40. **Fusarium louisianense**: nivalenol
41. **Fusarium mangiferae**: azepinostatin
42. **Fusarium meridionale**: nivalenol
43. **Fusarium mesoamerricanum**: nivalenol, 3A- Deoxynivalenol
44. **Fusarium musae:** moniliformin
45. **Fusarium musarum**: trichothecenes
46. **Fusarium napiforme**: moniliformin, fusaric acid, fumonisins
47. **Fusarium nepalense**: 15A- Deoxynivalenol
48. **Fusarium nisikadoi**: moniliformin
49. **Fusarium nygamai**: beauvericin, fusaric acid, fumonisins, moniliformin
50. **Fusarium oxysporum**: beauvericin, bikaverin, enniatins, fusaric acid, fusarin C, isoverrucanol, moniliformin, sambutoxin, wortmannin, fumonisins

51. **Fusarium phyllophilum**: fumonisins, moniliformin, beauvericin, fusaproliferin
52. **Fusarium poae**: beauvericin, fusarin C, trichothecenes
53. **Fusarium polyphialidicum**: fuminosins
54. **Fusarium proliferatum**: gibberellic acid, beauvericin, fusaproliferin, fusaric acid, fusarins,,moniliformin
55. **Fusarium pseudoanthophilum**: beauvericin
56. **Fusarium pseudocircinatum**: moniliformin, fusaproliferin, fumonisins
57. **Fusarium pseudograminearum**: deoxynivalenol, 3-acetyl deoxynivalenol, zearalenone
58. **Fusarium pseudonygamai**: moniliformin, fusaproliferin, fumonisins
59. **Fusarium ramigenum**: moniliformin, fusaproliferin, beauvericin, fumonisin B1, fumonisin B2
60. **Fusarium redolens**: fusaric acid, fumonisins
61. **Fusarium sacchari**: fusaric acid, fumonisins
62. **Fusarium sambucinum**: enniatins, beauvericin, fusaric acid, fusarin C, sambutoxin, wortmannin
63. **Fusarium semitectum**: apicidins, beauvericin, equisetin, fusapyrone, moniliformin, sambutoxin, trichothecenes, zearalenone
64. **Fusarium sibiricum** : trichothecenes
65. **Fusarium solani**: deoxynivalenol, T-2 toxin, zearalenone
66. **Fusarium sporotrichioides**: butenolide, fusarin C, monilformin, scirpentriol, zearalenone, T-2 toxin
67. **Fusarium sterilihyphosum**: monilformin
68. **Fusarium subglutinans**: moniliformin, beauvericin, fusaric acid, fusaproliferin, fumonisins
69. **F. succisae** fusaproliferin
70. **Fusarium temperatum**: moniliformin, beauvericin, enniatins, fumonisin B1
71. **Fusarium thapsinum**: moniliformin, fusaric acid, fumonisins
72. **Fusarium torulosum**: enniatin B, wortmannin
73. **Fusarium tricinctum** :fusarin C, enniatins, moniliformin

74. **Fusarium tumidum**: neosolaniol
75. **Fusarium udum**: fusaric acid
76. **Fusarium ussurianum** : trichothecenes 3A- Deoxynivalenol
77. **Fusarium venenatum**: trichothecenes
78. **Fusarium virguliforme**: toxin FvTox1
79. **Fusarium verticillioides** : fumonisins, fusaric acid, fusarin C, beauvericin
80. **F. vorosi**: trichothecenes 3A-Deoxynivalenol

5. Distribution and diversity of Fusarium species

Fusarium species are widely distributed in all major geographic regions of the world

- They are commonly found in soils, and persist as chlamydospores or as hyphae in plant residues and organic matter.
- Many Fusarium species are abundant in fertile cultivated and rangeland soils, rather than in forest soils
- Fusarium colony was found abundant and diverse in cultivated soils.
- A high degree of variability in morphology and physiological characteristics enable some species such as F. oxysporum and F. equiseti to occupy the diverse ecological niches in many geographic regions

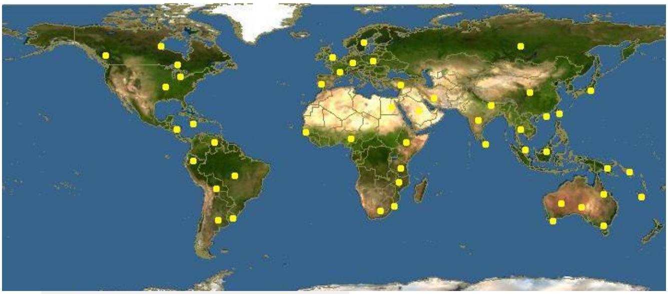
5.1. F. graminearum

- **F. graminearum** is the most important Fusarium species in central Europe and in large areas in North America and Asia
- During the last years F. graminearum has been spreading to the north in Europe in the Netherlands, England, Sweden, Finland

and north-western Russia and it has been replacing the closely related F. culmorum, which is less effective in producing DON .

- F. graminearum is dominant in Europe and North America. Lineage 7 of F. graminearum dominates in northern Europe and Asia and has been replacing the closely related F. culmorum in northern Europe.
- **In Iran**, the diversity and prevalence of Fusarium species and their chemotypes on wheat in the North-West and North of Iran was determined. Wheat in these areas is severely affected by Fusarium Head Blight (FHB), with Fusarium graminearum as prevalent species causing 96% of the infections in the North-West and 50% in the Northern provinces. Fusarium graminearum strains producing 15-ADON were abundant in Ardabil (NW of Iran), while in Golestan province (N of Iran) at the other side of the Caspian Sea especially nivalenol-producing strains and a variety of other Fusarium species were observed. Strains producing 3-ADON were rarely found in both areas.
- **In Canada,** Fusarium head blight of wheat and ear rot of corn causes significant yield and quality losses as well as contaminates grains with trichothecene mycotoxins. The fungus is also a potato pathogen and is routinely recovered from potato tubers showing symptoms of Fusarium dry rot in Canada. Interestingly, all the G. zeae strains from potatoes were 3-Acetyl-DON (3ADON) types. The ability of representative isolates to produce 3ADON and 15ADON was verified in rice culture
- **In Brazil**, F. graminearum with a 15-ADON genotype is dominant in wheat (83%), followed by F. meridionale with a NIV genotype (12.8%), F. cortaderiae with mostly NIV and a few 3-acetyl deoxynivalenol (3-ADON) (2.6%), F. austroamericanum with mostly 3-ADON and a few NIV (1.2%)

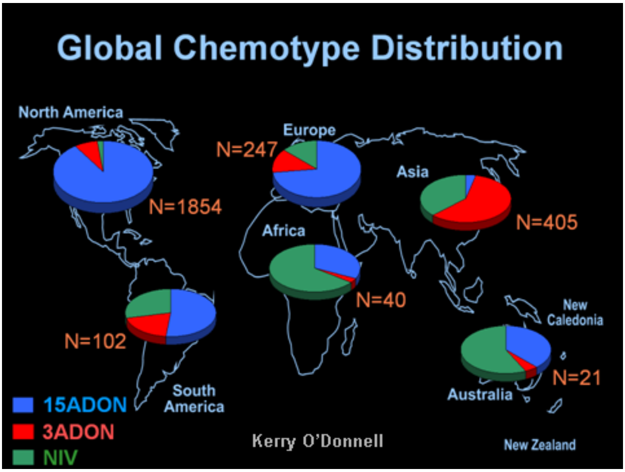
and F. asiaticum with the NIV genotype (0.4%). Frequency of F. meridionale in wheat increased with the decrease of latitudes. For the maize kernel population, F. meridionale is dominant (72%), followed by F. graminearum with the 15-ADON genotype (14.5%) and F. cortaderiae with the 3-ADON and NIV genotypes (13.5%). For the maize stubble population, F. meridionale is dominant (50%), followed by F. graminearum with the 15-ADON genotype (30%) and F. cortaderiae with the NIV and 3-ADON genotypes (20%). F. asiaticum with the NIV genotype is the sole species found in rice kernels. These results show that several species coexist in the subtropical to tropical agricultural regions of Brazil where host and geographic (climatic) region shape species composition.



Fusarium graminearum www.discoverlife.org

- The 3ADON chemotype of F. graminearum is prevalent in Scandinavia, Finland and north-western Russia
- The 15ADON chemotype of F. graminearum is more common in the more southern areas in Europe and China.

- Both the 3ADON and 15ADON chemotypes of F. graminearum are common in the Russian Far East.



Fusarium root rot is a widespread disease of soybean in the United States and elsewhere in the world. Affecting seedlings as well as adult plants, it can be caused by numerous Fusarium species, and its severity is highly variable.

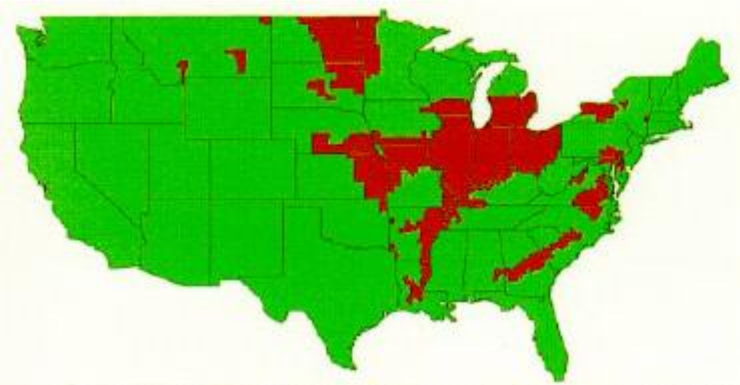
- Fusarium oxysporum is the most common species, followed by F. solani, F. graminearum, and F. acuminatum.
- Representative isolates of these species cause seedling blight, root rot symptoms and detrimental effects on root system growth and development.
- F. graminearum isolates are consistently aggressive pathogens on soybean roots.
- Several species other species such as are also involved as F. armeniacum, F. commune, F. proliferatum

Fusarium root rot, caused by *Fusarium solani* can cause damping-off of seedlings and root rot on older plants. Infected seedlings can result in poor weak stands, late emergence or stunted plants.

- Fusarium root rot is an important widespread disease of field pea worldwide • Can attack the crop at various growth stages, symptoms in seedlings to mature plants • Problematic in Alberta since ~2010
- Fusarium root rot is common in North Dakota but severe damage has often been observed in association with stressed plants, such as in drought conditions or with herbicide damage.
- Fusarium root rot, or dry root rot, is the most common and important root rot of beans in North Carolina. Green bean is the main host but lima bean, southern pea, and garden pea are also affected. It occurs mostly in hot weather in acid and poorly fertilized soils. The disease tends to be evenly distributed over a field.

Fusarium head blight is one of the most devastating plant diseases in the world.

- The United States Department of Agriculture (USDA) ranks FHB as the worst plant disease to hit the US since the rust epidemics in the 1950s. Since 1990, wheat and barley
- Farmers in the United States have lost over $3 billion dollars due to FHB epidemics.
- Canada has also experienced severe losses since 1990.



Major outbreaks of Fusarium head blight (red) on wheat and barley. www.apsnet.org

The Fusarium head blight causing species are common all over Europe but their importance is different depending on the climatic conditions.

- The increase in importance of F. graminearum reported earlier in Central Europe has been observed during the past ten years, especially in Norway where high deoxynivalenol contents have been frequently analysed in oats in some areas.
- Signs of the same development have also been observed in Sweden and Finland, where DON contaminations have previously been lower.

Fusarium head blight species can produce mycotoxins that accumulate in the grains, creating a threat to human and animal health.

- In Europe, type B trichothecenes, especially deoxynivalenol (DON), are frequently found in grain batches.
- Most of the genes involved in producing these mycotoxins (TRI genes) are grouped in a 12-gene core cluster (TRI cluster).
- Fusarium graminearum, F. culmorum and F. cerealis possess this cluster, but the presence or absence of certain TRI genes, as well as their functionality, results in a strain capable of

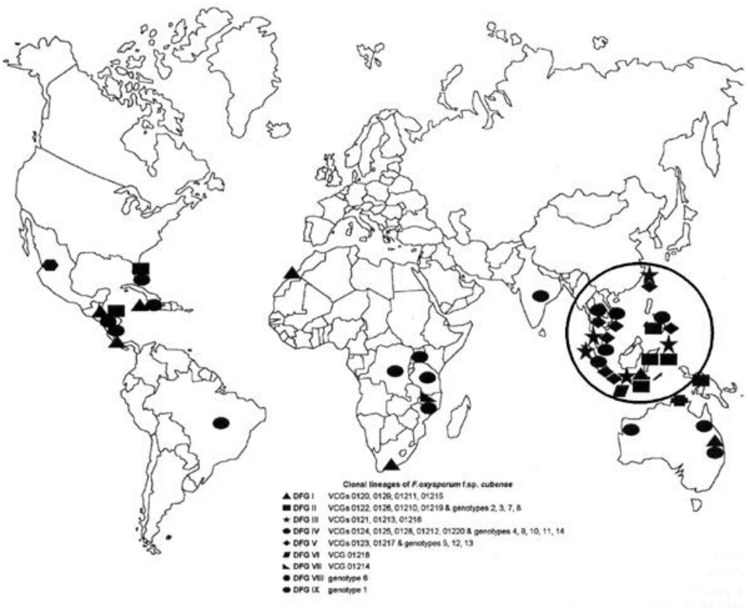
producing either nivalenol (NIV) or deoxynivalenol and a related acetylated derivative (3- or 15-ADON).

5.2. F. oxysporum

- Fungi of the *Fusarium oxysporum* species complex are ubiquitous soil and plant inhabiting microbes.
- As plant pathogens, *F. oxysporum* appears to be largely **cosmopolitan** meaning that it can be found almost everywhere, with higher concentrations of the various *Formae speciales* in different areas across the globe.
- FOSC strains can cause wilt and root rot diseases on over 120 plant species. Many FOSC strains can infect plant roots without apparent effect or can even protect plants from subsequent infection
- FOSC isolates also have been identified as human pathogens causing localized or disseminated infections that may become life-threatening in neutropenic individuals

Fusarium wilt of banana (Panama disease) is a destructive fungal disease of banana plants.

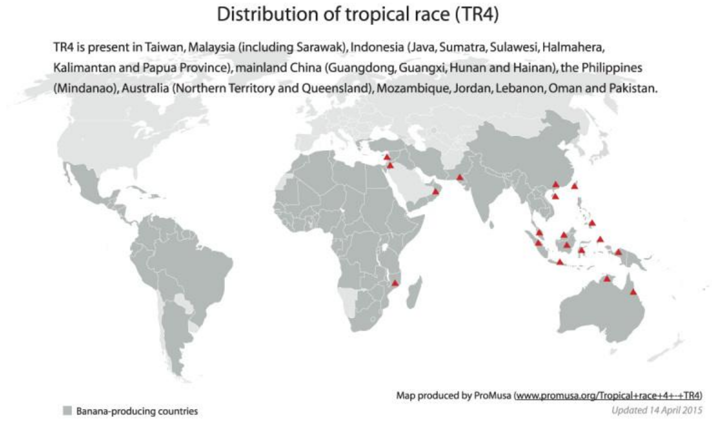
- It is caused by Fusarium oxysporum f. sp. cubense (Foc).
- It first became epidemic in Panama in 1890 and proceeded to devastate the Central American and Caribbean banana industries that were based on the ‘Gros Michel’ (AAA) variety in the 1950s and 1960s.
- Once Foc is present in the soil, it cannot be eliminated.
- Fusarium wilt of banana is caused by 35 different strains or genotypes of *Fusarium oxysporum* f. sp. *cubense*.



The distribution of clonal lineages of *Fusarium oxysporum* f. sp. *cubense*on banana plantations around the world. Each symbol represents a different clonal lineage. The most diverse concentration of lineages corresponds with the presumed center of origin in Southeast Asia (circled). www.apsnet.org

- There are four recognised races of the pathogen which are separated based on host susceptibility.
    - Race 1, which was responsible for the epidemics in ‘Gros Michel’ plantations, also attacks ‘Lady Finger’ (AAB) and ‘Silk’ (AAB) varieties.
    - Race 2 affects cooking bananas such as ‘Bluggoe’ (ABB)
    - Race 3 affects Heliconia spp., a close relative of banana, and is not considered to be a banana pathogen. ‘
    - Race 4 is capable of attacking ‘Cavendish’ (AAA) as well as the other varieties of banana affected by races 1 and 2. These three races have been present on the east

    coast of Australia for many years and race 1 is present in WA.
  - Race 4 is further divided into ‘sub-tropical’ and ‘tropical’ strains. ‘Tropical’ race 4 is a more virulent form of the pathogen and is capable of causing disease in ‘Cavendish’ growing under any conditions, whereas ‘subtropical’ race 4 generally only causes disease in plants growing sub-optimally (cool temperatures, water stress, poor soil).
- The strain associated with TR4 was identified in 1990 in samples from Taiwan[1]. For the next 20 years or so, the distribution of
  - TR4 was limited to parts of Asia and Australia's Northern Territory.
  - The first report of TR4 outside the Asia-Pacific region dates to 2013 when it was announced that the fungal strain had been confirmed in Jordan.
  - Later that year it was also reported to be in Mozambique.
  - The capacity of TR4 to survive decades in the soil, along with its lethal impact and wide host range, are among the main reasons it was ranked as the greatest threat to banana production.
  - The severity of the damage depends on interactions between the strain, its host and environmental conditions.
  - To avoid further losses to the pathogen, the United Nations' Food and Agriculture Organization (FAO) has called on banana-producing countries to step up monitoring and reporting, and to contain suspected incursions to prevent the fungus from getting established



Distribution of tropical race (TR4)

TR4 is present in Taiwan, Malaysia (including Sarawak), Indonesia (Java, Sumatra, Sulawesi, Halmahera, Kalimantan and Papua Province), mainland China (Guangdong, Guangxi, Hunan and Hainan), the Philippines (Mindanao), Australia (Northern Territory and Queensland), Mozambique, Jordan, Lebanon, Oman and Pakistan.

Map produced by ProMusa (www.promusa.org/Tropical+race+4+-+TR4)

Updated 14 April 2015

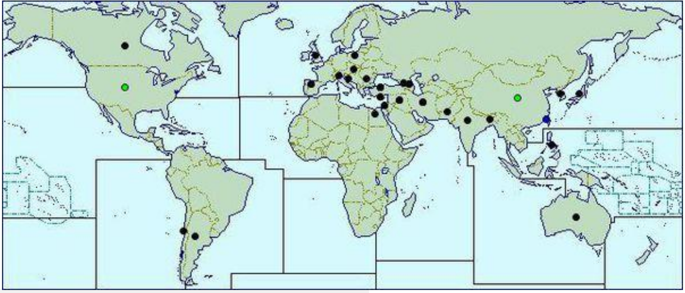
Fusarium wilt of tomatoes was first described by G.E. Massee in England in 1895.

- It is of worldwide importance where at least 32 countries had reported the disease, which is particularly severe in countries with warm climate.
- At one time, the disease nearly destroyed tomato production in parts of Florida and the southeastern states of United States. However, the development and use of resistant cultivars have nearly eliminate the concern over this disease.

- Three physiological races of this pathogen have been reported.
    - Race 1 is the most widely distributed and has been reported from most geographical areas.
    - Race 2, though it was first reported in Ohio in 1940, it did not become widespread or of economic concern until its discovery in Florida in 1961. Since then, it was rapidly reported in several of the states and in several other countries, including Australia, Brazil, Great Britain, Israel, Mexico, Morocco, the Netherlands, and Iraq.

- Race 3 was reported in 1966 in Brazil. Thereafter, it has been found in Australia and in Florida and California.

- *F. oxysporum f.sp. lycopersici*, which causes tomato wilt, has been found in at least 32 different countries alone. *F. oxysporum* distribution maps show that this fungus has invaded North and South America, Europe, Africa, Asia, and Oceania.



Fusarium oxysporum - MicrobeWikiThis map depicts how F. oxysporum affects 6 of the 7 continents on Earth.

Fusarium wilt of watermelon is one of the oldest described Fusarium wilt diseases and the most economically important disease of watermelon worldwide. It occurs on every continent except Antarctica and new races of the pathogen continue to impact production in many areas around the world. Long-term survival of the pathogen in the soil and the evolution of new races make management of Fusarium wilt difficult.

Fusarium wilt of hemp (Fusarium oxysporum f.sp. cannabis)

The disease was first described on hemp in Eastern Europe about 50 years ago, but is now found throughout the Northern hemisphere.

- Fusarium wilt of hemp is a serious disease in eastern Europe, Italy and southern France.
- Extremely virulent strains reduce Cannabis survival by up to 80%

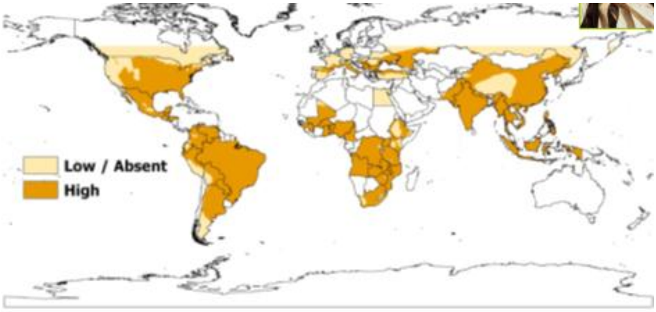
Fusarium wilt of hemp (**Fusarium oxysporum f.sp**. **cannabis**).

Fusarium wilt of lettuce is of worldwide occurrence of 1955 Japan 1990 U.S. (California; Fresno County) 1995 Iran 1998 Taiwan 2000 Brazil 2001 U.S. (Arizona; Yuma County) 2002 Italy. Races of Fusarium oxysporum f. sp. lactucae Races 1,2,3: Japan Race 1: Brazil, Iran, Italy, Taiwan, United States

- **Fusarium wilt of cotton**, caused by the fungus Fusarium oxysporum Schlechtend. f. sp. vasinfectum, was first identified in 1892 in cotton growing in sandy acid soils in Alabama (8). Although the disease was soon discovered in other major cotton-producing areas, it did not become global until the end of the next century. After its original discovery, Fusarium wilt of cotton was reported in Egypt (1902), India (1908), Tanzania (1954), California (1959), Sudan (1960), Israel (1970), Brazil (1978), China (1981), and Australia (1993). In addition to a worldwide distribution, Fusarium wilt occurs in all four of the domesticated cottons, Gossypium arboretum L., G. barbadense L., G. herbaceum L., and G. hirsutum L.. Disease losses in cotton are highly variable within a country or region. In severely infested fields planted with susceptible cultivars, yield losses can be high

5.3. Fusarium verticillioides is the causal agent of kernel and ear rot of maize. This destructive disease occurs virtually everywhere that maize is grown worldwide. In years with high temperatures, drought, and heavy insect damage, the disease can significantly diminish crop quality.

- Fusarium verticillioides (teleomorph Gibberella moniliformis) is the main fungal agent of ear and kernel rot of maize (Zea mays L.) worldwide. F.verticillioides is a highly toxigenic species since it is able to produce the carcinogenic mycotoxins fumonisins.
- The most significant economic impact of *F. verticillioides* is its ability to produce fumonisin mycotoxins. Various diseases caused by fumonisins have been reported in animals, such as liver and kidney cancer as well as neural tube defects in rodents, leukoencephalomalacia in equines and pulmonary edema in pigs
- Epidemiological correlations have been established between human esophageal cancer and the consumption of fumonisin-contaminated maize in some regions of the world where maize is a dietary staple.



Battilani, Logrieco, 2010

5.4. Fusarium fujikuroi is a phytopathogenic ascomycete causing the bakanae disease (“foolish seedlings”) in rice plants. This disease is triggered by the best known secondary metabolites produced by the fungus, namely gibberellins.

- F. fujikuroi is able to produce several other well investigated secondary metabolites which we can easily detect and quantify by now (i.e. bikaverin, fusarubin, fusarin C).
- F. fujikuroi also possesses the potential to produce a broad spectrum of further, yet unknown, secondary metabolites. A genome-wide bioinformatical screening approach revealed that the F. fujikuroi genome encodes 45 key enzymes for secondary metabolite production, like 18 polyketide synthases (PKSs) and 16 nonribosomal peptide synthetases (NRPSs), all organized in putative gene clusters.

5.5. Fusarium avenaceum is often associated with diseased grains in temperate areas, either alone or in co-occurrence with other Fusarium species, but its prevalence is also increasing in warmer regions throughout the world. The major problems caused by F. avenaceum are crown rot and head blight of wheat and barley, and the contamination of grains with mycotoxins

- **In Finland** and other northern agricultural areas, F. avenaceum is a common fungus on living and dead organic substrates It is frequently found on cereal grains, where it may cause seedling and head blight and produce mycotoxins. F. avenaceum is associated with foot and root rot diseases of all cereals grown in Finland. A wide range of variation in pathogenicity between isolates has been reported
- **In Norway**, Fusarium avenaceum, F. graminearum, F. culmorum, F. langsethiae, and F. poae are some of the most common fungal species causing Fusarium Head Blight in cereals. F. graminearum has shown increased prevalence the last decade, resulting in increased deoxynivalenol contamination of cereal grains. The increased prevalence of F. graminearum in

Norwegian cereals is likely to be associated with the recent increased use of reduced tillage in combination with weather conditions promoting development and dispersal of this fungal species.

5.6. Fusarium proliferatum is considered worldwide as an emerging pathogen of garlic. F. proliferatum is know to produce Fumonisins B1 and B2 on different vegetable matrices and Fumonisins contamination of garlic bulbs has been already reported in Germany.

5.7. Fusarium. langsethiae is a new European species of type A trichothecene producer. F.langsethiae can be divided into two lineages based on molecular markers. T-2-producing.

- **The European F. langsethiae** has only been found in Europe, while the Asian F. langsethiae in Siberia and the Russian Far East seems actually to be a lineage of F. sporotrichioides based on molecular data.
- In Finland, increase of F. langsethiae, the most important producer of T-2 and HT-2- toxins has already been observed on oats and barley under reduced tillage. While DON production is enhanced by high humidity, F. langsethiae can infect and produce toxins in dry conditions

5.8. F. sibiricum is distributed in Siberia and Russian Far East with two single isolates from Norway and Iran. So, it is probable that the actual distribution of F. sibiricum will be much larger than the present known distribution.

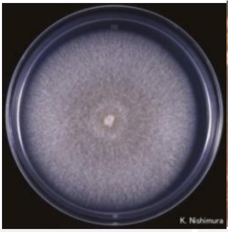
5.9.Fusarium temperatum is a new described species occurring on maize in Belgium, closely related to F. subglutinans. Both species are considered morphologically identical and associated to the Fusarium maize ear rot disease complex.

6. Fusarium morphology

6.1.Macromorphology

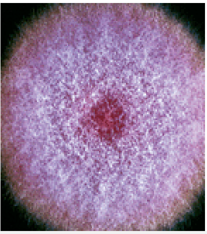
Most Fusarium species produce woolly to cottony, flat, spreading colonies. The colour of the colony may be white, cream, tan, salmon, cinnamon, yellow, red, violet, pink or purple; and on the reverse, it may be colorless, tan, red, dark purple, or brown

Courtesy: Leslie & Summerell International Institute of Tropical Agriculture – Institut international d'agriculture tropicale – www.iita.org



www.pf.chiba-u.ac.jp

www.medical-labs.net



www.mycology.adelaide.edu.au

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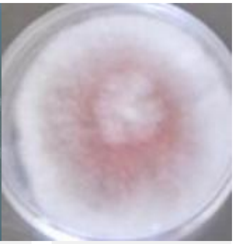

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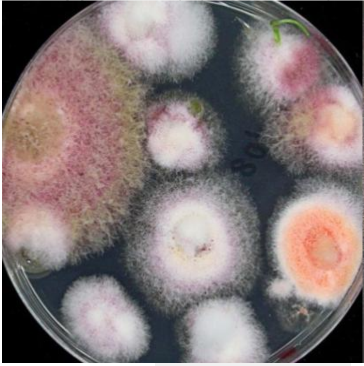


www.bioforsk.no

show.wnmu.edu

6.2. Microscopic morphology

Sporodochia

Sporodochia consist of masses of branched conidiophores,.In culture they build up and are seen macroscopically as light coloured raised bodies on the surface of the plectochymatic culture mat.

Macroconidia

Macroconidia are borne in sporodochia. They are mostly long, slender, rather pointed at both end, dorso-ventrally curved, sickle-shaped, septated, and posses a basal foot cell (that is, the basal cell of the septated spore has a slight notch on the dorsal side near the attachment point to the conidiophore). Macroconidia are phialospores, i.e. they are produced in a phialide, which is a small opening at the tip of the conidiophore from which the spores emerge one by one, appearing apex end first, all initially attached to the conidiophore.

Microconidia

Microconidia may be formed. Typically they are present on the aerial mycelium of the culture growth, appearing as small, usually one-celled spores, and oval-shaped, although in some species they may be apiculate, tear-drop or pear-shaped and sometimes even spherical. Microconidia may be phialospores or they may also be blastospores, which are dry spores produced by budding at the tip of the conidiophore. These sporogenesis features are also used by taxonomists to distinguish species, however they are often difficult to ascertain and in some isolates production of both spore types occur. Sometimes microconidia from phialides remain attached to each other in sequence to form chains. This is also a character used in taxonomy. Microconidia are usually moisture-borne, but they can be air-borne, usually for relatively short distances.

Mesoconidia.

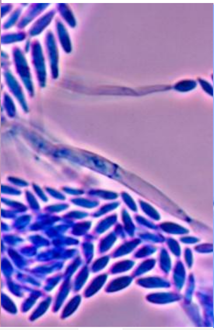
Mesoconidia are the fusoid conidia that are longer than microconidia with 3-4 septa but shorter than macroconidia with lack of foot-shaped and notched basal cell. These conidia are produced in the aerial mycelium on the polyphialides that appear as “rabbit ears” when viewed in-situ

Chlamydospores

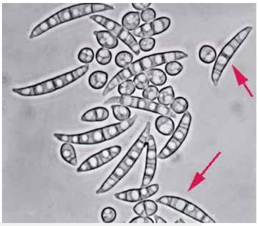
Chlamydospores, exist in some, but not all Fusarium spp. Such spores are more or less sphaerical, approximately 7-16 in diameter. They occur often singly, but sometimes they are doubles or are even in chains or in big clumps in some species. They have thick, double, often very rough cell walls, and their cytoplasm contains a great deal of nutrients, as is evident by oily globules therein. Microscopically the walls appear as light yellowish in colour, but when viewed en masse macroscopically they are brown. Thus large clumps in culture may appear as brown clumps, sometimes below the agar surface. They form in conidia or in hyphae, either terminally or intercalary, and appear usually when the available nutrients are becoming depleted and the culture is already old.

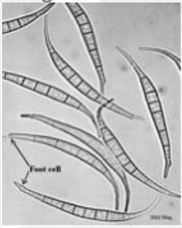
Perithecia

Some Fusarium species are capable of producing a sexual stage. Perithecia bearing ascospores may appear in nature and in culture under certain specific conditions, such as proper lighting, temperature and moisture.



www.e-ijd.org en.wikipedia.org





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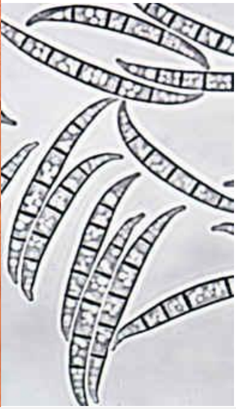

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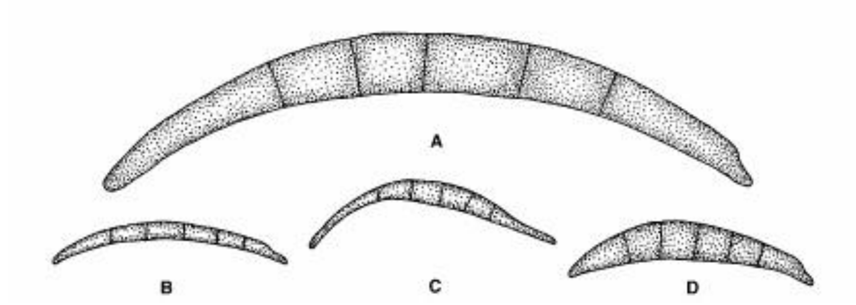
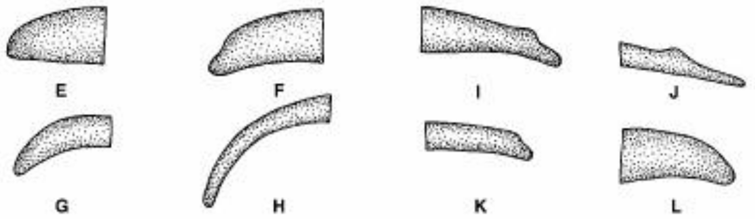
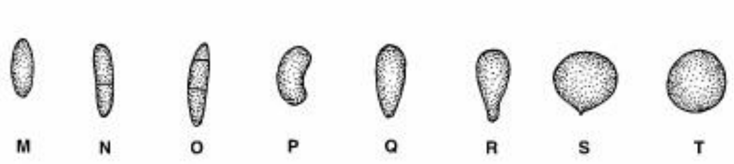
6.3. Descriptioon of macro- and microconidia and chlamydodpores



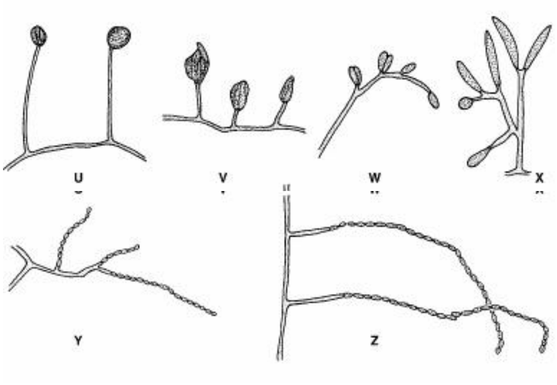
Macroconidial shapes: A: Typical macroconidia with apical cell on the left and basal cell on the right, C: macroconidia with dorsoventral curvature, D: macroconidia with dorsal side more curved than the ventral



Apical cell, E: apical cell blunt, F: apical cell papillate, G:apical cell hooked, H:apical cell tapering,
Basal cell, I: basal cell foot-shaped, J: basal cell elongated foot-shaped, K: basal cell distinctly notched, L: basal cell barely notched



Microconidia M: oval, N: two-celled, O: three-celled, P: rentiform, Q: obvoid with a truncate base, R: pyriform, S: napiform, T: globose



Phialides U and V: monophialides, W and X:polyphialides,: Microconidial chains Y: short, Z : long. From Fusarium Laboratory Manual www.mycologia.org

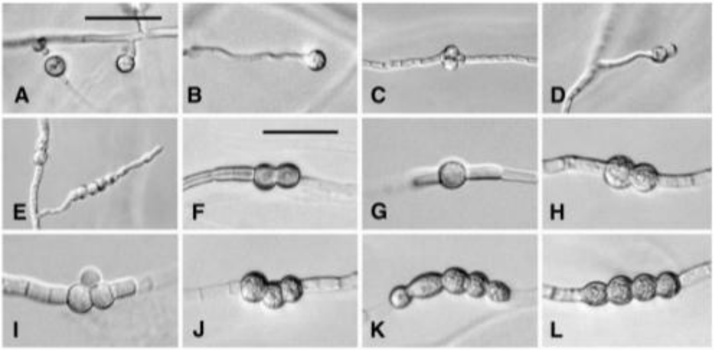


Figure 12-2. Chlamydospores of *Fusarium* species. **A-B:** Single, verrucose chlamydospores of *F. solani*. **C-D:** Clustered chlamydospores of *F. compactum*. **E:** Chain of verrucose chlamydospores of *F. compactum*. **F:** Paired, smooth-walled chlamydospores of *F. solani*. **G:** Single, verrucose chlamydospore of *F. scirpi*. **H:** Paired, verrucose chlamydospores of *F. compactum*. **I:** Clustered, smooth-walled chlamydospores of *F. scirpi*. **J** and **L:** Chains of verrucose chlamydospores of *F. compactum*. **K:** Chain of verrucose chlamydospores of *F. scirpi*. A-E: Scale bar = 50 µm; F-L: Scale bar = 25 µm.

From Fusarium Laboratory Manual

7. Fusarium genomics

7.1. The *Fusarium* Comparative Project

The *Fusarium* comparative genomics database provides accesses to multiple sequenced *Fusarium* genomes simultaneously to facilitate the comparative analysis among these closely related fungal species. The *Fusarium* comparative project is part of the **Broad Fungal Genome**

Initiative and was funded by the U.S. Department of Agriculture's National Institute for Food and Agriculture.

The main collaborators of *Fusarium* comparative project

Dr. Corby Kistler at USDA, ARS Cereal Disease Lab of University of Minnesota, Dr. Jin-Rong Xu ant Purdue University, Dr. Frances Trail at Michigan State University, Dr. Seogchan Kang at Penn State University, Dr. Won-Bo Shim at Texas A&M University, Dr. Charles Woloshuk at Purdue University

Activities

- In 2002, the *F. graminearum* sequencing project was funded by the National Research Initiative, which is within the U.S. Department of Agriculture's National Institute for Food and Agriculture.
- The *Fusarium graminearum* sequencing project represents a partnership between the Broad and the International Gibberella zeae Genomics Consortium (IGGR).
- *Fusarium oxysporum* and *F. verticillioides* have been selected at the same time to study evolutionary biology among these closely related but biologically distinct *Fusarium* species.
- A three-way comparison of *F. oxysporum*, *F. verticillioides* and *F.graminearum* offers powerful synergy in studies of pathogenicity and virulence factors, and their evolution within this genus.

1. *Fusarium oxysporum*

- The *F. oxysporum* comparative genomes project has sought to make available genome sequence data for FOSC strains with a range of host specificities. The first genome made available in 2007 was from a tomato wilt strain FOL 4287 (NRRL 34936) which was used for comparative analysis with the genomes of *F. graminearum* and *F. verticillioides*.
- Results of this comparison led to the discovery of mobile supernumerary chromosomes in this strain of *F. oxysporum* f. sp. *lycopersici* (race 2 - VCG 0030) containing genes required for host specific infection and disease (Ma et al., 2010).
- Eleven additional FOSC strains now have been sequenced. Two of these additional strains also infect tomato.
    - MN25 (NRRL 54003) is a strain of *F. oxysporum* f. sp. *lycopersici* (race 3 - VCG 0033) from Manatee County, Florida.
    - CL57 (NRRL 26381) is a tomato crown rot pathogen *F. oxysporum* f. sp. *radicis-lycopersici* (VCG 0094) from Collier County, Florida.
- Two FOSC strains sequenced have specificity to crucifers.
    - PHW808 (NRRL 54008) is a strain of *F. oxysporum* f. sp. *conglutinans*, race 2 (VCG 0101) from California that causes cabbage yellows disease.
    - PHW815 (NRRL 54005) is a strain of *F. oxysporum* f. sp. *raphani* (VCG 0102) from France that causes radish wilt. Both strains cause wilt disease in *Arabidopsis*.
- A strain of *F. oxysporum* f. sp. *cubense* tropical race 4 (VCG 01213) Fusarium wilt of banana in Indonesia was sequenced.
- Strains of the fungus causing wilt disease on melon (*F. oxysporum* f. sp. *melonis*NRRL 26406), cotton (*F. oxysporum* f. sp. *vasinfectum* NRRL 25433) and pea (*F. oxysporum* f. sp. *pisi* NRRL 37622) also were sequenced.
- *F. oxysporum* strain NRRL 32931, obtained from human blood, represents a distinct haplotype ST 128 and is closely related to FOSC 3-a/ST 333-a

- *F. oxysporum* strain Fo47 (NRRL 54002) well-known for its biological control properties, originally isolated from disease suppressive soils from the Chateaurenard region of France and demonstrated to colonize host roots and to be the biotic component of wilt disease suppression.

Summary Table of the strains:

NRRL	**Strain**	**forma specialis**	**Host**
37622	HDV247	*pisi*	*Pisum*
32931	NRRL32931	(human)	*Homo*
54002	Fo47	(biocontrol)	Soil
54003	MN25	*lycopersici* race 3	*Lycopersicum*
54008	PHW808	*conglutinans*, race 2	*Brassica/Arabidopsis*
54005	PHW815	*raphani*	*Raphanus/Arabidopsis*
26381	CL57	*radicis-lycopersici*	*Lycopersicum*
54006	II5	*cubense* tropical race 4	*Musa*
26406		*melonis*	*Cucurbita*
25433		*vasinfectum*	*Gossypium*

2. *Fusarium graminearum*

- The strain chosen for sequencing by the International Gibberella zeae Genomics Consortium (IGGR) was PH-1 (NRRL 31084).
- It is the predominant FHB species causing scab of wheat and barley in North America and Europe and is distributed worldwide
- Isolated in Michigan,

- PH-1 is highly fertile,
- It produces trichothecenes and zearalenone ,
- It sporulates abundantly in pure culture and is highly pathogenic to wheat and barley.
- The strain can be readily transformed and is closely related to strain GZ3639 (NRRL 29169) that has been studied for trichothecene biosynthesis and strain 00-676 (NRRL 34097) used as one parent with PH-1 for the genetic map

3, *Fusarium verticillioides*

- Strain 7600 (FRC M3125=NRRL 20956), which has been used extensively in molecular and pathological studies, was selected for the genome project.
- This strain is available at FGSC, NCAUR-ARS-USDA and the Fusarium Research Center at Penn State.
- The genome size is estimated to be 46 Mb with 12 chromosomes

Genome Statistics Summary

	Size	Chrs	%GC	Genes	tRNAs	rRNAs
F. verticillioides 7600 (FV3)	41.78 Mb	--	48.70	15,869	296	75
F. verticillioides 7600 mito	93.92 Kb	--	32.06	0	31	--
F. graminearum PH-1 (FG3)	36.45 Mb	--	48.33	13,321	322	88
F. graminearum PH-1 mito	107.73 Kb	--	31.86	0	21	--
F. oxysporum 4287 (FO2)	61.36 Mb	--	48.40	20,925	308	121
F. oxysporum 4287 mito	84.76 Kb	--	31.01	0	21	--
F. oxysporum Fo47	49.66 Mb	--	47.68	18,191	305	60
F. oxysporum NRRL32931	47.91 Mb	--	47.63	17,280	302	60
F. oxysporum HDV247	55.19 Mb	--	47.61	19,623	318	59
F. oxysporum MN25	48.64 Mb	--	47.75	17,931	305	61
F. oxysporum CL57	49.36 Mb	--	47.62	18,238	313	59

F. oxysporum Cotton	52.91 Mb	--	47.67	18,905	305	61
F. oxysporum II5	46.55 Mb	--	47.51	16,634	281	60
F. oxysporum melonis	54.03 Mb	--	47.51	19,661	311	61
F. oxysporum PHW808	53.58 Mb	--	47.73	19,854	311	67
F. oxysporum PHW815	53.5 Mb	--	47.83	19,306	299	58
F. oxysporum Fo5176 (454)	54.95 Mb	--	47.81	21,087	296	58

Size length of complete genome sequence, calculated by adding lengths of all scaffolds together **Chrs** number of chromosomes, **%GC** GC content of scaffolds, **Genes** number of predicted protein-coding genes in genome, **tRNAs** number of predicted tRNA genes in genome, **rRNAs** number of predicted rRNA genes in genome

Genome statistics..of F. oxysporum, F. verticillioides and F. graminearum. Li-Jun Ma *Nature* 464, 367-373 (2010)

Species	**F. oxysporum**	**F. verticillioides**	**F. graminearum**
Strain	4287	7600	PH-1
Sequence coverage (fold)	6	8	10
Genome size (Mb)	59.9	41.7	36.2
Number of chromosomes	15	11[*]	4
Total scaffolds	114	31	36
N_{50} scaffold length (Mb)	1.98	1.96	5.35
Coding genes	17,735	14,179	13,332
Median gene length (bp)	1,292	1,397	1,355

Repetitive sequence (Mb)	16.83	0.36	0.24
Transposable elements (%)	3.98	0.14	0.03

*Fv was reported to contain 12 chromosomes7, 11 chromosomes were mapped to the assembled genome, and no genetic markers from the smallest chromosome (600 kb or less) were found in the sequence data. N50 represents the size N such that 50% of the nucleotides is contained in scaffolds of size N or greater.

7.2.Publications on Fusarium genome sequences

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Li-Jun Ma

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Kemal Kazan

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Jana Sperschneide Louise F. Thatcher, Rebecca Lyons

7.3. Synopsis of Fusarium genomics results

- The five completely sequenced Fusarium genomes which also have mostly completed genetic and physical maps available, are
    1. F. graminearum,
    2. F. oxysporum f. sp. lycopersici,
    3. F. pseudograminearum,

4. F. ‘solani’ f. sp. pisi, and
5. F. verticillioides),

- Their genomes vary greatly in size and repeat content
    - genome of F. graminearum: 36-Mb
    - genome of F. ‘solani’ f. sp. pisi genome: 51 Mb.
    - genome of F. oxysporum f. sp. Lycopersici: 61-Mb , which is the largest fusarial genome sequenced so far.

F. verticillioides has distributed fumonisin and gibberellin gene clusters, are present in some but not all species of the F. fujikuroi and F. oxysporum species complexes and fusarin biosynthetic genes, which are widely distributed in Fusarium are absent in all F. oxysporum isolates that have been examined

- Comparative analyses have revealed that the Fusarium genome is compartmentalized into regions responsible for primary metabolism and reproduction (core genome), and pathogen virulence, host specialization, and possibly other functions (adaptive genome).
- Genes involved in virulence and host specialization are located on pathogenicity chromosomes within strains pathogenic to tomato (Fusarium oxysporum f. sp. lycopersici) and pea (Fusarium ‘solani’ f. sp. pisi).
- The experimental transfer of pathogenicity chromosomes from F. oxysporum f. sp. lycopersici into a nonpathogen transformed the latter into a tomato pathogen. Thus, horizontal transfer may explain the polyphyletic origins of host specificity within the genus.

- The genome assembly of *Fol* has 15 chromosomes, the *Fv* assembly 11 and the*Fg* assembly only four

- The smaller number of chromosomes in *Fg* is the result of chromosome fusion relative to *Fv* and *Fo*, and fusion sites in *Fg*match previously described high diversity regions
- Global comparison among the three *Fusarium* genomes shows that the increased genomic territory in *Fol* is due to additional, unique sequences that reside mostly in extra chromosomes.
- Syntenic regions in *Fol* cover approximately 80% of the *Fg* and more than 90% of the *Fv* genome referred to as the ‘core’ of the genomes.
- Except for telomere-proximal regions, all 11 mapped chromosomes in the *Fv* assembly (41.1 Mb) correspond to 11 of the 15 chromosomes in *Fol* (41.8 Mb).
- The co-linear order of genes between *Fol* and *Fv* has been maintained within these chromosomes, except for one chromosomal translocation event and a few local rearrangements

F. oxysporum genome is divided into “core” and “accessory” regions.

- The vertically transmitted “core” is conserved and performs all essential functions.
- The horizontally transmitted “accessory” genome in the form of lineage-specific (LS) chromosomes –
    - ➢ The *Fol* LS regions differ considerably in sequence among *Fo* strains with different host specificities
    - ➢ only occurs in specific pathotypes and encodes host-specific virulence factors.
    - ➢ The lineage-specific (LS) genomic regions in *F. oxysporum* include four entire chromosomes and account for more than one-quarter of the genome.
    - ➢ The transfer of the LS chromosomes between strains of *F. oxysporum* was demonstrated experimentally and resulted in the conversion of a non-pathogenic strain into a pathogen

Origin of LS regions

Three possible explanations for the origin of LS regions in the *Fol* genome were considered:

(1) *Fol* LS regions were present in the last common ancestor of the four *Fusarium* species but were then selectively and independently lost in *Fv*,*Fg* and *Fs* lineages during vertical transmission;

(2) LS regions arose from the core genome by duplication and divergence within the *Fol* lineage; and

(3) LS regions were acquired by horizontal transfer.

Secondary metabolite biosynthetic genes in Fusarium.

the five genomes have 35 and 31 nonorthologous PKS and NRPS genes, respectively (12, 33), indicating that the five species have the collective potential to produce 35 and 31 distinct families of polyketide and nonribosomal peptide-derived secondary metabolites.

- **Pathogenicity genes**
  - **Basic pathogenicity genes**
    - shared by Fusarium and other pathogenic fungi;
    - encode essential components of pathways involved in sensing of exogenous or endogenous signals,
  - **Specialized pathogenicity genes**
    - specific to individual Fusarium spp. on specific hosts.
    - directly involved in host-pathogen interactions:
      - F. oxysporum f. sp. lycopersici has established a gene-for-gene interaction with its tomato host.
      - Virulence factors, such as SIX (secreted in xylem) genes , play significant roles in determining host specificity.

    - SIX genes are located on the F. oxysporum f. sp. lycopersici pathogenicity .
    -
- **Other specialized virulence factors** that act in a host- or pathogen-specific manner include mycotoxins.

Comparative analyses have revealed

- Fusarium genomes are compartmentalized into regions responsible for essential functions (core genome) and for host specialization and pathogen virulence (adaptive/accessory genome).

- Horizontal inheritance of supernumerary chromosomes enriched for host-specific virulence may have played a major role in the polyphyletic distribution of host specificity within the F. oxysporum species complex and the rapid emergence of novel pathogens.

- Comparative genome analyses suggest that Fusarium has the genetic potential to produce many more secondary metabolites than previously indicated by chemical analyses.

- Multiple evolutionary processes, including vertical inheritance, horizontal gene transfer, gene duplication, and gene deletion, could have given rise to the current distribution of secondary metabolite biosynthetic gene clusters and production in Fusarium.

- Deletion of genes with roles in the production of asexual and sexual spore types tends to have pleiotropic effects. Transcriptomic studies indicate that a large number of genes are differentially expressed in the sexual cycle.

7.4. Fusarium genomics databases

Cyber infrastructure for *Fusarium* (CiF);

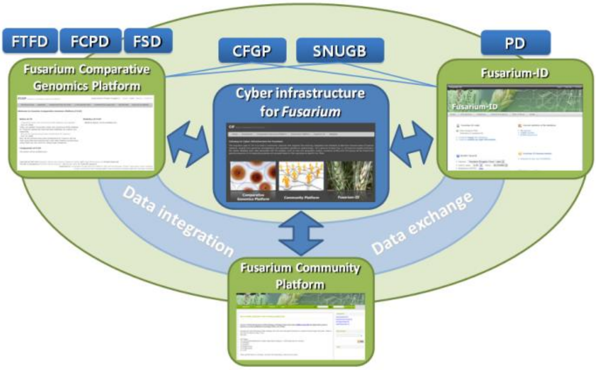
http://www.fusariumdb.org/;

The CiF consists of three components:

- Fusarium-ID
- Fusarium Comparative Genomics Platform (FCGP),
- Fusarium Community Platform (FCP),

Several databases specialized for fungal genome sequences or gene families and functional groups, include

- Fungal Transcription Factor Database (FTFD),
- Fungal Cytochrome P450 Database (FCPD),
- Fungal Secretome Database (FSD),
- Comparative Fungal Genomics Platform (CFGP),
- Seoul National University Genome Browser (SNUGB),
- Phytophthora Database (PD)



1. Fusarium-ID

Current statistics of the database

- » 78 Species

There are 7 species complex

- » 1,905 Isolates
- » 5,747 Sequences

- The Fusarium-ID enables users to explore the diversity of *Fusarium* and accurately identify new isolates based on their sequence similarity to previously characterized species.
- The Fusarium-ID was first released in 2004 (Geiser et al., 2004) based on sequences of the translation elongation factor 1 alpha (*EF-1α*) gene.
- Since then, sequences of multiple marker loci that represent almost all known species have been added, as well as information associated with characterized isolates, and more data analysis and visualization tools.
- More than 35,000 strains isolated from various substrates around the world are accessioned in the Fusarium Research Center (FRC) at Penn State University and the USDA-ARS NRRL Culture Collection in Peoria (Illinois).
- Using this rich strain resource, extensive molecular phylogenetic studies have been conducted to asses their diversity and evolutionary relationships (Aoki et al., 2005; Geiser et al., 2004; O'Donnell et al., 1998a; O'Donnell et al., 2009; O'Donnell et al., 1998b; O'Donnell et al., 2000a; O'Donnell et al., 2000b; O'Donnell et al., 2007; O'Donnell et al., 2004a; O'Donnell et al., 2004b; O'Donnell et al., 2010; Schroers et al., 2009; Starkey et al., 2007; Zhang et al., 2006).
- Despite these advances, a significant amount of diversity has yet to be explored, and some species complexes are quite poorly characterized phylogenetically.

- The main goal of Fusarium-ID is to support and coordinate these remaining tasks by systematically archiving available phylogenetic data and associated cultures in a format that is readily accessible and searchable by members of the global *Fusarium* research community.
- Without a robust phylogenetic framework and community-wide knowledge sharing, discovery and characterization of novel *Fusarium* species will likely be fragmented, creating confusion instead of the order that taxonomy should provide.
- Via the Folder function, users can create two types of data storage space:
    - private folder for storing selected data and results from previous analyses and
    - (ii) shared folder that permits data sharing with others designated by the creator of the folder (by assigning user IDs permitted to access the folder).
- A suite of web tools, named the Phyloviewer, allows users to build phylogenetic trees on the fly using sequences in BLAST outputs, including the query sequence, and any data stored in the Cart.
- Sequence data in the resulting tree are linked to information associated with corresponding isolates so that users can browse if any notable patterns exist among the isolates included in the tree.
- Restriction fragment length polymorphism (RFLP) analysis of PCR products has been utilized as a means for rapid strain identification.
- The Virtual Gel function supports this diagnostic method by generating predicted RFLP patterns from chosen sequences and restriction enzyme(s) via a virtual gel.
- A geographic information system (GIS) tool will function as a digitized atlas showing the genotypic and phenotypic diversity of *Fusarium* worldwide in geospatial and temporal contexts. This functionality will help establish a baseline for monitoring the migration and variation of *Fusarium* species.

*Correspondence concerning phylogenetics data stored in Fusarium-ID should be sent to: KerryO'Donnell (309-681-6383) and/or David M. Geiser (814-865-9773)

2. *Fusarium* Comparative Genomics Platform (FCGP)

Introduction to the Fusarium Comparative Genomics Platform (FCGP)

- Rapidly accumulating genome sequence data from diverse Fusarium species with different traits offers tremendous opportunities for understanding the molecular and evolutionary mechanisms underpinning functional diversification at a genome level. The FCGP was developed to facilitate the realization of such opportunities. Currently, the genomes of four *Fusarium* species, including *F. graminearum* (two strains), *F. oxysporum*, *F. verticillioides*, and *F. solani*, have been published (Coleman et al., 2009; Cuomo et al., 2007; Ma et al., 2010) with more species and isolates currently being sequenced or annotated.
- The first three species were sequenced by the Broad Institute, while the Department of Energy Joint Genome Institute sequenced *F. solani*.
- The SNU Genome Browser (SNUGB) (Jung et al., 2008) supports visualization and utilization of genome sequences and features both within and across species.
- All sequence data and contig information are displayed through the Contig Browser.
- Annotation information in a chosen region, such as transcripts, ORFs, tRNAs/rRNAs, exon/intron structure, SignalP, PSort and InterPro domains, can be displayed in multiple formats.

- The Chromosome Viewer shows the chromosomal locations of the phylogenetic markers stored in Fusarium-ID. The FCGP also presents computed characteristics of multiple gene families and functional groups using the Fungal Transcription Factor Database (FTFD) (Park et al., 2008b), the Fungal Cytochrome P450 Database (FCPD) (Park et al., 2008a), and the Fungal Secretome Database (FSD) (Choi et al., 2010).

- Currently available data include 3,095 transcription factors (TFs), 579 cytochrome P450s, and 11,905 putative secretory proteins, and provide an overview of these proteins within and across species.

- A BLAST server for each dataset is available for quick search. Moreover, genes that appear unique to each species, as well as those that are present in subsets of the four species, were identified through BLASTMatrix2, a modified BLAST program that searches gene(s) homologous to a query in multiple species simultaneously.

In addition to depositing newly released Fusarium genome sequences,

- characteristics of additional protein groups, such as ABC transporters and carbohydrate degrading enzymes, will be added once the corresponding fungal kingdom-wide databases are established.

- Available expressed sequence tags from Fusarium species will also be archived and linked to the corresponding genomes.

- In combination with the phylogenetic framework and accessioned cultures available through Fusarium-ID,

- the FCGP will help users study the evolution of Fusarium genes, gene networks, and whole genomes.

Fusarium Comparative Genomics Platform (FCGP)

Statistics of the FCGP

Species name	**# of chromosomes**	**# of proteins**	**# of TFs**	**# of P450s**
Fusarium verticillioides	11	14,188	626	129
Fusarium oxysporum f. sp. lycopersici	15	17,701	810	169
Fusarium graminearum	4	13,321	648	118
Fusarium solani f. sp. batatas	17	15,707	991	162
Total		60,917	3,075	578

List of sequences of Fusarium species

This is the first page, as example, of 288 pages containing a list of 5747 sequences of Fusarium species

Sequence Name	Species Name	Isolate	Marker
FD_01791_RPB2-711	*Fusarium lunatum*	FD_01791	RPB2-711
FD_00705_EF-1a_2	*Fusarium oxysporum*	FD_00705	EF-1a
FD_01170_BTub	*Fusarium sacchari*	FD_01170	BTub
FD_01865_ITS	*Fusarium solani*	FD_01865	ITS
FD_01866_ITS	*Fusarium solani*	FD_01866	ITS
FD_01867_ITS	*Fusarium solani*	FD_01867	ITS

FD_01692_EF-1a_2	*Fusarium sp*	FD_01692	EF-1a
FD_00001_EF-1a	*Fusarium graminearum*	FD_00001	EF-1a
FD_00033_EF-1a	*F.mesoamericanum*	FD_00033	EF-1a
FD_00034_EF-1a	*F.pseudograminearum*	FD_00034	EF-1a
FD_00038_EF-1a	*Fusarium graminearum*	FD_00038	EF-1a
FD_00077_BTub	*Fusarium sp*	FD_00077	B-tub
FD_00930_EF-1a	*Fusarium langsethiae*	FD_00930	EF-1a
FD_00929_EF-1a	*Fusarium sp*	FD_00929	EF-1a
FD_00002_EF-1a	*Fusarium graminearum*	FD_00002	EF-1a
FD_00036_EF-1a	*F.pseudograminearum*	FD_00036	EF-1a
FD_00037_EF-1a	*F.pseudograminearum*	FD_00037	EF-1a
FD_00035_EF-1a	*F. pseudograminearum*	FD_00035	EF-1a
FD_00032_EF-1a	*Fusarium meridionale*	FD_00032	EF-1a
FD_00030_EF-1a	*Fusarium asiaticum*	FD_00030	EF-1a

3. FUSARIUM MLST DATABASE

Because less than one-third of clinically relevant fusaria can be accurately identified to species level using phenotypic data (i.e., morphological species recognition), we constructed a three-locus DNA sequence database to facilitate molecular identification of the 69 Fusarium species associated with human or animal mycoses encountered in clinical microbiology laboratories.

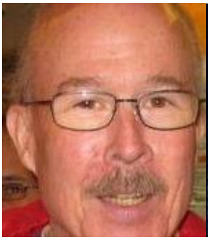
- The database comprises partial sequences from three nuclear genes: translation elongation factor 1α (EF-1α), the largest subunit of RNA polymerase (RPB1), and the second largest subunit of RNA polymerase (RPB2).
- These three gene fragments can be amplified by PCR and sequenced using primers that are conserved across the phylogenetic breadth of Fusarium.
- Phylogenetic analyses of the combined dataset reveal that, with the exception of two monotypic lineages, all clinically relevant

fusaria are nested in one of eight variously sized and strongly supported species complexes.

- The monophyletic lineages have been named informally to facilitate communication of an isolate's clade membership and genetic diversity.
- To identify isolates to species included within the database, partial DNA sequence data from one or more of the three genes can be used as a BLAST query against the database which is web-accessible at FUSARIUM-ID (http://isolate.fusariumdb.org) and the CBS-KNAW Fungal Biodiversity Center (http://www.cbs.knaw.nl/Fusarium).
- Alternatively, isolates can be identified via phylogenetic analysis by adding sequences of unknowns to the DNA sequence alignment, which can be downloaded from the two aforementioned websites.
- The utility of this database should increase significantly as members of the clinical microbiology community deposit cultures of novel mycosis-associated fusaria in internationally accessible culture collections (e.g., CBS-KNAW or the Fusarium Research Center), along with associated, corrected sequence chromatograms and data, so that the sequence results can be verified and isolates are made available for future study.

People involved in the Fusarium MLST project

Kerry O'Donnell, Deanna A. Sutton, Michael G. Rinaldi, Brice A. J. Sarver[3], S. Arunmozhi Balajee[4], Hans-Josef Schroers, Richard C. Summerbell, Vincent A. R. G. Robert, Pedro W. Crous[7], Ning Zhang, Takayuki Aoki, Kyongyong Jung, Jongsun Park, Yong-Hwan Lee[10], Seogchan Kang, Bongsoo Park[11], and David M. Geiser


Kerry O'Donnell


Deanna A. Sutton


Michael G. Rinaldi


Hans-Josef Schroers


R. C. Summerbell


Pedro W. Crous


Takayuki Aoki


David M. Geiser

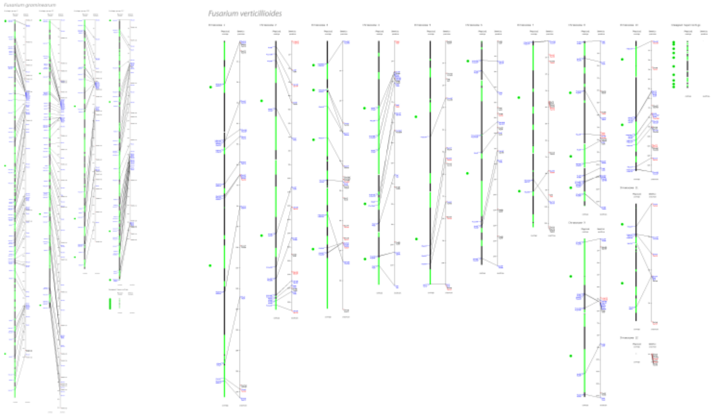
Searching and Identification

The Fusarium MLST website hosted by the CBS-KNAW Fungal Biodiversity Centre allows one to access a database of 1365 well studied isolates and 2692 associated sequences from the following regions: Translation elongation factor 1 alpha gene (EF1), RNA polymerase I beta subunit gene (RPB1), RNA polymerase II beta subunit gene (RPB2), Calmodulin gene (CAL), beta-tubulin gene (TUBB), Histone gene, IGS, Internal transcribed spacers (ITS1 and ITS2), 28S ribosomal RNA large subunit (28S - LSU) and Mitochondrial gene. It must be noted that, for the time being, only a small portion of the strains have been sequenced for all the genes. In Fusarium chlamydosporum species complex, EF1, RPB2, CAL, ITS and LSU sequences are available. For Fusarium dimerum species complex, EF1, TUBB, ITS and LSU are most of the time present. Strains belonging to Fusarium incarnatum-equiseti species complex have been sequenced for EF1, RPB2, CAL, ITS and LSU. Fusarium oxysporum species complex is well represented in terms of strains but only a few EF1, and LSU are more or less consistently present while TUBB as well as ITS have been sequenced in a few cases. For Fusarium solani species complex, several genes (EF1, RPB2, CAL, TUBB, ITS and LSU) are represented but few strains have been sequenced for all of them. Finally, Gibberella fujikuroi species complex have been well studied and most strains have data for EF1, CAL, TUBB, Histone, IGS, ITS, LSU and Mitochondrial gene.

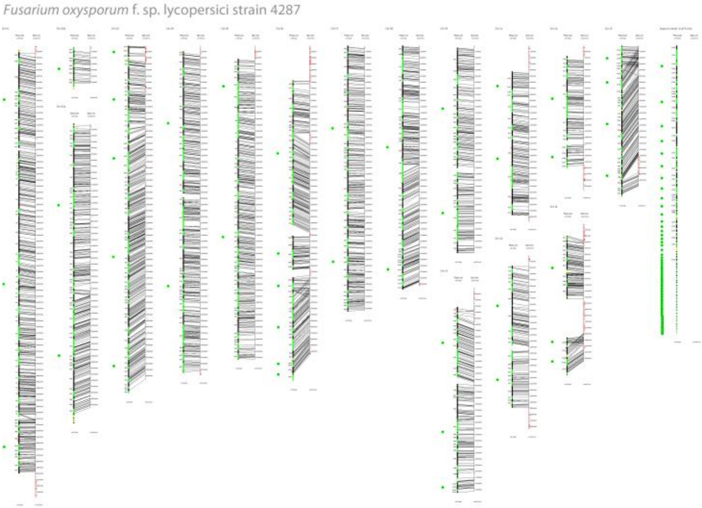
Simple and advanced queries on the strains table are possible via a user-friendly interface.

For the identification, two major options are possible. The first one is the *Single sequence* alignment algorithm comparing a unique unknown sequence against the ones present in our Fusarium MLST sequences reference database. It's also possible to compare it against all fungal sequences available from both Genbank and the CBS-KNAW sequences database . The second option (*Multiple sequences*) allows the alignment of several sequences of several loci at the same time against the Fusarium MLST database using the polyphasic comparison tools of the BioloMICS software. Since not all the sequences are available for all the strains, comparisons will be based on unequal datasets and might lead to unbalanced identifications. This being said, these multi-locus sequences comparisons are extremely powerful and usually allow more reliable identifications

Examples of physical and optical maps **of Fusarium species**



F. graminearum F.verticillioides



Fusarium oxysporum physical map of 15 chromosomes

8. Fusarium diseases in plants, man and animals

8.1. Fusarium diseases in plants

Fusarium species are among the most diverse and widely dispersed plant-pathogenic fungi, causing economically important blights, root rots or wilts[1]. Some species, such as *F. graminearum* and *F. verticillioides* , have a narrow host range, infecting predominantly the cereals. By contrast, *F. oxysporum*, has a remarkably broad host range, infecting both monocotyledonous and dicotyledonous plants

Fusarium graminearum is one of the causal agents of head blight disease in wheat and barley. This devastating pathogen and other head blight causes important losses in crops worldwide

Fusarium oxysporum comprises a group of soil inhabitants that can exist as saprophytes in the soil debris but also as pervasive plant endophytes colonizing the plant roots. Many strains of these species are pathogenic to plant crops. One of these strains, *Fusarium oxysporum f.sp. lycopersici*, is the causal agent of fusarium wilt in tomatoes. The first symptoms of the plant are yellowing and weakness in one side of the plant and progress with wilting of the leaves and browning of the vascular system leading eventually to leaf death and inhability to produce fruits.

Fusarium oxysporum has many *Formae speciales* that exist as plant pathogens, which are differentiated by host range, causing storage, root, stem, and fruit rot, as well as vascular wilt.

- *F. oxysporum f.sp. cubense* causes **Banana wilt**
- *F. oxysporum f.sp. vasinfectum* causes **wilt of cotton**
- *F. oxysporum f.sp. batatas* causes **wilt of sweet potatoes** and **stem rot**
- *F. oxysporum f.sp. lycopersici* causes **tomato wilt**
- *F. oxysporum f.sp. asparagi* causes **asparagus wilt**
- *F. oxysporum f.sp. melonis* causes **muskmelon** and **cantaloupe wilt**
- *F. oxysporum f.sp. zingiberi* causes **ginger wilt**

Fusarium solani is responsible for disease on about 100 genera of plants.

Fusarium verticillioides is a fungal plant pathogen. It causes a disease in rice called bakanae, which is japanese and means "foolish seedlings". The afflicted plants are at best infertile with empty panicles, producing no edible grains; at worst, they are incapable of supporting their own weight, topple over, and die (hence "foolish seedling").The earliest known report of bakanae is from 1828. Bakanae affects rice crops in Asia, Africa, and North America; in 2003, the International Rice Research Institute estimated bakanae-related crop losses at between 20% and 50%.

Fusarium verticillioides is the causal agent of kernel and ear rot of maize. This destructive disease occurs virtually everywhere that maize is grown worldwide. In years with high temperatures, drought, and heavy insect damage, the disease can significantly diminish crop quality.

Gallery of fusarium infections in plants

1. Fusarium wilt



Fusarium wilt of banana www.apsnet.org, pixgood.com


galleryhip.com Fusarium Wilt Little trip Fusarium Wilt Palm pixgood.com


www.ext.colostate.edu, Tomato www.infonet-biovision.org Chili plant wilt

2. Head scab and head blight



fyi.uwex.edu . Fusarium head scab on a wheat head wikimedia.org Fusarium head blight of barley.

3. Fusarium ear rot in corn


www.strikepointpioneer.com Fusarium ear rot is the most widespread disease of all corn kernel

4. Fusarium Crown and Foot Rot


ag.umass.edu Fusarium Crown and Foot Rot of pumpkin, Squash www.plantvillage

pnwhandbooks.org Fusarium Root and Crown Rot. Red clover, Crown and root rot diseases of strawberries .www.agric.wa.gov.au

5. Fusarium Basal Rot

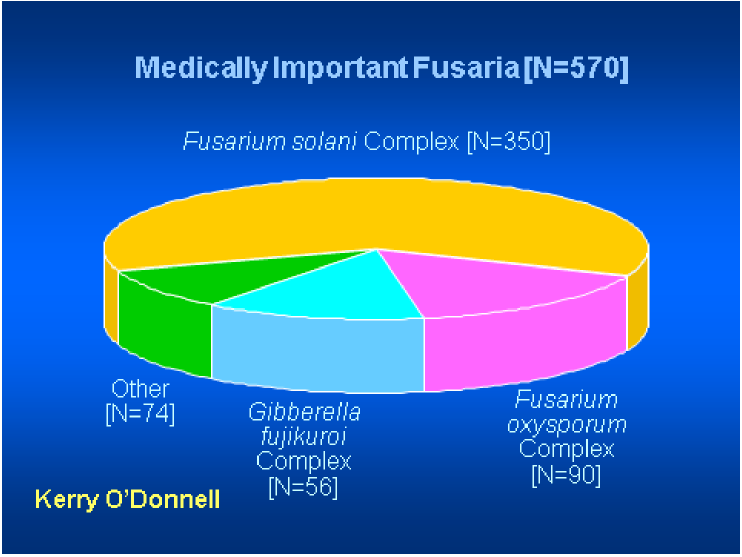
www.alamy.comgardener.wikia.com Onion Fusarium basal rot Iris, Bulbous -Fusarium Basal Rot..pnwhandbooks.org

8.2. Fusarium infections in human

- Fusarium is capable of causing mycetomas,
- Fusarium has repeatedly been isolated from human keratitis and corneal ulcers. Most cases concern keratitis.
- Fusarium has been reported as an agent in endophthalmitis,
- Fusarium has been reported as an agent in subcutaneous and cutaneous infections,
- Fusarium has been reported as an agent in septic arthritis.
- Cases of sinusitis and catheter infection have been reported.
- Upon initial exposure, Fusarium generally ascends right into the colon, then through the tissues and through the central nervous system.

- Seven Fusarium species complexes are associated with described cases of human infections:

1. F. dimerum species complex (FDSC),
2. F. solani species complex (FSSC),
3. F. oxysporum species complex (FOSC),
4. F.fujikuroi species complex (FFSC, encompassing F. proliferatum and F. verticillioides),
5. F. incarnatum-equiseti species complex (FIESC)
6. F. chlamydosporum species complex (FCSC), and
7. F. sporotrichioides (FSAMSC).



- Only a few other Fusarium species outside these species (complexes) have occasionally been implicated in human or mammal infections.The majority of Fusarium human infections are due to members of the FSSC, followed by FOSC.
-

The commonly recorded diseases are:

- **Onychomycoses and skin infections**
    - Etiological agents: members of FSSC, FOSC, FFSC, rarely FDSC and FIESC.
    - The prevalence of onychomycoses in humans lies in the range of 5–15 % of the adult population. Fusarium spp. can make up to 10–15 % of the cases
    - Suggested predisposing factors for onychomycosis in general include increasing age, but also immunosuppression, poor peripheral circulation, trauma, and tinea pedis.
- **Fungal keratitis** is often linked with trauma, especially with vegetable or other organic matter. The infection is more common in tropical areas and in areas with a relatively large agrarian population. However, prevalence data are still approximate.
- **Disseminated fusarioses** in the immunocompromised host,
    - Etiological agents: members of FSSC, FFSC, FOSC, FDSC, or rarely by FIESC.

Clinical Spectra of Fusarium Species

- **The Fusarium solani species complex (FSSC)** globally is the most common group encountered in human infections. It contains sixty or more haplotypes, some of which are predominant in patients.
    - Of these, F. falciforme, F. keratoplasticum, F. lichenicola, and F. petroliphilum are capable of human infection.
    - Reported cases by members of FSSC range from onychomycosis to disseminated infection
- **The Fusarium dimerum** species complex (FDSC) contains at least 12 lineages, of which at least F. dimerum sensu stricto, F. delphinoides, and F. penzigii have been involved in human

infection. Most case reports on F. dimerum were published prior to its recognition as a species complex.
the infections range from onychomycoses, keratitis, and other localized infections to disseminated infections in haemato-oncological patients.

- **Fusarium chlamydosporum** species complex (FCSC) (F. chlamydosporum sensu lato) contains at least four distinct species. The complex has only once been implicated in a keratitis, but more often in onychomycoses, cutaneous and deep localized infections, and in disseminated infections in haemato-oncological patients.

- **Fusarium incarnatum-equiseti species complex (FIESC)**
at least 28 species can be recognized. They have repeatedly been involved in onychomycoses, skin, eye, and deep localized and disseminated infections, especially in leukemic patients.

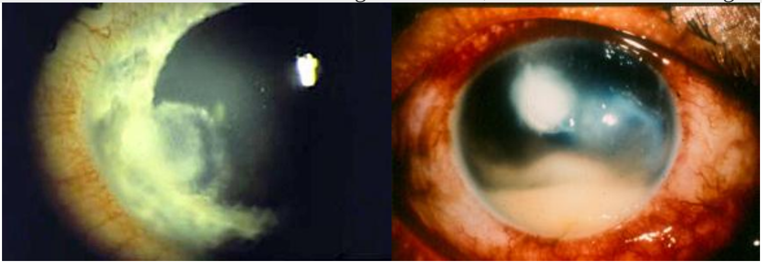
- **Fusarium fujikuroi species complex (FFSC)**
    - F. proliferatum and F. verticillioides are most commonly observed in human infections are However,
    - members of FFSC are increasingly identified in especially invasive and disseminated infections in haematooncological patients.
    - some species of FFSC species, e.g., F. acutatum, F. anthophilum, F. andiyazi, F. nygamai, and F. sacchari have a limited geographic distribution and/or are associated with specific climatic conditions.

Outside the above-described species complexes, a few other Fusarium species have been implicated. Both F. lateritium and F. polyphialidicum were recorded causing keratitis, while F. lateritium also caused a disseminated infection in an HIV-patient.

Gallary of some clinical cases

Slit lamp photograph showing infected cornea involving regions of sclera, ***Fusarium temperatum.*** Al-Hatmi *et al., 2014*

A, Patient 1 has classic characteristics of fungal keratitisB, Patient 2 has severe fungal keratitis



Left: www. consumerist.com, A 34-year-old man, a piece of wood hit his eye. Culture results were positive for F. solani.
Right: www.intechopen.com Satellite lesions, hypopyon in anterior and posterior chamber in a Fusarium keratitis in 45 year-old male.

Onychomycosis in a male gardener (a, b) Finger and thumb nails showing signs of total dystrophic onychomycosis. Fusarium equiseti , Jandial S, Sumbali G.m 2012

Onychomycosis in a male: (a, b) Big toe and little toe finger nails showing signs of onychomycosis. *Fusarium heterosporum* , Jandial S, Sumbali G.m 2012

Toenail Fusarium infection, habee.hubpages.com EARL et al., 1959
Case Reports Cutaneous Infection by Fusarium solani in a Patient ...www.thinkzon.com

A and B – Fingers nail with yellow-white discoloration roughness and thickening in distal surfaces. C and D – Toenails with yellowish discoloration, hyperkeratosis and roughness of the distal nail plates. *Fusarium oxysporum* Vania O. Carvalho et al., 2014

multiple cutaneous ulcers, F. solani. www.perfecthealthinfo.com. **Alex Banger**

Cutaneous fusariosis by a species of the Fusarium dimerum species .www.elsevier.es

Heel of left foot showing swelling with nodules and verrucous hyperplasia, **Plantar surface of right forefoot showing a superficial ulcer,** *Fusarium solani*, Kudur MH et al., 2013

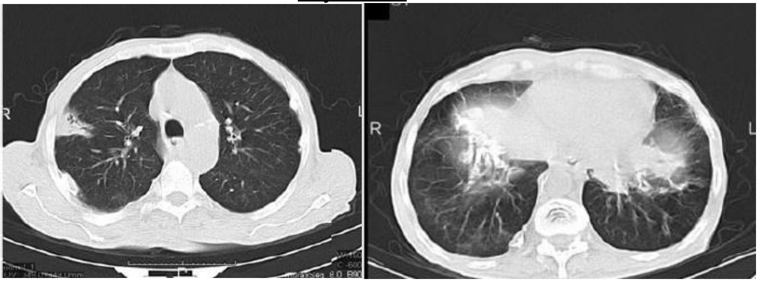
Ulcer with black eschar on forehead, Lesion on left knee
Kritika Vishwanath Singha et al., 2012

Disseminated Fusarium infection with skin lesions

Left: Fatal disseminated infection with Fusarium petroliphilum Ersal et al., 2015, Disseminated Fusarium infection in a patient with acute myeloid leukemia and prolonged neutropenia. (A) Multiple tender cutaneous nodules

Liu, Y., Wang, N., Ye, R., & Kao, W. (2014). Disseminated Fusarium infection in a patient with acute lymphoblastic leukemia: A case report and review of the literature. Oncology Letters, 7, 334-336.

Fusarium solani: An Emerging Fungus in Chronic Diabetic Ulcer..Pai R et al., J Lab Physicians. 2010

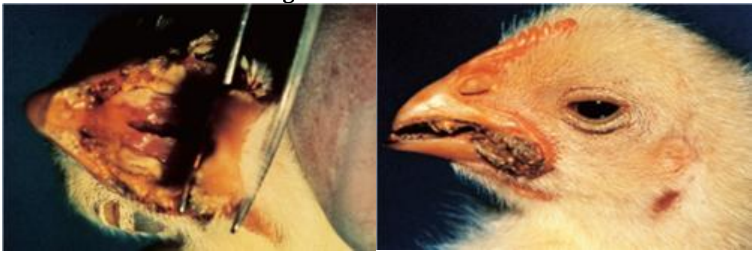


Non-specific infection and calcificated thickening of pleura (asbestos exposure). New infiltration areas and cavitations in someconsolidations. N. Kebabcı et al. 2013 Blackwell Verlag GmbH

8.3. Fusarium infections and fusariotoxicosis in birds

A sandhill crane suffering from fusariotoxicosis, Fluid beneath the skin of the head and neck of a sandhill showing wing and head droop, **Ronald M. Windingstad** crane with fusariotoxicosis. **J. Christian Franso**

Inflammation and ulceration of the mucosal surface of the oesophagus in a sandhill crane with fusariotoxicosis. James Runningen

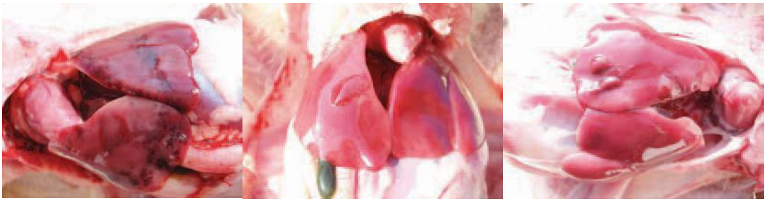


Stomatitis following consumption of T2 fusariotoxin. Chick showing stomatitis attributed to T2.fusariotoxicosis, **Dr.Mohamed Abdel - Moniem Amer**

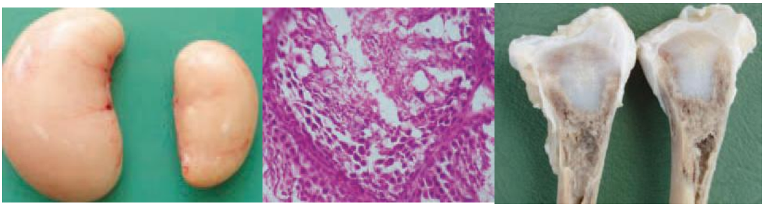
Ivan Dinev, Diseases of Poultry

erosions and ulcers in gizzard cuticulum , thickened wall of the proventriculus hyperaemic and haemorrhagic mucous coat of the gizzard **Ivan Dinev, Diseases of Poultry**

reddening and hemorrhage of intestinal muscosa. **Ivan Dinev, Diseases of Poultry**



.Frequent findings in fusariotoxicoses are the massive subcapsular liver haematomas, causing sudden death in broilers. **Ivan Dinev, Diseases of Poultry**



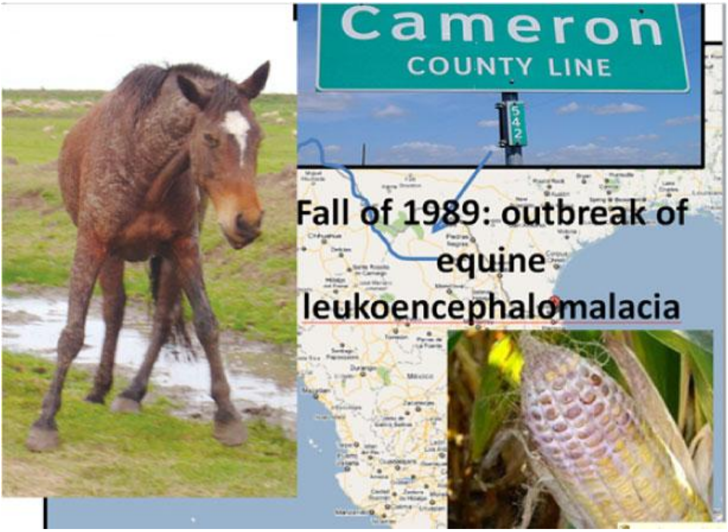
The fusariotoxin zearalenone has an effect, identical to that of oestrogenic hormones and results in reduction of testes in cocks. Left - normal; right -

atrophied testis in a cock, in whose diet high zearalenone concentrations have been determined. Microscopically, the testes of cocks with zearalenone fusario-toxicosis, show a fatty infiltration and atrophy of the germinative epithelium with the exception of the basal layer as well as interruption of the spermatogenesis., Fusarochromanone causes tibial dyschondroplasia in broiler chickens, manifested with long bone deformation. **Ivan Dinev, Diseases of Poultry**

8.4. Fusariotoxicosis in animals

- **Fumonisins** cause a neurological disease, equine leucoencephalomalacia in horses, pulmonary edema in swine, hepatotoxic and nephrotoxic effects in other domestic animals, and carcinogenesis in laboratory animals.
- **Vomitoxin** causes pigs to vomit following consumption of feed with high concentrations of the toxin. Swine are the most sensitive livestock species to vomitoxin. The most common effect of vomitoxin is reduced feed intake or feed refusal. Ruminants appear to be less sensitive to dietary vomitoxin concentrations than are monogastrics (particularly swine), perhaps due to the presence of rumen microorganisms.
- **Zearalenone** possesses estrogenic activity and, When consumed by animals, has been associated with reproductive problems, such as abortions, false heat, recycling, reabsorption of fetuses and mummies, and vulvaluterine prolapse. Swine are the most susceptible to the effects of zearalenone. Poultry Broiler chicks and laying hens are not greatly affected by zearalenone, even when consuming large quantities of the toxin

Zearalenone, in swine www.apsnet.org



this horse isdisplaying: staggering, ataxia, paresis. drowsiness, listlessness. Death will occurr after a few days. www.healthvalue.net

9. Isolation and identification of Fusarium species

9.1. Media used

Selective culture media, such as Nash and Snyder medium (NS), dichloran-chloramphenicol peptone agar (DCPA), modified Czapek-Dox agar (MCz), Czapek Dox iprodione dichloran agar (CZID), potato dextrose iprodione dichloran agar (PDID), or malachite green agar (MGA 2.5), have been developed for isolating and enumerating Fusarium spp. from natural samples.

Tap water Agar (TWA)

Agar	20.0 g
Distilled water ad	1000.0 ml

Sterilise by autoclaving at 121°C for 15 minutes.

Carnation Leaf-Piece Agar (CLA).

Fresh carnation leaves cut into 5-8 mm² pieces, dried in a forced-air oven (~ 70°C) for 1-2 hours, sterilized by gamma irradiation (2.5 megarads), placed into a Petri dish, add sterile 1.2% water agar

Carrot Agar.

Fresh carrots, washed, peeled and diced 400 g add in a flask in 400 ml of water, autoclave for 20 minutes, blend, add 500 ml of distilled water, add 20 g of agar, autoclave for 30 minutes.

Oat Agar,

whole (OA) Quaker Oats*................	10 flakes/20 ml
Agar*...	15 g
Distilled water...............................	1 liter 5.

Potato Dextrose Agar (PDA)*

Potato extract (see below)	200 ml
Glucose*	10 g
Agar*...	15 g
Distilled Water...........................	1 liter

To prepare potato extract:

place 200 g diced potatoes into 500 ml dist. water,
cook 1 hour in steamer or 40 min. in autoclave.
strain potato infusion through cloth,
melt agar in 500 ml dist. water,

add 200 ml potato extract to melted agar,
add glucose,
adjust volume to 1000 ml
autoclave.

Soil Agar (SA).

250-500 g of sieved dry soil into a flask

add to 1 L with tap water

autoclave for 15 min.

add 15 g agar

autoclave for 15 min.

Komada's Medium.

D-Galactose		20.0 g
L-Asparagine		2.0 g
K_2HPO_4		1.0 g
KCl		0.5 g
$MgSO_4 \bullet 7H_2O$		0.5 g
PCNB (Terraclor 75 % WP)		1.0g
Fe_3Na EDTA		10.0 mg
Distilled water	to	1000.0 ml

The streptomycin stock solution is 5 g of streptomycin in 100 ml distilled H_2O, and is used at the rate of 6 ml/L of medium.

The Oxgall stock solution contains 5 g Oxgall and 10 g $Na_2B_4O_7 \bullet 10H_2O$ in distilled H_2O, and is used at the rate of 10 ml/L of medium.

Nash-Snyder Medium

Difco peptone	15.0 g
K_2HPO_4	1.0 g
$MgSO_4 \bullet 7\ H_2O$	0.5 g
Agar	15.0 g

Distilled water	1000.0.ml
PCNB (Terraclor 75 % WP)	1.0 g
Streptomycin	0.3 g
neomycin sulfate	0.12 g

Dichloran-chloramphenicol peptone agar (DCPA)

Peptone	15.0 g;
KH2PO4,	1.0 g;
MgSO4 7H20,	0.5 g;
chloramphenicol,	0.2 g;
Dichloran (0.2% solution in ethanol),	1 ml (equivalent to 2 pg/ml);
Agar,	20.0 g;
Distilled water to	1000.0 ml.

The medium is sterilized at 121°C for 15 min; the final pH was;

Czapek’s Agar (CZ)*

Sucrose (commercial grade).	30.0 g
NaNO3	3.0 g
K2HPO4	1.0 g
MgSO4 x 7 H2O	0.50 g
KCl	0.50 g
FeSO4 x 7 H20	0.01 g
Agar	20.0 g
Distilled water	1000.0ml

9.2. Identification of Fusarium species

9.2.1. Morphological identification

Fusarium cultures are examined for macromophological features typical for Fusarium species namely, woolly to cottony, flat, spreading colonies, white, cream, tan, salmon, cinnamon, yellow, red, violet, pink or purple; and on the reverse, it may be colourless, tan, red, dark purple, or brown, and the micromorphological features namely: curved, transversely septate conidia macroconidia, produced from sporodochia or pionnotes, smaller conidia of various shapes and septation ("microconidia" and/or "mesoconidia") produced from unbranched or branched mycelial conidiophores, producing conidiogenous cells with monophialidic polyphialidic openings, and chlamydospores which are thick-walled, generally globose thallospores, produced in or on hyphae or conidia, singly or in chains or bunches, in addition to sexual spores, when observed, which are produced in flask-shaped fruiting bodies (perithecia) that are usually in shades of red, orange, blue or purple, with little or no stromatal tissue. Asci produced from distinct hymenia, single-walled (unitunicate) containing eight ascospores, which usually possess one or more septa, but can be aseptate.

9.2.2. Molecular Methods for Identification of Fusarium

Molecular biology has offered a number of insights into the detection and enumeration of fungal pathogens and information on identifying unknown species from their DNA sequences. In recent years, there has been vast progress in the development of molecular biological tools and technologies. Each technique can be used as a tool to study variation amongst fungal isolates, and hence provide important information on genetic relationships, taxonomy, population structure and epidemiology associated with fungi.

Molecular markers used for identification of Fusarium

- sequence characterized amplified regions (SCAR),
- single strand conformational polymorphism (SSCP),
- randomly amplified polymorphic DNA (RAPD),
- amplified fragment length polymorphism (AFLP),
- restriction fragment length polymorphism (RFLP),
- sequence related amplified polymorphism (SRAP),
- single nucleotide polymorphism (SNP),
- variable number of tandem repeat (VNTR)

- SNP-based multilocus genotyping assay

Steps:

- PCR amplification DNA sequencing of, e.g.
    - the translation elongation factor 1 alpha gene (*EF-1*α);
    - the nuclear rRNA internal transcribed spacer (ITS),
    - the large subunit (LSU),
    - the intergenic spacer (IGS) regions;
    - the second largest subunit of the RNA polymerase gene (*RPB2*);
    - the calmodulin gene (*CAM*);
    - the mitochondrial small subunit (mtSSU) rRNA gene. Comparison of sequenced DNA to DNA sequence databases

- **Identification by comparison with databases**
    - The FUSARIUM-ID server at http://fusarium.cbio.psu.edu
    - BLAST search tool that allows users to query unknown sequences against the database.
    - GenBank database is publicly available for identification purposes, and can be accessed via the Entrez website at the US National Center for Biotechnology Information (NCBI): http://www.ncbi.nlm.nih.gov/Entrez/.
    - It is strongly recommend to use FUSARIUM-ID because it contains vouchered and well-characterized sequences that correspond to publicly available cultures that can be used for confirmation.
    - FUSARIUM-ID can be used in conjunction with GenBank.

Primers used for Fusarium

List of primers developed for rapid detection of Fusarium sp. and F. solani. (Arif et al., 2012)

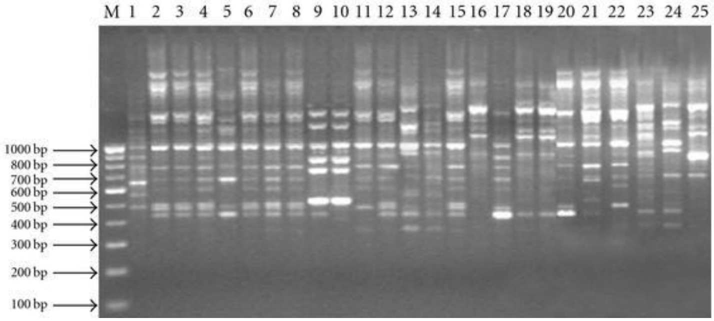
TEF-1α ~420 bp Fusarium species
TEF-Fu3f GGTATCGACAAGCGAACCAT
TEF-Fu3r TAGTAGCGGGGAGTCTCGAA

ITS2-rDNA subunit ~466 bp Fusarium species
ITS-Fu1f ACAACTCATAACCCTGTGAACAT
ITS-Fu1r CAGAAGTTGGGTGTTTTACGG

TEF-1α 658 bp F. solani
TEF-Fs4f ATCGGCCACGTCGACTCT
TEF-Fs4r GGCGTCTGTTGATTGTTAGC

ITS1, ITS2 595 bp F. solani
ITS-Fu2f CCAGAGGACCCCCTAACTCT
ITS-Fu2r CTCTCCAGTTGCGAGGTGTT

ITS2-rDNA subunit 485 bp F. solani
ITS-Fs5f CGTCCCCCAAATACAGTGG
ITS-Fs5r TCCTCCGCTTATTGATATGCTT



Amplification profile of 25 isolates of Fusarium spp. obtained using PP1 primer.(Arif, et al., 2011)

List of primers designed from the sequences of F. sambucinum and F. coeruleum ITS region using primer set ITS1 x LR1. (Assefa et al., 2012)

C1F TCAAGCTCTGCTTGGTGTTG
C1R TTGACCTCGGATCAGGTAGG F. coeruleum

C2R ACTCGCCTCAAAACAATTGG

C3R1ATTTCGGAGCGCAGTACATC

C4F ACAAGGTTTCCGTAGGTGA
C4R AGACTCGCCTCAAAACAATT

C5F GCTTTGCCTGCTACTATCTCTTAC
C5R TCAATAAGCGGAGGAAAAG

S1F ATCTCTTGGTTCTGGCATCG
S1R AAATACATTGGCGGTCTTGC F. sambucinum
S2R CGAAATACATTGGCGGTCTT

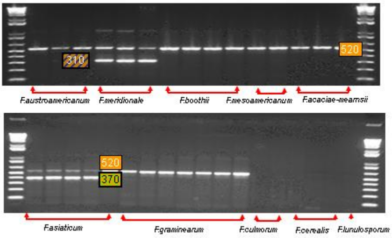
S3F GGAGGGATCATTACCGAGTTTACA
S3R TAAAACCCCAACTTGTGAATGTGA

Species-specific PCR primers designed from the ITS region for the identification of Fusarium species (Prashan et al.,2003)

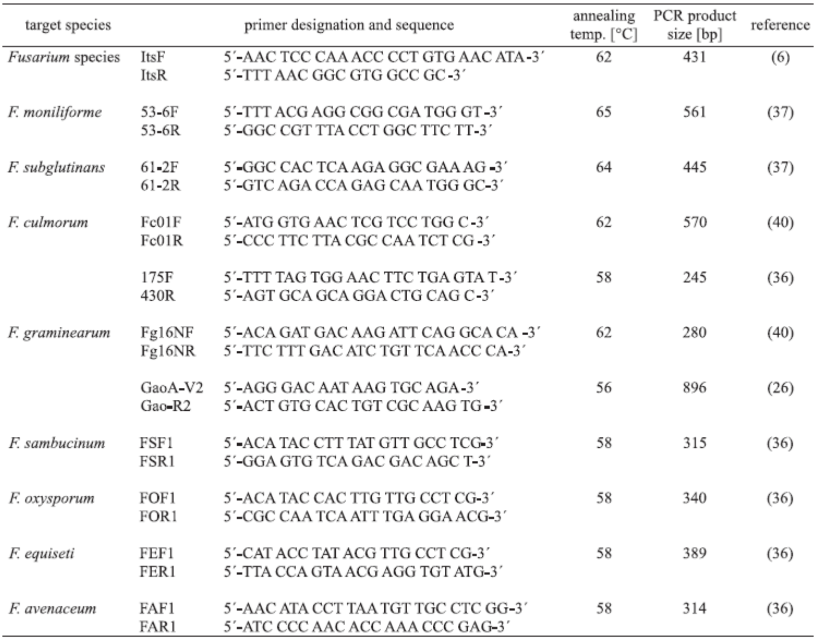
F. culmorum	175F	5P-TTTTAGTGGAACTTCTGAGTAT-3P
	430R	5P-AGTGCAGCAGGACTGCAGC-3P
F. sambucinum	FSF1	5P-ACATACCTTTATGTTGCCTCG-3P
	FSR1	5P-GGAGTGTCAGACGACAGCT-3P
F. oxysporum	FOF1	5P-ACATACCACTTGTTGCCTCG-
	FOR1	5P-CGCCAATCAATTTGAGGAACG-3P
F. equiseti	FEF1	5P-CATACCTATACGTTGCCTCG-3P
	FER1	5P-TTACCAGTAACGAGGTGTATG-3P
F. avenaceum	FAF1	5P-AACATACCTTAATGTTGCCTCGG-3P
	FAR	5P-ATCCCCAACACCAAACCCGAG-3

Genus and species-specific primers (KONIETZNY et al.,]. 2003)

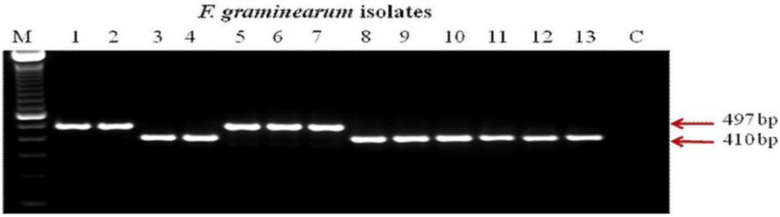
Species specific PCR for *F. asiaticum*, *F. meridionale* and Fg clade based on ammonia ligase 2 gene



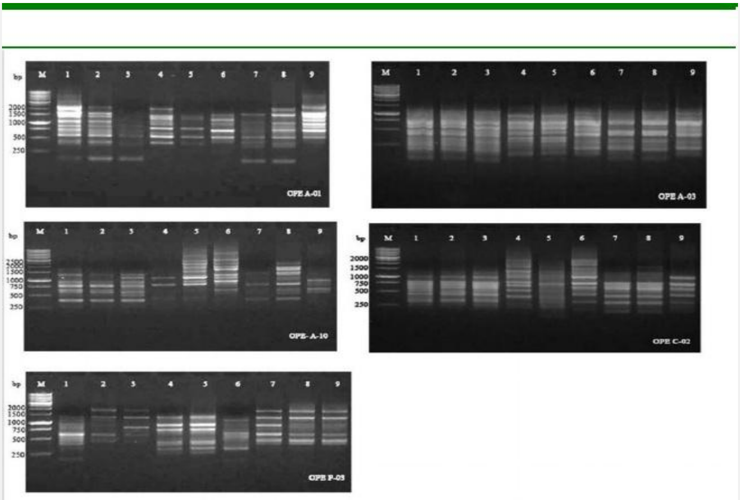
Yang *et al.*, 2008



target species	primer designation and sequence		annealing temp. [°C]	PCR product size [bp]	reference
Fusarium species	ItsF ItsR	5′-AAC TCC CAA ACC CCT GTG AAC ATA-3′ 5′-TTT AAC GGC GTG GCC GC-3′	62	431	(6)
F. moniliforme	53-6F 53-6R	5′-TTT ACG AGG CGG CGA TGG GT-3′ 5′-GGC CGT TTA CCT GGC TTC TT-3′	65	561	(37)
F. subglutinans	61-2F 61-2R	5′-GGC CAC TCA AGA GGC GAA AG-3′ 5′-GTC AGA CCA GAG CAA TGG GC-3′	64	445	(37)
F. culmorum	Fc01F Fc01R	5′-ATG GTG AAC TCG TCC TGG C-3′ 5′-CCC TTC TTA CGC CAA TCT CG-3′	62	570	(40)
	175F 430R	5′-TTT TAG TGG AAC TTC TGA GTA T-3′ 5′-AGT GCA GCA GGA CTG CAG C-3′	58	245	(36)
F. graminearum	Fg16NF Fg16NR	5′-ACA GAT GAC AAG ATT CAG GCA CA-3′ 5′-TTC TTT GAC ATC TGT TCA ACC CA-3′	62	280	(40)
	GaoA-V2 Gao-R2	5′-AGG GAC AAT AAG TGC AGA-3′ 5′-ACT GTG CAC TGT CGC AAG TG-3′	56	896	(26)
F. sambucinum	FSF1 FSR1	5′-ACA TAC CTT TAT GTT GCC TCG-3′ 5′-GGA GTG TCA GAC GAC AGC T-3′	58	315	(36)
F. oxysporum	FOF1 FOR1	5′-ACA TAC CAC TTG TTG CCT CG-3′ 5′-CGC CAA TCA ATT TGA GGA ACG-3′	58	340	(36)
F. equiseti	FEF1 FER1	5′-CAT ACC TAT ACG TTG CCT CG-3′ 5′-TTA CCA GTA ACG AGG TGT ATG-3′	58	389	(36)
F. avenaceum	FAF1 FAR1	5′-AAC ATA CCT TAA TGT TGC CTC GG-3′ 5′-ATC CCC AAC ACC AAA CCC GAG-3′	58	314	(36)



DNA of Chinese and Canadian *Fusarium graminearum*chemotypes amplified using Fg16 F/R primers. The 497 bp represents SCAR group V and 410 bp represents SCAR group I. Lane M: Marker; Lanes 1 and 2: NIV chemotypes, China (Fg-0921, 0905); Lanes 3 and 4: 15-ADON chemotype, China (Fg-1960, 0819); Lanes 5-7: 3-ADON chemotypes, China (Fg-0919, 0926, 0970); Lanes 8-10: 3-ADON chemotypes, Canada (M5-06-01, ON-06-39, DF-Fg-2); Lanes 11-13: 15-ADON chemotypes, Canada (DF-Fg- 144, ON-06-05, 55-1); Lane C: Control. Amarasinghe et al., 2011

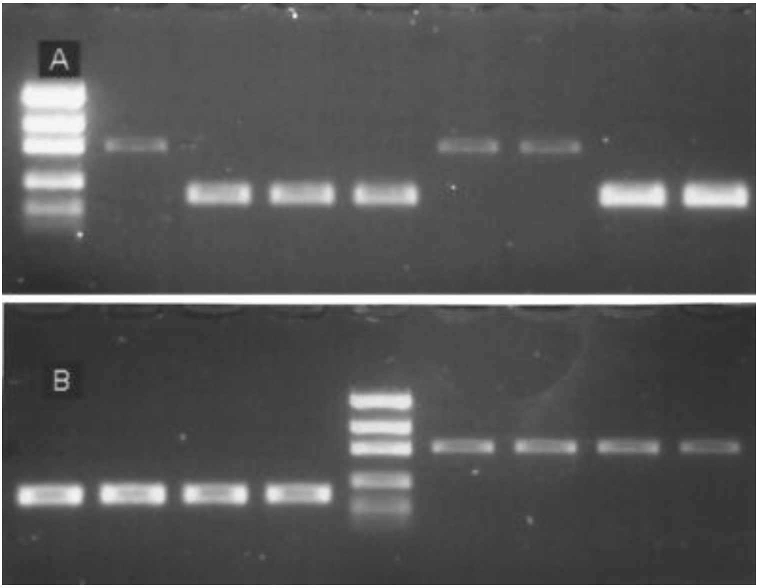


RAPD banding patterns of nine fusarium isolates isolated from horse feed staff using five selected random primers, M: 1 kbp plus DNA ladder, Lane (1-3): *F. verticillioides*, Lane 4-6 are*F. anthophilum* and lane 7-9 *F. proliferatum* (Abo El Yazid *et al.* (2011)

Diagnostic multiplex PCR for *MAT-1* and *MAT-2* (Steenkamp et al., 2000).

The multiplex PCR included the four primers GFmat1a, GFmat1b, GFmat2c, and GFmat2d:

GFmat1a (5′-GTTCATCAAAGGGCAAGCG-3′)
GFmat1b (5′-TAAGCGCCCTCTTAACGCCTTC-3′)
Gfmat2c (5′-AGCGTCATTATTCGATCAAG-3′).
GFmat2d (5′-CTACGTTGAGAGCTGTACAG-3′).

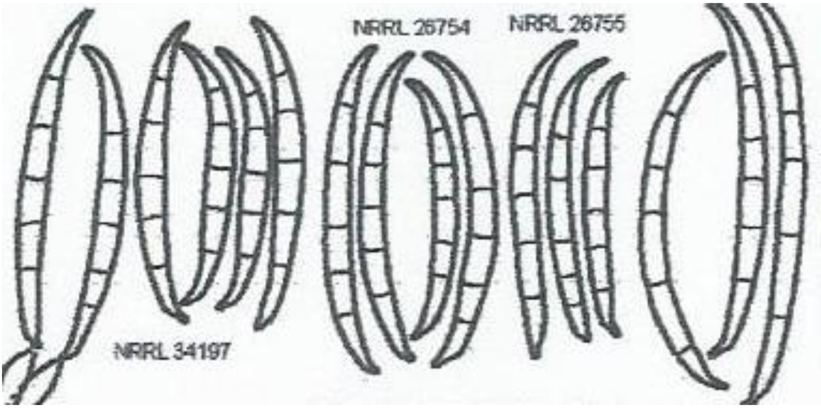


PCR amplification of the *MAT* region by using a multiplex PCR. The larger differential band (~800 bp) is from amplification of the *MAT-2* region. The smaller differential band (~200 bp) is from amplification of the *MAT-1* region. The constant band beneath both of the amplified bands is unincorporated primer. (A) Segregation of *MAT-1* and *MAT-2* in 8 of the progeny from the mapping cross of *F. verticillioides* (23). Lane 1, size markers (200, 400, 800, 1,200, and 2,000 bp); lanes 2 to 9, progeny from A-0015 × A-4643. (B) *MAT-1* and *MAT-2* alleles from the mating-type tester strains for *G. fujikuroi* mating populations A, B, D, and H. Lane 5, size markers; lanes 1 to 4, *MAT-1* tester strains; lanes 6 to 9, *MAT-2* tester strains.

10. Description of Fusarium species

1. Fusarium acacia-mearunsii

Macroconidia 5-septate,gradually curved, asymmetric upper and lower haves, widest above and lower mid-region,narrow apical beak

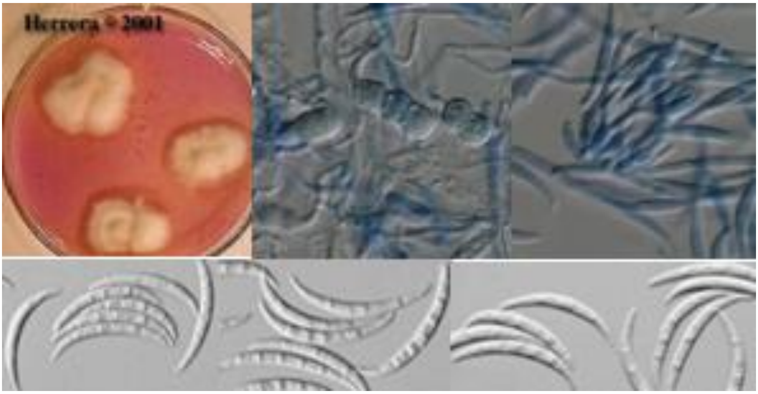


2. Fusarium acuminatum **Ellis & Everh., Proc. Acad.Nat. Sci.Philad. 47: 441 (1895)**

≡Fusarium scirpi var. acuminatum (Ellis & Everh.) Wollenw., Fusaria Autographice Delineata 3: 930-933 (1930)
≡Fusarium scirpi subsp. Acuminatum (Ellis & Everh.) Raillo, Fungi of the genus Fusarium: 177 (1950)
≡Fusarium gibbosum var. acuminatum (Ellis & Everh.) Bilai, Mykrobiologichnyi Zhurnal Kiev 49 (6): 6 (1987)

Morphology

Colonies are slow-growing, with white aerial mycelium, developing brownish pigmentation in the center on PDA. The dorsal side of the colony has rose to burgundy pigmentation. Macroconidia are broadly falcate with 3-5 septa, apical cell long and tapered, basal cell foot-shaped. Microconidia are sparse, fusiform, 0-1 septa, conidiogenous cell monophialides and chlamydospores formed in chains.



F. acuminatum colony, Paul Cannon
Chlamydospores, conidiogenous cells, macroconidia, Leslie and Summerell

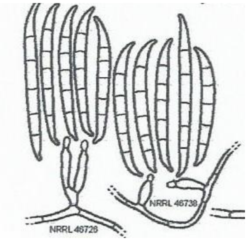
3. Fusarium acutatum Nirenberg & O'Donnell, Mycologia 90: 435 (1998)

Colonies produce white to pinkish-white mycelium with light orange pigments in the agar. Macroconidia sparse, fulacate, thin-walled, 3-septate, apical cell bent, basal cell foot-shaped. Microconidia abundant, oval-fusoid, conidiogenous cell mono- or polyphialides. Chlamydospores develop slowly, in chains and clusters

Fusarium acutatum colony www.boldsystems.org,, conidia, Leslie and Summerell

4. Fusarium aethiopicum O'Donnell, Aberra, Kistler & T. Aoki (2008)

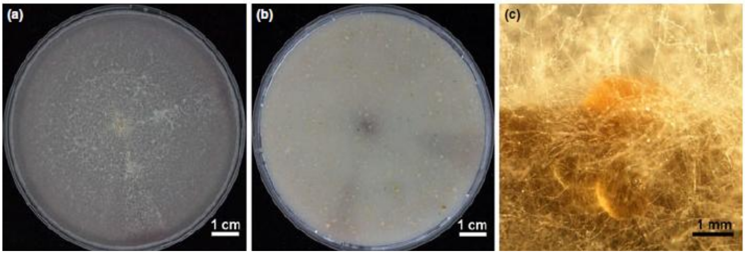
F. aethiopicum produces mostly straight conidia, which are asymmetrical in that they are typically widest above the mid-region



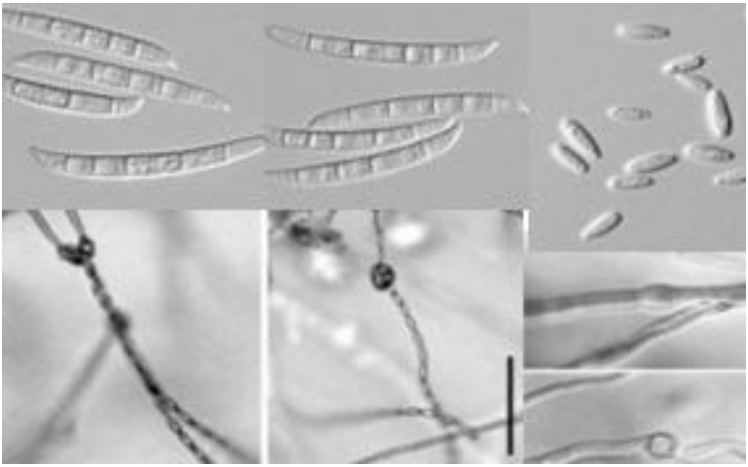
5. Fusarium andiyazi **Marasas, Rheeder, Lampr., K.A. Zeller & J.F. Leslie, Mycologia 93: 1205 (2001)**

= Fusarium moniliforme
= Fusarium verticillioides

Colonies on PDA produce white powdery to floccose mycelium and orange sporodochia, violet pigmentation is seen in the agar. Macroconidia are formed in sporodochia, on monophilides or on branched conidiophores, 3-6 septa, apical cell slightly curved, basal cell pedicillate. Microconida abundant, clavate to ovoid, in chains on monophilides, 0-septa. Chlamydospores absent, pseudochlamydospores may be present.



A,b 10-day old culture of Fusarium andiyazi on oatmeal agar,
C sporodochia,. Kebabci et al., 2013

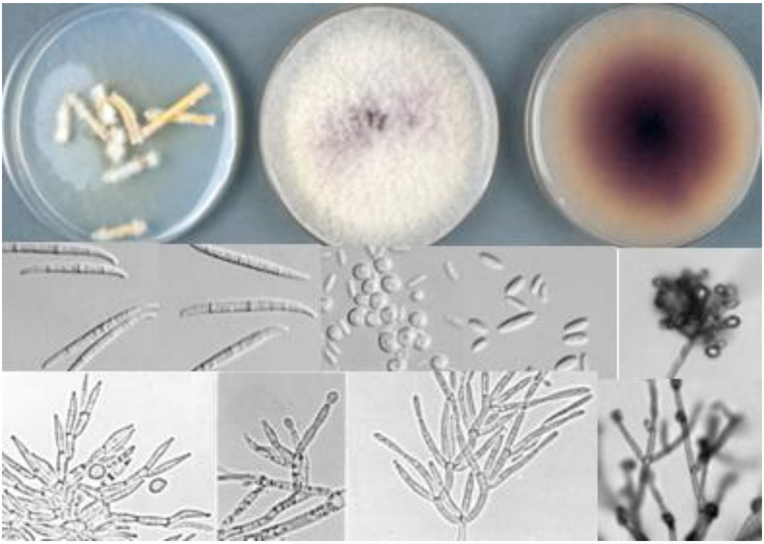


Macroconidia, microconidia,pseudochlamydospores, John F. Leslie and Brett A. Summerell

6. Fusarium anthophilum (A. Braun) Wollenw., Fusaria Autographice Delineata 1: 176 (1916)

≡Fusisporium anthophilum A. Braun, Fung. Europ.: no. 1964 (1875)
≡Fusarium moniliforme var. anthophilum (A. Braun) Wollenw., Fusaria Autographice Delineata 3: 975 (1930)
≡Fusarium wollenweberi Raillo, Fungi of the genus Fusarium: 189 (1950)
≡Fusarium tricinctum var. anthophilum (A. Braun) Bilai, Fusarii (Biologija i sistematika): 251 (1955)
≡Fusarium sporotrichiella var. anthophilum (A. Braun) Bilai, Mykrobiologichnyi Zhurnal Kiev 49 (6): 7 (1987)

Colonies on PDA form abundant white floccose mycelium turn to greyish violet in old cultures. Pigmentation in agar violet grey or dark. Sporodochia pale orange. Macroconidia are thin-walled, long, slender, almost straight, 3-5 septa,produced from monophilides on branched conidiophores in the sporodochia or on the hyphae, basal cell notched or foot-shaped, apical cell curved and tapered. Microconidia are abundant, from poly- or monophialides, globose, 1-2 celled, globose, or ovoid, in false heads. Chlamydospores absent.

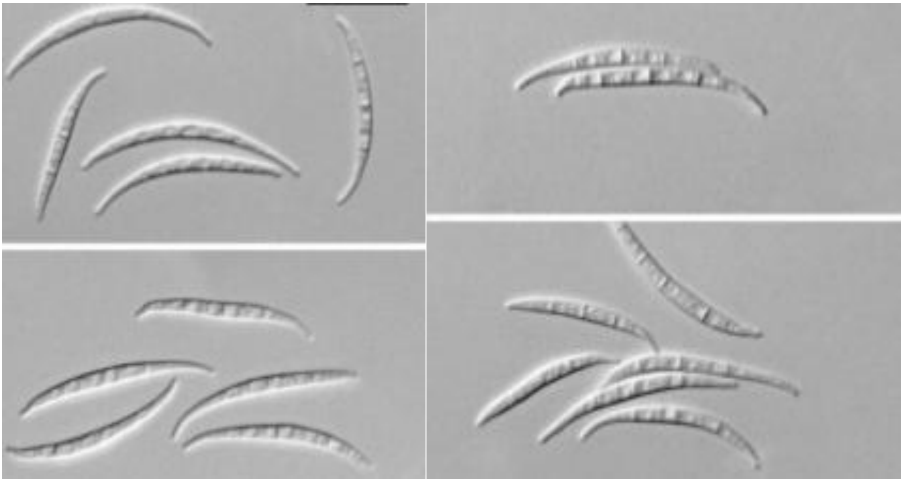


Leslie and Summerell , Hagedorn, Burhenne & Nirenberg

7. Fusarium armeniacum (G.A. Forbes, Windels & L.W. Burgess) L.W. Burgess & Summerell, Mycotaxon 75: 347 (2000)

≡Fusarium acuminatum subsp. Armeniacum G.A. Forbes, Windels & L.W. Burgess, Mycologia 85: 120 (1993)

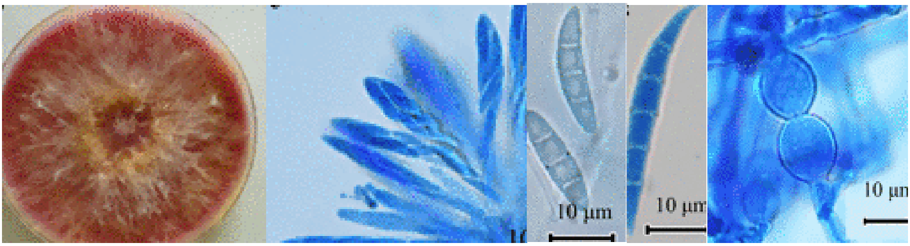
Colonies on PDA produce white aerial mycelium, red to apricot pigment in agar, and bright orange sporodochia in the center of the culture. Some isolates produce a pionnotal form of slow-growing colonies with little aerial mycelium and abundant orange sporodochia. Macroconidia in orange sporodochia and chlamydospores formed abundantly, but microconidia are absent.



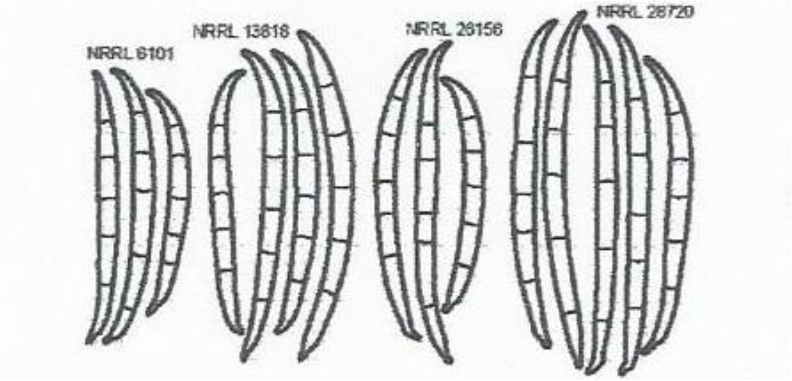
Leslie and Summerell

8. Fusarium asiaticum O'Donnell, T. Aoki, Kistler & Geiser, Fungal Genetics & Biology 41 (6): 619 (2004)

Colonies pink to dark red, cottony, produce white to pink mycelia Sporodochia pale orange. Macroconidia hyaline, falcate with single foot cella, 3-5 septate. Microconidia absent. Chlamydospores round, single or in chains

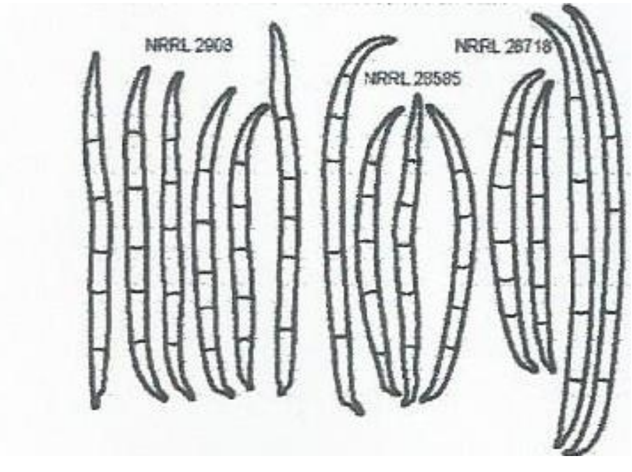


Kawakami, et al., 2015



9. Fusarium austroamericanum. T. Aoki, Kistler, Geiser & O'Donnell, Fungal Genetics & Biology 41 (6): 617 (2004)

Macroconidia 5-septate, with longitudinal axis typically straight, asymmetric lower and upper halves, widest in mid-region, with narrow apical beak.



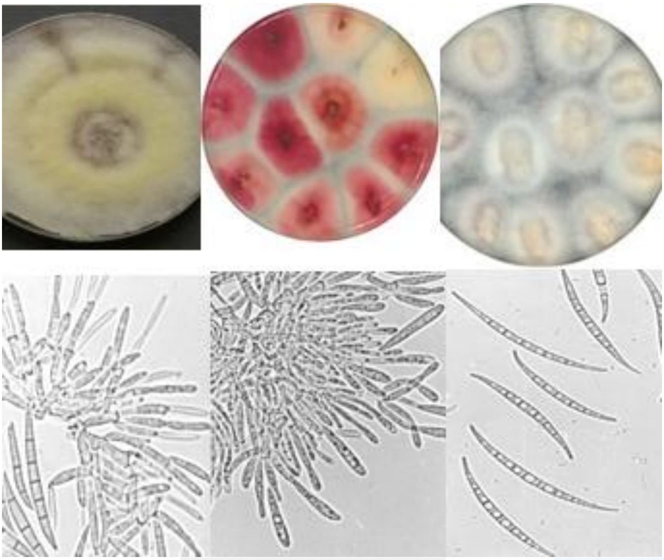
10. Fusarium avenaceum **(Fr.) Sacc., Sylloge Fungorum 4: 713 (1886)**

Fusisporium avenaceum Fries, Systema Mycologicum 3: 444 (1832)
≡Fusarium herbarum var. avenaceum (Fries) Wollenw., Fusaria Autographice Delineata

3: 899 (1930) [MB#252553]

=Selenosporium herbarum Corda, Icones fungorum hucusque cognitorum 3: 34, t. 6:88 (1839)

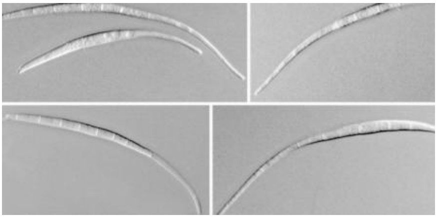
Colonies initially form abundant fluffy white mycelium and produce a golden orange pigment on PDA at 25°C. Sporodochia pale orange, Macroconidia are slightly falcate, thin-walled, usually 3 to 5 septate, with a tapering apical cell , basal cell notched. Microconidia are rare, fusoid, 1-2 septa, single. Chlamydospores are absent.



F, avenaceum colonies, www.grainscanada.gc.ca. Mycota, G. Hagedorn, M. Burhenne & H. I. Nirenberg

11. Fusarium aywerte **(Sangal. & L.W. Burgess) Benyon & L.W. Burgess, Mycological Research 104 (10): 1171 (2000)**

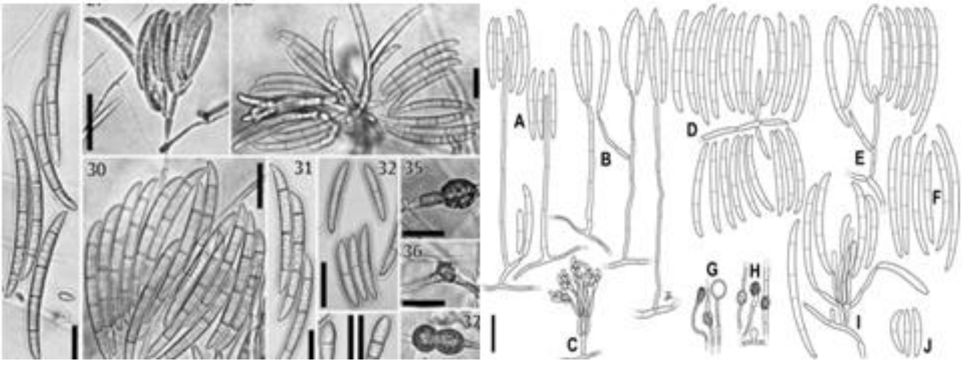
≡Fusarium avenaceum subsp. Aywerte Sangal. & L.W. Burgess, Mycological Research 99: 287 (1995)



John F. Leslie and Brett A. Summerell

12. Fusarium azukiicola T. Aoki, H. Suga, F. Tanaka, Scandiani & O'Donnell (2012). Mycologia. 2012 t;104(5):1068-84.

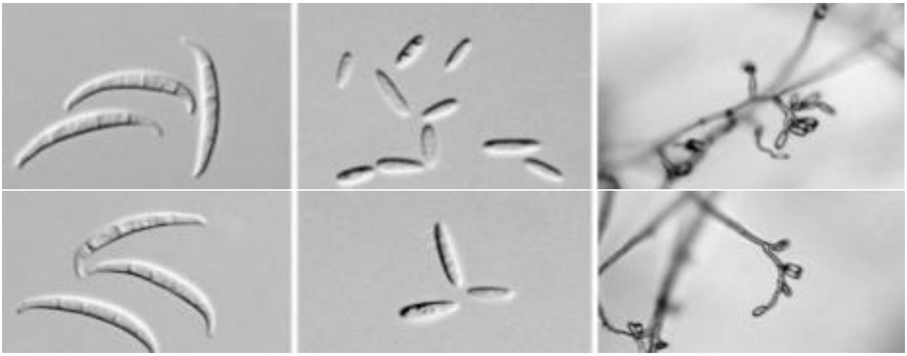
Colonies produce loose to floccose, white to yellowish white or reddish white to pale red aerial mycelium. Reverse pigmentation absent or sometimes grayish yellow, grayish orange to brownish orange. Macroconidia mostly falcate, sometimes cylindrical and gradually curved, widest at midregion or more frequently widening gradually upward, often with a slightly rostrate apex, sometimes with a rounded apex, gradually narrowing toward base often with a distinct, slightly protruding basal foot cell or sometimes rounded, 1–5-septate. Microconidia oblong to naviculate or short-clavate, sometimes ellipsoidal, straight or curved, with a rounded apex and a truncate base, 0–2-septate. Chlamydospores formed abundantly in hyphae and in conidia, mostly subglobose, intercalary or terminal, mostly single, rarely in chains.



Aoki et al., 2012

13. Fusarium babinda **Summerell, C.A. Rugg & L.W. Burgess, Mycological Research 99: 1345 (1995)**

Colonies produce floccose aerial mycelium, initially white, later darkening to pink or pale orange, in some strains with a violet centre; reverse salmon pink, in some strains becoming violet topurple slate; Microconidia formed from scattered conidiogenous cells, monophialides and polyphialides, aggregating in slimy droplets, hyaline, 0-1 septate, ovoid, ellipsoid to allantoid. Macroconidia formed from scattered conidiogenous cells (monophialides) in the aerial mycelium, later from irregularly branching clusters of conidiogenous cells on the agar surface, developing into slimy, pale pink sporodochia, 3-5-septate, fusiform to cylindrical, slightly curved, apical cell strongly curved, tapering to a point; basal cell with projecting pedicel. Chlamydospores subglobose, thick-walled, hyaline to pale brownish, mostly intercalary, in chains or clusters, sometimes single.



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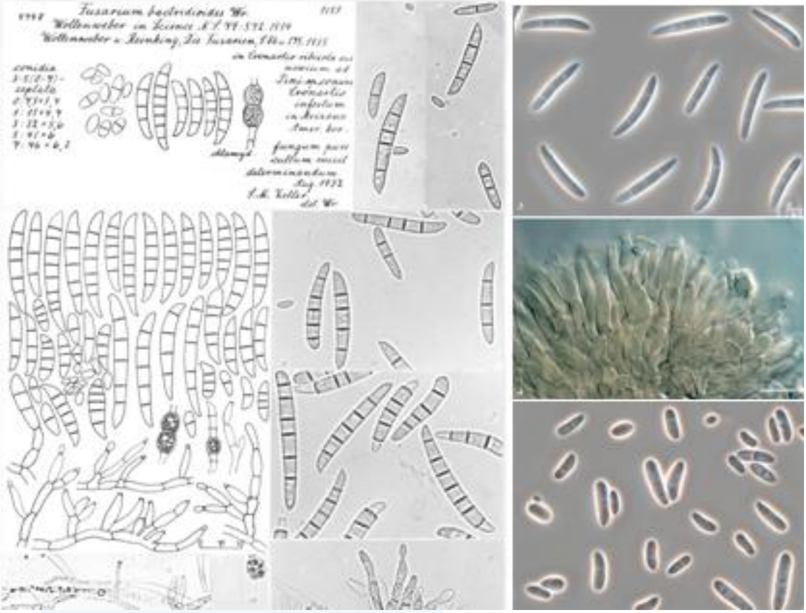
14. Fusarium bactridioides **Wollenw., Science 79: 572. 1934.**

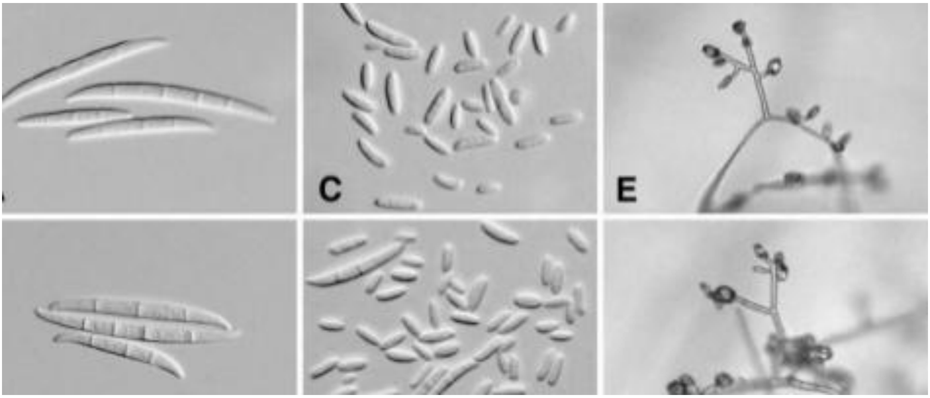
Colonies produce poorly developed stroma and orange-white to light orange sporodochia. Macroconidia 3–6 septate; the ventral surface is more or less straight or gently curved, and the dorsal surface is moderately curved, with the walls more or less parallel in the central two cells of the conidia, with the widest point near the middle or above the middle. The apical cell is bluntly rounded, and roughly the same length as the penultimate cell. The basal cell is tapered more acutely than apical cell; the base is rounded, flat, or has a slight indentation on the dorsal side or central papilla, indicating a foot cell. Microconidia are abundant in the sporodochia, are 0–3 septate, and vary in shape and size from small, ellipsoidal, oblong-ellipsoidal or allantoid cells that are obviously microconidia to fusiform to clavate, septate spores that intergrade with macroconidia.



Hagedorn, Burhenne & Nirenberg,Seifert & Gräfenhan, 2002

15. Fusarium begoniae **Nirenberg & O'Donnell, Mycologia 90: 446 (1998)**

Colonies with entire margin. Aerial mycelium almost white, cottony. Pigmentation in reverse greyish-yellow. Microconidia borne in the aerial mycelium oval to allantoid and obovoid, 1-0 Septate, Macroconidia, abundant, borne in sporodochia slender, long falcate but almost straight, with a slightly beaked apical cell and a footlike basal cell, mostly 3-4 septate. Chlamydospores absent.



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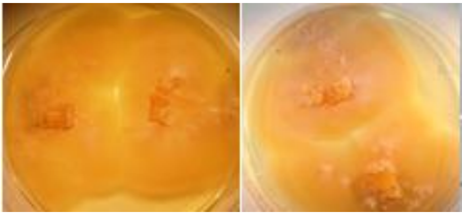
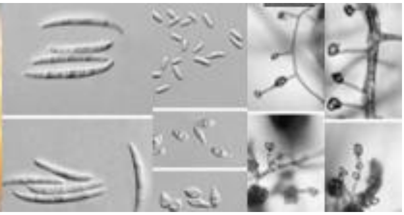
16. Fusarium beomiforme **P.E. Nelson, Toussoun & L.W. Burgess, Mycologia 79: 884-889 (1987)**

Colonies with floccose, white-pink aerial mycelium, developing a diffuse, orange-reddish-brown colouration in reverse. Microconidia of two forms: (a) abundant, ovoid to cylindrical; (b) less abundant, larger, globose to napiform, typically vacuolate; chains absent, spores collecting in slimy droplets. Conidiogenous cells monophialides, cylindrical, tapering slightly at the tip, with periclinal thickening. Macroconidia 3-4 (-5)-septate, falcate, apical cell slightly curved, tapering to a point, basal cell pedicellate. Chlamydospores hyaline, smooth, typically terminal, single or in pairs, not in intercalary chains.



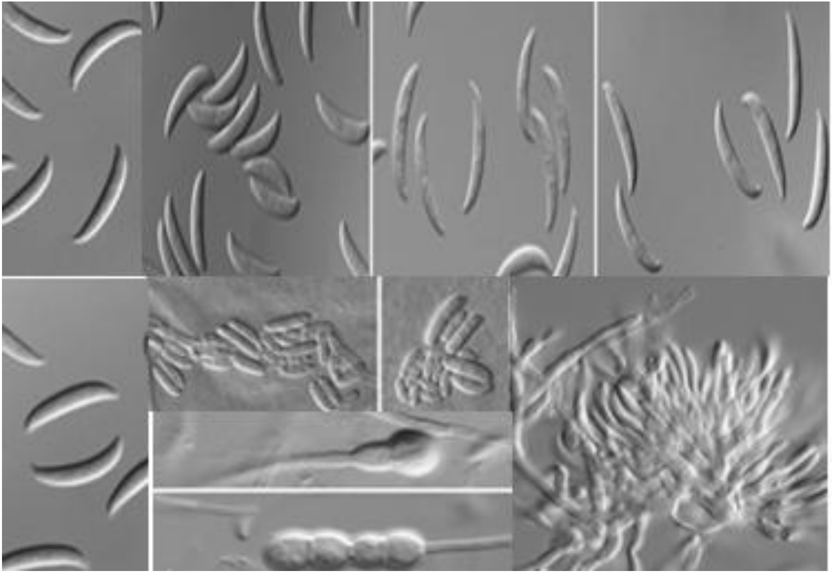


Fusarium beomiforme colonies,Truman State University

Macroconidia and microconidia of Fusarium beoforme, Leslie and Summerell

17. **Fusarium biseptatum** Schroers, Summerb. & O'Donnell (2009),

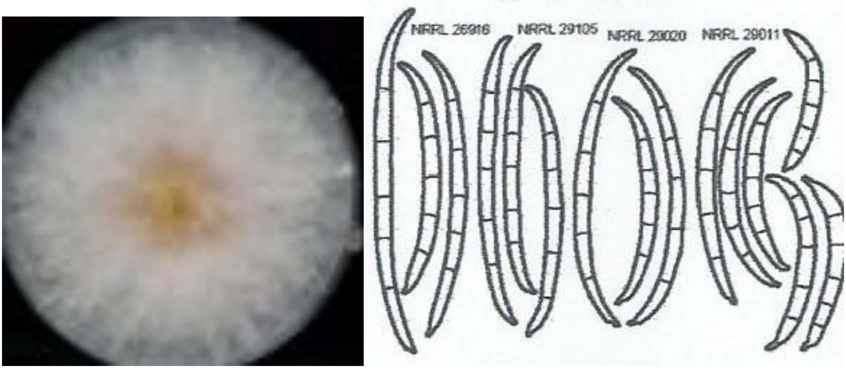
Colonies produce sparse white or slightly rose to pale orange aerial mycelium on agar. Colony reverse on PDA with ochraceous or brown pigments, mostly without orange pigments. Monophialides formed terminally or laterally on hyphaemin well developed sporodochia, forming few-membered whorls on short supporting cells. Microconidia mostly 0-, rarely 1-septate, typically ellipsoidal, straight or curved, allantoid formed on SNA on submerged or aerial hyphae. Macroconidia typically widest in the upper third or the middle, with central part minutely curved or nearly straight, a pointed and mostly beaked distal end and a slightly pedicellate and curved proximal end; from well developed sporodochia, 0-3-septate. Chlamydospores common, typically intercalary, solitary in short chains or terminal.



Fusarium biseptatum. Schroers, Summerb. & O'Donnell (2009),

18. Fusarim boothii O'Donnell, T. Aoki, Kistler & Geiser, Fungal Genetics & Biology 41 (6): 618 (2004)

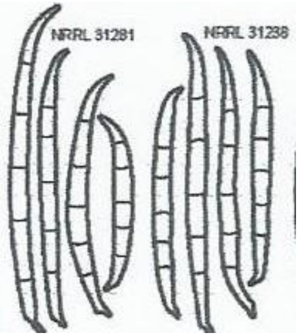
Colonies produce white mycelium with light brown coloue in the center, macroconida 5-septate , gradually curved, upper and lower halves are mostly symmetric, widest in the mid-region, with a narrow apical peak,



Lee et al., 2011

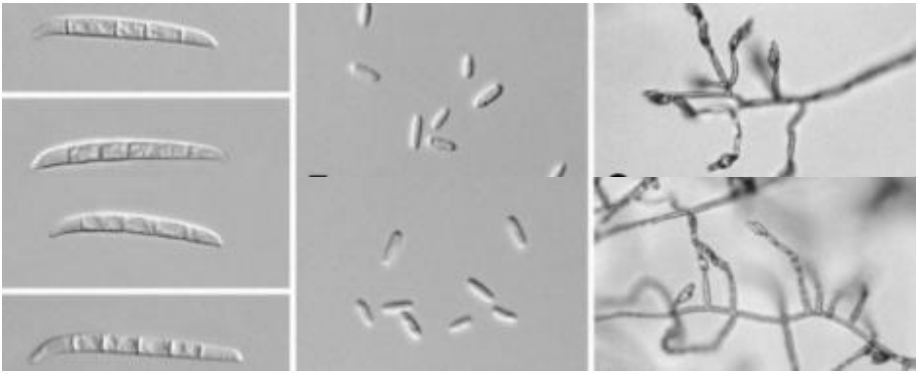
19. Fusarium brasilicumT. Aoki, Kistler, Geiser & O'Donnell, Fungal Genetics & Biology 41 (6): 620 (2004)

Macroconidia 5-septate , straight or gradually curved, upper and lower halves asymmetrical, widest below the mid- region and narrow apical peak



20. Fusarium brevicatenulatum **Nirenberg & O'Donnell, Mycologia 90: 446 (1998)**

Colony margin entire. Aerial mycelium whitish; lanose to fluffy. Pigmentation in reverse greyish orange, becoming dark bluish-gray. Sporodochia formed after 10 days. Conidiophores on the aerial mycelium prostrate, mostly identical with phialides, occasionally with one lateral branch. Phialides of conidiophores on the aerial mycelium cylindrical, mostly monophialidic, occasionally polyphialidic. Microonidia borne on the aerial mycelium long-oval to obovoid, mostly O-septate, sometimes 1- and 2-septate. Macroconidia borne in sporodochia rare, falcate, slender, straight, up to 3-4 septate, apical cell bent, basal cell foot-like. Chlamydospores absent.



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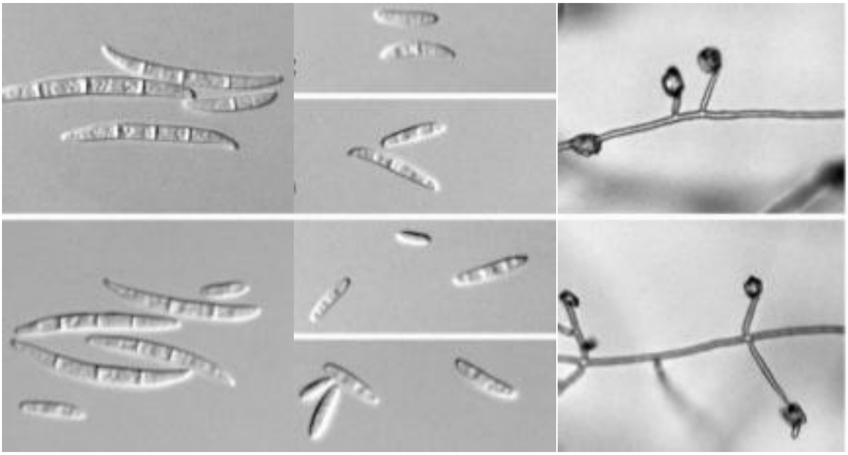
21. Fusarium bulbicola **Nirenberg & O'Donnell, Mycologia 90: 446 (1998)**

≡Fusarium sacchari var. elongatum Nirenberg, Mitteilungen der Biologischen Bundesanstalt für Land- und Forstwirtschaft 169: 59 (1976)

Colony margin entire. Aerial myclium almost white. later tinged ruby by the substrate: short. hairy to lanose. Pigmentation in reverse dark ruby. Conidiophores in the aerial mycelium erect, branched in 1 or 2 cylindrical phialides. Sporodochial conidiophores verticillately branched. Conidiophores in the aerial mvcelium mono- and polyphialidic; sporodochial phialides flask- shaped and monophialidic. Micronidia borne on the aerial mycelium long-oval to allantoid, mostJy O-Septate. Macronidia borne in sporodochia long and slender. falcate with a slightly elongate apical cell and a foot-like basal cell. mostly 3- to 5 septate: 3-septate. Chlamydospores absent.



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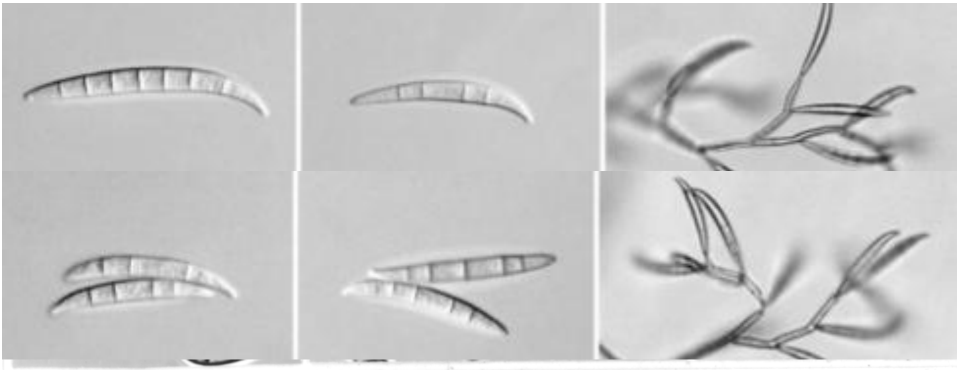
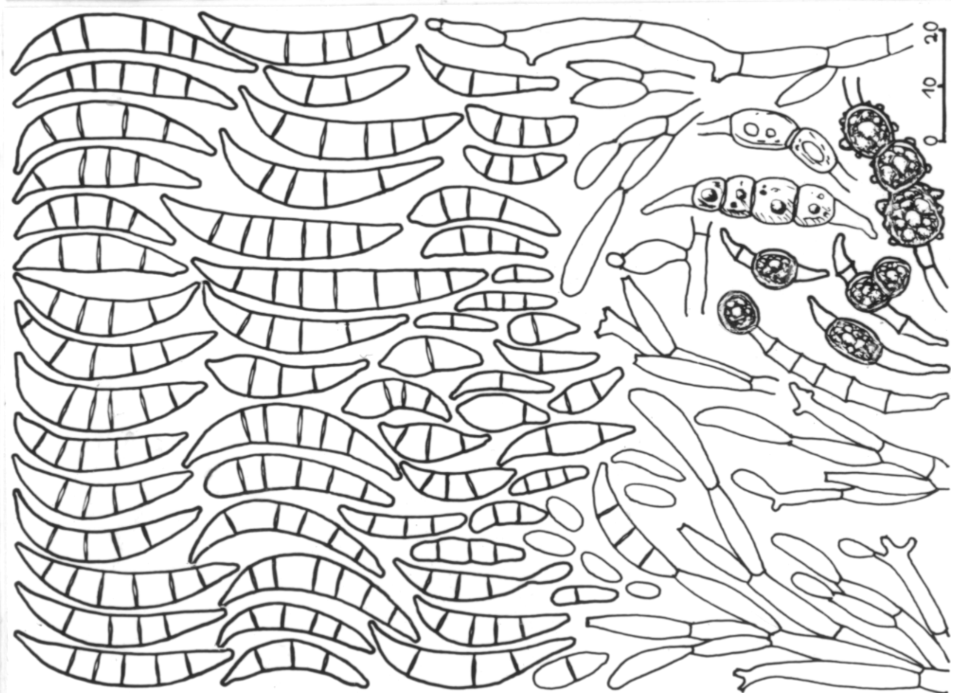
22. **Fusarium camptoceras** **Wollenw. & Reinking, Phytopathology 15 (3): 158 (1925)**

Colonies form white to cream-coloured mycelium and produce pigmentation in the agar. Macroconidia: predominantly 3-7 cells, falcate, abundant in sporodochia, apical cell pointed, basal cell pointed and notched. Sporodochia: cream-orange. Microconidia: long, up to 6 septe, single from a phialide, abundant. Chlamydospores : sparse, on aerial hyphae or submerged in agar, in pairs, chains or clusters





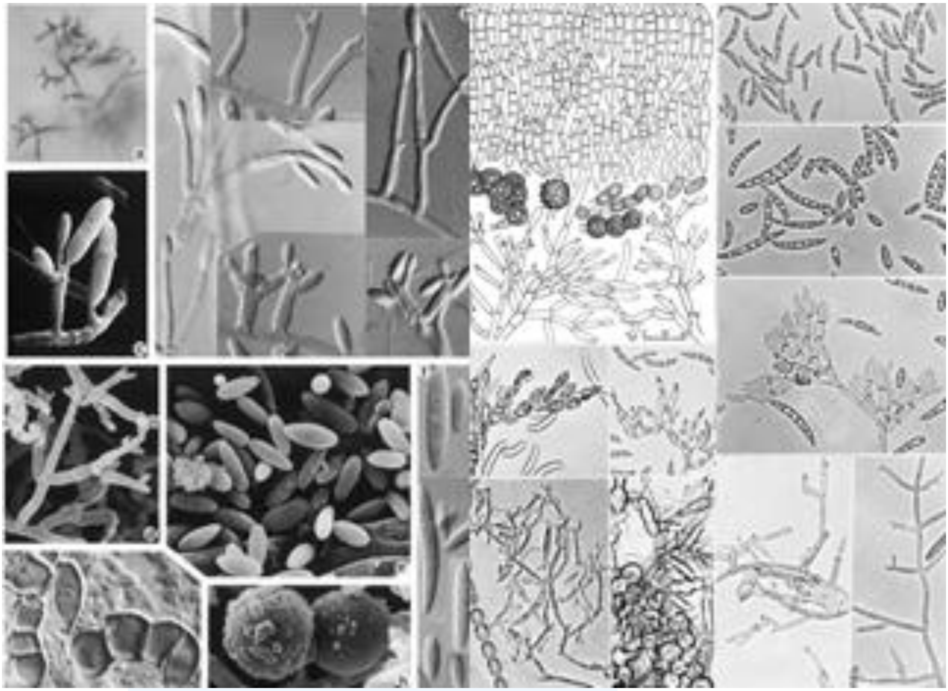
Fusarium camptoceras Wollenweber et Reinking Phytopathology 15 (1925) 158.
Reinking et Wollenweber, Philippine Journ. Science 32 (1927) 121, fig. 4.

904

23. Fusarium chlamydosporum **Wollenw. & Reinking, Phytopathology 15 (3): 156 (1925)**

=Fusarium sporotrichioides var. chlamydosporum (Wollenw. & Reinking) Joffe, Mycopathologia et Mycologia Applicata 52 (1-4): 211 (1974)

Colonies produce white mycelium with grayish rose to burgundy or yellowish to pale brown pigmentation.Macroconidia: abundant, thick-walled, moderately curved, 3-5 septa, apicalcell short, curved and pointed, basal cell notched or foot-shaped. Sporodochia: rare. Microconidia: comma-shaped, 0-2 septe, single or in pairs fro, a phialide, abundant. Chlamydospores : abundant after 2-4 weeks, on aerial hyphae or submerged in agar, in pairs, chains or clusters, pale brown



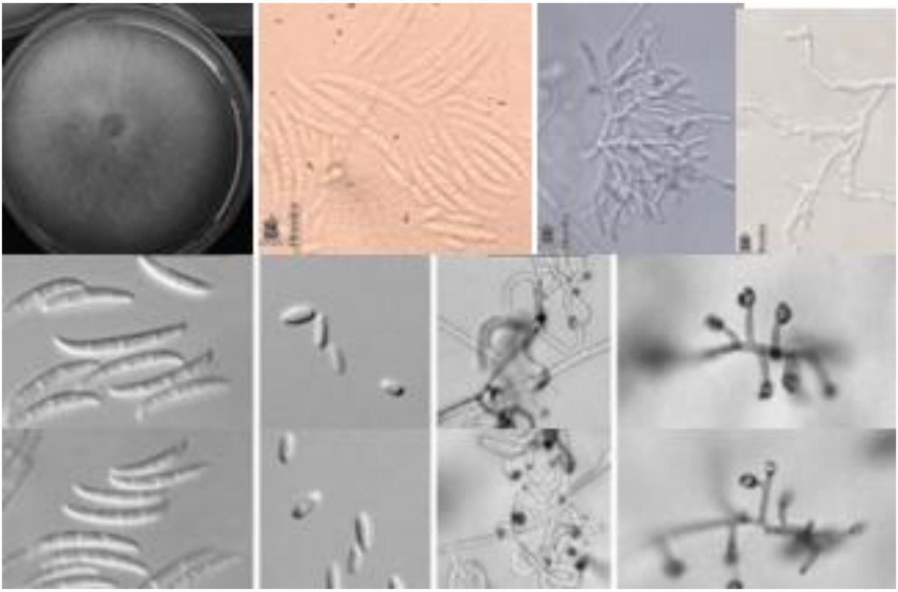
Mycobanc, G. Hagedorn, M. Burhenne & H. I. Nirenberg

24. Fusarium cicatricum (Berkeley) O'Donnell & Geiser, Phytopathology 103 (5): 404 (2013)

Colony reverse lacking red pigments, after 14-21 d on PDA at 15-25 °C with weak pigment production, pale to light yellow (4A3-4A5), at 30 °C, somewhat pale orange. Colony surface on PDA with pustules or cushions of white aerial mycelium with scattered sporodochia covered with pale yellow conidial masses, smooth at margin, wax-like, pale yellow. Phialides more or less cylindrical, tapering towards apex, wide at base and in middle. Microconidia not observed. Macroconidia formed in pale yellow slimy masses, typically gently curved throughout, less commonly almost straight, with pronounced pedicellate foot cell, and a more or less inequilaterally fusoid and hooked apical cell, 2-8-septate: Chlamydospores not observed

25. Fusarium circinatum **Nirenberg & O'Donnell, Mycologia 90: 446 (1998)**

Colonies on PDA with entire margin. Aerial mycelium almost white, hairy to lanose-funiculose. Pigmentation in reverse greyish white to grey to dark violet at the center of the colom. Conidiophores of the aerial mycelium erect. strongly branched, branches terminating mostly in I or 2 phialides. Sporodochial conidiophores verticillately branched. Phialides of the aerial conidiophores cylindrical, mono- and polyphialidic. Micrconidia borne in the aerial mycelium mostly obovoid, occasionally oval to allantoid, mostly 0-1 septate, occasionally l-septate. Macronidia borne in sporodochia slender, cylindrical, mostly 3-septate. Chlamydospores absent.

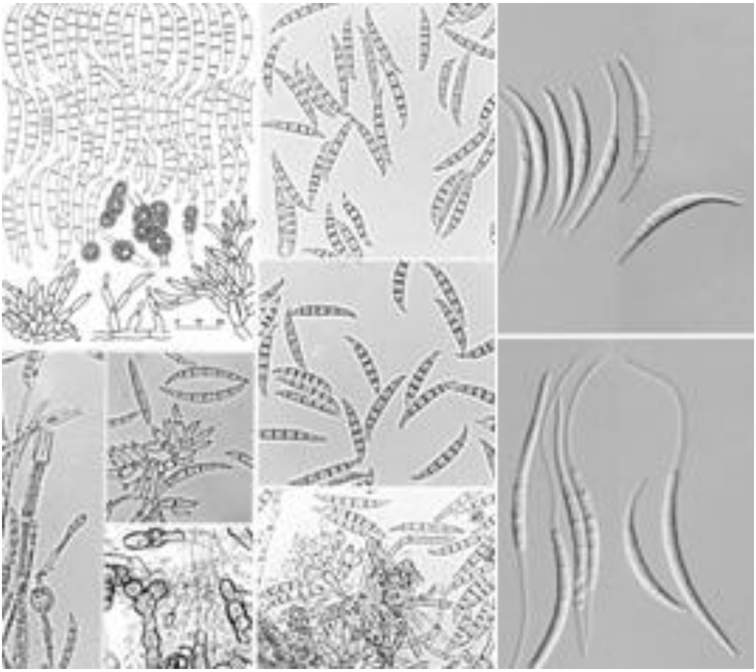


F. circinatum www.scielo. Circinus Macro and Microconidias Mono and Poly-Phialides, www.efa-dip.org, John F. Leslie and Brett A. Summerell

26. Fusarium compactum **(Wollenw.) Raillo, Fungi of the genus Fusarium: 180 (1950)**

≡Fusarium scirpi var. compactum Wollenw., Fusaria Autographice Delineata 3: 924 (1930) [MB#124046]
≡Fusarium compactum (Wollenw.) W.L. Gordon, Canadian Journal of Botany 30 (2): 224 (1952) [MB#532662]
≡Fusarium equiseti var. compactum (Wollenw.) Joffe, Plant and Soil 38: 440 (1973)

Macroconidia: abundant, thick-walled, strongly curved, 5 septa, apicalcell elongate and tapering, curved and pointed, basal cell foot-shaped. Sporodochia: orange. Microconidia: absent. Chlamydospores abundant after 2-4 weeks, on aerial hyphae or submerged in agar, in chains or clusters



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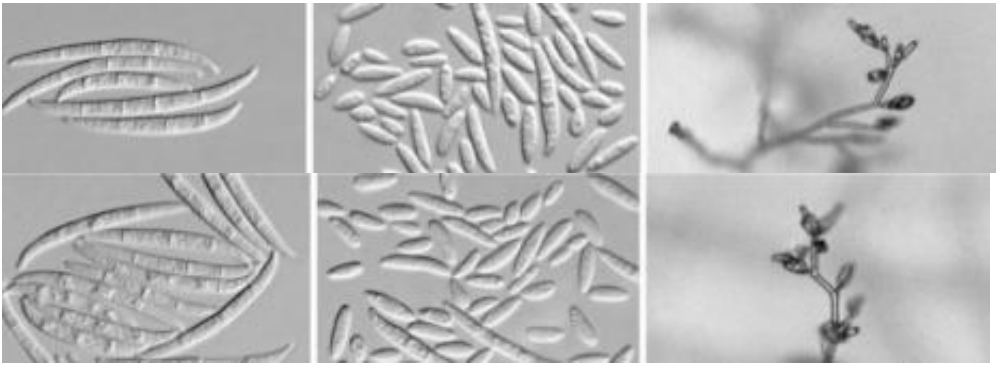
27. Fusarium concentricum **Nirenberg & O'Donnell, Mycologia 90: 446 (1998)**

Colonies on PDA show entire margin. aerial mycelium reddish-white: velvety to lanose, reverse pale orange and reddish-grey concentric rings. Conidia borne in false heads: later forming pale orange sporodochia on the surface of the substrate. Conidiophores of the aerial mycelium mainly prostrate. unbranched, with one lateral branch. usually with one phialide. sometimes with a whorl of 4 phialides at the tip; sporodochial conidiophores verticillately branched. Phialides of the aerial conidiophores cylindrical, mono- and polyphialidic, sporodochial phialides flask-shaped. Microconidia borne in the aerial mycelium obovoid or oval to allantoid, O-1 septate. Macroconidia borne in sporodochia slender, long, with a slightly beaked apical cell and a footlike basal cell, 3-5 septate. Chlamydospores absent.



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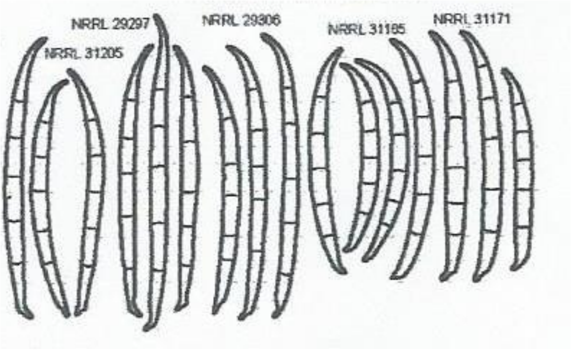
28. Fusarium cortaderiae O'Donnell, T. Aoki, Kistler & Geiser, Fungal Genetics & Biology 41 (6): 620 (2004)

Macroconidia 5-septate, straight or gradually curved, asymmetric upper and lower halves, widest below mid-region, narrow apical peak

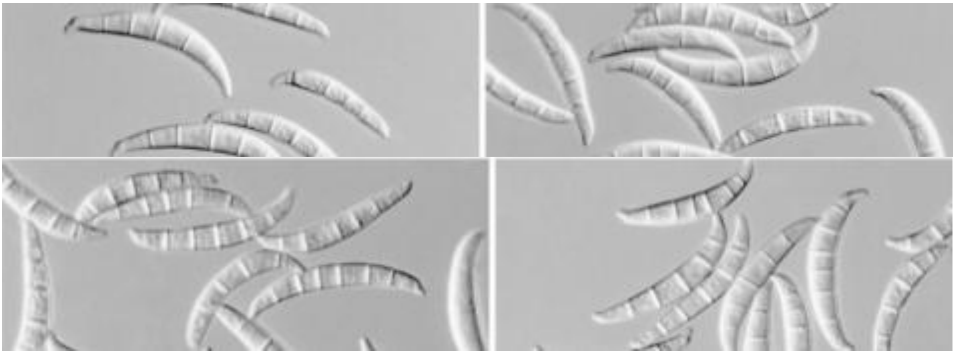


29. Fusarium crookwellense **Burgess, Nelson & Toussoun, Transa. Brit. Mycol. Soci.79,498 (1982)**

=Fusisporium cereale Cooke, Grevillea 6 (40): 139 (1878)

=Fusisporium cerealis Cooke, Grevillea 6 (40): 139 (1878)
=Gibberella roseum f. cerealis (Cooke) W.C. Snyder & H.N. Hansen, American Journal of Botany 32: 664 (1945)

Macroconidia: abundant, pronounced dorsal curvature and straight ventrally, 5 septa, apical cell curved and tapering and pointed , basal cell foot-shaped. Sporodochia: pale orange –dark brown, abundant. Microconidia: absent. Chlamydospores : abundant after 4-6 weeks, smooth, in chains and clusters



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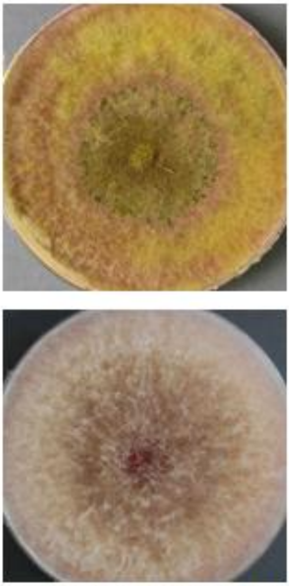
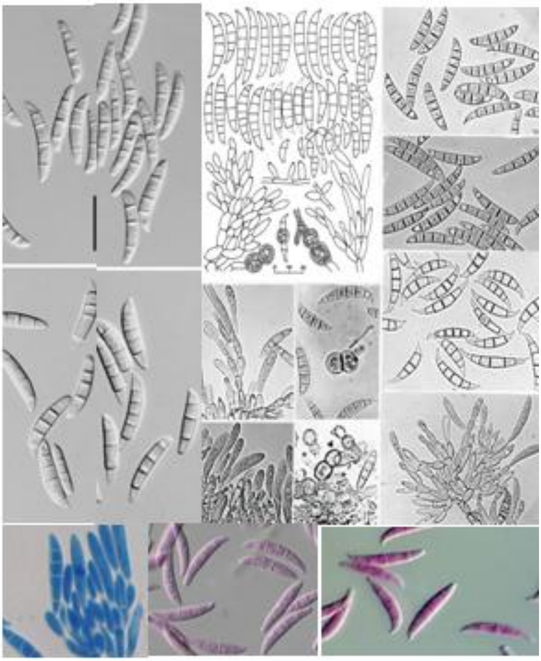
30. Fusarium culmorum **(W.G. Sm.) Sacc., Sylloge Fungorum 11: 651 (1895)**

=Fusisporium culmorum Wm.G. Sm., Diseases of field and garden crops, chiefly as are caused by fungi: 209 (1884)
≡Fusarium culmorum (W.G. Sm.) McAlpine, Agricultural Gazette of New South Wales 7: 299-306 (1896)

Macroconidia: abundant, relat. Short, thick-walled, dorsal curvature and straight ventrally, 5 septa, apical cell rounded ant blunt , basal cell notched. Sporodochia: orange –brown, abundant. Microconidia: absent. Chlamydospores : abundant in 3-5 weeks, in hyphae and macroconidia, in chains and clusters



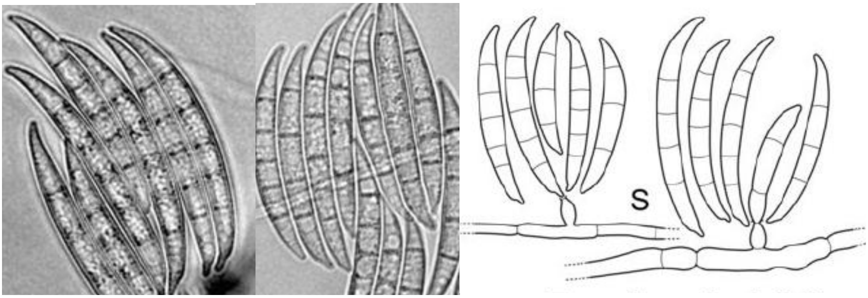
colonies on PSA agar. uploaded by: PaulCanno



John F. Leslie and Brett A. Summerell , G. Hagedorn, M. Burhenne & H. I. Nirenberg, Wikipedia

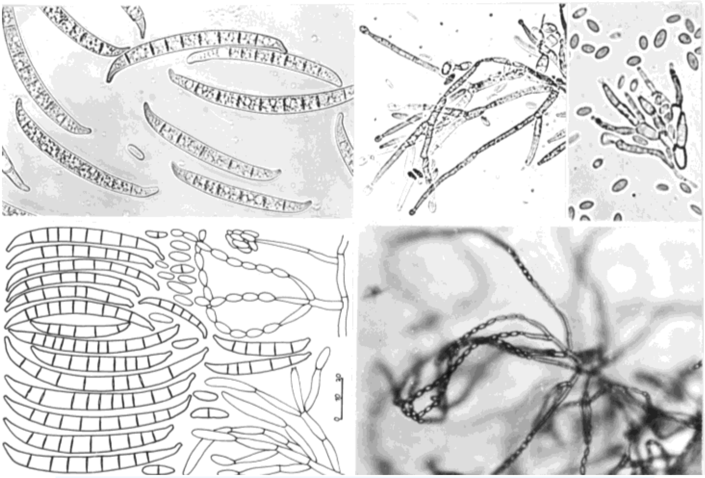
31. Fusarium dactylidis. Takayuki Aoki, Martha M. Vaughan , Susan P. McCormick Mark Busman,Todd J. Ward, Amy Kelly Kerry O'Donnell, Peter R. Johnston and David M. Geise. at Mycologia, 2014

Colonies produce abundant loose to densely floccose aerial mycelium ; reverse white at margin, reddish pigmentation centrally, reddish white, pale red to violet brown. Sporodochia formed on agar surface. Sporodochial conidia formed directly from phialides on substrate hypha. Sporodochial conidiophores form conidia on monophialides. Macroconidia of a single type, typically falcate and curved, dorsiventral, 1–7-septate, usually widest at or slightly above the midregion of their length, tapering and curving equally toward both ends, with an acute apical cell and a distinct basal foot cell. Upper and lower halves of conidia nearly symmetrical. Chlamydospores and sclerotia absent, but round intercalary or terminal cell swellings sometimes present in hyphae or older conidia.



32. Fusarium decemcellulare **Brick, Jahrb. Vereinig. Angew. Bot.: 227 (1908)**

Macroconidia: abundant, very long, curved, thick-walled, 5-9 septa, apicalcell rounded and blunt , basal cell foot-shaped. Sporodochia: yellow. Microconidia: abundant, 0-septe, in long chains. Chlamydospores : absent

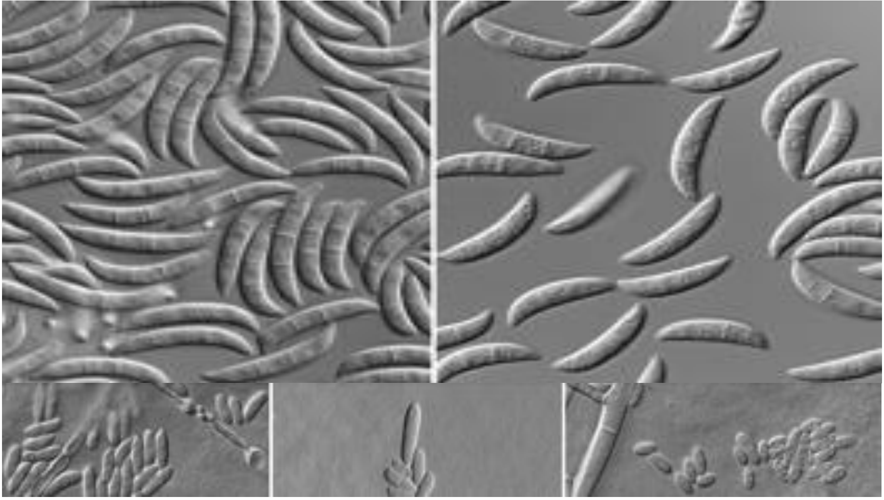


G. Hagedorn, M. Burhenne & H. I. Nirenberg

33. Fusarium delphinoides Schroers, Summerb., O'Donnell & Lampr., Mycologia 101 (1): 57 (2009)

= Fusarium dimerum Penzig var. majusculum Wollenw., Fus. autogr. delin. 1:90. 1916.

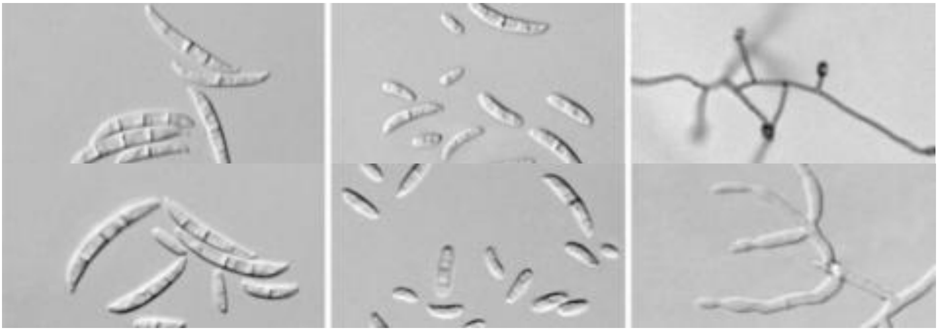
Colonies produce sparse white or pale orange aerial mycelium. Colony reverse pale orange and with dark dirty orange or brown hues; often with brownish pigment. Monophialides formed terminally or laterally along hyphae formed well developed sporodochia, polyphialides not seen. Microconidia mostly 0-1-septate, typically ellipsoidal, straight or curved, allantoid. Macroconidia typically widest in the upper third, with central and basal cells nearly straight but basal cells minutely curved, tapering and pedicellate, distal ends mostly more strongly curved than the proximal end and gently beaked; 0-3-septate. Chlamydospores common, typically intercalary, solitary, in short chains or terminal, not or rarely aggregated



34. Fusarium denticulatum Nirenberg & O’Donnell, Mycologia 90: 445 (1998)

Colonies on PDA are funiculose. Pigmentation in reverse greyish-orange to brownish-orange with the center blackish-blue.

Conidiophores of the aerial mycelium, prostrate, short. often identical with phialides, sometimes branched; sporodochial conidiophores verticillatelv branched. Phialides of the aerial conidiophores. mono- or polyphialidic; polyphialidic openings often denticulate in a rectangular arrangement. Macroconidia: abundant, relatively slender, slightly curved , 5-9 septa, apical cell beaked and blunt , basal cell foot-shaped. Sporodochia: yellow. Microconidia: abundant, long, oval, 0-1 septe .Chlamydospores : absent



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35. Fusarium dimerum **Penzig., Michelia 2 (8): 484 (1882)**

≡Fusarium aquaeductuum var. dimerum (Penz.) Raillo, Fungi of the genus Fusarium: 279 (1950)
≡Microdochium dimerum (Penz.) Arx, Transactions of the British Mycological Society 83 (2): 374 (1984)
≡Bisifusarium dimerum (Penzig) L. Lombard & Crous, Studies in Mycology 80: 225 (2015)

Macroconidia: abundant, very, short , evenly curved on both sides, 0-2 septa, apical cell rounded and often hooked, basal cell blunt . Sporodochia: not distinct. Microconidia: absent . Chlamydospores : rare, single, in pairs or in chains

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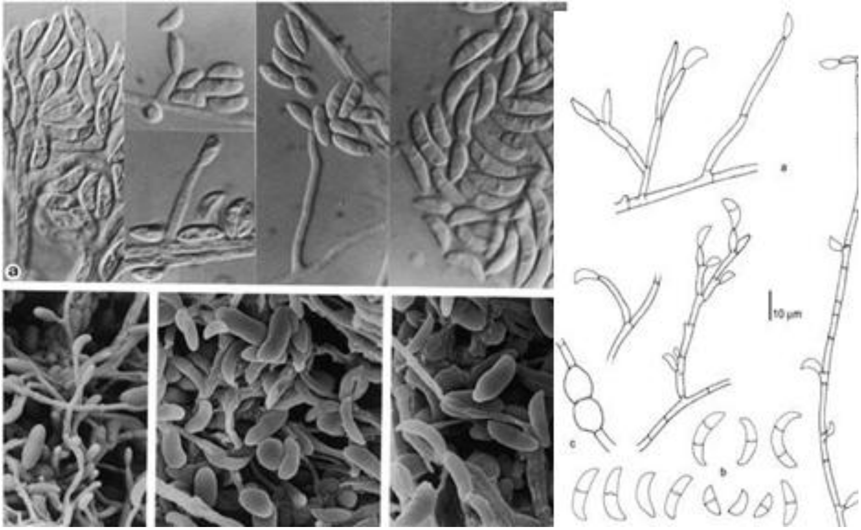
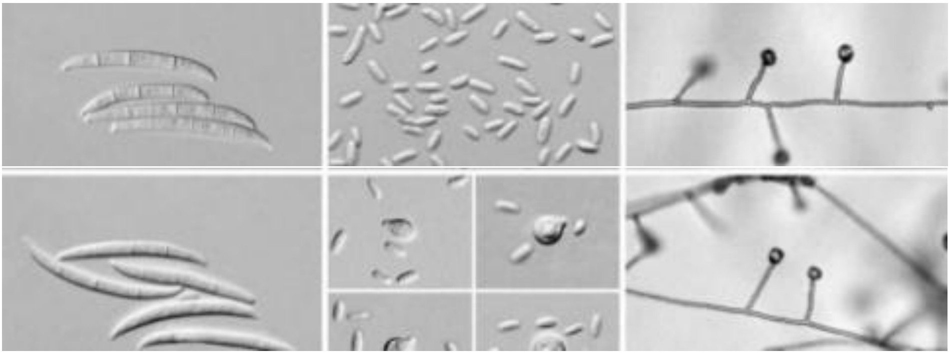


Fusarium dimerum , Mycobank

36. Fusarium dlaminii **Marasas, P.E. Nelson & Toussoun, Mycologia 77: 971 (1986)**

Macroconidia: abundant in sporodochia , moderately long , thin-walled, falcate or straight, 3-5 septa, apical cell curved and tapering, basal cell foot-shaped. Sporodochia: orange. Microconidia: abundant on aerial myceliamostly fusiform non-septate and some are napiform , 0-1 septa. Chlamydospores abundant in 4-6 weeks, single, in pairs , in chains, or in clumps, in aerial or submerged, terminal or intercalary



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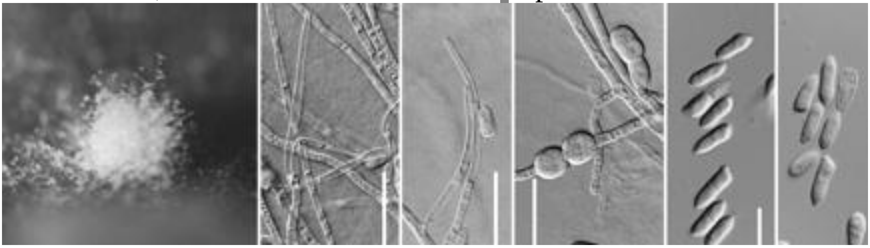
37. Fusarium domesticum (Fr. : Fr.) Bachmann, LWT -Food Sci Tech 38:405. 2005.

?Trichothecium domesticum Fr., Syst. mycol. (Lundae) 3:427. 1832

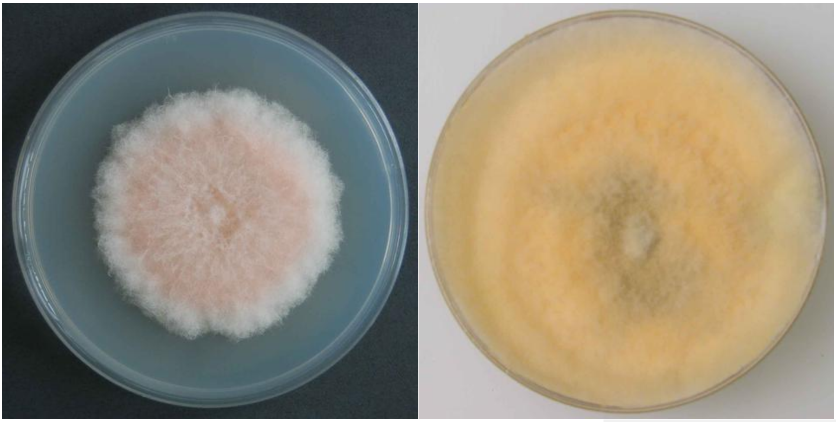
Colonies produce scanty, felt-like to somewhat cottony aerial mycelium. Colony reverse off-white to cream or somewhat pale yellow. Phialides cylindrical and slightly tapering toward the tip. Macroconidia cylindrical to ellipsoidal, straight, distally weakly tapering, rarely rounded, typically with a laterally displaced and slightly extruding hilum, 1- 2-septate. Microconidia clavate to pyriform, formed in small heads on the phialide tip. Chlamydospores intercalary, subglobose, in short chains, 1-celled or with 1 median septum.



38. Fusarium equiseti (Corda) Sacc., Sylloge Fungorum 4: 707 (1886)

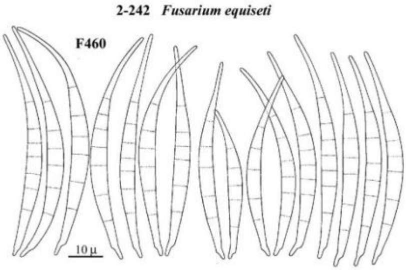
≡Selenosporium equiseti Corda, Icones fungorum hucusque cognitorum 2: 7, t. 9:32 (1838)
=Fusarium gibbosum Appel & Wollenw., Arbeiten aus der Kaiserlichen Biologischen Anstalt für Land- und Forstwirtschaft 8: 190 (1910)
=Fusarium caudatum Wollenw., Journal of Agricultural Research 2: 262 (1914)
=Fusarium bullatum Sherb., Memoirs Cornell Univ. Agri. Exper. Stat. 6: 198-201 (1915)

Macroconidia: abundant in sporodochia , long , slender, dorsoventral curvature, 5-7 septa, apical cell elongate and tapering, basal cell foot-shaped. Sporodochia: orange. Microconidia: absent. Chlamydospores abundant in 2 -6 weeks, single, in pairs , in chains, or in clumps, in aerial or submerged, terminal or intercalary

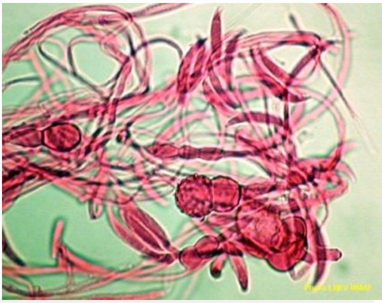


Fusarium equiseti, colony on potato sucrose agar, fungi.myspecies.info

Fusarium equiseti, macroconidia, conidiogenous cells stained in lactofuchsin. fungi.myspecies.info



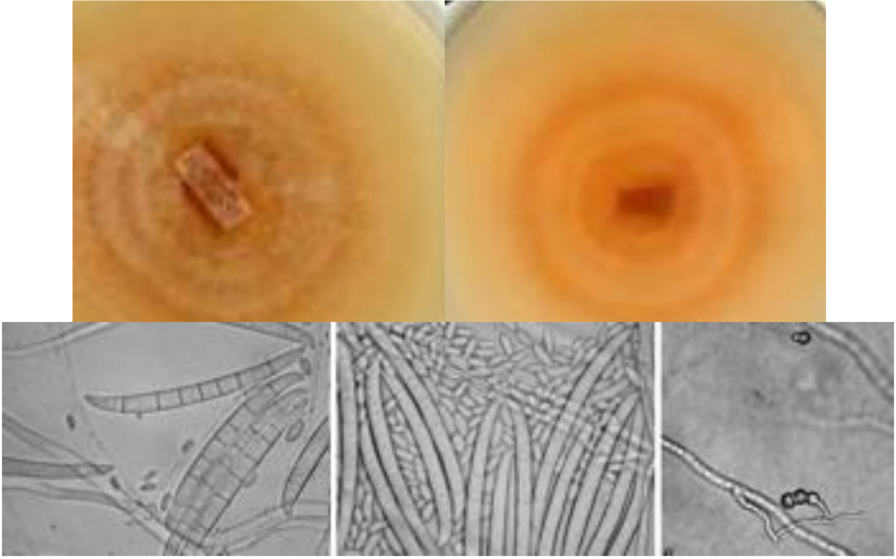
Mycobank



draaf.lorraine.agriculture.gouv.fr

39. Fusarium ensiforme , **Samuels, Nalim & Geiser Mycologia,. 103, 6 1302-1330 (2011);**

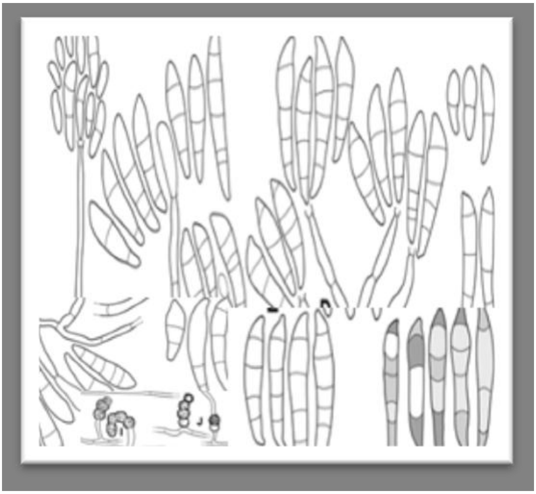
The macroconidia arise from sporodochia, long, slightly curved with 3–8-septate , with papillate and somewhat curved apical cell and well-developed foot cell. The microconidia are oval and elongated oval, mostly 0-septate. Chlamydospores are smooth walled



Fusarium ensiforme , multiseptate macroconidiaconidia and Chlamydospores. Samuels, Nalim & Geiser (2011);

40. Fusarium euwallaceae **S. Freeman, Z. Mendel, T. Aoki & O'Donnell, Mycologia 105 (6): 1599 (2013)**

Colonies produce sparse aerial loose to floccose, white to yellowish white, or reddish gray, brownish gray, or purplish gray mycelium. Reverse pigmentation absent or pale yellow grayish orange to brownish orange or sometimes with diffusing pigmentation of brown to reddish brown. Microconidia ellipsoidal, fusiform-ellipsoidal to short clavate, occasionally reniform, 0−2-septate. Macroconidia falcate to long clavate, sometimes curved cylindrical, 1-4-septate, swollen in upper parts, tapering toward the base, often with a round and papillate apical cell, and a distinct foot-like basal cell. Chlamydospores formed abundantly in hyphae and in conidia, mostly subglobose to round ellipsoidal, intercalary or terminal, single, or often in chains, ordinary hyaline to pale yellow, later becoming bluish to brownish when strongly pigmented, smooth to often rough-walled.

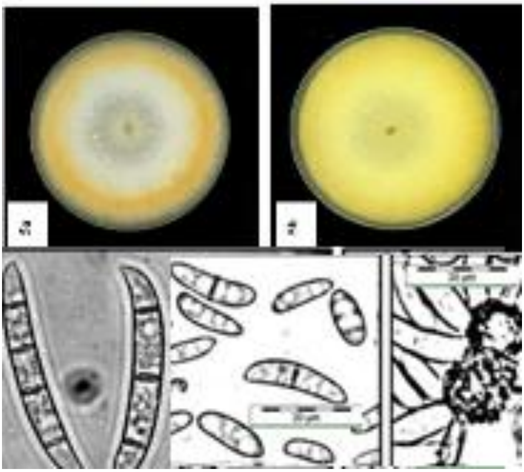


S. Freeman, Z. Mendel, T. Aoki & O'Donnell, Mycologia 105 (6): 1599 (2013)

41. **Fusarium falciforme** (Carrion) Summerb. & Schroers, Journal of Clinical Microbiology 40 (8): 2872 (2002)

≡Cephalosporium falciforme Carrión, Mycologia 43: 523 (1951)
≡Acremonium falciforme (Carrion) W. Gams, Cephalosporium-artige Schimmelpilze: 139 (1971)
≡Neocosmospora falciformis (Carrión) L. Lombard & Crous, Studies in Mycology 80: 227 (2015)

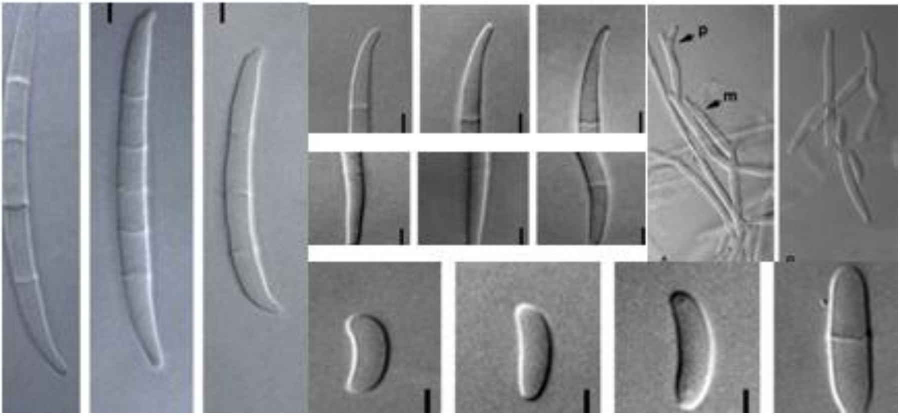
Colonies on malt agar off-white to pale cream, velvety or slightly fluffy. Conidiophores sparse, more or less erect, septate, unbranched, colourless, thin-walled, variable in length, not noticeably tapered towards the apex. Conidiogenous cells terminal, with no distinct collarette, producing conidia from the apex in succession. Conidia colourless, ellipsoidal to reniform, aseptate or septate, sometimes with a somewhat truncated base, sometimes aggregating in small groups. 'Chlamydospores' produced abundantly, sometimes in greater numbers than conidia, either singly or in chains, terminal or intercalary, elongated or swollen, with thin or substantially thickened walls.



Fusarium falciforme , *Chehri et al., 2015*

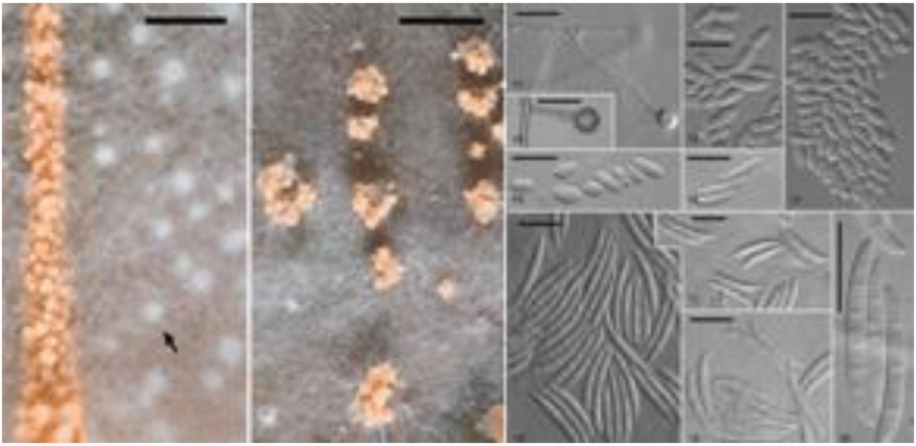
42. Fusarium fracticaudum Herron, Marinc. & M.J. Wingf., . Studies in Mycology 2015 No. 80 pp. 131-150

Macroconidia abundant, elongate, straight, 3–5 septa, apical cells tapering, curved, basal cells distinctly notched to foot-shaped. Microconidia abundant, fusiform to obovoid, occasionally curved, 0–1 septum, arranged in false heads. Conidiogenous cells monophialidic or polyphialidic, microconidia

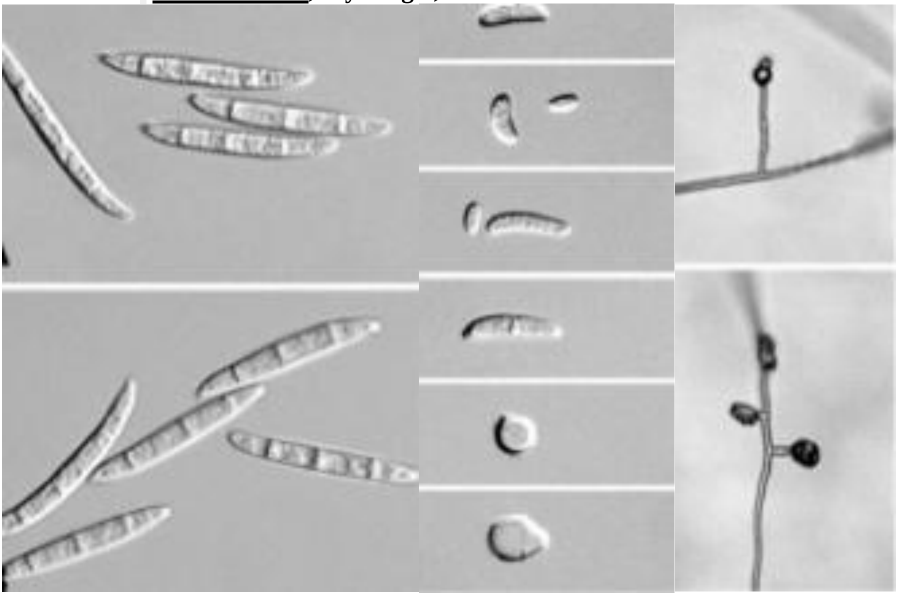


43. Fusarium foetens Schroers, O’Donnell, Baayen & Hooftman, Mycologia 96 (2): 398 (2004)

Macroconidia: abundant in sporodochia, falcate, 3-5 septa, apical cell curved, basal cell rounded to foot-shaped. Sporodochia: pale- light orange. Microconidia: ovoid, 0-septa, abundant on the aerial mycelia. Chlamydospores few, single, terminal , smooth or verrucose



Fusarium foetens on OA. Densely aggregated sporodochial conidiomata, each forming several hemispherical to allantoid conidial masses along the streaked inoculum after 14 d. Solitary sporodochia in other parts of the colony after 28 d. and chlamydospores,micro and macroconidia. **H.-J. Schroers, Mycologia, 2004**



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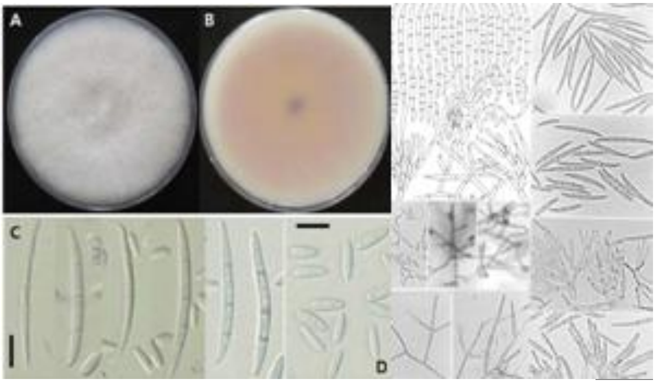
44. Fusarium fujikuroi **Nirenberg, Mitteilungen der Biol. Bundesanstalt Land-** Forstwirtschaft 169: 32 (1976)

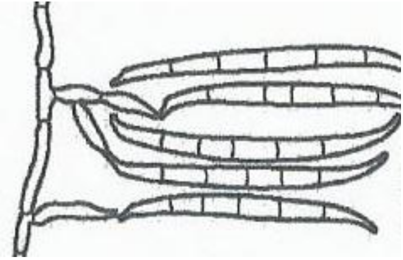
Macroconidia: abundant in sporodochia, slender, insign. Curved, medium length, 3-5 septa, apical cell tapered, basal cell poorly developed. Sporodochia: orange. Microconidia: ovoid or club-shaped, 0-1 septa, abundant on the aerial mycelia. Chlamydospores : absent



A, B; colony of F. fujikuroi, C; macroconidia, D; microconidia,Tae Jin An et al.,2013, G. Hagedorn, M. Burhenne & H. I. Nirenberg

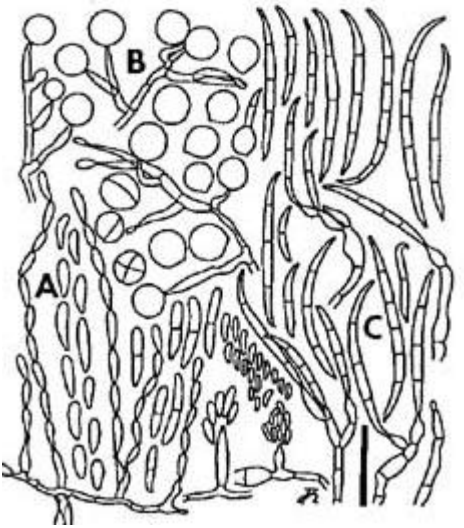
45. Fusarium gerlachii T. Aoki, Starkey, L.R. Gale, Kistler & O'Donnell (2007);

Fusarium gerlachii is morphologically similar to F. graminearum including colony characters on PDA, but has slightly different conidial features from it and other species within the F. graminearum clade. Macroconidia 5-septate, gradually curved and often widest at the mid-region, and frequently with a narrow beak at the apex



46. Fusarium globosum **Rheeder, Marasas & P.E. Nelson, Mycologia 88: 509 (1996)**

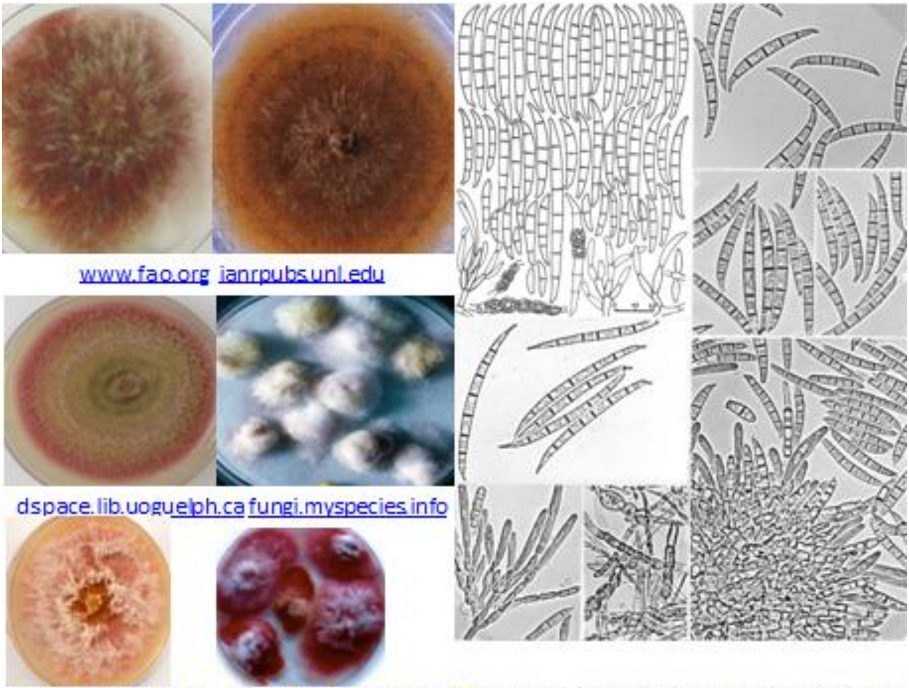
Macroconidia: abundant in sporodochia, slender-slightly curved, thin-walled, 3-5 septa, apical cell slightly curved, basal cell foot-shaped. Sporodochia: orange. Microconidia: oval-clavate in chains, globose more common single or in small clumps. Chlamydospores : absent.



F. globosum, www.nias.affrc.go.jp

47. Fusarium graminearum **Schwabe, Flora Anhaltina 2: 285 (1839)**

Macroconidia: abundant in sporodochia, slender-slightly curved, thick-walled, 5-6 septa, apical cell tapering, basal cell foot-shaped. Sporodochia: pale orange. Microconidia: absent . Chlamydospores : are formed in the macroconidia, finely roughened, single, in chains or clumps



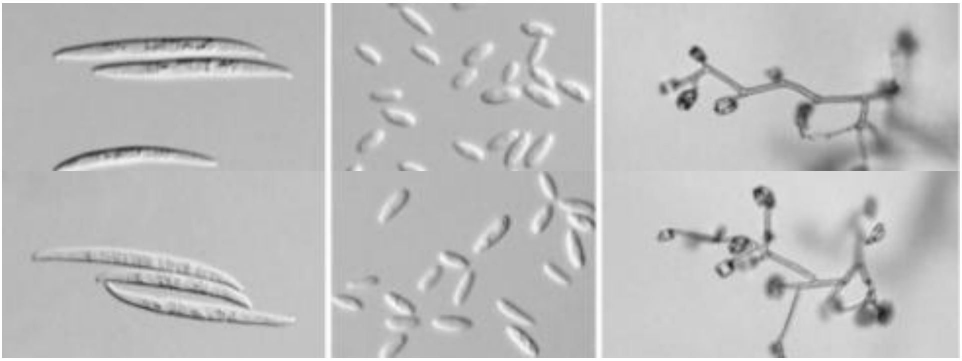
www.fao.org ianrpubs.unl.edu

dspace.lib.uoguelph.ca fungi.myspecies.info

www.apsnet.org www.maisadour-semences.fr G. Hagedorn, M. Burhenne & H. I. Nirenberg

48. Fusarium guttiforme Nirenberg & O'Donnell, Mycologia 90: 446 (1998)

Colonies on PDA showing average mycelial growth rate; colony margin entire. Aerial mycelium almost white. later sometimes tinged greyish-violet by the substrate; short, lanose. Pigmentation in reverse greyish-orange to dark-violet. Sporulation starting early in the aerial mycelium, conidia aggregated in false heads; sporodochia not observed. Conidiophores of the aerial mycelium erect or prostrate, strongly branched, branches terminating mostly in 1 or 2 phialides. Phialides of the aerial mycelium cylindrical, monophialidic but mostly polyphialidic. Micronidia borne in the aerial mycelium obovoid, mostly o-septate, occasionally l-septate. Chlamydospores absent.



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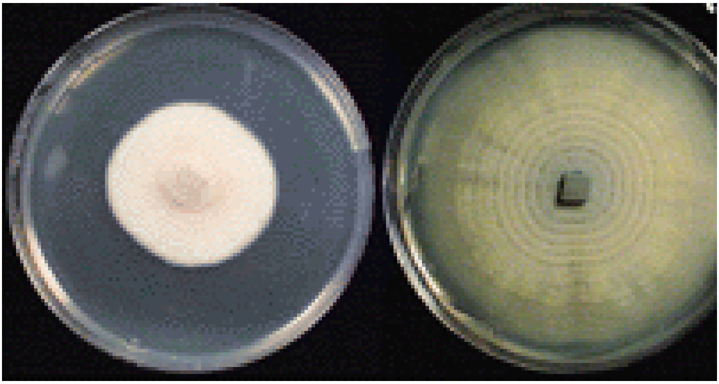
49. Fusarium haematococcum **Nalim, Samuels & Geiser, Mycologia 103 (6): 1322 (2011)**

Colonies produce abundant white, slimy sporodochia on the surface of the agar, scant erect, mononematous, acremonium-like conidiophores from the agar surface and the aerial mycelium. Mononematous conidiophores unbranched, monophialidic, tip of phialide with periclinal thickening, collarette not flared. Sporodochial conidiophores typically repeatedly branched, ultimate branches terminating in one or two phialides; phialides typically somewhat swollen toward the middle. Macroonidia uniformly arcuate, apical cell often beaked; basal cell pedicellate, 5-7septate. Perithecia subglobose, orange-red with lighter warts, basally immersed, grossly warted, becoming cupulate or laterally pinched when dry, gregarious. Asci clavate,, apex broad, simple, ascospores biseriate with overlapping ends. Ascospores ellipsoidal to subfusiform.



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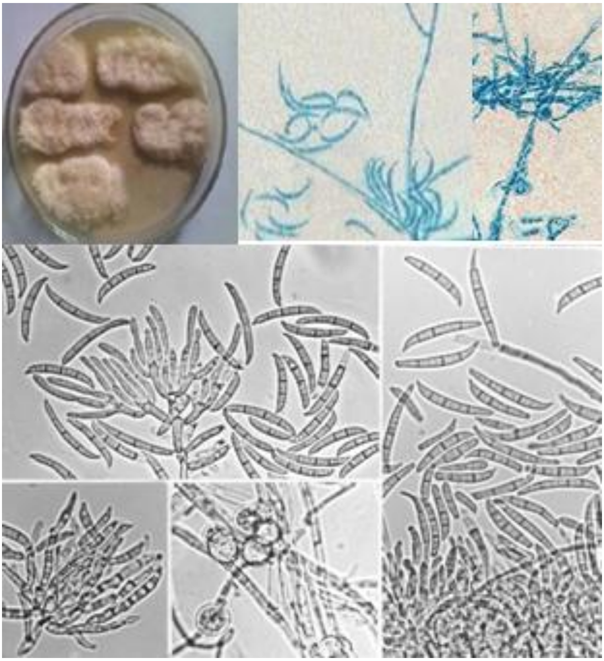
Nalim, Samuels & Geiser, Mycologia 103 (6): 1322 (2011)

50. Fusarium heterosporum **Nees, Nova Acta Acad. Caes. Leop.-Carol. German. Nat. Cur.: 135 (1817)**

Fusisporium lolii Wm.G. Sm., Diseases of field and garden crops, chiefly as are caused by fungi: 213 (1884)

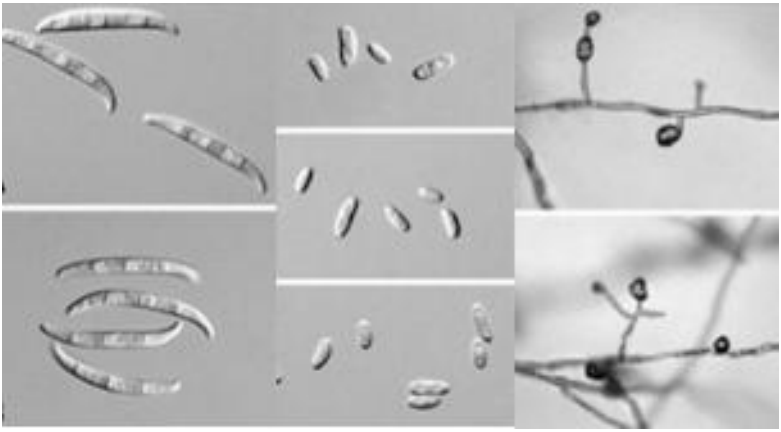
Macroconidia: abundant, 3-5 septa, thin-walled, slender to straight . Apical cell tapering, basal cell foot-shaped. Sporodochia: abundant, bright orange. Microconidia: absent. Chlamydospres: absent



Jandial and Sumbali, 2012
G. Hagedorn, M. Burhenne & H. I. Nirenberg

51. Fusarium hostae **Geiser & Juba, Mycologia 93: 672 (2001)**

Colonies form limited aerial mycelium/ Macroconidia: rare, 2-4 septa, fulcate to fusiform . Apical cell curved or hooked, basal cell foot-shaped. Sporodochia: abundant, purple-yellow-pink. Microconidia: abundant, on aerial mycelia, fusiform, 0-2 septa. Chlamydospres: abundant in 4-6 weeks, single, in chains or clumps, interstitial or terminal.



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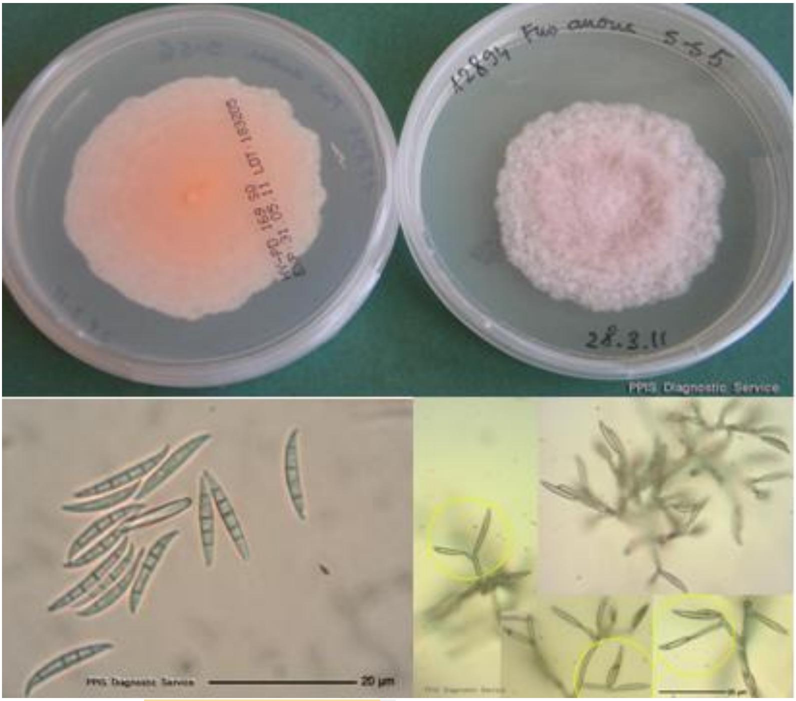
52. Fusarium incarnatum (Roberge) Sacc., Sylloge Fungorum 4: 712 (1886)

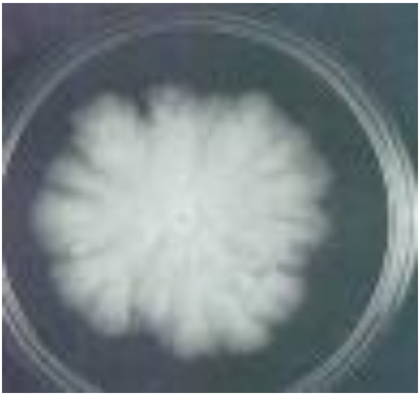
≡Fusisporium incarnatum Roberge ex Desm., Ann Sci Natur Bot 11: 274 (1849)
=Fusarium semitectum Berk. & Ravenel, Grevillea 3 (27): 98 (1875) [MB#179598]
=Fusarium semitectum var. semitectum (1875)
=Fusisporium pallidoroseum Cooke, Grevillea 6 (40): 139 (1878)
=Fusarium semitectum var. majus Wollenw., Fusaria Autographice Delineata 3: 907-910 (1931)

Colonies produce floccose aerial mycelium, at first whitish, later becoming avellaneous to buff-brown; reverse pale, becoming peach-coloured. Conidiophores scattered in the aerial mycelium, loosely branched; polyblastic conidiogenous cells abundant. Sporodochial macroconidia slightly curved, with foot-cell, 3-7-septate. Conidia on aerial conidiophores (blastoconidia) usually borne singly on scattered denticles, fusiform to falcate, mostly 3-5-septate. Microconidia sparse or absent. Chlamydospores sparse, spherical, intercalary, single or in chains

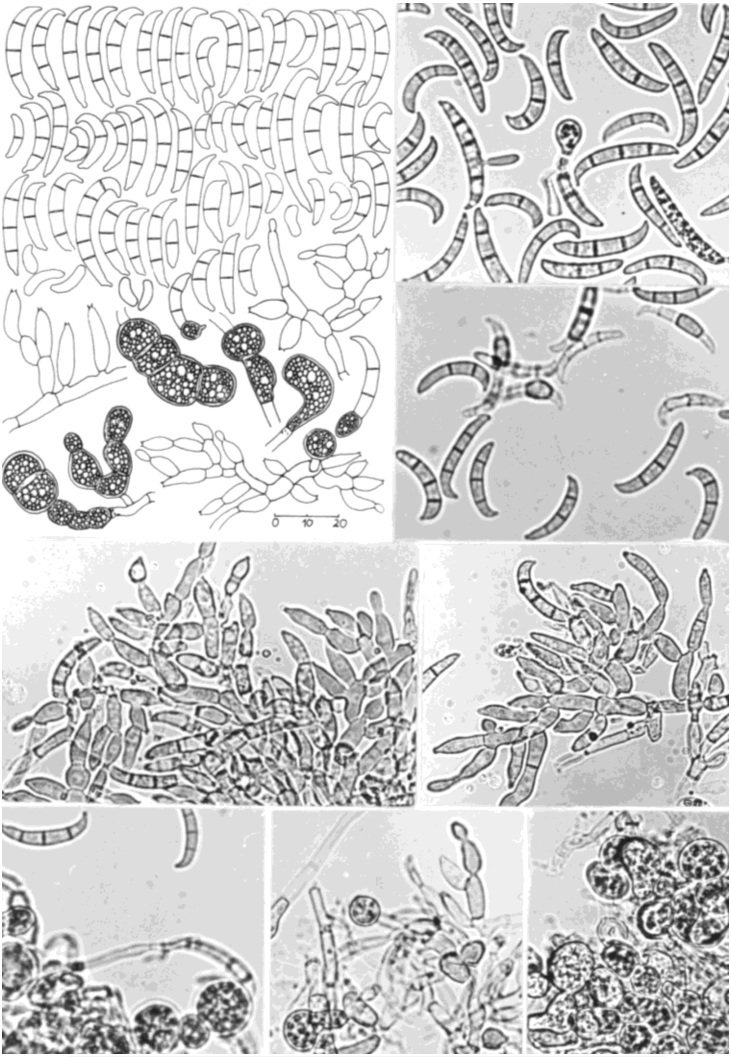


Fusarium incarnatum www.ppis.moag.gov.il

53. **Fusarium inflexum** R. Schneid., Phytopathologische Zeitschrift 82 (1): 80 (1975)



Fusarium inflexum colony



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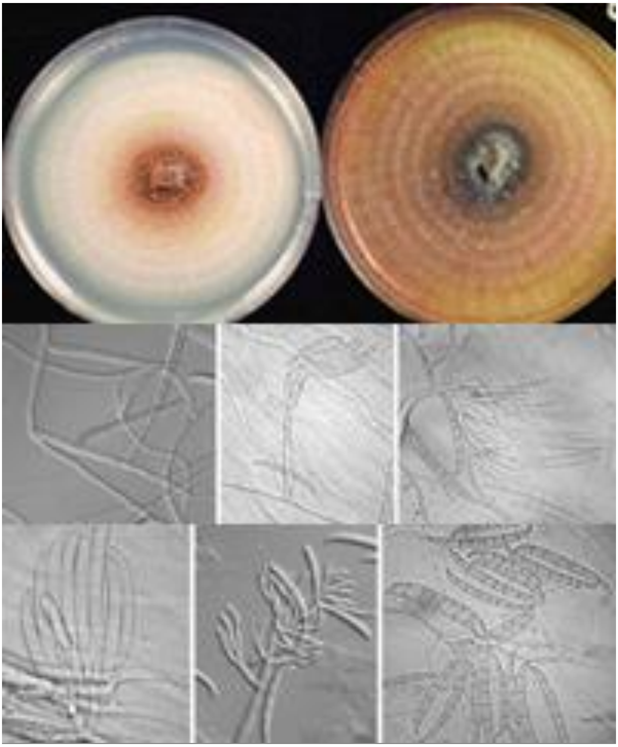
54. **Fusarium kelerajum** Samuels, Nalim & Geiser, Mycologia 103 (6): 1326 (2011)

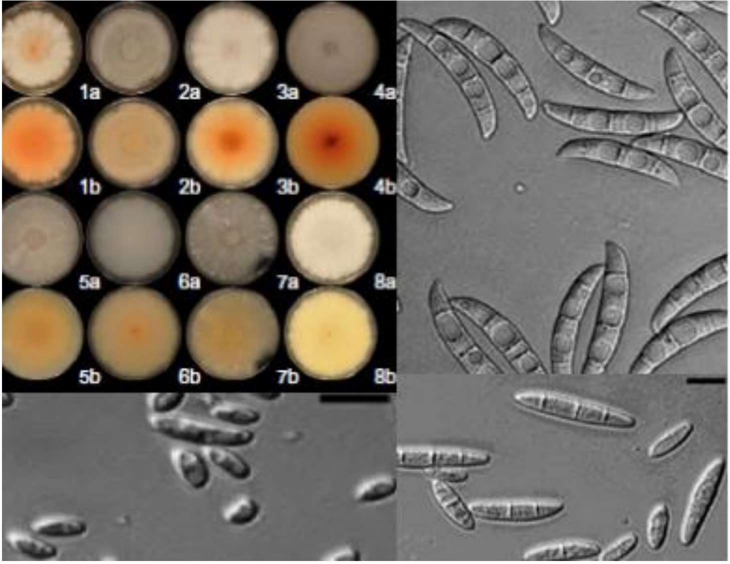
Colonies produce scanty aerial mycelium; conidia arise from scattered mononematous acremonium-like conidiophores and from white to pale orange, slimy sporodochia on the agar surface. Sporodochial conidiophores richly branched, sometimes slightly stipitate; sporodochial phialides cylindrical or slightly swollen in the middle. Macroconidia slightly curved, tip acuminate and somewhat strongly beaked, with a well developed foot cell, 3-9-septate.



55. Fusarium keratoplasticum D. Geiser, O’Donnell, Short et Zhang, Fungal Genetics and Biology 53 (2013) 59–70

= Cephalosporium keratoplasticum T. Morik., Mycopathologia 2(1): 66 (1939), nom. nud. (Invalid.)
=Hyalopus keratoplasticum (T. Morik.) M.A.J. Barbosa, Notarisia: 19 (1941)

Colonies produce white, salmon, peach, vinaceous grey and pale olivaceous grey mycelium; reverse pigmentation in shades of pale olivaceous grey, flesh, salmon, olivaceous buff, ochreous and pale luteous. Macroconidia generally 3–5 septate, usually cylindrical and gently curved, sometimes falcate, with dorsal and ventral lines nearly parallel or gradually wider basally, with an acuate apical cell and a distinct basal foot cell.Aerial conidiophores formed abundantly, branched or unbranched; monophialides. Microconidiaconidia hyaline, oval, fusiform, pyriform, napiform or cylindrical, 0–3 septate. Chlamydospores formed frequently, after several weeks, in hyphae and in conidia, mostly subglobose, often intercalary, single, frequently in pairs, hyaline, pale to yellowish grey, smooth to rough-walled.



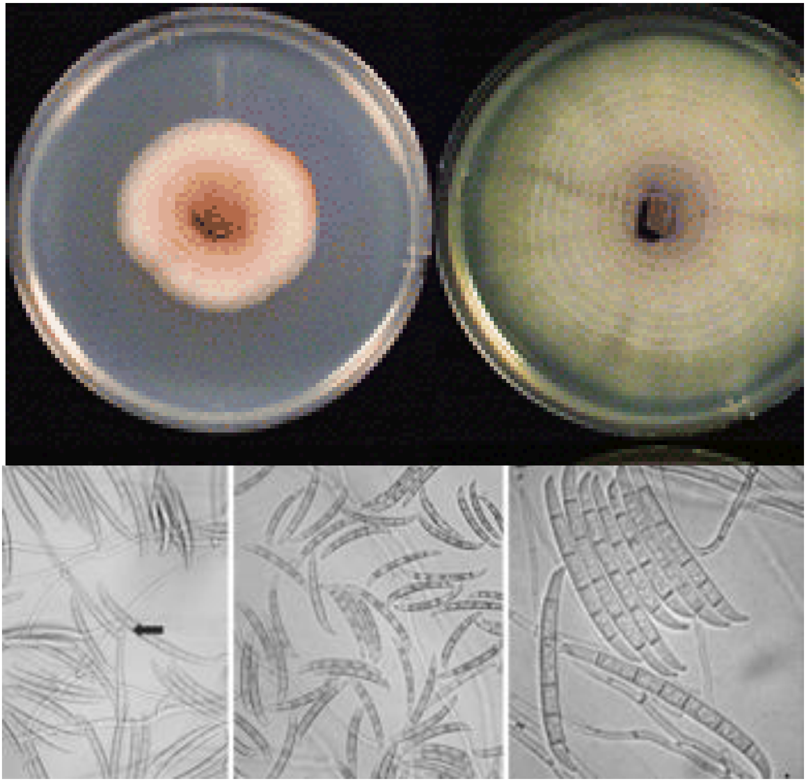
56. Fusarium konzum **Zeller, Summerell & J.F. Leslie, Mycologia 95 (5): 947 (2003)**

Colonies on PDA produce abundant floccose mycelium that are initially white and become violet. Sporodochia are rare; sporodochia from leaf pieces on CLA are pale orange. Macroconidia are not common. Typically macroconidia are hyaline, 3–5 septate, falcate, with a pedicellate foot cell and a slightly curved apical cell. Microconidia are produced on monophialides and polyphialides produced laterally in the aerial hyphae . Microconidia are produced either singly or in small false heads consisting of 2–4 microconidia per phialide. Three types of microconidia are produced: oval, hyaline 0–1 septate microconidia, pyriform, 0-1 septate and larger napiform to globose, 0-septate microconidia. Chlamydospores absent.

Zeller, Summerell & J.F. Leslie, Mycologia 95 (5): 947 (2003)

57. Fusarium kurunegalense **Samuels, Nalim & Geiser, Mycologia 103 (6): 1323 (2011)**

Colonies produce scanty aerial mycelium scant; conidia arising from mononematous conidiophores scattered throughout the colony and in white slime on the agar surface. Mononematous conidiophores acremonium-like, septate, terminating in a single phialide; tip of phialides with periclinal thickening, not flared; sometimes proliferating to form a second phialide. Macroconidia slightly curved or arcuate, tip more sharply hooked; basal cell typically wedge-shaped, weakly pedicelate, 4-10-septate

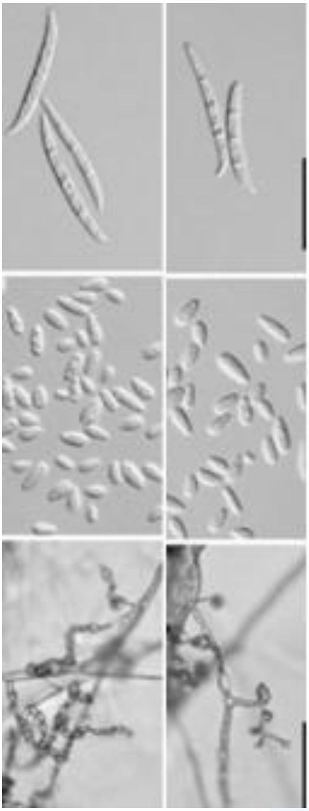


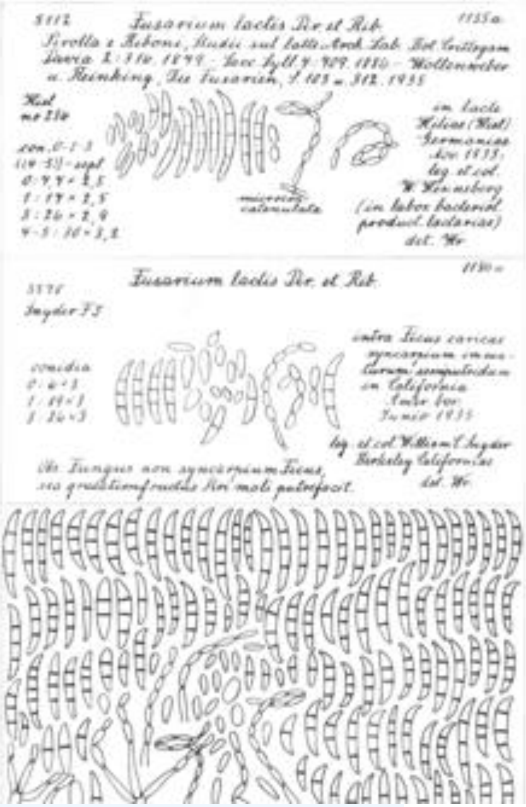
Fusarium kurunegalense Samuels, Nalim & Geiser (2011)

58. Fusarium lactis Pirotta & Riboni, Arch. Lab. Bot. crittog. Pavia: 316 (1879)

≡Fusarium moniliforme var. lactis (Pirotta & Riboni) Bilai, Mykrobiologichnyi Zhurnal Kiev 49 (6): 7 (1987)

Macroconidia: rare, 2-4 septa, thin-walled, slender and straight to slightly curved . Apical cell bent, basal cell notched. Sporodochia: rare, light orange. Microconidia: abundant in the aerial mycelia, obvoid, 0-1septa, short to medium lenthg zigzag chains. Chlamydospres: absent





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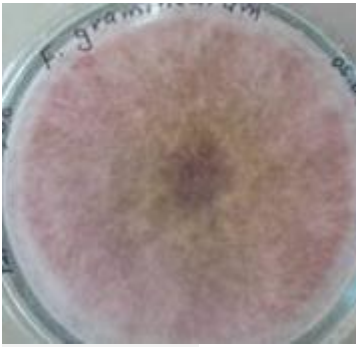
59. Fusarium langsethiae Torp & Nirenberg, Int. J.Food Microbiol. 95 (3): 248 (2004)

Fusarium langsethiae was initially referred to as ‘powdery F. poae’ due to its abundant production of small napiform to globose conidia, giving the colony a powdery-like appearance. It has spore morphology similar to F. poae. Fusarium langsethiae differs from F. poae by its slower growth, production of fewer aerial mycelia and lack of peach-like odour on synthetic media.The fungal colonies colour on synthetic solid media range from whitish, yellowish white, pinkish white, pale red and/or pastel red. Some of the strains can produce a pigment called aurofusarin, which is produced by nearly all strains of F. poae and F. sporotrichioides and influences colony colour development.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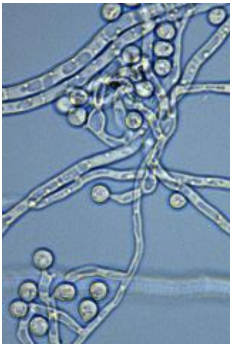
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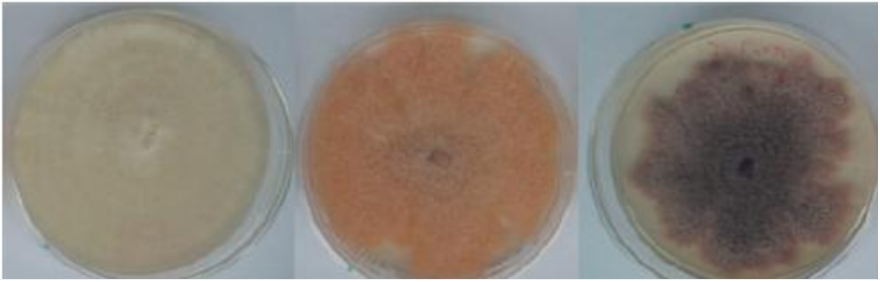
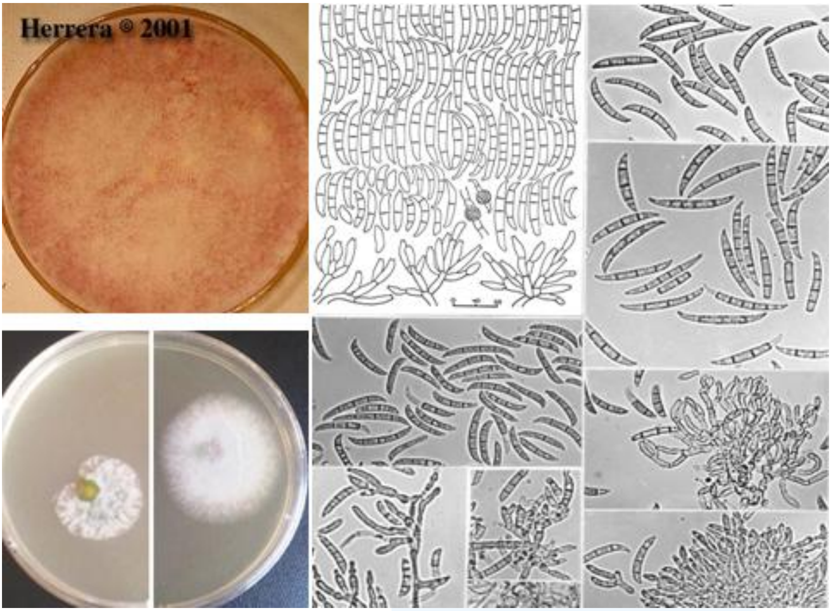

Imathiu et al., 2013

60. Fusarium lateritium Nees, System der Pilze und Schwämme: 31, t. 2:26 (1817)

Selenosporium lateritium (Nees) Desm., Flore Cryptogamique des Flandres 2: 99 (1867)

Macroconidia: rare, 2-4 septa, thin-walled, long,falcate to straight to slightly curved with parallel walls . Apical cell hooked, basal cell foot-shaped or notched. Sporodochia: abundant, pale orange. Microconidia: abundant in the aerial mycelia, elliptical, oval, spindle or club-shaped. Chlamydospres: may be present

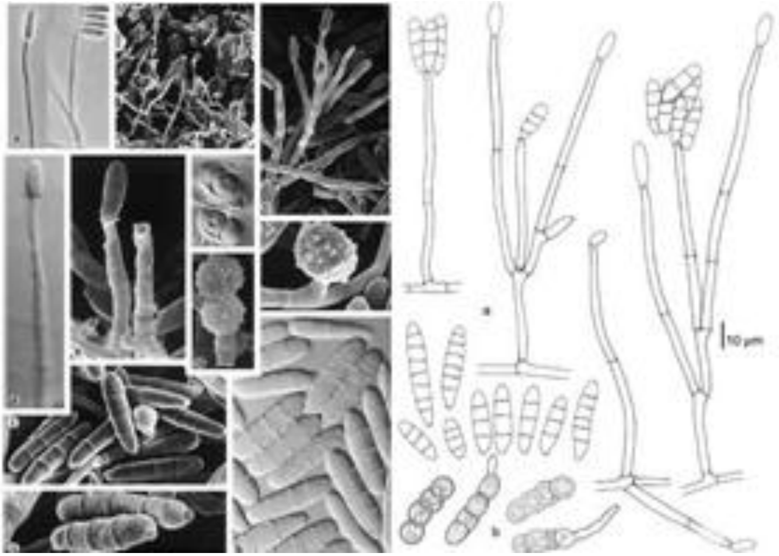


O. A. Awoyinka et al., 2012, Hagedorn, Burhenne & Nirenberg

61. Fusarium lichenicola **C. Massal., Ann. Mycol. 1 (3): 223 (1903)**

≡Bactridium lichenicola (C. Massal.) Wollenw., Fusaria Autographice Delineata 1: no. 456 (1916)
≡Bactridium lichenicolum (C. Massal.) Wollenw. (1916)
≡Cylindrocarpon lichenicola (C. Massal.) D. Hawksw., Bull. Brit. Museum Natural History 6 (3): 273 (1979)
=Cylindrocarpon tonkinense Bugnic., Encyclopédie Mycologique 11: 181 (1939) [MB#255134]
=Euricoa dominguesii Bat. & H. Maia, Anais da Soc.Biol.de Pernambuco 13 (1): 152 (1955)
=Euricoa dominguiesii Bat. & H. Maia (1955)
=Mastigosporium heterosporum R.H. Petersen, Mycologia 51: 729 (1959)
=Moeszia pernambucensis Bat., S.K. Shome & Maciel, Public. Instit. Micolo. Univ. Recife 445: 6 (1965)

Colonies produce white, floccose to felted aerial mycelium, becoming pale brown with age, and making the agar beige to dark brown with age. Conidia produced from simple, subulate conidiogenous cells on sparsely branched conidiophores. Conidiogenous cells with periclinal thickening and sometimes a distinct collarette at their apices. Macroconidia, 3-7septate, ellipsoid or obovate to cylindrical, each with a bluntly rounded apex and distinct basal pedicel. 'Chlamydospores' abundant, thick-walled, globose, pale brown, smooth or spinulose,

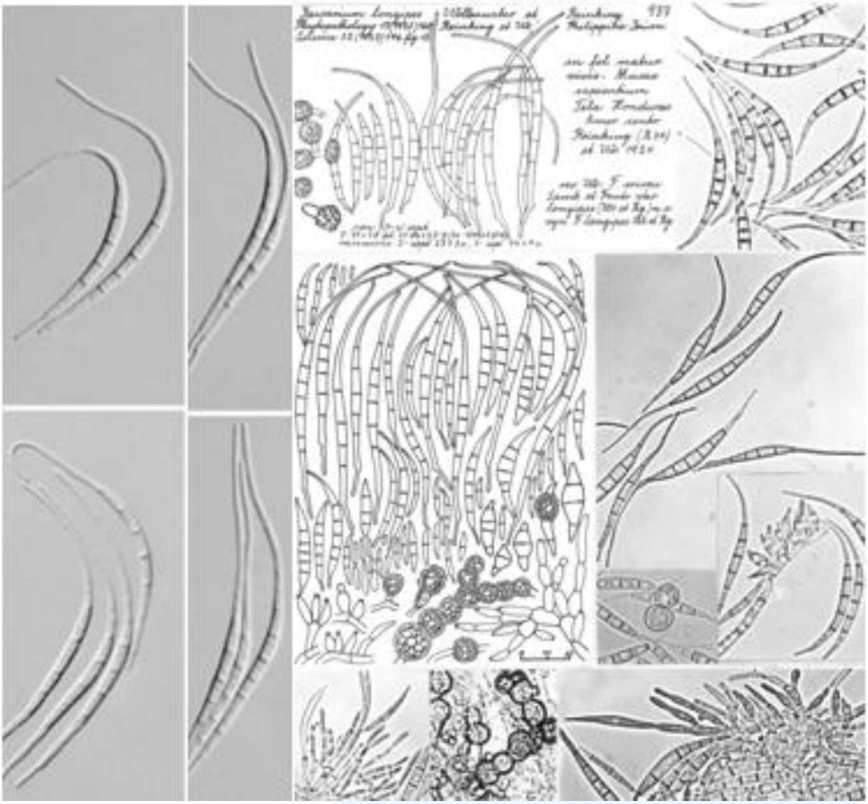


Mycobank

62. Fusarium longipes **Wollenw. & Reinking, Phytopathol 15 (3): 160 (1925)**

≡Fusarium scirpi var. longipes (Wollenw. & Reinking) Wollenw., Fusaria Autographice Delineata 3: 937 (1930) [MB#277671]
≡Fusarium equiseti var. longipes (Wollenw. & Reinking) Joffe, Mycopathologia et Mycologia Applicata 52 (1-4): 221 (1974)

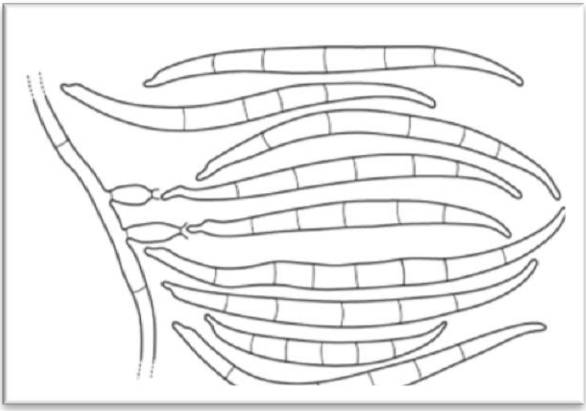
Macroconidia: rare, 5-7 septa, thin-walled, extremely long, pronounced curvure . Apical cell long and whip-like and tapering, basal cell elongated foot-shaped. Sporodochia: large, bright orange. Microconidia: absent. Chlamydospres: in chains or clusters



. Leslie and Summerell , Hagedorn, Burhenne &. Nirenberg

63. Fusarium louisianense Gale, Kistler, O’Donnell & T. Aoki, Fungal Genetics & Biology 48: 1105 (2011)

Colonies produce abundant, dense floccose to pannose, white, reddish-white, pale red to grayish red aerial mycelium on agar. Sporulation abundant, from conidiophores formed directly on hyphae or aggregated in sporodochia on or in the agar; sporodochia formed abundantly. Conidiophores branched verticillately or unbranched, terminating with monophialides, Phialides simple, subulate, ampulliform to subcylindric, monophialidic. Conidia of a single type, typically falcate and gradually curved, sometimes sigmoid or straight, dorsiventral, most frequently widest at the midregion of their length, tapering and curving toward both ends, with an arcuate apical cell and a distinct basal foot cell, upper and lower halves asymmetric, 3-7-septate. Chlamydospores absent

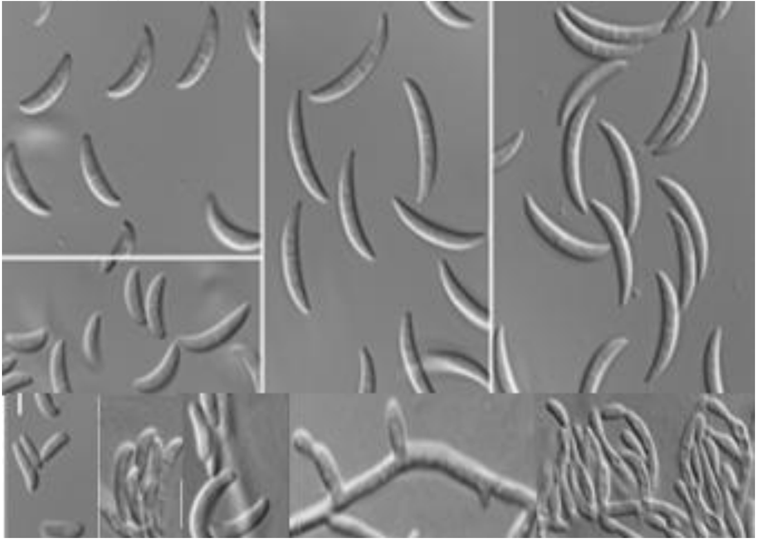


Sarver et al., 2011

64. Fusarium lunatum (Ellis & Everh.) von Arx, Verh Konink Akad Vetensch Amsterdam 51:101. 1957

≡Gloeosporium lunatum Ellis & Everh., Proc. Acad. Nat. Sci. Philadel 43: 82 (1891) [
≡Microdochium lunatum (Ellis & Everh.) Arx, Trans Brit Mycol So 83 (2): 374 (1984)
≡Bisifusarium lunatum (Ellis & Everhart) L. Lombard & Crous, Stud Mycol 80: 225 (2015)
=Fusarium dimerum var. violaceum Wollenw., Fusaria Autographice Delineata 3: 854 (1930)

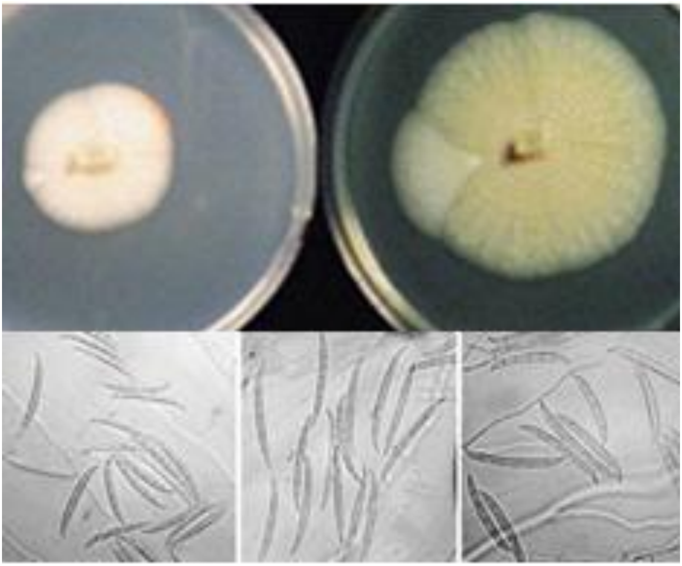
Colonies produce sparse white aerial mycelium on agar, colony reverse brownish yellow, brownish orange or vinaceous, dark violet or dark carmine. Sporulation sparse; monophialides formed terminally or laterally on hyphae, in well developed sporodochia, forming few-membered whorls on short supporting cells; polyphialides not seen. Microconidia mostly curved, allantoid to lunate, or less frequently almost straight and ellipsoidal; curved microconidia either almost uniformly rounded at both ends or with a minutely beaked and a slightly pointed distal and proximal end, mostly 0- 2-septate. Macroconidia 0-3-septate. Chlamydospores globose to subglobose,, partly branched chains or aggregated in irregular clusters



Fusarium lunatum, **Schroers, Summerb. & O'Donnell, Mycologia 101 (1): 61 (2009)**

65. Fusarium mahasenii **Samuels, Nalim & Geiser, Mycologia 103 (6): 1325 (2011)**

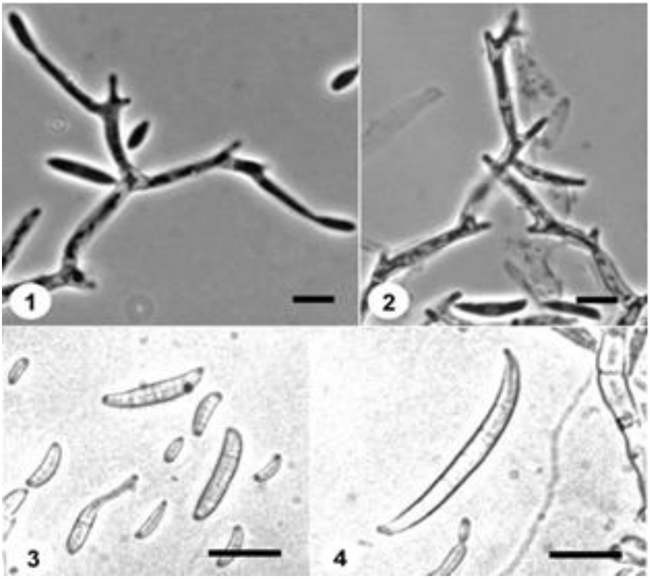
Colonies produce scanty aerial mycelium; conidia arise from mononematous conidiophores arising from the agar surface and sparsely from the aerial mycelium and from yellowish slimy sporodochia on the surface of the agar. Mononematous conidiophores acremonium-like, wide at base, tapering uniformly from base to tip; a single phialide comprising the terminal, tip with periclinal thickening, collarette not flared; sporodochial conidiophores richly branched, sometimes stipitate; sporodochial phialides cylindrical or slightly swollen in the middle. Macroconidia straight to slightly curved, with a well developed foot cell, 4-6-septate

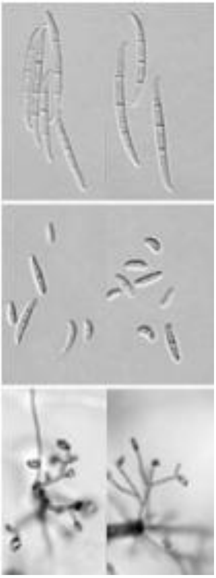


Fusarium mahasenii Samuels, Nalim & Geiser (2011);

66. Fusarium mangiferae **Britz, M.J. Wingf. & Marasas, Mycologia 94 (4): 725 (2002)**

Colonies forms white aerial mycelium, floccose. Reverse of colonies sometimes rosy buff to dark purple. Conidiophores on aerial mycelium originating erect and prostrate from substrate. Conidiophores sympodially branched bearing mono- and polyphialides. Polyphialides have 2–5 conidiogenous openings. Microconidia variable in shape, obovoid conidia the most abundant type, oval to allantoid conidia occurring occasionally . Microconidia mostly 0-1 septate , conidia occurring less abundantly . Sporodochia present, cream and orange. Macroconidia long and slender, usually 3–5 septate . Chlamydospores absent.

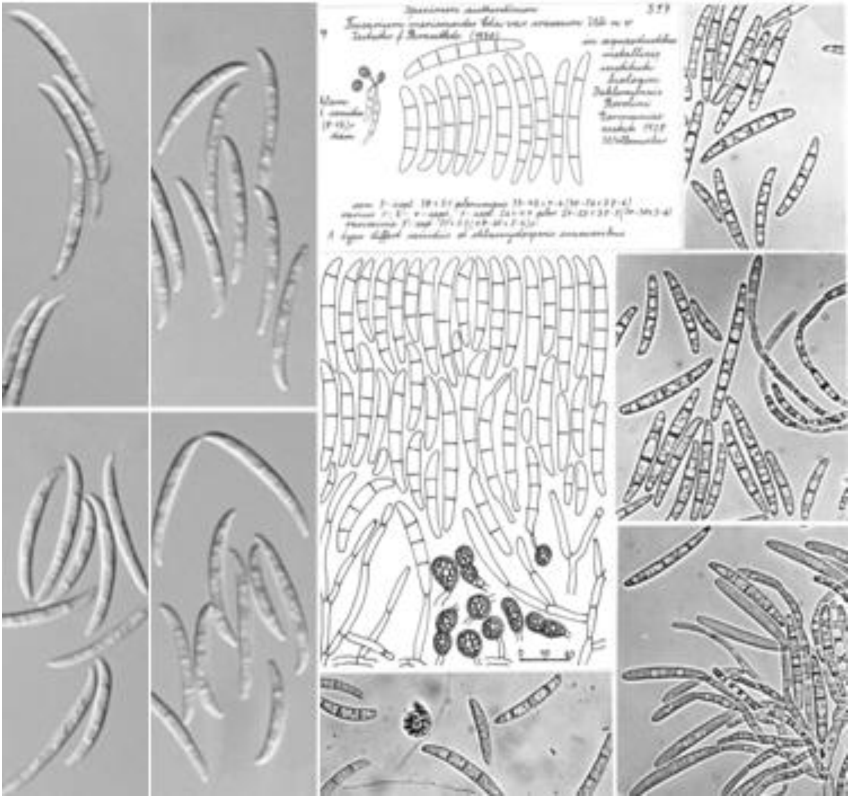




Britz et al., 2002.*Fusarium mangiferae*. 1. Branched conidiophores bearing polyphialides with 3 conidiogenous openings (scale bar: 5 µm). 2. Branched conidiophores bearing mono- and polyphialides (scale bar: 5 µm). 3. Microconidia (scale bar: 15 µm). 4. Macrocondium (scale bars: 15 µm)

67. Fusarium merismoides Corda, Icones fungorum hucusque cognitorum 2: 4, t. 8:16 (1838)

=Fusicolla merismoides (Corda) Gräfenhan, Seifert & Schroers, Studies in Mycology 68: 101 (2011)



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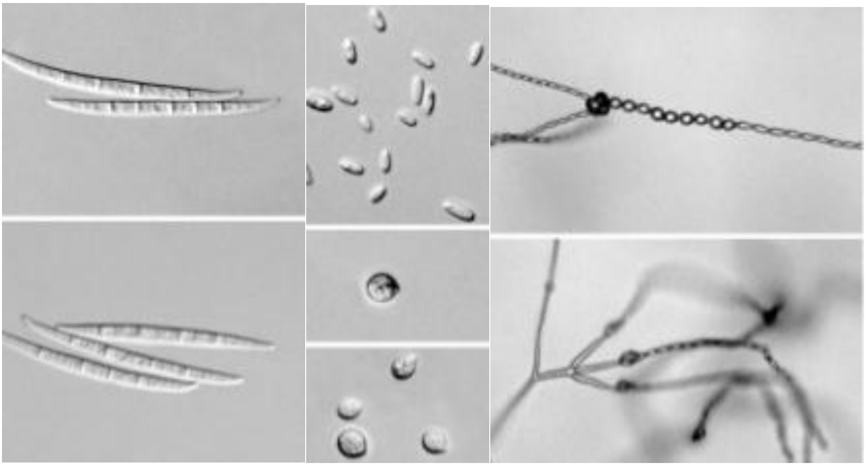
68. Fusarium miscanthi **W. Gams, Klamer & O’Donnell, Mycologia 91: 264 (1999)**

Macroconidia: abundant in sporodochia, 3-5 septa, thin-walled, straight to falcate, apical cell curved and tapering, basal cell foot-shaped. Sporodochia: pale orange after 3 weeks. Microconidia:pyriform and clavate, 0-septa, long chains. Chlamydospores: absent



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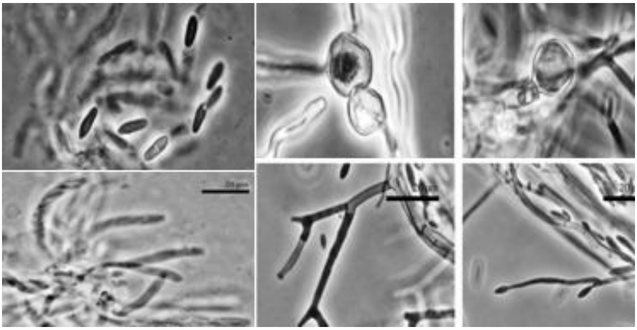
69. Fusarium musae **Van Hove, Waalwijk, Munaut, Logrieco & Moretti, Mycologia 103 (3): 579 (2011)**

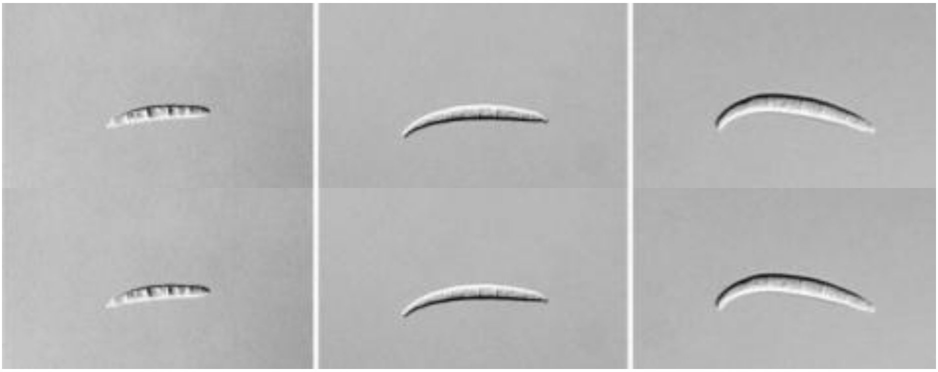
Colonies produce white to vinaceous aerial mycelium. Colonies from above and below reddish. Pseudochlamydospores single and globose, at the ends of hyphae, conidiophores unbranched or branched, bearing monophialidic conidiogenous cells. Microconidia abundant, borne in chains or false heads, hyaline, claviform or ellipsoidal, often truncated, aseptate or rarely one-septate. Sporodochia absent. Macroconidia absent.



Fusarium musae , **Van Hove, Waalwijk, Munaut, Logrieco & Moretti, Mycologia 103 (3): 579 (2011)**

70. Fusarium musarum **Logrieco & Marasas, Mycologia 90: 510 (1998)**

Macroconidia: absent. Sporodochia: absent. Microconidia/Mesoconidia: abundant, 2-9 septa, falcate and thick-walled with a pointed apical cell and a conical basal cell. Microconidia: pyriform and clavate, 0-septa, long chains. Chlamydospores: produced slowly and sparsely, smooth, globose, single, in clusters or in chains



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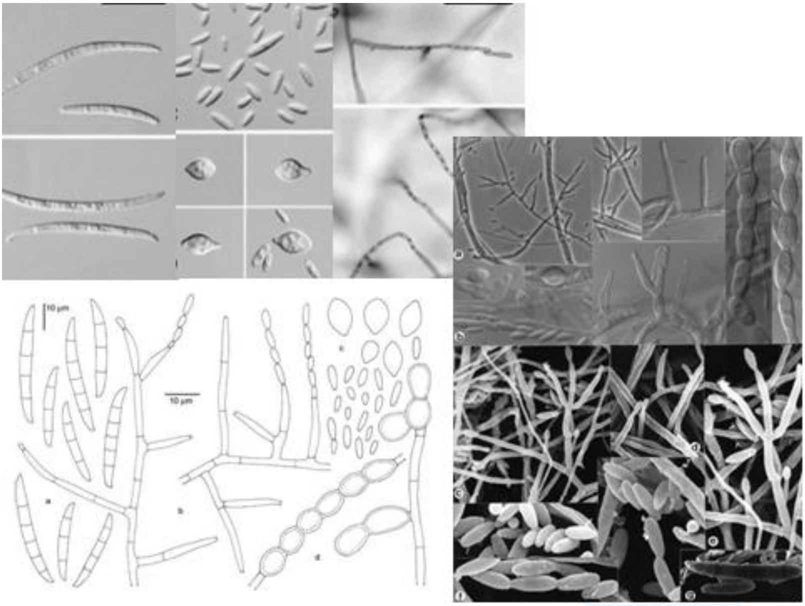
71. Fusarium napiforme **Marasas, P.E. Nelson & Rabie, Mycologia 79 (6): 910 (1987)**

Macroconidia: abundant in sporodochia, 3-5 septa, moderately long, falcate, apical cell curved and tapering, basal cell foot-shaped. Sporodochia: bright orange. Microconidia:lemon-shaped and napiform, 0-1 septa, long chains. Chlamydospores: produced slowly



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72. Fusarium nelsonii Marasas & Logrieco, Mycologia 90: 508 (1998)

Macroconidia: abundant in sporodochia, 3-5 septa, straight or curved and falcate, apical cell curved and beak-shaped, basal cell foot-shaped. Sporodochia: pale cream. Microconidia: abundant, fusiform or straigt to slightly curved, 0-3septa. Chlamydospores: abundant, produced rapidly

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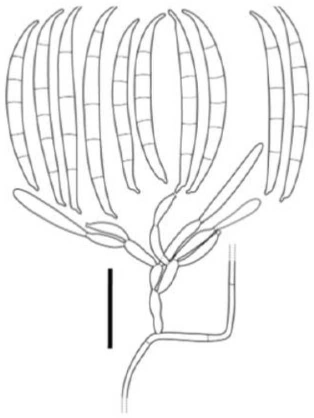
73. Fusarium nepalense **T. Aoki, Carter, Nicholson, Kistler & O'Donnell, Fungal Genetics & Biology 48: 1105**

Colonies abundant, sometimes sparsely developed, loosely to dense floccose, white, reddish-white, pale red to grayish red, grayish-orange aerial mycelium. Colony margin entire to undulate, often forming colony sectors of different growth rates. Sporodochia formed abundantly or sparsely. Conidiophores branched or unbranched, terminating with monophialides on the apices. Phialides simple, subulate, ampulliform to subcylindric, monophialidic. Conidia of a single type, typically falcate and curved, dorsiventral, most frequently widest slightly above the midregion of their length, tapering and gradually curving toward both ends, with an arcuate and beaked apical cell and a distinct basal foot cell, upper and lower halves asymmetric, 3-7-septate. Chlamydospores absent.

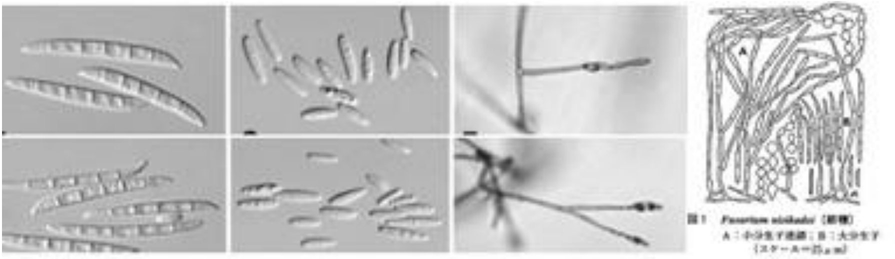


Fusarium nepalense NRRL 54221
(Bar: 25 um)

Sarver BA1, Ward TJ, Gale LR, Broz K, Kistler HC, Aoki T, Nicholson P, Carter J, O'Donnell K Fungal Genet Biol.

74. Fusarium nisikadoi **T. Aoki & Nirenberg, Mycoscience 38 (3): 330 (1997)**

Macroconidia: abundant in sporodochia, 1-9 septa, long, straight and falcate, apical cell curved and beak-shaped, basal cell foot-shaped. Sporodochia: rare, orange. Microconidia: abundant,occasionaly pyriform 0-3septa , commonly clavate, long chain, often zigzag.Chlamydospores: absent



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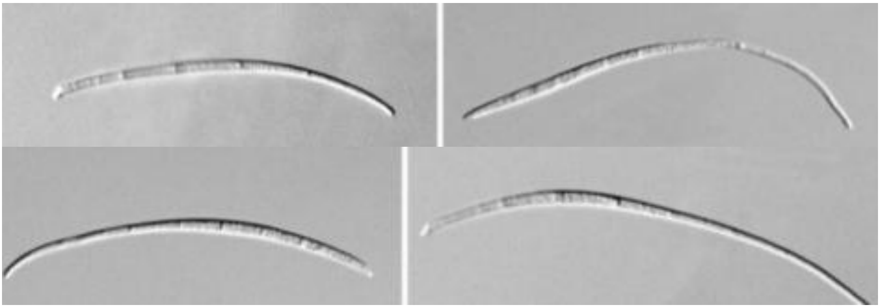
Mycoscience

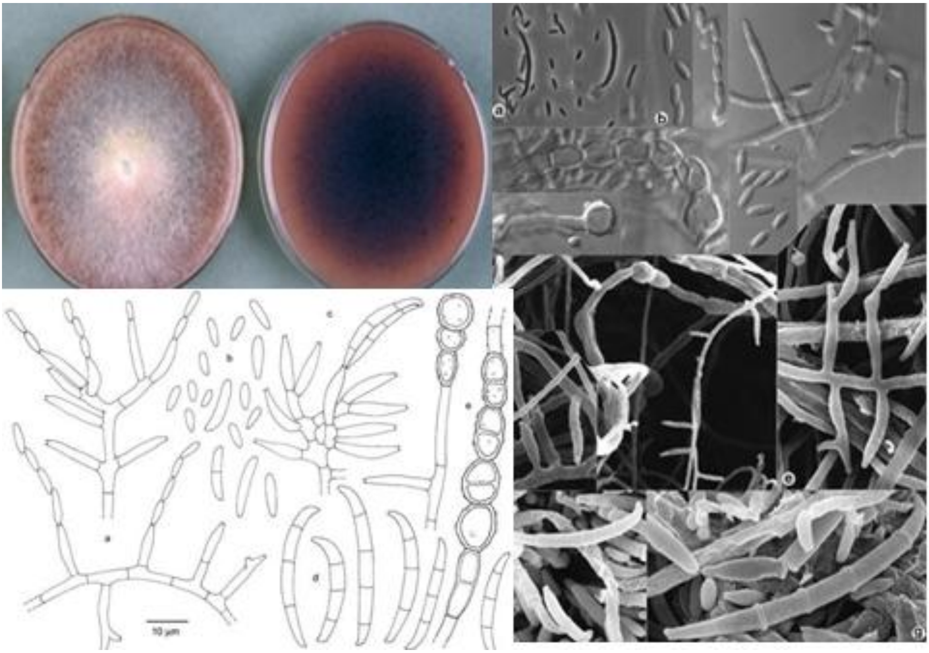
75. Fusarium nurragi **(Summerell & L.W. Burgess) Benyon, Summerell & L.W. Burgess, Mycological Research 104 (10): 1171 (2000)**

Macroconidia: abundant in sporodochia, 5- septa, long, thin and whip-like, straight and falcate, apical cell long and tapering, basal cell elongate foot-shaped. Sporodochia: orange. Microconidia: absent. Chlamydospores: absent



76. Fusarium nygamai **L.W. Burgess & Trimboli, Mycologia 78: 223 (1986)**

Macroconidia: abundant in sporodochia, 5-septa, moderately long, straight to slightly curved, apical cell short and tapering, basal cell notched or foot-shaped. Sporodochia: abundant, orange. Microconidia: small, oval or club-shaped, 0-1 septa. Chlamydospores: rare to abundant



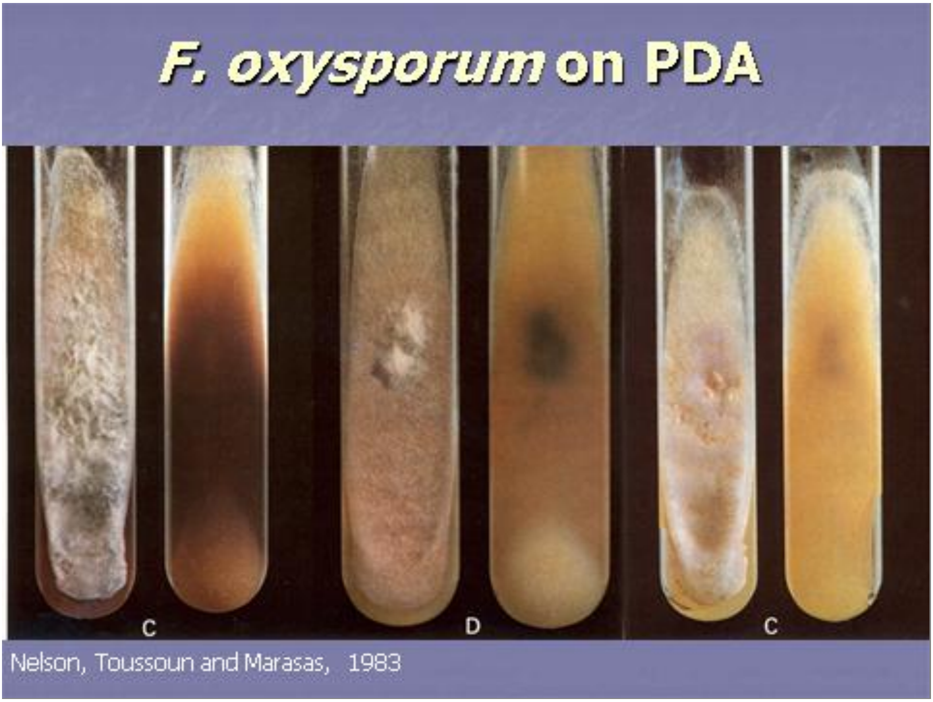
Mycobank

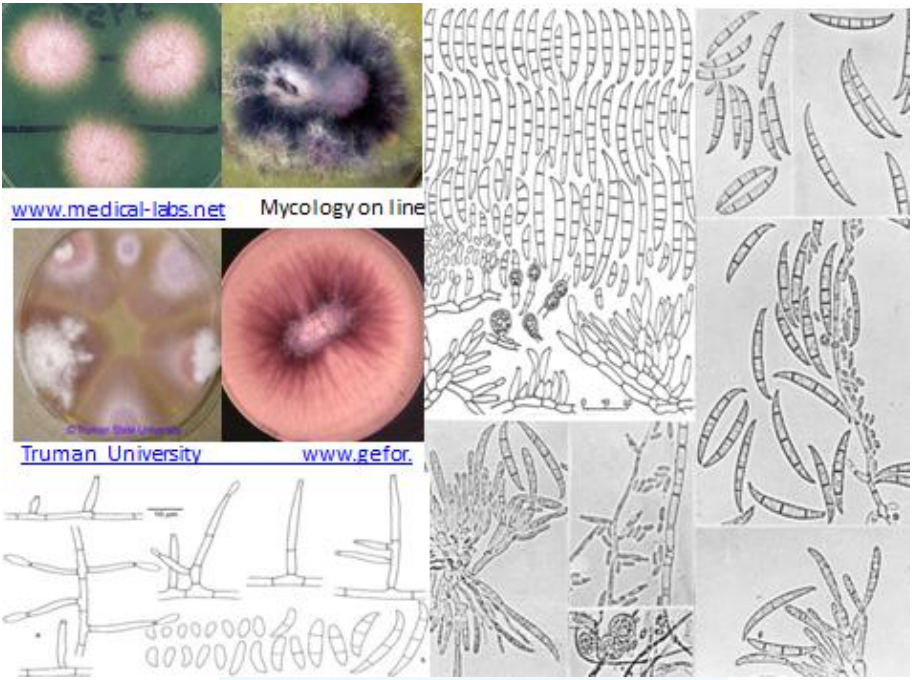
77. Fusarium oxysporum **Schltdl., Flora Berolinensis, Pars secunda: Cryptogamia: 106 (1824)**

=Fusarium bulbigenum Cooke & Massee, Grevillea 16 (78): 49 (1887)
=Fusarium orthoceras Appel & Wollenw., aus der Kaiserlichen Biologischen Anstalt für Land- und Forstwirtschaft 8: 152 (1910)
=Fusarium citrinum Wollenw., Bull. Maine Agric. Exp. Sta.: 256 (1913)
=Fusarium angustum Sherb., Memoirs of the Cornell University Agricultural Experimental Station 6: 203 (1915)
=Fusarium oxysporum var. longius Sherb., Memoirs of the Cornell University

Agricultural Experimental Station 6: 223 (1915)
=Fusarium lutulatum Sherb., Memoirs of the Cornell University Agricultural Experimental Station 6: 209 (1915)
=Fusarium lutulatum var. zonatum Sherb., Memoirs of the Cornell University Agricultural Experimental Station 6: 214 (1915)
=Fusarium bostrycoides Wollenw. & Reinking, Phytopathology 15 (3): 166 (1925)
=Diplosporium vaginae Nann., Atti Reale Accad. Fisiocrit. Siena: 491 (1926)

Macroconidia: abundant in sporodochia, 3- septa, thin-walled, short to moderately long, straight , apical cell short and slightly hooked, basal cell notched or foot-shaped. Sporodochia: abundant, pale orange . Microconidia: small, oval , elliptical or kidney-shaped, 0- septa. Chlamydospores: abundant

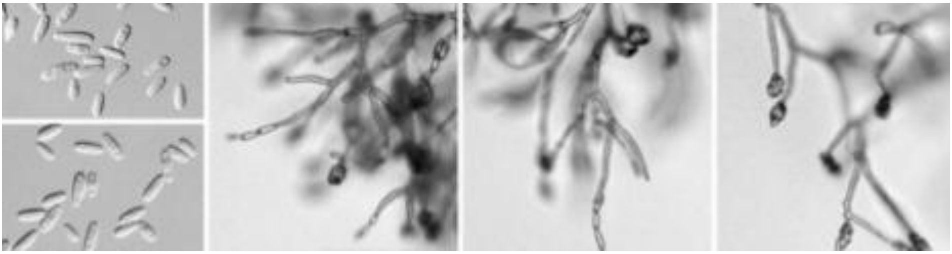




Mycobank G. Hagedorn, M. Burhenne & H. I. Nirenberg

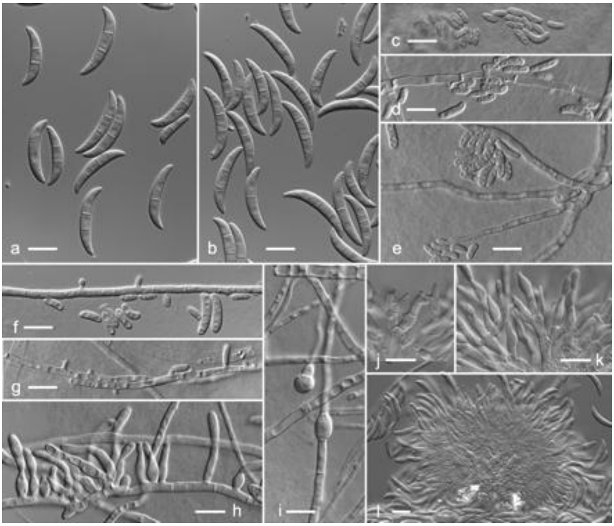
78. Fusarium phyllophilum Nirenberg & O'Donnell, Mycologia 90: 447 (1998)

Colonies produce white aerial mycelium, later tinged greyish-violet; lanose to funiculose. Pigmentation in reverse in some isolates greyish-white or greyish-orange to greyish-violet, or greyish-violet to bluish-grey. Sclerotia absent. Conidiophores of the aerial mycelium prostrate and erect, unbranched, with one lateral branch or verticillately branched, terminating mostly in 1 to 3 phialides, cells beneath the phialides often swollen; sporodochial conidiophores absent. Phialides of the aerial mycelium cylindrical, mono- and polyphialidic. Microconidia borne in the aerial mycelium clavate, mostly O-septate. occasionally 1-2-septate. Macroconidia few thin. falcate up to 5-septate. Chlamydospores absent.



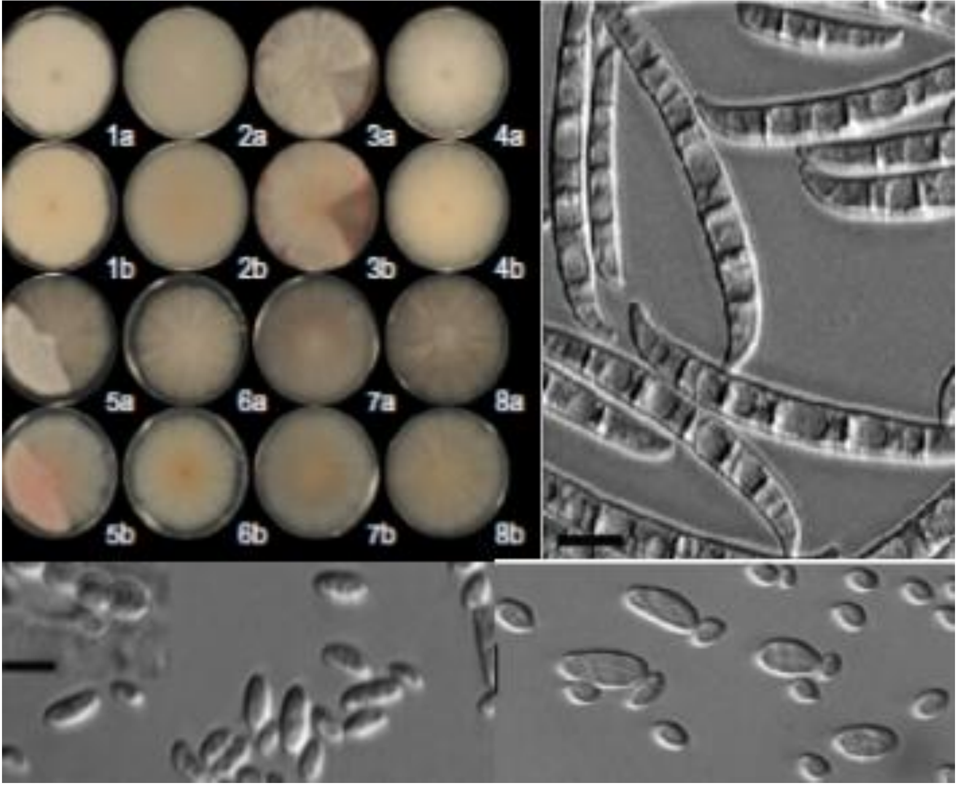
79. Fusarium penzigii **Schroers, Summerb. & O'Donnell, Mycologia 101 (1): 61 (2009)**

Aerial mycelium sparse, white, felt-like to cottony. Monophialides formed terminally or laterally on hyphae, in well developed sporodochia, forming few whorls on short supporting cells, polyphialides sometimes observed in several week old, well developed sporodochia. Microconidia mostly 0-1-septate, typically ellipsoidal, straight or curved, allantoid. Macroconidia typically widest in the upper third or the middle, with central part minutely curved or nearly straight, a pointed and mostly beaked distal end and a slightly pedicellate and curved proximal end; 0-3-septate. Chlamydospores common, typically intercalary, solitary, in short chains or terminal, rarely in groups.



80. Fusarium petroliphilum: (Q.T. Chen & X.H. Fu) D. Geiser, O’Donnell, Short et Zhang,

Microconidia formed directly on the side of hyphae in the pionnotal mycelium, 0-septate, oval, ellipsoid, and reniform, long conidiophores and macroconidia typical for members of the FSSC



81. Fusarium pininemorale Herron, Herron, Marinc. & M.J. Wingf., Studies in Mycology 2015 No. 80 pp. 131-150.

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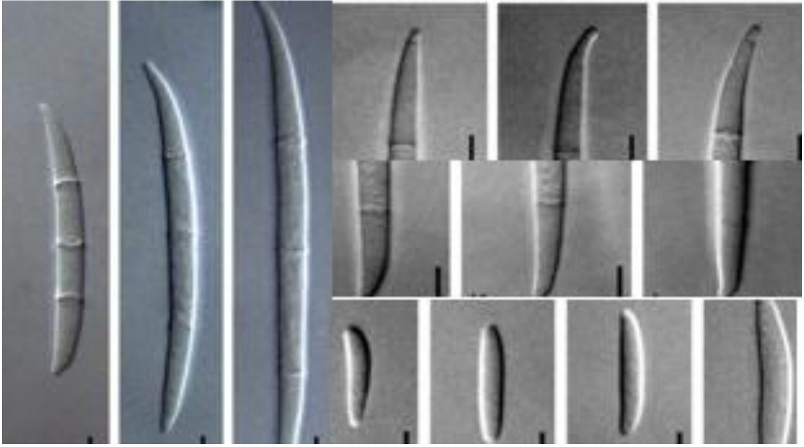
Macroconidia abundant, elongate, straight, with 3–4 septa, apical cells tapering, curved, basal cells foot-shaped, elongated foot shape, barely to distinctly notched. Microconidia scarce, fusiform to obovoid, 0–1 septa, arranged in false heads. Conidiogenous cells monophialidic or polyphialidic,



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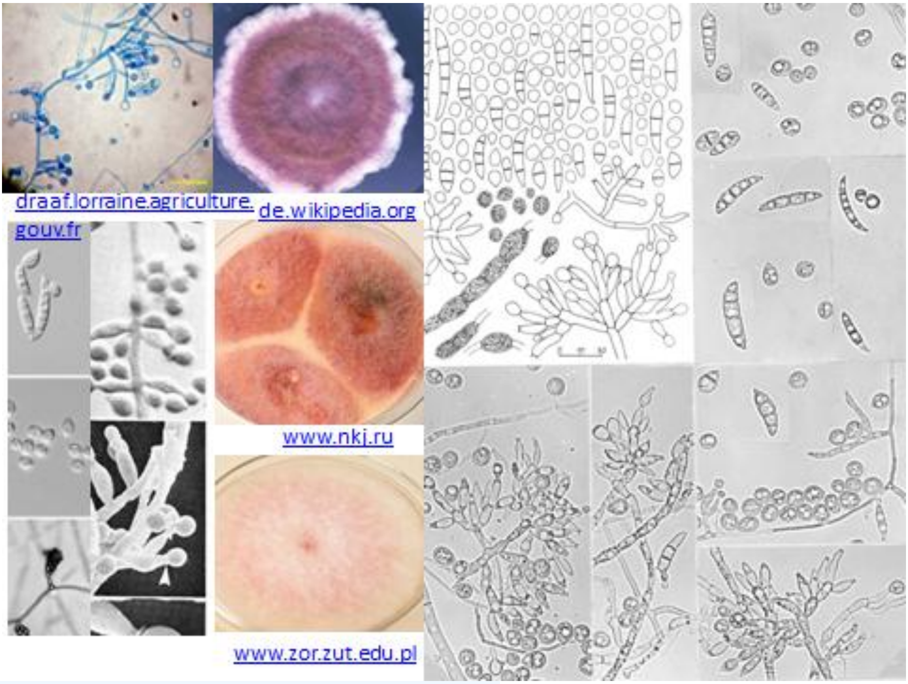
82. Fusarium poae (Peck) Wollenw., Bull. Maine Agric. Exp. Sta.: 254 (1914)

≡Sporotrichum poae Peck, Bulletin of the New York State Museum 67: 29 (1903) [MB#206241]
≡Fusarium tricinctum f. poae (Peck) W.C. Snyder & H.N. Hansen, American Journal of Botany 32: 663 (1945) [MB#351715]
≡Fusarium sporotrichiella var. poae (Peck) Bilai, [Poisonous fungi on cereal seed]: 86 (1953) [MB#448746]
≡Fusarium sporotrichiella var. poae (Peck) Bilai, Mykrobiologichnyi Zhurnal Kiev 49 (6): 6 (1987) [MB#353477]
=Sporotrichum anthophilum Peck, Bulletin of the New York State Museum 105: 28 (1906)

Macroconidia: sparse, 3- 5 septa, slender and short, fulcate to lunate, apical cell curved and tapering, basal cell foot cell well developed. Sporodochia: absent. Microconidia: abundant, globose to napiform, 0-1 septa . Chlamydospores: rare, in clumps or chains in mycelium of old cultures



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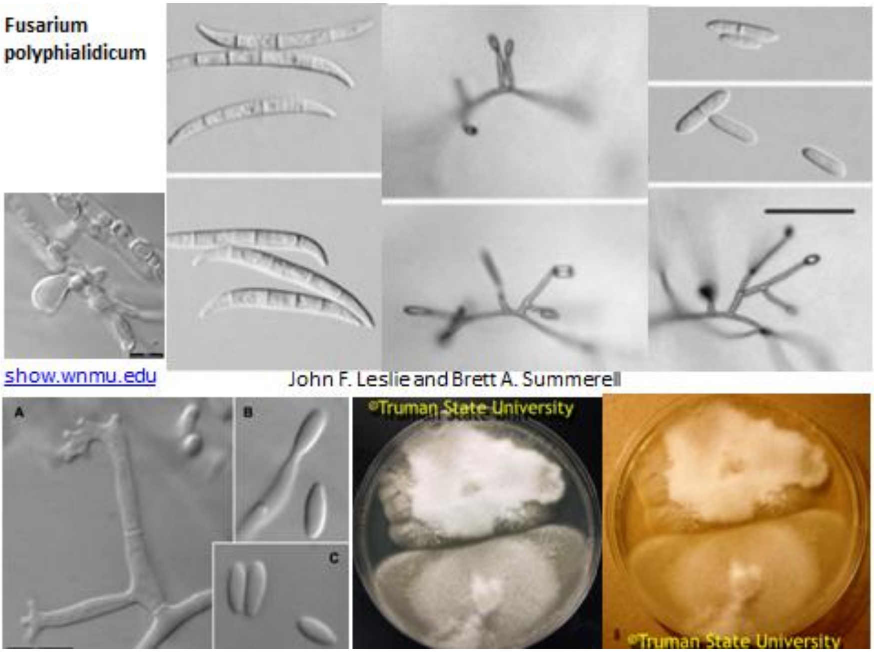
83. Fusarium polyphialidicum Marasas, P.E. Nelson, Toussoun & P.S. van Wyk, Mycologia 78 (4): 678 (1986)

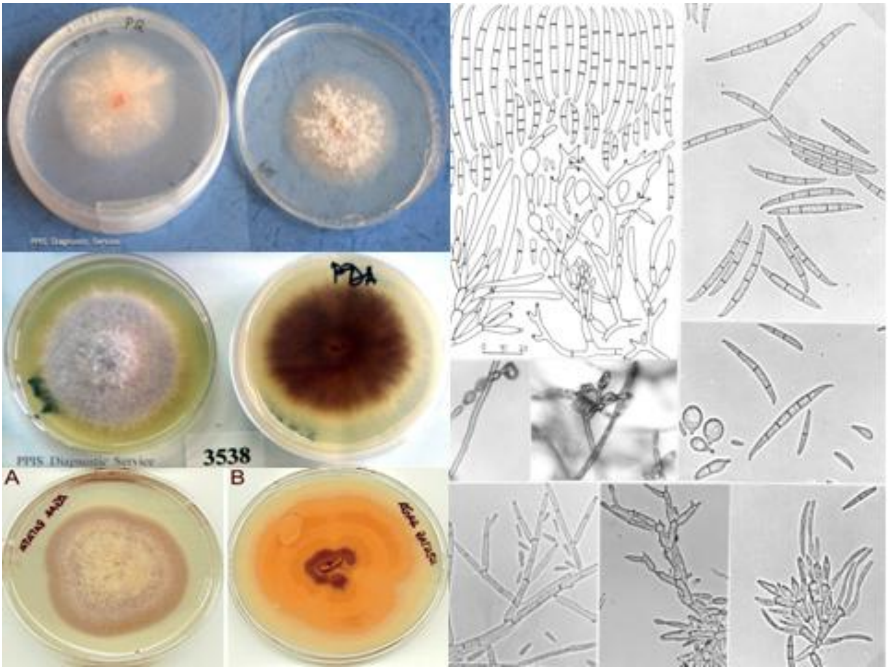
Macroconidia: abundant, large, 3-7 septa, slightly falcate, thick-walled, apical cell curved and tapering, basal cell foot-shaped. Sporodochia: white to pale orange. Microconidia: abundant in the aerial mycelia, fusiform or subclavate, 0-3 septa. Chlamydospores: in pairs, clumps or chains



84. Fusarium proliferatum (Matsush.) Nirenberg, Biologischen Bundesanstalt für Land- und Forstwirtschaft 169: 38 (1976)

≡Cephalosporium proliferatum Matsush., Microfungi of the Solomon Islands and Papua-New Guinea: 11 (1971)
≡Fusarium proliferatum (Matsush.) Nirenberg ex Gerlach & Nirenberg, Mitteilungen der Biologischen Bundesanstalt für Land- und Forstwirtschaft 209: 309 (1982)

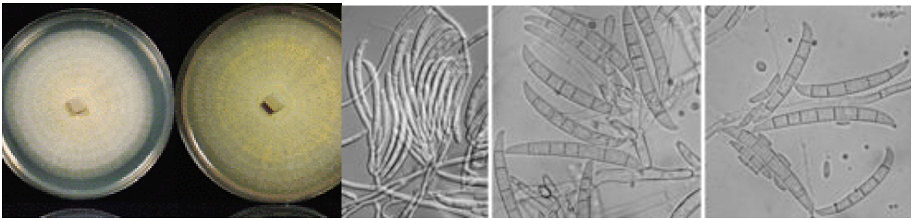
Macroconidia: in chains of moderate length, thin-walled, straight, 3-5 septa, apical cell curved, basal cell poorly developed,. Sporodochia: pale orange. Microconidia, club-shaped to pyriform, 0-septa, may be in chains. Chlamydospores: absent



www.ppis.moag.gov.il www.ppis.moag.gov. jcm.asm.org G. Hagedorn, M. Burhenne & H. I. Nirenberg, Ferrer et al., 2005

85.Fusarium pseudensiforme Samuels, Nalim & Geiser, Mycologia 103 (6): 1323 (2011)

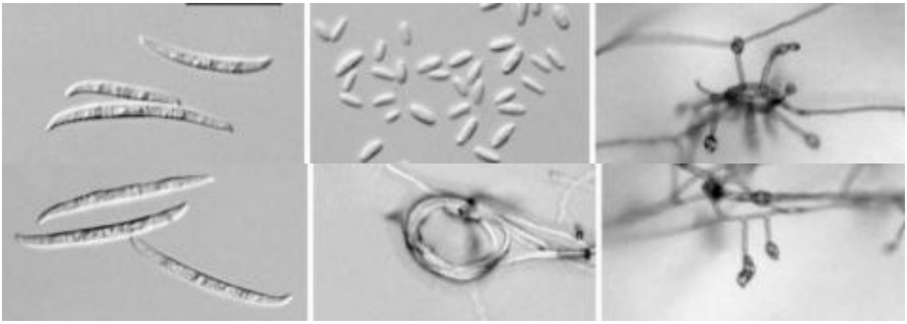
Colonies produce scanty aerial mycelium; conidiophores arising abundantly in the aerial mycelium and in white slimy sporodochia on the agar surface. Phialides arise from conidiomata, cylindrical or somewhat swollen in the middle. Macroconidia arise from sporodochia, 0-8-septate, typically slightly curved with a well developed foot cell.



Fusarium pseudensiforme Samuels, Nalim & Geiser (2011);

86. Fusarium pseudocircinatum **Nirenberg & O'Donnell, Mycologia 90: 448 (1998)**

Macroconidia: abundant, slender, slightly falcate, thin-walled, apical cell beaked, basal cell foot-shaped Sporodochia: sparseMicroconidia: abundant, oval, 0-1 septa



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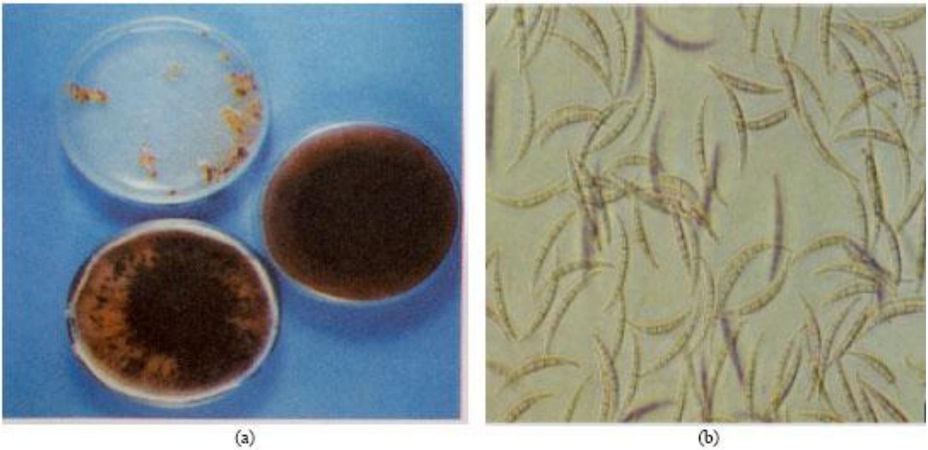
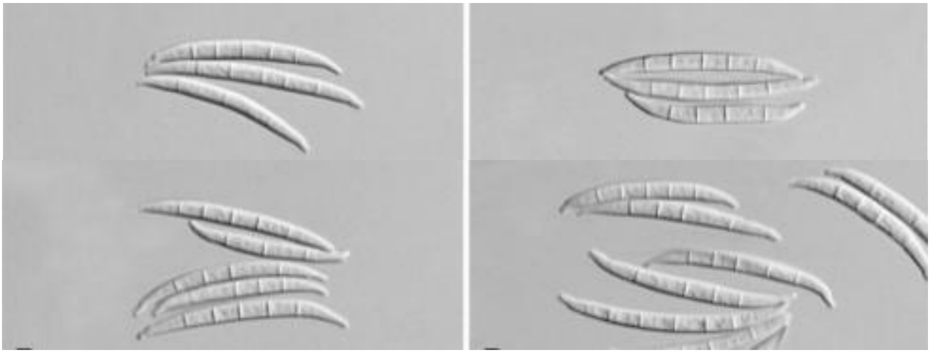
87. Fusarium pseudograminearum **O'Donnell & T. Aoki, Mycologia 91 (4): 604 (1999)**

Macroconidia: slender, almost straight to moderately curved, 1-11 septa, apical cell curved, basal cell foot-shaped. Sporodochia: abundant, pale orange. Microconidia: absent. Chlamydospores: abundant within 4 weeks



Colony morphology (a) and macroconidia of Fusarium pseudograminearum, Saremi et al., 2007



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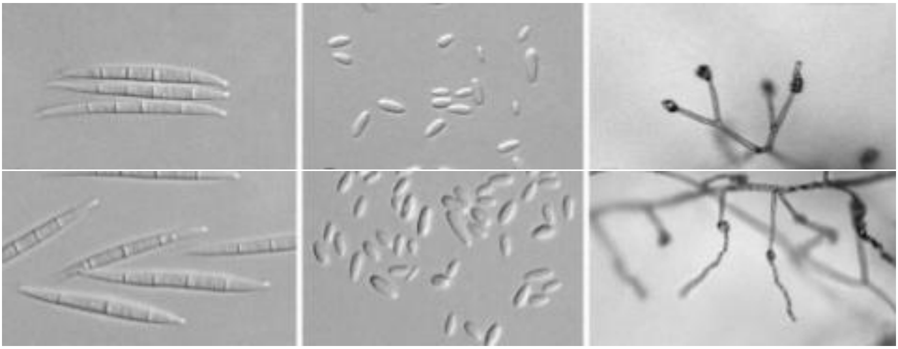
88. Fusarium pseudonygamai **Nirenberg & O'Donnell, Mycologia 90: 449 (1998)**

Macroconidia: rare, 3-4 septa, fusoid, apical cell gapering, basal cell poorly foot-shaped. Sporodochia: rare. Microconidia: abundant in the aerial mycelia, obvoid to clavate, 0-septa. Chlamydospores: absent



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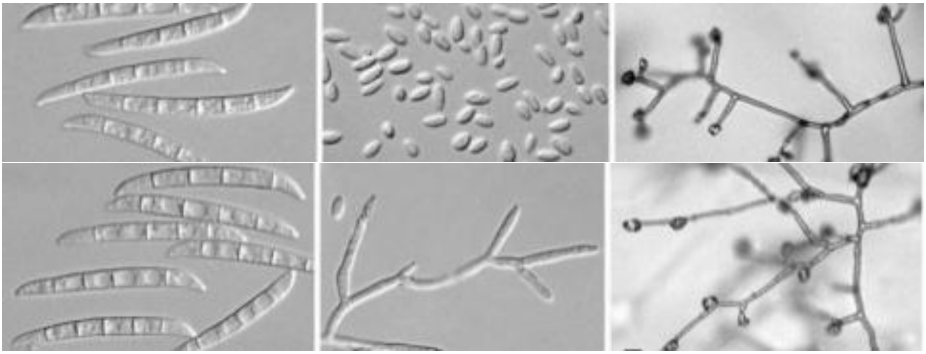
89. Fusarium ramigenum **Nirenberg & O'Donnell, Mycologia 90: 451 (1998)**

Macroconidia: rare, 5- septa, falcate, apical cell bent, basal cell notched. Sporodochia: rare. Microconidia: abundant in the aerial mycelia, obvoid, 0-1 septa. Chlamydospores: absent



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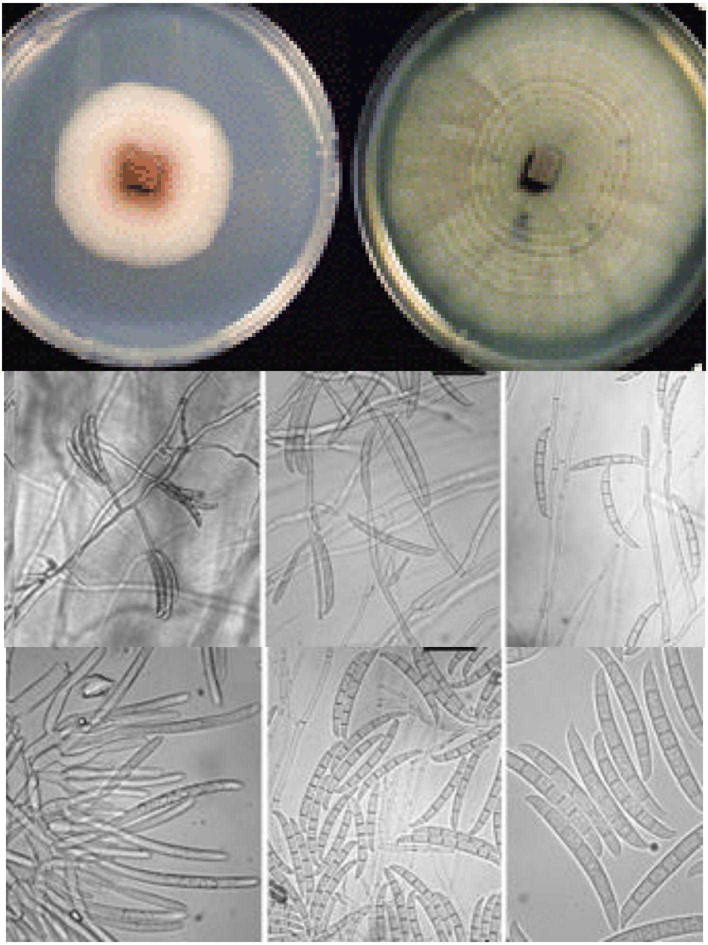
90. Fusarium rectiphorum **Samuels, Nalim & Geiser, Mycologia 103 (6): 1324 (2011)**

=Fusarium rectiphorus Samuels, Nalim & Geiser, Mycologia 103 (6): 1324 (2011)

Colonies produce scanty aerial mycelium; conidia produced by erect, mononematous conidiophores arising from the surface of the colony and sparingly in the aerial mycelium and from cream-coloured sporodochia on the surface of the agar. Mononematous conidiophores unbranched and acremonium-like or branched, or branched once or twice and each branch terminating in two or three phialides, or phialides arising directly from the lower half of the acremonium-like conidiophore. Macroconidia slightly curved, more strongly at tip, basal cell pedicellate, 3-8-septate

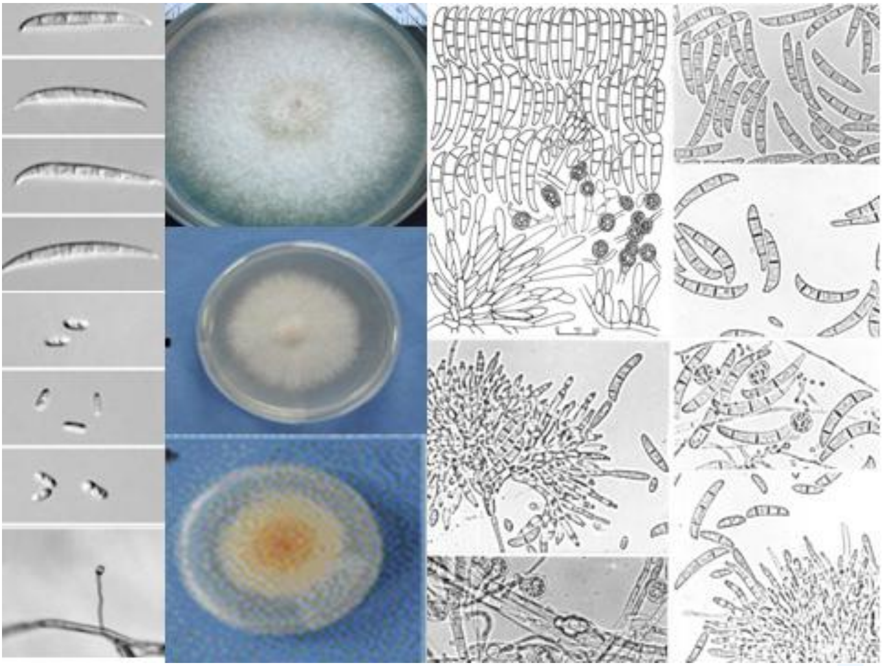


Samuels et al., 2011

91. Fusarium redolens **Wollenw., Phytopathology 3 (1): 29 (1913)**

≡Fusarium oxysporum var. redolens (Wollenw.) W.L. Gordon, Canadian Journal of Botany 30 (2): 238 (1952)

Macroconidia: abundant, 3-5 septa, thick-walled, upper third wide, apical cell hooked, basal cell foot-shaped. Sporodochia: sparse, pale brown. Microconidia: common in the aerial mycelia, oval to cylidrical, 0-1 septa. Chlamydospores: absent

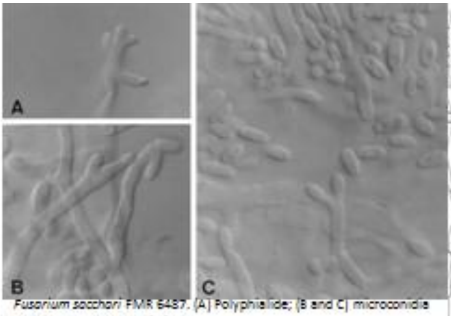


John F. Leslie and Brett A. Summerell ,Truman Univ. Feng Pan et al.,2015 G. Hagedorn, M. Burhenne & H. I. Nirenberg

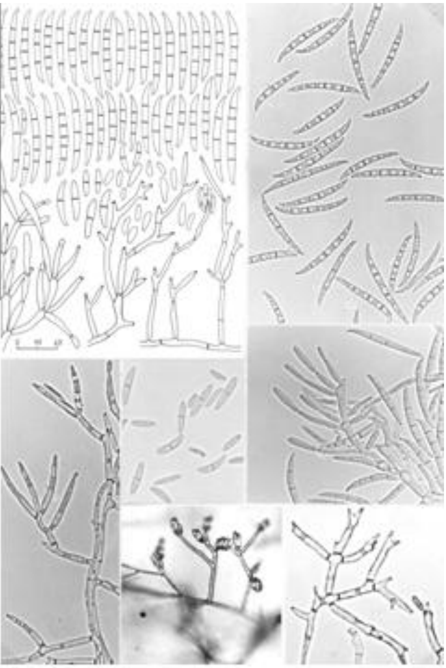
92. Fusarium sacchari **(E.J. Butler) W. Gams, Cephalosporium-artige Schimmelpilze: 218 (1971)**

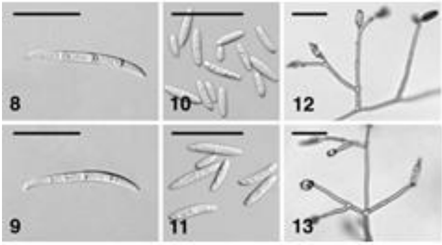
Macroconidia:sparse, 3- septa, thick-walled, slender, apical cell curved, basal cell poorly developed. Sporodochia: sparse, orange. Microconidia:

abundant, common in the aerial mycelia, oval, 0- 2 septa.
Chlamydospores: absent



Fusarium sacchari FMR 6487. (A) Polyphialide; (B and C) microconidia and mono- and polyphialides





8–9. Macroconidia. 10–11. Oval to obovoid microconidia. 12–13. Microconidia on monophialides and polyphialides produced in carnation leaf agar cultures. Bars = 25 µm

Leslie JF, Summerell BA, Bullock S, Doe FJ,Mycologia, 2—5, G. Hagedorn, M. Burhenne & H. I. Nirenberg

93. Fusarium sambucinum **Fuckel, Hedwigia 2 (15): 135, Fung. Rhen. no 211 (1863)**

=Fusarium roseum Link, Magazin der Gesellschaft Naturforschenden Freunde Berlin 3: 10, t. 1:10 (1809)
=Fusarium sulphureum Schltdl., Flora Berolinensis, Pars secunda: Cryptogamia: 139 (1824)
=Fusarium sambucinum var. sambucinum , Jahrbücher des Nassauischen Vereins für Naturkunde 23-24: 167 (1870) [
=Fusarium trichothecioides Wollenw., Journal of the Washington Academy of Sciences 2: 147 (1912)
=Fusarium sambucinum var. minus Wollenw., Fusaria Autographice Delineata 3: 941

(1930)
=Fusarium sambucinum f. 2 Wollenw., Fusaria Autographice Delineata 3: 942 (1930)
=Fusarium sambucinum var. medium Wollenw., Zeitschrift für Parasitenkunde 3: 358 (1931)
=Fusarium sambucinum f. 6 Wollenw., Zeitschrift für Parasitenkunde 3: 358 (1931)

Macroconidia: abundant in sporodochia, 3-5 septa, falcate, slender, short, apical cell pointed, basal cell foot-shaped. Sporodochia: orange, common. Microconidia: oval, 0-1 septa. Chlamydospores: in chains or clusters

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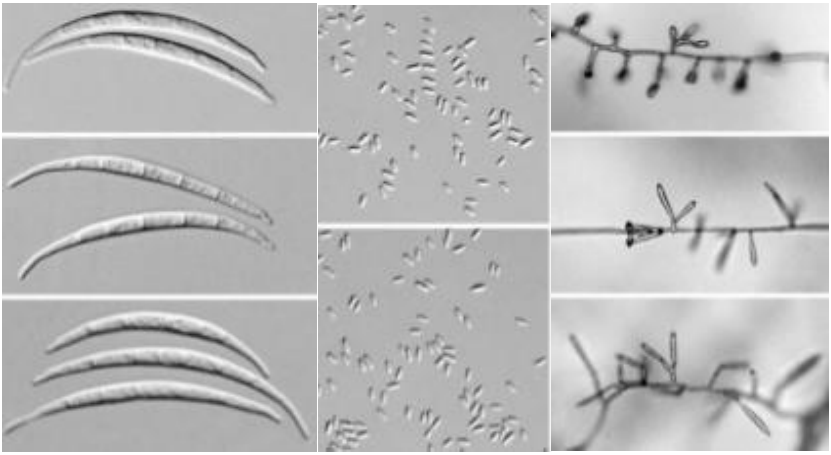
94. **Fusarium scirpi** Lambotte & Fautrey, Revue Mycol. (Toulouse): 111 (1894)

Macroconidia: abundant, long. slender, thin-walled, curved, 6-7 septa, apical cell tapering and elongate, basal cell foot-shaped. Sporodochia:

orange. Microconidia: club-shaped on short phialides. Chlamydospores: abundant, in clumps or chains



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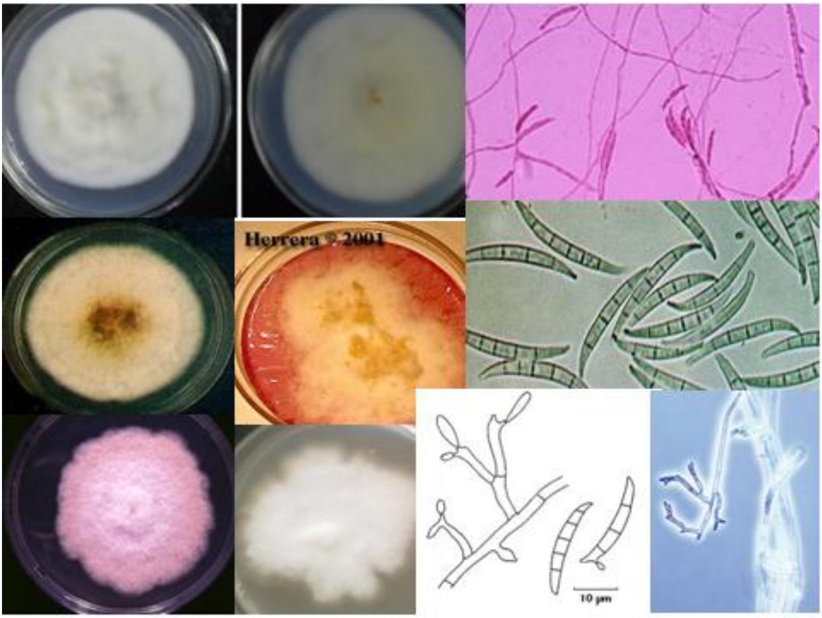
95. Fusarium semitectum **Berk. & Ravenel, Grevillea 3 (27): 98 (1875)**

≡Pseudofusarium semitectum (Berk. & Ravenel) Matsush., Icones Microfungorum a Matsushima lectorum: 119 (1975)
=Fusisporium incarnatum Roberge ex Desm., Annales des Sciences Naturelles Botanique 11: 274 (1849)
=Fusarium semitectum var. semitectum (1875)
=Fusisporium pallidoroseum Cooke, Grevillea 6 (40): 139 (1878)
=Fusarium semitectum var. majus Wollenw., Fusaria Autographice Delineata 3: 907-910 (193]

Macroconidia: abundant, slender, curved dorsal surface, 3-5 septa, apical cell curved and tapering , basal cell foot-shaped. Sporodochia: orange. Microconidia: pyriform, 1-septa, mesoconidia spindle-shaped, 3-5 septa. Chlamydospores: globose

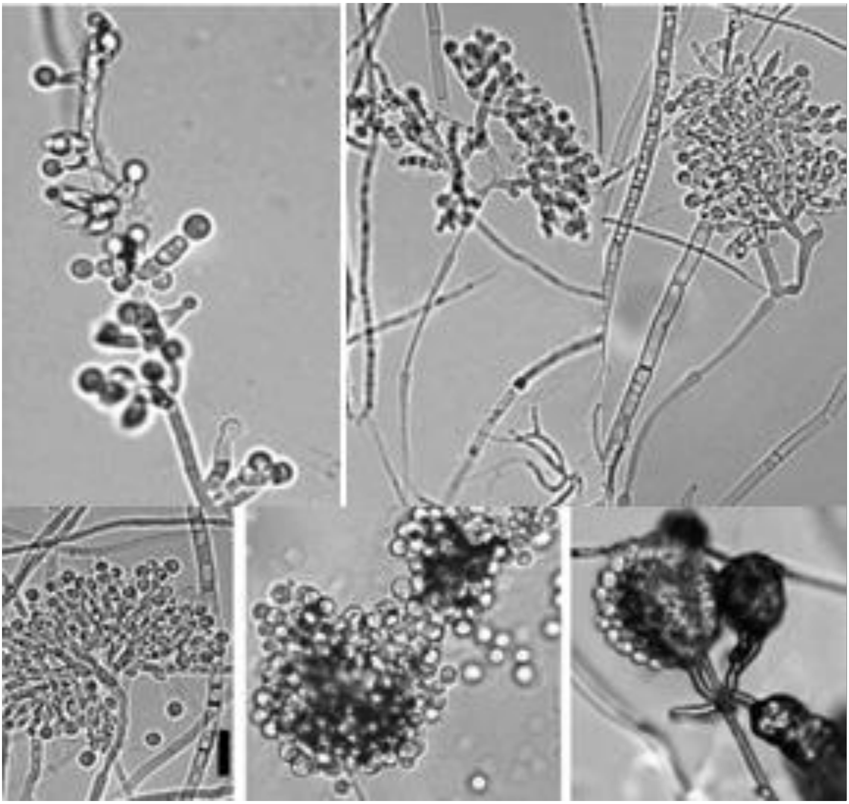


file.scirp.org, ecoport.org, Galería de imágenes, **EcoPort Picture, Databank**

96. Fusarium sibiricum Gagkaeva, Burkin, Kononenko, Gavrilova, O'Donnell, T. Aoki, et Yli-Mattila, International Journal of Food Microbiology 147: 64 (2011)

Colonies produce sparse to floccose aerial mycelium on PSA, more abundant centrally, often crateriform with bald spot in the very centre of colonies. Colour of aerial mycelium white, sometimes with a tint of orange grey. Reverse with white to cream shades. Conidiophores formed in aerial mycelium or on running hyphae on the agar, erect or prostrate, at first unbranched, later branched densely terminating with ampuliform monophialides, having a noticeable collarette and rarely with cylindrical, straight monophialides. Conidiophores often consist of a long and nodose stipe terminating with a whorl of phialides, intermingled with the short monophialides formed directly on the aerial mycelium. Polyphialides not observed. Microconidia apiculate and globose, mostly one-celled, hyaline, formed abundantly in false heads;

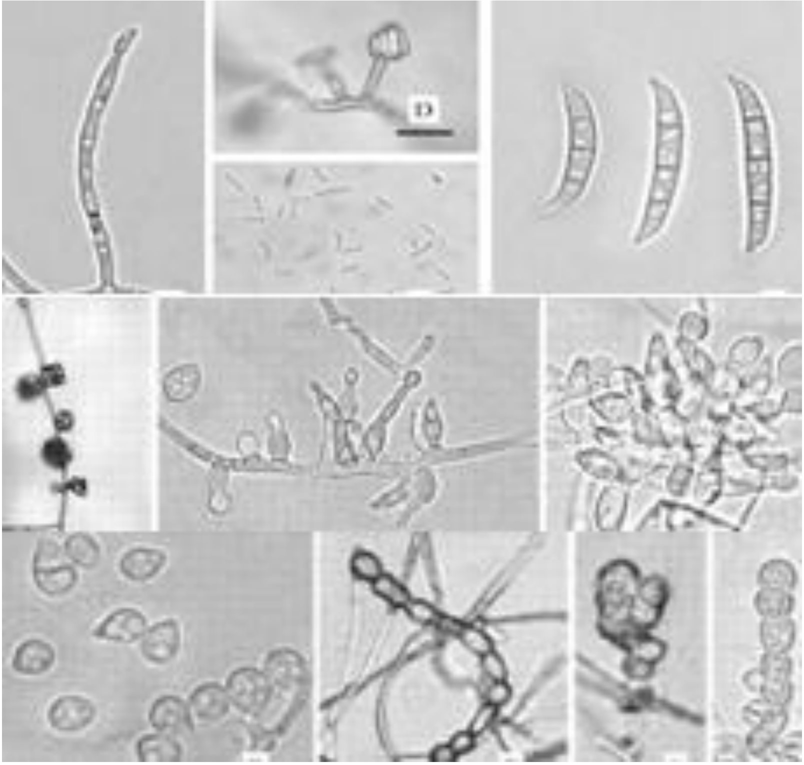
0-septate. Multiseptate macroconidia. sporodochia. chlamydospores and sclerotial bodies absent.



Mattila et al., 2011

97. Fusarium sinensis **Z.H. Zhao & G.Z. Lu, Mycologia 100 (5): 747 (2008)**

Colonies are villous-floccose, yellow brown in the center and rose-to-carmine often with a white margin. Colony reverse red brown. Conidiophores single or simply branched on the aerial mycelium and monophialidic. Two types of microconidia are formed: fusiform-to-reniform and napiform-to-pyriform,1-2-septate, formed on monophialides. Macroconidia rare, straight or slightly curved; 3-septate, apical cells slightly curved and narrowing to a point; basal cells foot-shaped to distinctly notched. Chlamydospores found in chains or clumps, oval to globose, hyaline to pale brown, smooth to warted.



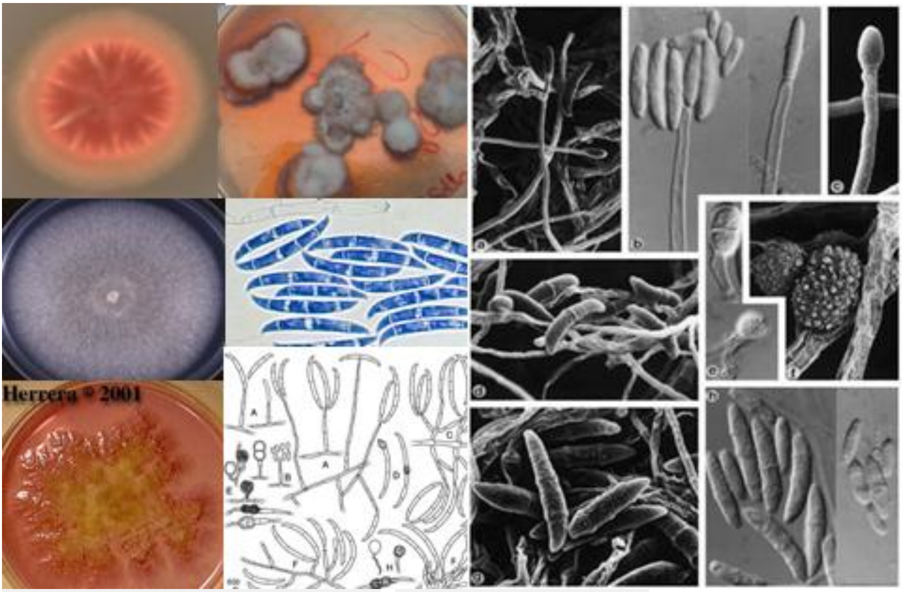
Zhao and Lu, 2008

98. Fusarium solani (Mart.) Sacc., Michelia 2 (7): 296 (1881)

≡Fusisporium solani Mart., Die Kartoffel-Epidemie der letzten Jahre oder die Stockfäule und Räude der Kartoffeln: 20 (1842)
≡Fusarium solani (Mart.) Appel & Wollenw., Kaiserlichen Biologischen Anstalt für Land- und Forstwirtschaft 8: 64-78 (1910)
≡Neocosmospora solani (Martius) L. Lombard & Crous, Studies in Mycology 80: 228 (2015)
=Fusarium martii Appel & Wollenw., Arbeiten aus der Kaiserlichen Biologischen Anstalt für Land- und Forstwirtschaft 8: 83 (1910)
=Nectria cancri Rutgers, Ann. Jard. Bot. Buitenzorg, II: 59 (1913)

=Fusarium striatum Sherb., Memoirs of the Cornell University Agricultural Experimental Station 6: 255 (1915)
=Fusarium solani var. minus Wollenw., Fusaria Autographice Delineata 1: 403 (1916)
=Fusarium solani f. 2 W.C. Snyder, Zentralblatt für Bakteriologie und Parasitenkunde Abteilung 2 91: 174 (1934)
=Cephalosporium keratoplasticum T. Morik., Mycopath. Mycol. appl.: 66 (1939)
=Fusarium solani f. keratitis Y.N. Ming & T.F. Yu, Acta Microbiologica Sinica 12: 184 (1966)
=Cylindrocarpon vaginae C. Booth, Y.M. Clayton & Usherw., Proc. Indian Acad. Sciences (Plant Sciences) 94 (2-3): 436 (1985)

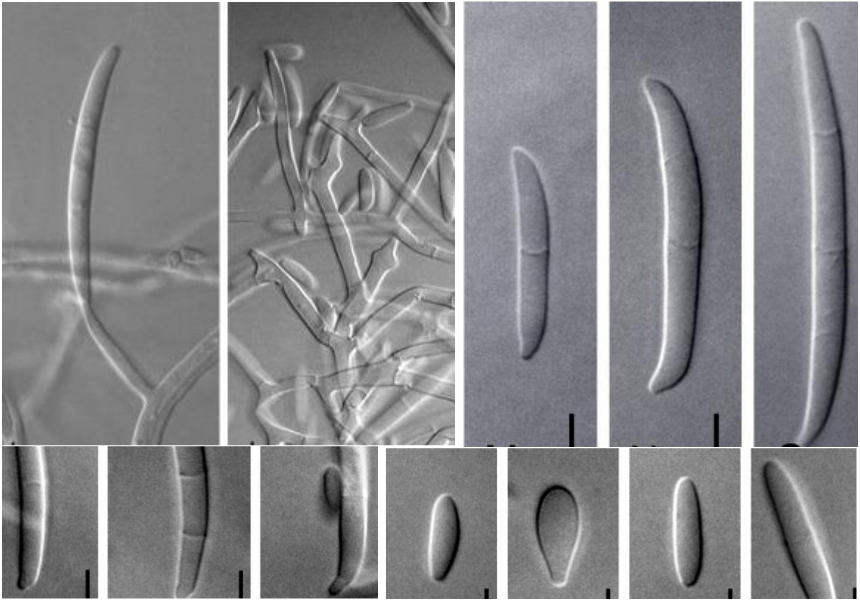
Macroconidia: abundant, wide, straight or slightly curved , 3-7 septa, apical cell blunt and round, basal cell foot-shaped or cylindrical with notched end. Sporodochia: abundant, cream, blue or green. Microconidia: oval to fusiform, 0-2 sept. Chlamydospores: abundant, in 2-4 weeks, single, in pairs, in clumps or chains, terminal or intercalary



www.mycology.adelaide.edu.au, www.pf.chiba-u.ac.jp, Mycoya, Mycobank, Br J Ophthalmol. 2002, Mycobank

99. Fusarium sororula Herron, Marinc. & M.J. Wingf., Studies in Mycology 2015 No. 80 pp. 131-150

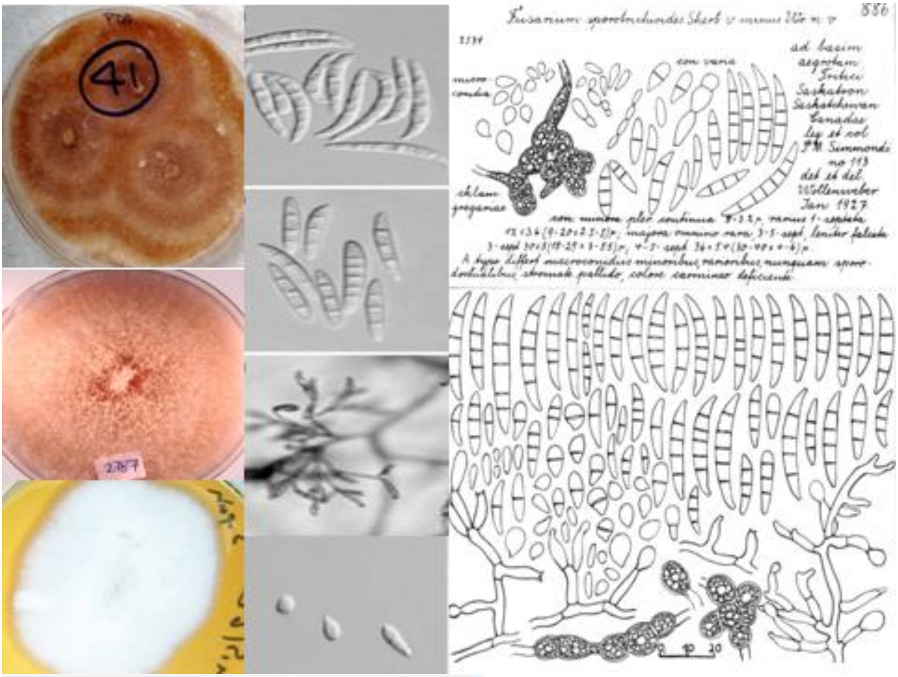
Macroconidia scarce, elongate, straight, with 1–3 septa, apical cells hooked, basal cells foot-shaped, barely to distinctly notched, some producing secondary conidia. Microconidia abundant, fusiform to obovoid or pyriform, arranged in false heads, with 0–1 septum. Conidiogenous cells monophialidic or polyphialidic.



100. Fusarium sporotrichioides Sherb., Memoirs of the Cornell University Agricultural Experimental Station 6: 183 (1915)

≡Fusarium sporotrichiella var. sporotrichioides (Sherb.) Bilai, [Poisonous fungi on cereal seed]: 87 (1953)

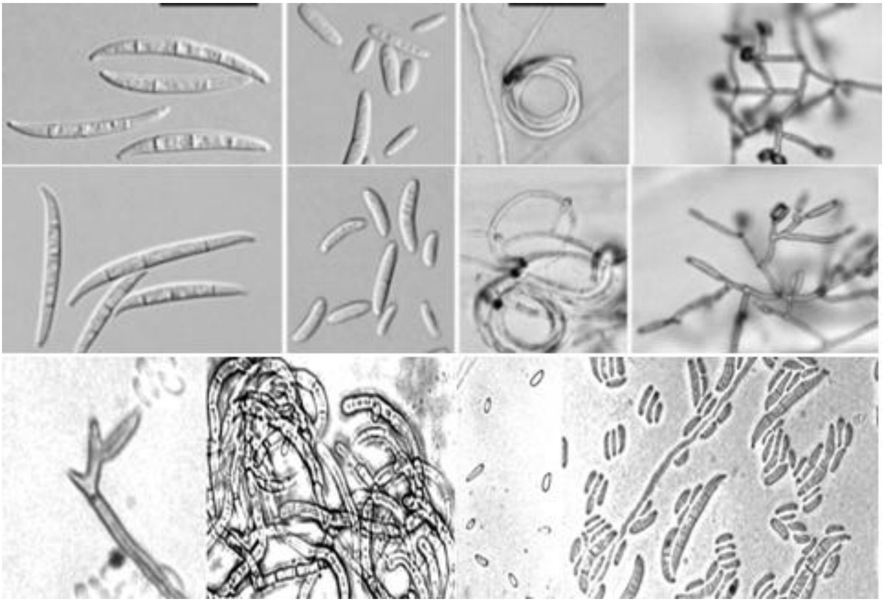
Colonies produce profuse white to pale red mycelium. Macroconidia abundant in orange sporodochia, falcate to lunate,3-5 septate, apical cell curved and tapering, basal cell poorly developed. Microconidia produced from mono- or polyphialides, pyriform 0-1 septate or fusiform up to 5-septate. Chlamydospores abundant.



www.drjacksonkungu.com www.flickr.com John F. Leslie and Brett A. Summerell www.marmaramedicaljournal.org G. Hagedorn, M. Burhenne & H. I. Nirenberg

101. Fusarium sterilihyphosum **Britz, Marasas & M.J. Wingf., Mycologia 94 (4): 726 (2002)**

Colonies on PDA, aerial mycelium almost white, reverse straw to grayish rose and light purple. Conidiophores on aerial mycelium erect, occasionally prostrate. Conidiophores sympodially branched bearing mono- and polyphialides. Phialides on aerial conidiophores mono- and polyphialidic. Sterile hyphae present. Microconidia obovoid, oval to allantoid, 0-1 septate, abundant. Sporodochia rare, cream. Macroconidia slightly beaked apical cells, a footlike basal cell, 3–5 septate. Chlamydospores absent.



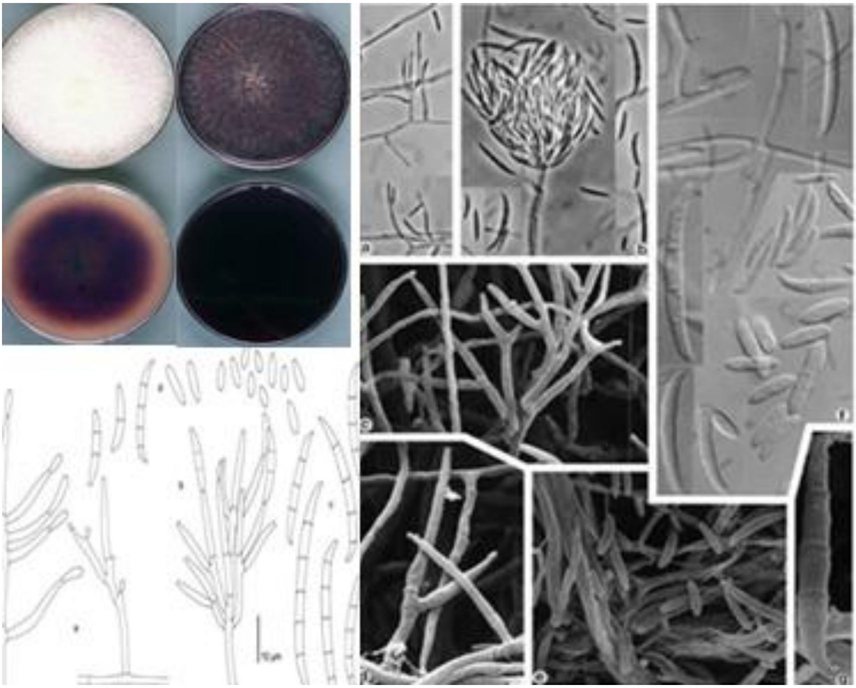
John F. Leslie and Brett A. Summerell, Britz et al., 2002

102. Fusarium subglutinans (Wollenw. & Reinking) P.E. Nelson, Toussoun & Marasas, Fusarium species, an illustrated manual for identification: 135 (1983)

≡Fusarium moniliforme var. subglutinans Wollenw. & Reinking, Phytopathol 15 (3): 163 (1925)
≡Gibberella fujikuroi var. subglutinans (Wollenw. & Reinking) E.T. Edwards, Agri. Gazette of New South Wales 44 (12): 896 (1933)
≡Fusarium neoceras var. subglutinans (Wollenw. & Reinking) Raillo, Fungi of the genus Fusarium: 263 (1950)
≡Fusarium sacchari var. subglutinans (Wollenw. & Reinking) Nirenberg, Mitteil. Biolog. Bund.. Land- un. Forstwirt. 169: 53 (1976)
≡Gibberella subglutinans (E.T. Edwards) P.E. Nelson, Toussoun & Marasas, Fusarium species, an illustrated manual for identification: 135 (1983)

Colonies produce white mycelium, becomes violate in old cultures. Macroconidia sparse, in tan-orange sporodochia, slender, slighltly falcate, thin-walled, apical cell curves, basal cell poorly developed.

Microconidia in false heads from mon- and polyphialides, oval 0-septate or fusiform 2-3 septate. Chlamydospores absent

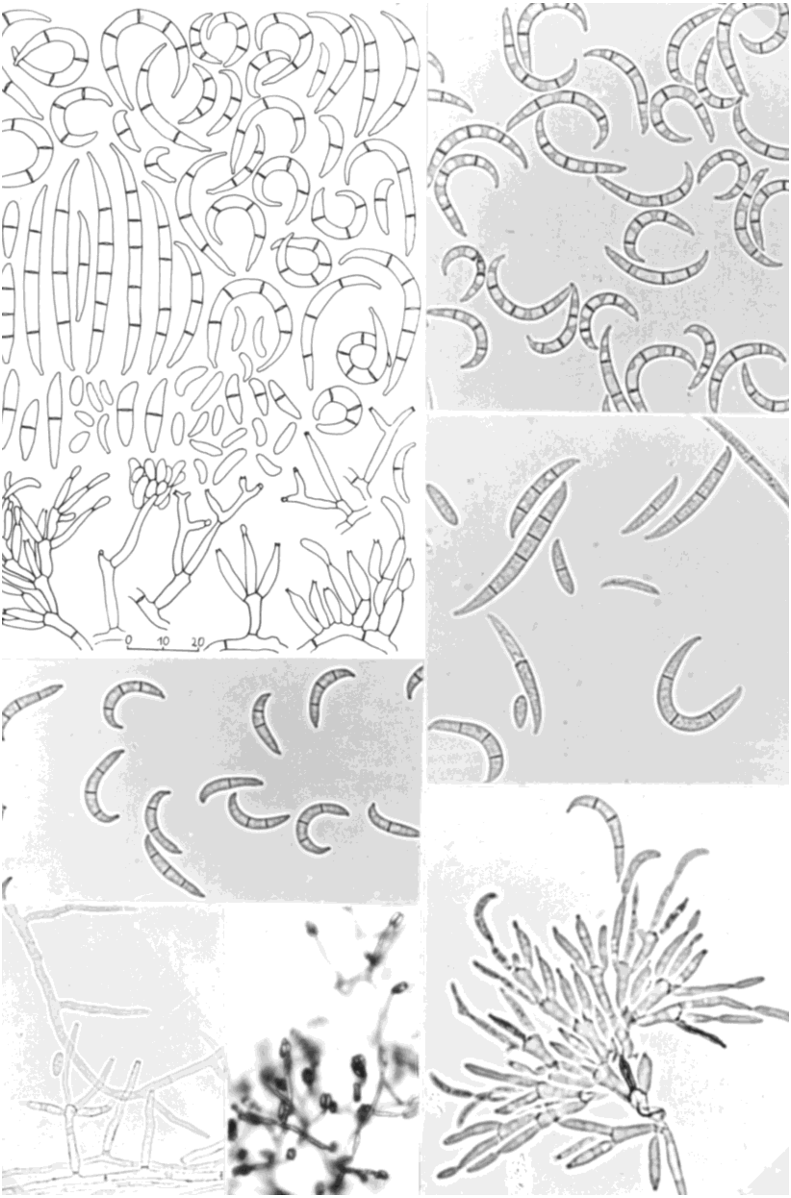


Nelson et al., 1983, Mycobank

103. Fusarium succisae (J. Schröt.) Sacc., Sylloge Fungorum 10: 724 **(1892)**

≡Fusisporium succisae J. Schröt., Hedwigia: 180 (1874)
≡Fusarium subglutinans var. succisae (J. Schröt.) F.J. Chen, Variation within Fusarium section Moniliforme (= Liseola) [Ph.D.Thesis]: 150 (1991)

Colonies produce white mycelium, turne grey-violate and red, and bright orange sporodochia. Macroconidia sparse, falcate to u-shaped curved,3-septate, basal cell foot-shaped, apical cellcurved and tapering. Microconidia abundant,oval or ellipsoid, 0-2 septate, in false heads on mono- or polyphialides. Chlamydospores absent



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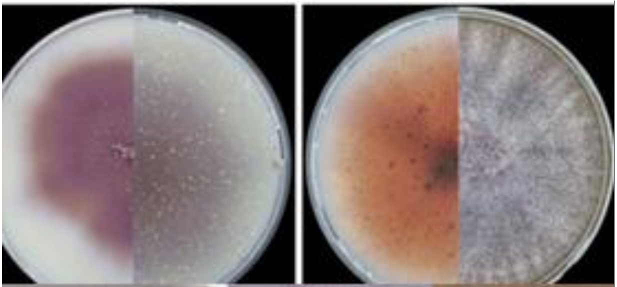
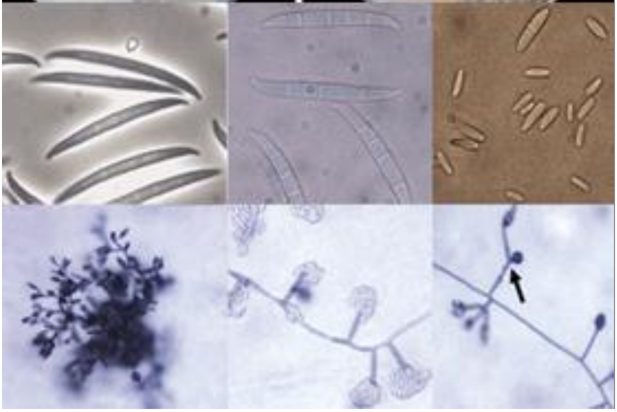
104. Fusarium temperatum J. Scauflaire & F. Munaut, Mycologia 103 (3): 593 (2011)

Colonies produce yellowish orange sporodochia. Agar pigmentation ranges from colorless to dark purple on OA; pigmentation of colony reverse is in shades of light pink. Aerial mycelium cottony, initially white, becoming pinkish white, turning violet in the colony center in a later stage. Conidiophores in the aerial mycelium erect, branched, terminating in 1-3 phialides. Microconidia oval, abundant, grouped in masses; hyaline and non-septate. Macroconidia hyaline, with 3-6, slender, slightly falcate, with a beaked, curved apical cell and a foot-like basal cell, thin cell wall. Polyphialides and monophialides are present. Chlamydospores absent.

Fusarium temperatum colonies. Al-Hatmi *et al.*, 2014

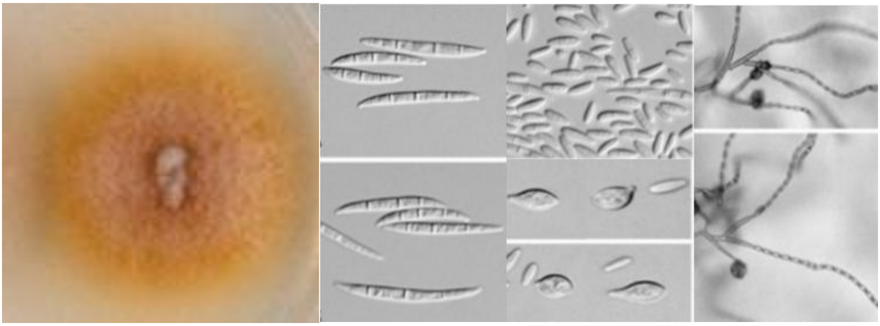




Fusarium temperatum, Scauflaire et al., 2011

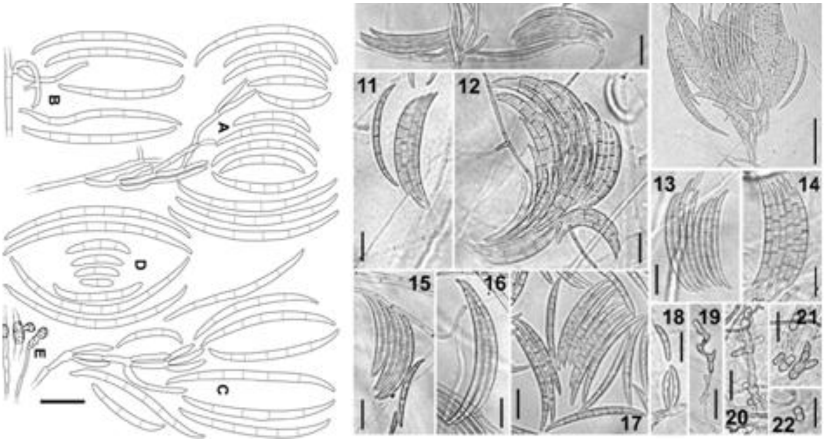
105. Fusarium thapsinum **Klittich, J.F. Leslie, P.E. Nelson & Marasas, Mycologia 89: 644 (1997)**

Colonies produce white mycelium, violete pigments with age. Sporodochia rare, pale orange. Macroconidia rare, slender, falcate or straight, thin-walled, 3-5-septate, apical cell curved and tapering, foot cell poorly-shaped, Microconidia abundant, on monophiliedes, club-shaped, 0-septate. Chlamydospores absent



106. Fusarium torreyae. **Aoki T , Smith JA, Mount LL, Geiser DM, O'Donnell K. Mycologia. 2013,105(2):312-9**

Colonies produce loosely floccose, sometimes funiculose, white to yellowish white mycelium. Pigmentation in the reverse pale yellow, or light orange, grayish orange, orange to reddish orange. Sporodochial conidiophores verticillately or irregularly branched, forming apical monophialides or sometimes intercalary phialides. Macroconidia variable in morphology, 1–9-septate, falcate and curved, often long and slender and cylindrical, dorsiventral, often widest around the midregion of their length, tapering gradually toward both ends, with an acuminate apical cell and a distinct foot-like basal cell. Chlamydospores present or absent, smooth to rough, thick-walled, intercalary or terminal, solitary, in pairs or catenate.

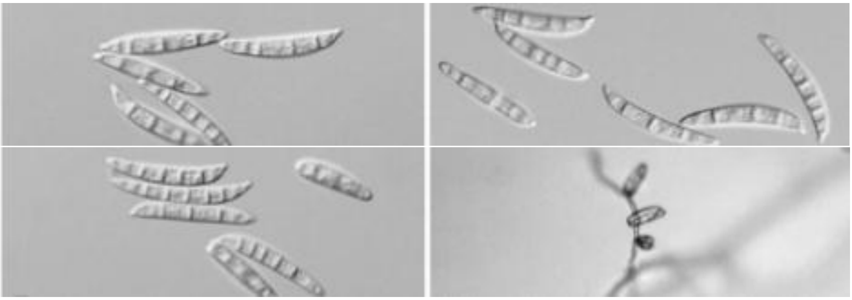


Aoki et al., 2013

107. Fusarium torulosum (Berk. & M.A. Curtis) Gruyter & J.H.M. Schneid., Jaarboek. Plantenziektenkundige Dienst: 135 (1991)

≡Fusidium torulosum Berk. & M.A. Curtis, Grevillea 3 (27): 112 (1875) [MB#207053]
≡Fusoma torulosum (Berk. & M.A. Curtis) Sacc., Sylloge Fungorum 4: 220 (1886)
≡Fusarium torulosum (Berk. & M.A. Curtis) Nirenberg, Mycopathol129 (3): 136 (1995)
=Fusarium sambucinum var. coeruleum Wollenw., Annales Mycologici 15 (1-2): 55 (1917)

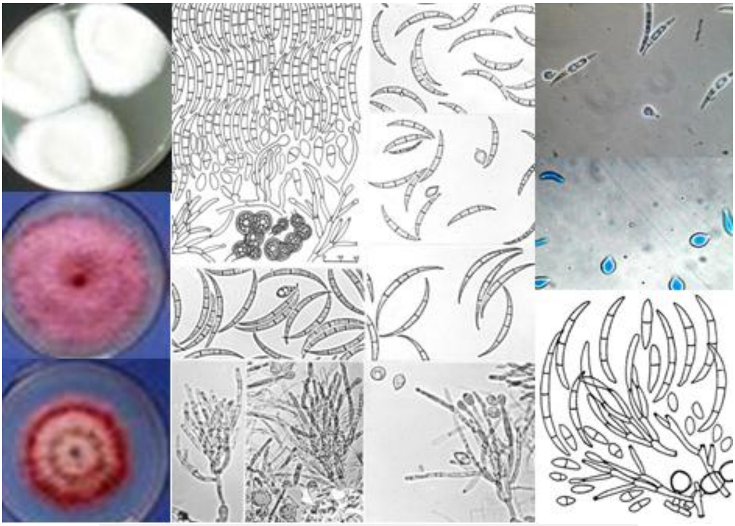
Colonies produce initially white lannose mycelium, red pigments in agar.Sporodochia orange. Macroconidia abundant, short, falcate, 5-septate, apical cell pointed, basal cell foot-shaped. Microconidia rare, oval, on monophilides, 0-1-septate, single or in false heads. Chlamydospores abundant



108. Fusarium tricinctum (Corda) Sacc., Sylloge Fungorum 4: 700 (1886)

≡Selenosporium tricinctum Corda, Icones fungorum hucusque cogn 2: 7, t. 9:33 (1838)
≡Fusarium sporotrichioides var. tricinctum (Corda) Raillo, Fungi of the genus Fusarium: 197 (1950)
≡Fusarium sporotrichiella var. tricinctum (Corda) Bilai, [Poisonous fungi on cereal seed]: 87 (1953)
≡Fusarium sporotrichiella var. tricinctum (Corda) Bilai, Mykrobiologichnyi Zhurnal Kiev 49 (6): 7 (1987)
=Fusarium citriforme Jamal., Valt. Maatalousk. Julk.: 11 (1943

Colonies form dense white mycelium, become pink, red or purple. Sporodochia pale orange, abundant. Macroconidia abundant, slender to falcate, 3-5 –septate, apical cell curved and tapering, basa; cell foot-shaped. Microconidia abundant, napiform, oval, pyriform and citriform, 0-1-septate, may be clustered in false heads. Chlamydospores found singly or in chains



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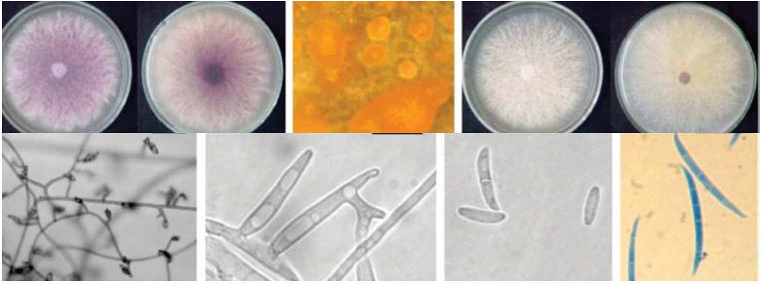
draaf.lorraine.agriculture.gouv.fr, en.engormix.com

109. Fusarium tupiense Lima, Pfenning & Leslie, Mycologia 104 (6): 1414 (2012)

Colonies produce white, in some cultures grayish violet; hairy to lanose-funiculose aerial mycelium. Pigmentation in reverse grayish white to gray to dark violet. Microconidia borne in the aerial mycelium mostly obovoid, occasionally oval to allantoid, 0-3 –septate, aggregated in false heads. Conidiophores on aerial mycelia erect, occasionally prostrate, sympodially branching, branches terminating in up to five phialides, often proliferating and associated with coiled sterile hyphae; phialides of aerial conidiophores cylindrical, mono- and polyphialidic. Sporodochia cream to orange. Sporodochial conidiophores verticillately branched. Macroconidia slightly beaked in the apical cells, with a foot-like basal cell, 3-5 septate. Chlamydospores absent.

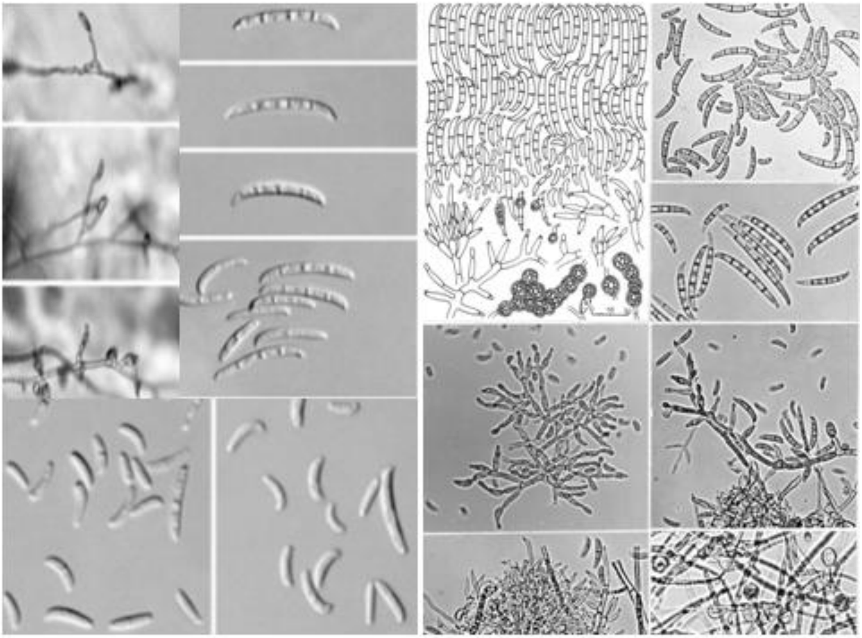


Lima et al., 2012

110. Fusarium udum E.J. Butler, Mem. Dept. Agric. India: 54 (1910)

≡Fusarium oxysporum f.sp. udum (E.J. Butler) W.C. Snyder & H.N. Hansen, American Journal of Botany 27: 66 (1940) [MB#509372]
=Fusarium uncinatum Wollenw., Annales Mycologici 15 (1-2): 54 (1917)

Colonies form white mycelium with pink to purple pigments in the agar, pink to salmon sporodochia. Macroconidia abundant in sporodochia, straight to fulcate, thin-walled, 1-5-septate, apical cell curved-hooked, basal cell foot-shaped. Microconidia sparse, fusiform or oval, 0-1 septate. Chlamydospores single or in clusters.



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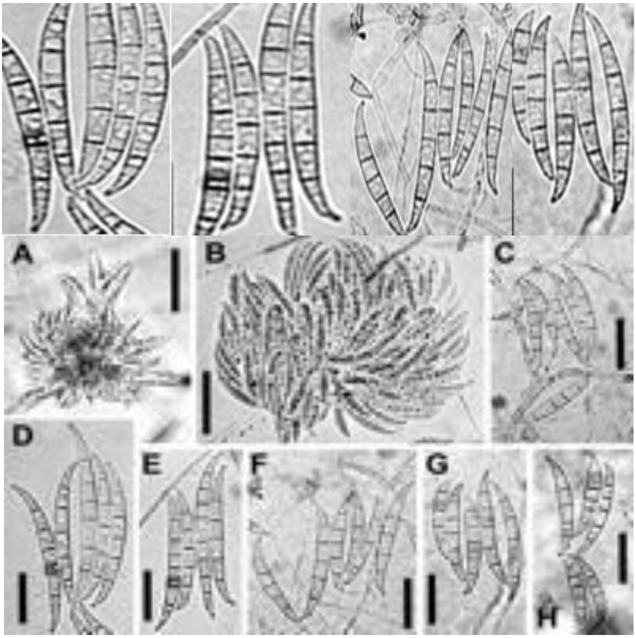
111. Fusarium ussurianum T. Aoki, Gagkaeva, Yli-Mattila, Kistler & O'Donnell, Mycologia 101 (6): 841-852 (2009)

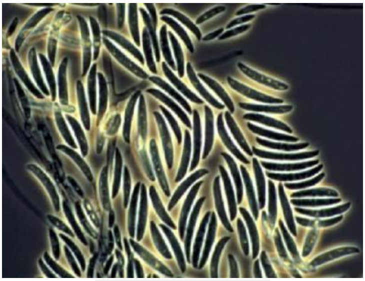
Colonies produce loose to densely floccose, white, reddish-white, brownish-yellow, brownish-orange to grayish-brown mycelium. Conidiophores branched verticillately or unbranched, forming monophialides. Phialides simple, subulate, ampulliform to subcylindrical, sometimes doliiform, monophialidic. Conidia of a single type, typically falcate and curved, dorsiventral, most frequently widest slightly above the mid-region of their length, mostly tapering and curving equally toward both ends, with an arcuate apical cell and a distinct basal foot cell, forming symmetrical upper and lower halves, 1-7-septate. Chlamydospores and sclerotia absent but some globose hyphal swelling sometimes present, intercalary or occasionally terminal.



Fusarium ussurianum , **T. Aoki et a;. (2009)**

112. Fusarium venenatum Nirenberg, Mycopathologia 129 (3): 136 (1995)

Colonies produce long, dense, cottony, white toorange, gray or red mycelium, Red pigments. Sporodochia abundant, reddish brown to brown. Macroconidia abundant, short, slender, 5-septate. Microconidia absent. Chlamydospores abundant, singly and in chains

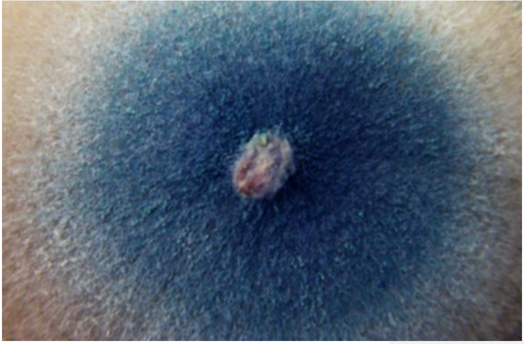


twicemice.com

113. Fusarium virguliforme **O'Donnell & T. Aoki, Mycologia 95 (4): 667 (2003) [MB#489315]**

≡Neocosmospora virguliforme (O'Donnell & T. Aoki) L. Lombard & Crous, Studies in Mycology 80: 228 (2015)

Colonies are white to yellowish-white or pale yellow, sometimes with bluish-gray. Aerial mycelium sparse or sometimes developed abundantly, then loose to dense floccose. Colony margin entire to often undulate. Reverse pigmentation often absent, sometimes grayish, grayish-orange to brownish-orange or olive brown to yellowish-brown. Yellowish exudate sometimes present. Chlamydospores formed abundantly in mycelium and in conidia, mostly subglobose, intercalary or terminal, mostly single, rarely in chains, hyaline to pale or pale-yellow, smooth to rough-walled. sporodochia normally formed abundantly. Aerial conidiophores unbranched or sparsely branched, forming monophialides integrated in the apices. Aerial phialides simple, subulate to subcylindrical, often with a conspicuous collarette at the tip.
Macroconidia typically falcate, dorsiventral, most frequently widest at the midregion of their length, often tapering and curving equally toward both ends, with the apex and foot cell typically similarly pointed and often indistinguishable, 2-5-septate. Microconidia comma-shaped to sometimes short-clavate, with a swollen apex often rounded but rarely pointed and with a tapering and curving base, 0--2-septate.



Fusarium virguliforme Kevin Bugg, 2010, www.cals.ncsu.edu

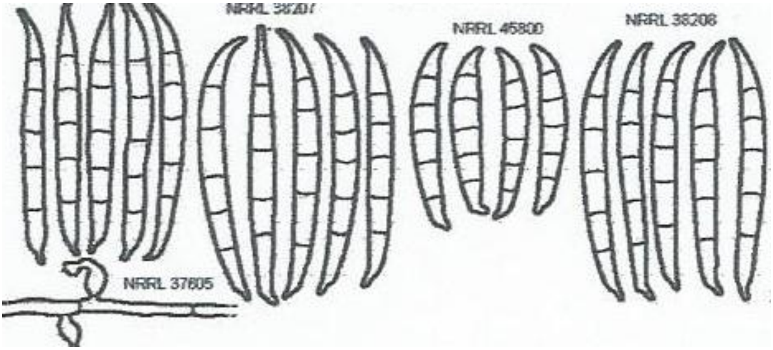
114. Fusarium verticillioides (Sacc.) Nirenberg, Mitteilungen der Biologischen Bundesanstalt für Land- und Forstwirtschaft 169: 26 (1976)

≡Oospora verticillioides Sacc., Fung. Ital.: fig. 789 (1881)
≡Alysidium verticillioides (Sacc.) Kuntze, Revisio generum plantarum 3: 442 (1898)
≡Alysidium verticilliodes (Sacc.) Kuntze (1898)
=Fusarium moniliforme J. Sheld., Annual Report of the Nebraska Agricultural Experimental Station 17: 23 (1904)
=Fusarium celosiae Abe, Mem. Coll. Agric. Kyoto Univ.: 51-64 (1928)
=Oospora cephalosporioides Luchetti & Favilli, Ann. Fac. Agrar. R. Univ. Pisa N.S.: 399 (1938)

Colonies produce white mycelium, violete pigmenta with age. Macroconidia rare, in pale orange sporodochia, long. Slender,thin-walled, 3-5-septate, apical cell curved and pointed, basal cell notched to foot-shaped. Microconidia, monophilides abundant on the aerial mycelium, club-shaped, 0-septate. Chlamydospores absent

115. Fusarium vorosii B. Tóth, Varga, Starkey, O'Donnell, H. Suga & T. Aoki, Fungal Genetics & Biology 44 (11): 1191-1204 (2007)

Fusarium vorosii is morphologically similar to F. graminearum including colony characters on PDA, but has slightly different conidial features from it. Macroconidia 5-septate, typically straight but sometimes gradually curved and frequently widest above the mid-region.



O’Donnell et al 2008

116. Fusarium xylarioides **Steyaert, Bulletin de la Société Royale de Botanique de Belgique 80 (1-2): 42 (1948) [MB#286515]**

≡Fusarium oxysporum f.sp. xylarioides (Steyaert) Delassus, Bull. Sci. Minist. Colon. Sect. Agric. trop.: 347 (1954)
≡Fusarium oxysporum f. xylarioides (Steyaert) Delassus, Bull. sci. Minist. Colon. Sect. Agric. trop.: 347 (1954)
≡Fusarium lateritium f.sp. xylarioides (Steyaert). Gordon, Canad J Bot 43, 1317 (1965)

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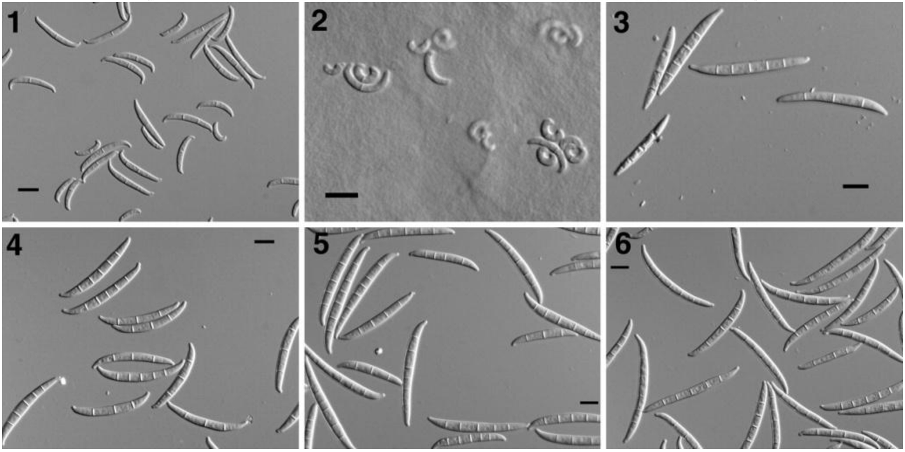
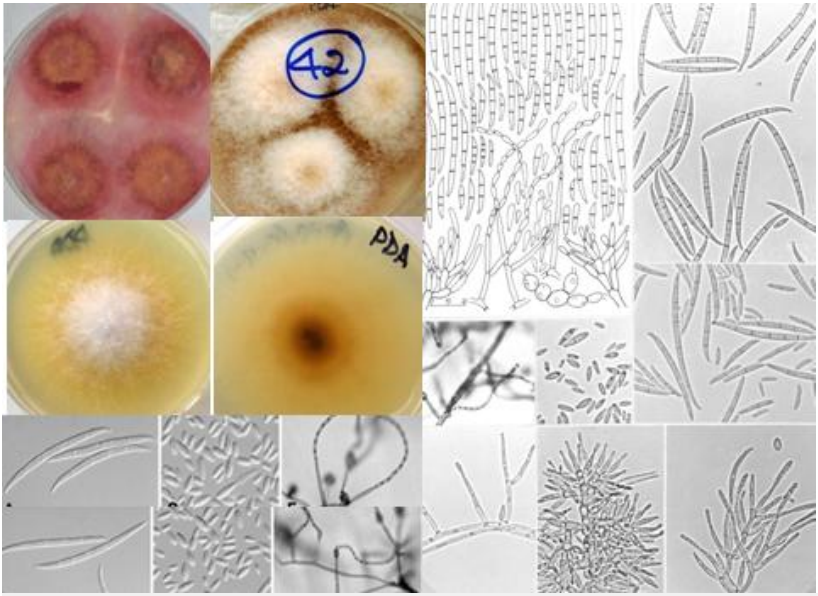


Schroers et al., 2009



www.ppis.moag.gov.il www.drjacksonkungu.com www.ianrpubs.unl.edu

11. Fusarium books

Die Fusarien

ihre Beschreibung, Schadwirkung und Bekämpfung

Von

Dr. H. W. Wollenweber und **Dr. O. A. Reinking**

Oberregierungsrat und Mitglied
der Biologischen Reichsanstalt
für Land- und Forstwirtschaft
Berlin-Dahlem

vorm. Professor der Phytopathologie
an der Universität der Philippinen;
Leiter der Tropenpflanzen-Krankheitsforschungen der United Fruit Co.,
Boston, U. S. A.

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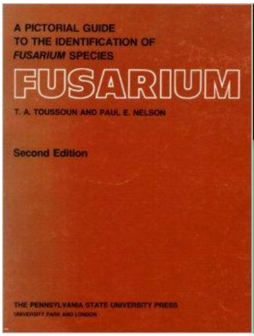
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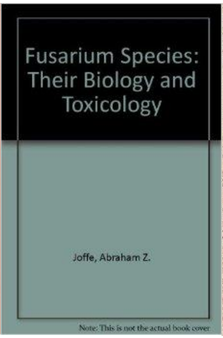
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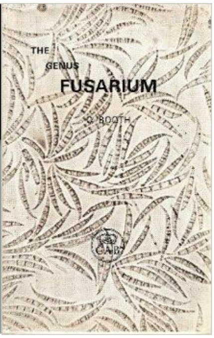
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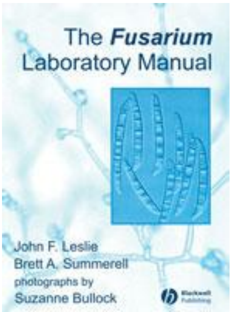
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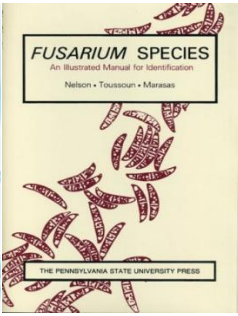
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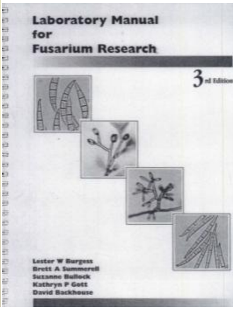
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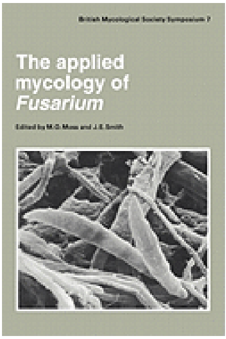
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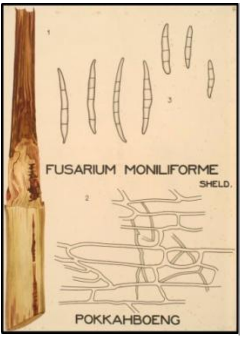
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FUSARIUM MONILIFORME
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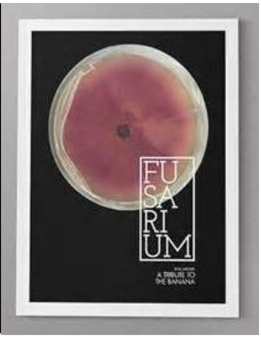
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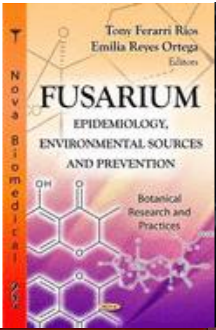

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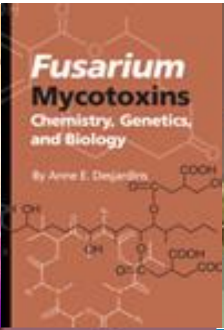

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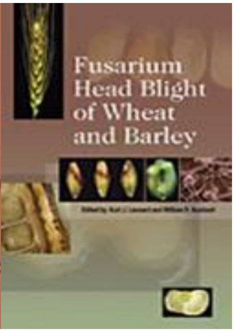

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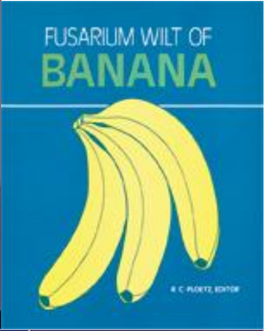

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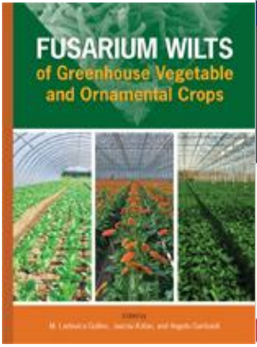

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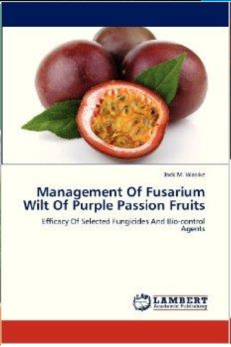

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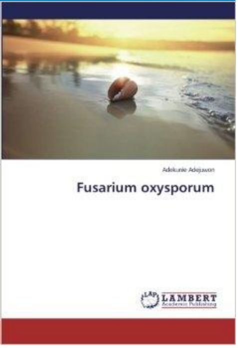

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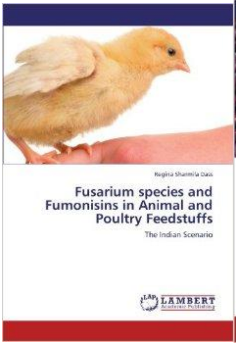
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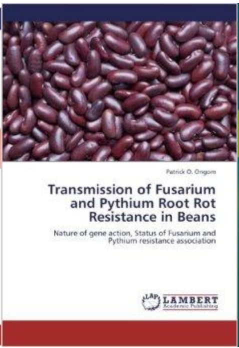
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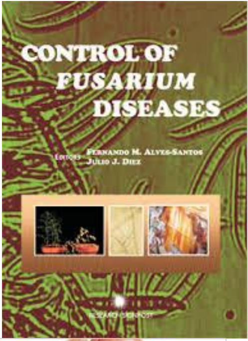
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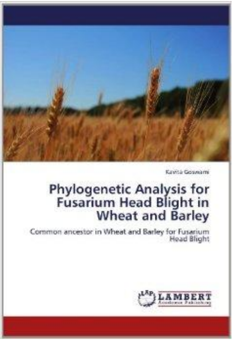
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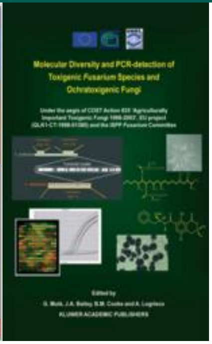
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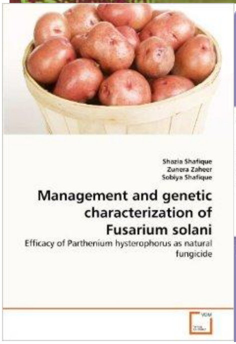
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Efficacy of Parthenium hysterophorus as natural fungicide


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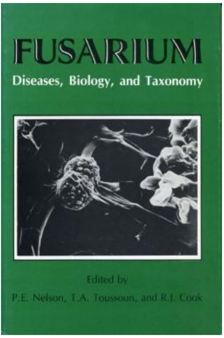
FUSARIUM

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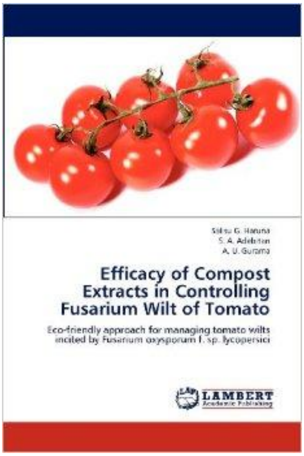


12. Research projects

1. Intestinal toxicity and oral resorption of conjugated *Fusarium* mycotoxins, frequently found in food & feed, Gent University

Promotor: Siska Croubels (UGent)

Within this project the first focus will lay on the synthesis and isolation of glycosylated derivates of deoxynivalenol (DON) and zearalenone (ZEN) as well as acetylated DON derivates, and this in amounts sufficient to conduct further *in vitro* and *in vivo* trials.These synthesized masked mycotoxins will be utilized to determine the intestinal cytotoxicity and the influence on the cytokine response of these compounds. In a further stage, the oral bioavailability and *in vivo* degree of hydrolysis will be determined of these conjugated toxins by using *in vitro* en *in vivo* toxicokinetic models. Pigs and chickens will serve as target animals as these animals have the highest natural exposure to these toxins and are economically relevant. Additionally, pigs can serve as a model for human toxicokinetics.The research will generate data concerning the toxicokinetic en toxicological properties of masked mycotoxins. Based on these properties one can make a more informed decision on the potential need to include these compounds in routine controls, and possibly legislation.

2. Rapid multiplex detection of toxigenic *Fusarium* species

The Norwegian Veterinary Institute (NVI)

Project leader:
Dr. Arne Holst-Jensen, Section of Food and Feed Microbiology, Department of Feed and Food Hygiene

In the present study the phylogenetic relationship between the most frequently isolated *Fusarium* species detected on Norwegian cereal grains was clarified. The phylogeny was largely concurrent with previous reports, but revealed lack of concordance between sections and the species traditionally assigned to the sections. All but one species formed monophyletic groups, and the phylogeny revealed a clear division between the trichothecene and non-trichothecene producing species. Phylotoxigenic relationship was observed for the major groups of trichothecene producers, and these trichothecene producing species could be divided into the strict type A trichothecene producers, the strict type B trichothecene producers and those that produce both type A and B trichothecenes. Based on the results of the phylogenetic analyses and published chemical and morphological reports, *F. arthrosporioides* was placed as a synonym to *F. avenaceum*. Potential diagnostic sequence motifs detected for molecular methods, were retrieved from the phylogenetic analyses.

Main goal::Develop a rapid multiplex phylogeny-based assay for identification of toxigenic *Fusarium* species in plant matrixes
Sub-goals::Sequence the ribosomal intergenic spacer (IGS), introns of b-tubulin , translation elongation factor 1a or other genes of approximately 150 strains of *Fusarium*/other relevant fungal/host plant taxa.

Perform phylogenetic analyses based on new sequences and sequences from databases and collaborators.
Map features associated with the strains on the phylogenetic trees, e.g. taxonomy, metabolite profile, geographic origin, host.
Retrieve diagnostic sequence motifs from phylogenetic trees.
Develop and validate diagnostic probes in single strain and multiplex PCR/hybridisation assays.

3. Mycotoxins and mycotoxigenic fungi in China: analytical tools, dietary exposure and *Fusarium* diversity

Promotor: Sarah De Saeger (UGent)

Belgian partners: Stéphane Declerck (Université catholique de Louvain, UCL), Alfons Callebaut (CODA-CERVA), Geert Haesaert (University College Ghent, Hogent)

Chinese partners: Dr.Y.Qi (Chinese Academy of Tropical Agricultural Sciences, CATAS), Prof. Y.-C. Liao (Huazhong Agricultural University, HZAU), S. Peng (Shanghai Food and Drug Administration, SHFDA), H. Gao (Shanghai Food and Drug Administration, SHFDA), Prof. J. Shen (China Agricultural University, CAU), Prof. S. Zhang (China Agricultural University, CAU), Prof. D. Zhang (Shanghai Jiao Tong University, SJTU), Dr. A. Wu (Shanghai Academy of Agricultural Sciences, SAAS)

Researchers: J. Diana Di Mavungu (Ghent University, UGent), N. Beloglazova (Ghent University, UGent), F. Munaut (Université catholique de Louvain, UCL), F. Van Hove (Université catholique de Louvain, UCL), Kris Audenaert (University College Ghent, Hogent), B. Huybrechts (CODA-CERVA), E. Tangni (CODA-CERVA), Ph. Debongnie (CODA-CERVA), H.-P. Li (Huazhong Agricultural University, HZAU), J.-B. Zhang (Huazhong Agricultural University, HZAU), J.-H.Wang (Huazhong Agricultural University, HZAU), Z. Wang (China Agricultural University, CAU)

The major aim of this proposal is to bring together experts from both China and Belgium to conduct research on mycotoxins and mycotoxigenic fungi, including Fusarium and related toxins. The different partners will be complementary as they are focused on different aspects of this research topic. Multidisciplinarity and cross-border research are the key issues in this project.

More specifically, the project will have the following objectives:

1. Development of analytical tools to assess mycotoxin dietary exposure in China.
2. Study on the genetic and mycotoxigenic diversity of Fusarium on wheat, maize and banana in China.

4. Assessment of mycotoxin exposure in the Belgian population using biomarkers

Promotors: Stefaan De Henauw (UGent) and Alfons Callebaut (Coda-Cerva)

The objectives of this project are:

- Measurement of mycotoxins via biomarkers in urine taken in samples of a representative part of the Belgian population, using validated analytical methods
- Perform an exposure assessment via biomarkers for a number of mycotoxins to which the Belgian population is exposed (mainly through dietary intake)
- Investigate the correlation between the measured biomarkers and the reported consumption of different groups of food commodities

5. MYTOXPLEX: Is the occurrence of the T2/HT-2 mycotoxin complex in cereals a new and actual problem in the food and feed chain?

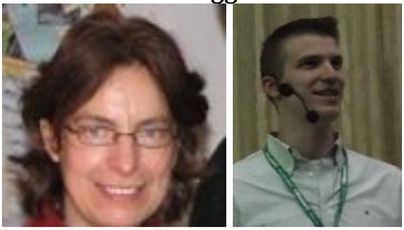
This project will use an explorative approach to:

1. Assemble qualitative and quantitative T2 and HT-2 data in small grain cereals (wheat, barley, oat, spelt and triticale) and derived cereal products produced and handled in Belgium.
2. Elucidate the occurrence of T2 and HT-2 producing *Fusarium* species and their genetic diversity in order to come up with appropriate control measures.

3. Identify the presence of other mycotoxins produced by *F. poae* and *F. langsethiae*.
4. Assess the importance of other *Fusarium* species within the T2/HT-2 complex.
5. Implement a preliminary risk assessment for T2, HT-2 and other eventual mycotoxins within the *F. poae* group based on an exposure estimation.

Promotors: Geert Haesaert (HoGent), Kris Audenaert (HoGent), Sarah De Saeger (Ugent), Françoise Munaut (UCL) and Mia Eeckhout (HoGent)

6. Researching Fusarium poae: its mycotoxines, chemotype and influence of oxidative stress triggers



Copromotors: Monica Höfte (HoGent)
Collaborator: Adriaan Vanheule (HoGent)

Thorough research at the Ghent University College recently attempted to shed light on the ever changing composition of the *Fusarium* complex. It was found that in Flanders, *Fusarium poae*has an important place within this disease complex. Up to recently, research in this field did not focus on *F. poae,* as other species were much more aggressive within the complex. Its rising presence, its nature as a secondary attacker and its potential to produce mycotoxins which could be much more toxic than those of other species, illustrate the large need for research on this topic.The Fusarium poae research at the Ghent University College aspires to fill the gaps in the scientific community's knowledge on this fungus. Field isolates that originate from several testing locations in Belgium are characterized pursuing a multidisciplinary approach of chromatographic, genetic and pathological methods. LC-MS/MS techniques are used to unravel the chemotype of the isolates. To this end, the *Fusarium poae* project has ties with the 'Mytox' Association Research Group (AOG), and research is carried out in the Bromatology lab at the Faculty of Farmaceutical Sciences at the University Ghent. The qualitative and quantitative production of toxins is examined under different conditions and influences of stress, such as fungicide treatment. A further characterization of the field samples involves fungicide resistance assays of *F.*

*poae*and the related species *F. langsethiae* to fungicides such as triazoles and strobilurines. Experiments to examine the physiological effects of fungicide treatments on both a macroscopic and a microscopic level are set up. This work is carried out in the broader framework of oxidative stress as a trigger for toxin production, which could be a central dogma in toxin production in all toxigenic fungi. To find a measure for aggressivity of the isolates, detached leaf assays are used. This technique also allows us to test several sources of resistance in wheat for its strength against *F. poae*. Again, microscopy visualization techniques are employed, this time to gain insight in the infection strategy of the fungus and the plant's corresponding response. The last piece of the puzzle is filled in when AFLP-fingerprinting lets us unravel the genotype of the different isolates.These different approaches of the *Fusarium poae* problem allow us to paint a fairly complete picture of the fungus, and as such meet the scientific community's need for more knowledge on this organism with its importance increasing now more than ever.

7. MycoHunt: Rapid biosensor for the detection of mycotoxin in wheat

Mia Eeckhout (coordinator HoGent), Collaborator: Yirong Guo (UGent), Melanie Sanders (UGent), Freya Martens MycoHunt is a project granted in the EU7 framework program for the development of a rapid online biosensor for the detection of mycotoxin in wheat.The project aims to increase the competitiveness of a large group of "Small and Medium Enterprises (SME) Associations" in Europe by developing a cost-effective method to detect the contamination of deoxynivalenol (DON) in wheat grains. This mycotoxin forms a major threat in the food and feed sector of the European industry. A group of SME Associations, covering the relevant sectors and representing a vast number of sector SMEs, participate in the project. In this way, they will gain knowledge and resources to further exploit the results of the novel technology developed by providing a thorough sampling and measurement method of grain.In the framework of the project the development of an online, non-destructive sampling apparatus for dust and other low molecular weight particles is targeted. Another aspect of the research is the development of a specific sensor based on an immunoassay method using DON specific monoclonal antibodies. Beside the technological objectives, the research focuses on the determination of parameters (temperature, pressure, vacuum, etc.) affecting the sampling precision. Also different immobilizing methods for the DON specific monoclonal antibodies will be investigated. The determination of the cross-reactivity of these monoclonal antibodies against other trichothecenes, like 3-acetyl-DON, 15-acetyl-DON, nivalenol, is also an interesting point to consider.

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8. Fusarium Research, at University of the Free State/ South Africa

The most effective means to prevent damage caused by *Fusarium* spp. to agricultural crops is by planting tolerant or resistant material. Such tolerance/resistance depends on the ability of the fungus to enter, colonise and damage the plant, and the ability of the plant to prevent or resist damage caused by the fungus. To exploit plant resistance as a means of disease management, a proper knowledge of *Fusarium*, its genetics, pathogenicity and toxicity, under different environmental conditions, is required. In this programme, the interaction between agricultural crops and *Fusarium* spp. is investigated by means of comparative and functional genetics of the *Fusarium*-plant interactions, the isolation and identification of defence-related genes in agricultural crops, the identification of virulence genes in *Fusarium*, studies on the evolutionary biology and phylogenetics of *Fusarium*, and the unconventional improvement of plants for resistance to *Fusarium* spp. Greenhouse and field evaluation of natural and induced resistance to *Fusarium* pathogens of agricultural crops are also conducted in collaboration with the ARC.

students

MSc students:



Ankia Rabie - Isolation and identification of putative pathogenicity genes in a mutant population of *Fusarium oxysporum* f. sp. *cubense*

Morgana Miller - Containment of *Fusarium oxysporum* f.sp. *cubense* 'tropical' race 4 on a banana farm in northern Mozambique

Anushka Gokul - Epidemiological investigations of the *Fusarium graminearum* species complex (FGSC) in South African wheat and maize, grown in rotation

Nakisani Netshifhefhe - Investigating the mechanisms of resistance in maize to *Fusarium verticillioides* and fumonisin

Londiwe Mabuza - Monitoring Fusarium and Gibberella ear rots and the mycotoxins they produce in maize grown under different conservation tillage/rotation systems

PhD students:

Lindy Rose - Unconventional improvement of maize for resistance to *Fusarium verticillioides* and their fumonisins

Gert van Coller - identification and management of toxin-producing *Fusarium* species responsible for head blight and crown rot of wheat in South Africa

Reuben Ssali - identification, characterisation and genetic mapping of Fusarium wilt resistance loci in *Musa*

Sharon McFarlane - Development of a management strategy for *Eldana saccharina* Walker in sugarcane using *Fusarium* endophytes

Edson Ncube - Interactive effect of *Busseola fusca* and *Fusarium verticillioides* on ear rot and fumonisin production in maize

Saif Al-Kaabi - The diversity, distribution and management of *Fusarium oxysporum* f.sp. *cubense* in the Sultanate of Oman

9. Characterisation and management of Fusarium wilt of watermelon

The project is financially supported by the NT DPIF, Horticulture Australia Limited, Monsanto Australia and Rijk Zwaan Australia.

Fusarium wilt is one of the most severe diseases in watermelon and is caused by a fungus called *Fusarium oxysporum* f. sp. *niveum* (Fon). This strain is only pathogenic on watermelons and can be divided into four races (0, 1, 2 and 3). The disease is one of the major yield limiting factors in production, worldwide. Fon was first detected in the Northern Territory (NT) in May 2011. The disease affected three different varieties of watermelon seedlings and plants from six different locations. To date, two of the races have been detected in Australia. However there is limited published information about the Australian Fon races. It is unclear what race the NT Fon strain is, whether it is a new race and its level of aggressiveness.

Lucy Tran-Nguyen (project leader): 8999 2235 (lucy.tran-nguyen@nt.gov.au), Barry Conde (project member) 8999 2265 (barry.conde@nt.gov.au).

The objectives of the projects are

- Identify the NT *Fusarium oxysporum* f. sp. *niveum* race(s) and compare with other Fon races (Australia and international).
- Screen rootstocks and grafted watermelons for resistance to Fusarium oxysporum f. sp. niveum [all race(s)].
- Extension strategies to raise awareness of Fusarium wilt of watermelon, deliver outcomes to industry and propose management strategies.

The project outcomes include

- Obtain a better understanding of the pathogen's biology by project completion.
- Determining the NT Fon race(s) and its relatedness to Australian and overseas Fon races by project completion. These findings would assist commercial breeding programs.
- By the end of 2015, seedling nurseries and growers are using an integrated strategy for management of Fon that allows them to sustainably produce watermelons on their current infected farms, as a result of the extension activities from this project.

Project update:

- Race differential trials in the NT have so far had mixed results. Trials on two varieties of watermelon, 'Kalahari' and 'SP-4' have suggested that two *Fon* NT isolates are of race 2. The most recent trial however, conducted again on the 'SP-4' variety, has suggested that the NT isolates may actually be of race 3. To date, race 3 has not been reported as present in Australia. This trial will be repeated, and highlights the importance of conducting race differential trials on several varieties of watermelon before race can be determined conclusively.

- Multiplication of 'Charleston Grey' and 'Calhoun Grey' seeds, which are traditionally used for *Fon* race differentials, has been completed and will be used for trials to determine which race is present in the NT and NSW.
- Samples from melon growing regions in the NT, NSW, Qld and WA have been taken by University of Sydney post graduate student, Victor Puno. Preliminary race differential trials have found that four isolates from Qld are race 2. Isolates from the NT, NSW and WA have been determined as being either race 2 or 3, with ongoing trials being conducted to differentiate them.
- Glasshouse and field trials to determine the effects of temperature on the susceptibility of plants to *Fon* are currently being conducted in 2014, after being disrupted in 2013 due to resource reallocation during the banana freckle outbreak. These trials will again be repeated in 2015 to assess the reliability of results.
- Molecular studies on *Fon* isolates aim to develop a relatively quick and reliable molecular test for race identification. Thus far, studies have been made difficult due to the restrictions on importing live Fusarium cultures into Australia and the lack of quarantine facilities for working with them. Instead DNA from two isolates of each *Fon* race are to be imported from the US for future inclusion in comparative molecular studies of *Fon*isolates.
- Molecular characterisation of *Fon* isolates has commenced by searching for pathogenicity genes. Genome sequencing has been conducted on two NT isolates, and the presence of pathogenic genes has been found. One isolate appears it may be slightly more virulent than the other, but this is yet to be verified.

10. Epidemiology and agro-ecology of Fusarium oxysporum f.sp. cubense (PANAMA DISEASE PhD project 3)

The aim of this PhD project is developing statistically sound sampling strategies and (quantitative) diagnostics. This will result in internationally sought 'TR4 alerts' and effective rational and quantifiable management practices.

Project code: PANAMA DISEASE
Status: In progress
Start project: Jan 1, 2012

End project: Dec 31, 2017
Partners:

- Plant Research International
- Soil Geography and Landscape
- Knowledge Technology and Innovation

Other parties involved:

Embrapa (Empresa Brasileira de Pesquisa Agropecuária); CIB (Cooperación de Investigaciónes Biológicas); UNAL (Universidad Nacional de Colombia, Medellín); Augura (National Banana Corporation of Colombia); Colciencias (National Science Foundation); CORBANA (Corporación Bananera Nacional); Bioversity International; Chiquita; Dole; Earth University; AEBE (Association of Ecuadorian Banana Exporters); Senescyt (National Science Foundation); ESPOL-CIBE (Escuela Superior Politecnica del Litoral, Centro de Investigaciones Biotecnológicas del Ecuador); FHIA (Fundación Hondureña de Investigación Agrícola); OIRSA (Organismo Internacional Regional de Sanidad Agropecuaria) (Philippines Banana Growers and Exporters Association); Federation of Cooperatives in Mindanao and MBFEA (Mindanao Banana Farmers and Exporters Association); University of the Philippines-Mindanao; University of the Philippines-Los Baños; CHED (Commissioner of Higher Education); PCCARD (Philippine Council for Agriculture, Forestry and Natural Resources Research and Development); IITA (International Institute for Tropical Agriculture); SUA (Sokoine University of Agriculture); CIRAD (Centre de coopération internationale en recherche agronomique pour le développement); FAO-World Banana Forum; AgroFair; BLGG (Bedrijfslaboratorium voor Grond en Gewasonderzoek

11. Panama disease: Multi-level solutions for a global problem

Panama disease: Multi-level solutions for a global problem is a collaborative project led by Wageningen University & Research Centre and funded by Wageningen University's Interdisciplinary Research and Education Fund (**INREF**)[1]. The premise of the project is that controlling Fusarium wilt, caused by Fusarium oxysporum f. sp. cubense (Foc), requires an approach that integrates new insights, such as on the impact of genetic and agro-ecological diversity on the spread and severity of the disease, with coordinated action and regulation. The project aims to address the management and containment of tropical race 4 (TR4) under different production settings in a range of agro-ecological environments and various governance structures by establishing methods for immediate containment and management of TR4 where it is present, or arrives, and by developing long-term control strategies in banana-producing regions affected by the other races of the Fusarium fungus.

The INREF project is one of three research projects on Fusarium wilt that are managed Wageningen University & Research Centre. The other two are: **KNAW-SPIN**, a Scientific Program Indonesia Netherlands (SPIN) funded by the Royal Netherlands Academy of Arts and Sciences, which aims to deliver fundamental knowledge on banana and Foc, and **PromoBanana** (Protect and Modernize Philippine Banana Production), which aims to establish a professional service laboratory to detect and contain rapidly spreading diseases, and to optimize fertilizer management[2].

Study areas

Project activities take place in the Philippines (where TR4 is present), Ecuador, Colombia, Costa Rica and Tanzania (where other Fusarium wilt races are present) and the Netherlands (for specific laboratory and greenhouse experiments). The study areas represent different types of production systems (smallholder and large-scale commercial plantations) as well as different agro-ecological setting and governance models and histories.

Main research questions

The analytical framework of the research approach considers three main domains that are important drivers of disease outbreaks: biology, environment and human action. The multidisciplinary approach is programmed in a series of projects that address seven main research questions linking the different domains and scale levels, from individual plants to entire regions.

1. What Foc genotypes are present in different banana growing regions, and which banana cultivars are susceptible to these strains?
2. What banana and plantain cultivars are resistant to TR4 and what is the genetic basis for resistance to TR 4 and other Foc strains?
3. What are the dispersal and survival strategies of Foc under various agroecological settings?
4. What is the contribution of diversified germplasm pools and diverse agroecological conditions to lowering Fusarium wilt pressure in mixed cropping systems?
5. What are the effects of abiotic stress or specific farm management strategies on the alleviation of disease pressure in susceptible banana germplasm in areas infested with Race 1 of Foc?

6. What are the enabling and constraining mechanisms for coordination and joint action in managing Fusarium wilt in the diverse banana industry in southern Mindanao?
7. What are the conditions for effective forms of governance that help to control Fusarium wilt at different levels?

Partners by country

The project brings together 25 partners in 10 countries.

Brazil Embrapa (Empresa Brasileira de Pesquisa Agropecuária), **Colombia**, CIB (*Cooperación de Investigaciónes Biológicas*), UNAL (*Universidad Nacional de Colombia*), Augura (National Banana Corporation of Colombia), Colciencias (National Science Foundation), **Costa Rica**, CORBANA (Corporación Bananera Nacional), Chiquita
Dole, Earth University, **Ecuador**, AEBE (Association of Ecuadorian Banana Exporters)
Senescyt (National Science Foundation), ESPOL-CIBE (*Escuela Superior Politecnica del Litoral, Centro de Investigaciones Biotecnológicas del Ecuador*), **El Salvador**, OIRSA (*Organismo Internacional Regional de Sanidad Agropecuaria*), **Philippines**, PBGEA (Philippines Banana Growers and Exporters Association)
Federation of Cooperatives in Mindanao, MBFEA (Mindanao Banana Farmers and Exporters Association), University of the Philippines-Mindanao, **Tanzania**, SUA (Sokoine University of Agriculture), **France**
CIRAD (*Centre de coopération internationale en recherche agronomique pour le développement*), **Italy**
FAO-World Banana Forum, **Netherlands**, AgroFair, BLGG (*bedrijfslaboratorium voor grond en gewasonderzoek*)

12. **PE 022 - Pepper: Improved control of Fusarium internal fruit rot through increased knowledge exchange with the Netherlands and Belgium and targeted application of plant protection products**

This project aims to reduce losses to Fusarium internal fruit rot through: (1) agreed information exchange and a joint work programme with Dutch/Belgium researchers; (2) examination of rockwool cubes as a source of F. lactis and F. oxysporum; (3) devising experiments to determine if the level of flower infection can be used to predict risk of fruit infection; (4) determining the duration of reduction in fruit infection provided by a single application of Serenade ASO to a crop row, cube surface and floor; (5) determining if use of biopesticides / plant resistance inducers applied preventatively provide protection to flowers and/or fruit against infection; (6) communication of results to growers.

13. Fusarium mycotoxins in straw and feed: Effedts on pig reproduction and health

Project manager:

Per Häggblom

CRC60097: Fusarium TR4 - PhD

This research project will increase our knowledge about the epidemiology and biology of the exotic plant pathogen*Fusarium* wilt of banana caused by *Fusarium oxysporum* f. sp. *cubense* ‘tropical' race 4 (*Foc* TR4)

14. Institute for Biotechnology in Plant Production
Research Projects

Christian Doppler Laboratory for Mycotoxin Metabolism (CDL Berthiller)

Project type: Research project (§ 26 & § 27)

Project Leader: Berthiller Franz ;

BOKU Research Units: Center for Analytical Chemistry ; Department of Applied Genetics und Cell Biology ;Institute for Biotechnology in Plant Production ; Institute of Animal Nutrition, Livestock Products, and Nutrition Physiology (TTE) ;

Funded by: Christian Doppler Forschungsgesellschaft (CDG), Sensengasse 1, 1090 Wien, Austria

Duration: 01.01.2011-31.12.2017

The effort will be concentrated on the Fusarium mycotoxins deoxynivalenol, zearalenone and fumonisin B1, as these compounds are significant contaminants of European cereal crops. The first module will establish the extent of formation of bound mycotoxins in plant systems. The second module will investigate microbial interactions with free and bound toxins with a view to identifying possible detoxification routes. The third module will pursue animal feeding trials to establish the fate of bound toxins in vivo, as well as the effectiveness of detoxification strategies. Radiolabeled mycotoxins will facilitate these studies and biomarkers will be used extensively to monitor the fate of toxins in ani-mal systems. In summary, the overall project aims to answer the following key questions: Which plant metabolites of mycotoxins are formed in agriculturally important crops and in which quantity? What is the bioavailability and toxicity of these soluble (conjugated) and insoluble (bound) forms compared to the native toxins? What is the influence of microbes (either gut bacteria or deactivators) to conjugated and bound toxins? How efficient are various mycotoxin deactivators to detoxify both native mycotoxins and their altered forms?

Plant metabolism of T-2 and HT-2 toxin in wheat, barley and oats
Project type: Research project (§ 26 & § 27)

Project Leader:
BOKU Research Units: Center for Analytical Chemistry ; Institute for Biotechnology in Plant Production ;
Funded by: Fonds zur Förderung der wissenschaftlichen Forschung (FWF) , Sensengasse 1, 1090 Wien, Austria
Duration: 01.12.2013-30.11.2016

In this project we want to 1) investigate the metabolic fate of T2/HT2 in planta, 2) develop suitable analytical methods for detection and quantification of possible new metabolites and 3) produce standards of such metabolites. To detect metabolites a 1:1 mixture of natural and U-[13C]-toxins will be applied on wheat/barley ears and oat panicles. At different time points after application both known (i.e. predicted) and unknown metabolites will be traced and identified by liquid chromatography – high resolution mass spectrometry (LC-HRMS). Similar tests will be done with 14C-labeled toxins to assess the insoluble amount, measured by scintillation counting. A solvolysis procedure will be established to access the extractable biopolymer-bound and the non-soluble toxin fractions from the plant matrix. A molar sum of all metabolites will be estimated and compared to the total amount of toxins applied. To demonstrate the significance of the detected T2/HT2 biotransformation products, we will confirm their production after artificial inoculation with T2/HT2 producing Fusarium spp. and we will study their presence in naturally infected samples in the scope of a small survey. The resistance mechanism to T2/HT2 in wheat carrying Fhb1 is investigated using near-isogenic wheat lines with and without this QTL. To this end differential formation of T2 and HT2 metabolisation products will be studied by LC-HRMS.

15. Integrated management of Fusarium wilt of bananas in the Philippines and Australia.(Australian Centre for International Agricultural Research)

Project Leader:: Mr Stewart Lindsay

Collaborating Institutions

Australian Banana Growers Council, Australia
Provincial Agricultural Office-Rigion XI, Davao Del Norte, Philippines
University of Southeastern Philippines, Philippines
MegaManila Pest Management Specialists Inc., Philippines

This project aims to identify practices for smallholder banana growers to reduce FW spread through soil movement, understand mechanisms that suppress the symptoms and identify effective disposal of infected plant residue. It also aims to profile current knowledge of banana growers and the barriers to adopting relevant practices. The project will draw on experiences managing the disease in Australia, Indonesia and the Philippines though various Australian industry-funded projects, ACIAR HORT/2008/040 and Bioversity International and their coordination role with other national research projects.

Commissioned Organisation

Queensland Department of Agriculture, Fisheries and Forestry, Australia

16. Cereal pathology: improving the genetic basis of host resistance to fungal diseases.

Fungal diseases pose a major problem for cereal production in Ireland for two reasons: firstly, they significantly reduce yield, and secondly, some fungal diseases lead to contamination of grains with mycotoxins, compounds that are harmful for both human and animal health. UCD currently has an active research programme in fungal molecular plant pathology. By increasing the **critical mass** of this research group, this project aims to use biotechnology to better understand the potential for reduced pesticide input for controlling such diseases, thus leading to more competitive and sustainable low-input crop production in Ireland. The specific objectives of this project are to:

1. Better understand the susceptibility/resistance of Irish-grown barley cultivars to*Fusarium* head blight disease and associated mycotixin contamination.
2. Dissect the genetics of wheat resistance to *Fusarium* head blight disease.

Achieving these objectives will allow the selection of wheat and barley cultivars with lower fungicide requirements and will thus facilitate the move towards competitive low-input sustainable crop production.

Funding:
Department of Agriculture, Food and Rural Development (Ireland).

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17. Reduction of fungicide input in Irish cereal farming: biological control of cereal foliar and head blight fungal pathogens.

Researchers:
Eleanor O`Brien, Mojibur Khan
Collaborators:
Dr. Brian Carney, Letterkenny Institute of Technology, Co. Donegal, Ireland.
Funding:
Department of Agriculture, Food and Rural Development (Ireland).

In Ireland, the most important fungal diseases of cereals in terms of yield loss include Septoria tritici leaf blotch of wheat, Pyrenophora (Dreschlera) teres net blotch of wheat and Fusariumhead blight (FHB) of both wheat and barley caused by various *Fusarium* species. FHB also poses a threat in terms of human and animal health in that many of the *Fusarium* species that we have commonly found in Ireland (*F. culmorum, F. graminearum* and *F. poae*) have the potential to produce a range of toxic secondary metabolites known as mycotoxins in grain. Currently, control of such diseases is attempted by fungicide application. Our ultimate aim is to ***reduce fungicide inputs in Irish tillage*** and in this project we will investigate the potential of developing ***environmentally friendly*** **alternatives: biological control microorganisms/biochemicals**. We will isolate, characterise and assess the biological control potential of microorganisms and crustacean biochemicals. We will determine the mode of action of potential biological control organisms/biochemicals using microscopic and molecular studies. In addition to our microbial studies, we will assess the effectiveness of chitosan, a deacetylated derivative of chitin that activates many of the plant's defense responses to microbial diseases against cereal pathogens.

18. Effect of trichothecene mycotoxins on programmed cell death in wheat

The selective regulation of programmed cell death (PCD) offers tremendous potential rewards for plant and animal disease modulation. We recently identified that several fungal toxins retard PCD in Arabidopsis in a concentration-dependent manner. To the best of our knowledge, this is the first evidence of a fungal toxic metabolite inhibiting cell death in either plant or animal cells. We wish to analyse the effect of this these mycotoxins on stress-induced PCD in host plants (wheat and maize). Also, we will determine if the retardation of plant PCD by mycotoxins is an attack strategy adopted by pathogens during plant pathogenesis.

Researcher: Guillaume Erard.
Collaborators: Dr. Paul McCabe, Dept. of Botany, UCD, Belfield, Dublin 4, Ireland.

19. Functional genomics of plant-mycotoxin interactions

Researchers: Dr. Josephine Brennan, Stephanie Walter
Collaborators:
Dr. Gerhard Adam, Center of Applied Genetics, University of Agricultural Sciences, Vienna 18, A-1190 Vienna, Austria.
Dr. Paul Nicholson, Disease and Stress Biology, John Innes Centre, Norwich Research Park, Colney, Norwich NR4 7UH, UK.
Dr. Bodo Trognitz, Austrian Research Centre Seiberdorf GmbH,A-2444 Seibersdorf, Austria.

Mycotoxins are toxic fungal secondary metabolites. *Fusarium* fungi pathogenic to wheat produce trichothecene mycotoxins that act as disease virulence factors, aiding host parasitism; the wheat genome has consequently co-evolved with the *Fusarium* pathogen and its toxic metabolites. Current knowledge about the influence of trichothecenes on eukaryotic signal transduction cascades and downstream gene products is limited, especially in plants. Trichothecene resistance is postulated to be one of wheat's mechanisms to resist Fusarium head blight disease.We have recently identified several trichothecene-responsive wheat genes; many show no homology to previously characterised genes. This project will use microarray analyses to identify more wheat genes overexpressed in response to trichothecenes. We will also elucidate gene function using host, heterologous expression and gene regulatory studies. Gene expression analysis in a range of wheat tissues and genotypes in response to various treatments will determine if trichothecene-responsive genes are a component of the plants general stress response, if they are specifically up-regulated in response to trichothecenes, how these genes are developmentally regulated, and if they play a role in disease resistance.

Analysis of the effect of trichothecenes on both *Saccharomyces cerevisiae* and*Arabidopsis thaliana* that are heterologously expressing trichothecene-responsive wheat genes will indicate the ability of genes to directly conferring trichothecene tolerance and their phenotypic effects. For genes differentially expressed among wheat genotypes, RNA stability studies and analysis of upstream regulatory elements will enable us to determine if genes are pre- or posttranscriptionally up-regulated due to trichothecene treatment and if regulatory region polymorphisms could account for differential gene expression.

20. Trichothecene mycotoxin up-regulated wheat genes: analysis of function and regulation.

Researcher: Khairul Ansari

Collaborators:

Prof. Dr. P. Ruckenbauer, Dr. M. Lemmens, Dr. H. Buerstmayr and Dr. U.
Scholz, Institute for Agrobiotechnology, Austria
Dr. K. Hjortsholm. Sejet Plantbreeding, Denmark
Dr. F. Lšschenberger, Saatzucht Donau GmbH., Austria
Dr. J. Weyen. Saaten-Union Resistenzlabor GmbH, Germany
Prof. Dr. A. Mesterhazy. Cereal Research non profit Co., Hungary
Prof. B. M. Cooke. University College Dublin, Ireland
Dr. G. Adam. University of Agricultural Sciences, Austria
Dr. P. Nicholson. Disease and Stress Biology, John Innes Centre, UK

Wheat-pathogenic Fusarium fungi produce toxic trichothecene mycotoxins that act as Fusarium head blight disease virulence factors, and trichothecene resistance is postulated to be one of wheat's mechanisms to resist Fusaria. We recently identified several characterised and uncharacterised trichothecene-responsive wheat genes. Wheat gene expression studies will determine if gene up-regulation is trichothecene-specific or part of the plants general stress response, how these genes are developmentally regulated and if they play a role in disease resistance. The ability of trichothecene-responsive wheat genes to enhance the trichothecene tolerance of Saccharomyces cerevisiae will elucidate their role, if any, in directly conferring trichothecene tolerance

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Candidate genes for resistance, toxification, detoxification and toxin efflux.

Deoxynivalenol (DON) is a trichothecene mycotoxin produced by cereal-pathogenic*Fusaria* and evidence suggests that it acts as a phytotoxic disease virulence factor aiding host pathogenesis. RNA fingerprinting offers the potential of identifying novel "expression" markers for screening for host trichothecene tolerance/degradation. We determined the effect of DON (20 ppm) on gene expression in roots of different wheat genotypes. Despite inhibition of protein synthesis being the mode of action of this toxin, at least 70 transcripts were overexpressed in the wheat roots of different cultivars in response to DON. We assessed the effect of DON treatment of wheat roots and *Fusarium culmorum* infection of wheat heads on the production of specific transcripts, including translation elongation factor 1□ (*EF-1*□), class III plant peroxidase, structure-specific recognition protein (*SSRP*),adenosine kinase (*ADK*), retrotransposon-like homologs and genes of unknown function. Ongoing research is investigating the potential implications of these genes on the host cell response to trichothecenes and trichothecene-producing *Fusaria*.

21. Project Part: Comparative annotation and analysis of multiple Fusarium genomes and the genomes of Brachypodium and crop plants with emphasis on toxin biosynthesis and detoxification reactions

Project Part Leader: Univ. Prof. Dr. Hans-Werner Mewes

This project part focuses on the bioinformatic analysis of fungal and plant genomes as well as integration of expression data. On the fungal part we aim to complete and improve the annotation of *Fusarium* genomes. This will be achieved by automatic and manual comparative gene calling methods. The main focus in the analysis is the identification of new targets in particular of fungal secondary metabolite and mycotoxin clusters. Expression data, functional annotation and putative regulatory motifs are all integrated to explore the pathogen-host interaction.

The model plant *Brachypodium distachyon* will be annotated. The *Brachypodium* genome will sub-sequentially be used as a model for the closely related but much more complex and larger genomes of barley and wheat although their genomes are currently not fully sequenced. Specific targets of interest are UDP-glucosyltransferases, acetyltransferases among others. They will be first identified in the model genome and via homology and synteny driven orthology assignments counterparts in the crop genomes will be identified and knowledge transferred to the more complex genomes.

22, projects at University of Massachusetts, Amherst. The Department of Biochemistry and Molecular Biology

Li-Jun Ma, Principal Investigators
Professor Li-Jun Ma is interested in using the rich fungal genomic resources to explore the mechanisms that guide eukaryotic genome evolution. Dr. Ma is leading several comparative genomics projects to study the genetic determinants of fungal pathogenicity and host specificity, and participating in functional studies to test the hypotheses generated through genomic analyses.

Li Guo, Post-Doctoral Research, Biochemistry and Molecular Biology
Dr. Guo, completed his PhD through the Plant Pathology Graduate Program at Penn State, is focusing on functional genomics

of *Fusarium* species using comparative approaches. He studies comparative transcriptomics using both microarray and RNA-seq data.

Greg DeIulio , Ph.D Candidate (Plant Biology Graduate Program)

Greg is interested in understanding the epigenomic influence on genome evolution of *Fusarium* species using bisulfite-sequencing.

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