

Supplementary Materials

Applied Microbiology and Biotechnology

Echinocandins: Structural diversity, Biosynthesis and Development of Antimycotics

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A) Biosynthetic gene clusters

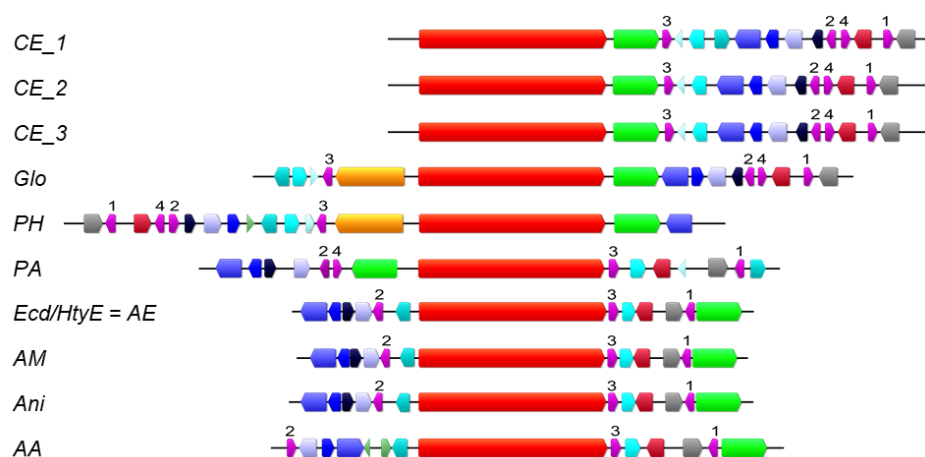


Figure S1: Maps of echinocandin biosynthetic gene clusters. The organisms are listed in Tables S1, and the color code of genes is explained in Table S2.

Table S1. Echinocandin biosynthetic gene clusters.

Cluster	Organism	NCBI-ID
CE_1	<i>Coleophoma cylindospora</i> F-11899, FERM:BP-2635 (previously <i>C. empetri</i>)	AB723722
CE_2	<i>Coleophoma cylindospora</i> No. 14573, FERM:BP-6252 (previously <i>C. empetri</i>)	AB720725
CE_3 ^{cc}	<i>Coleophoma cylindospora</i> FERM:BP-5796 (previously <i>C. crateriformis</i>)	AB720076
GL/Glo	GL: <i>Glarea lozoyensis</i> wild-type strain ATCC 20868 Glo: <i>Glarea lozoyensis</i> mutant strain ATCC 74030	NW007360987 AGUE01000179
PH	<i>Phialophora</i> cf. <i>hyalina</i> No. 16616 (previously <i>Tolypocladium parasiticum</i>)	AB720726
PA	<i>Penicillium arenicola</i> NRRL 8095 (suggested genus: <i>Phialomyces</i> ; previously <i>Acrophialophora limonispora</i> nov. spec.)	MN518690
Ecd/Hty = AE	<i>Ecd/Hty</i> : <i>Aspergillus pachycristatus</i> NRRL 11440 (previously <i>Emericella rugulosa</i>) [virtually identical with the AE cluster, originally deposited as a sequence from <i>Aspergillus spinulosporus</i> NRRL 3860, (previously <i>Aspergillus delacroixii</i> and <i>Emericella nidulans</i> var. <i>echinulatus</i>)](Hüttel et al. 2016)	alignment of <i>Ecd</i> : JX421684 and <i>Hty</i> : JX421685 AE: AB720074
AM	<i>Aspergillus mulundensis</i> DSMZ 5745	KP742486
Ani	<i>Aspergillus nidulans</i> NRRL 8112	KT806042
AA	<i>Aspergillus aculeatus</i> ATCC 16872	GOLD Project ID: Gp0010055

Table S2: Proteins encoded in echinocandin biosynthetic gene clusters.

Color	Name	Protein function	Remarks
	NRPS	nonribosomal peptide synthetase	
	MDT	multidrug transporter	
	FAC	long-chain fatty acyl-CoA ligase	
	IPMS	isopropylmalate synthase	homotyrosine biosynthesis
	ACN	aconitase	homotyrosine biosynthesis
	IPMDH	isopropylmalate dehydrogenase	homotyrosine biosynthesis
	TA	transaminase	homotyrosine biosynthesis, not in cluster AA
	P1	putative protein, unknown function	
1	LDO	α KG-dependent L-leucine dioxygenase	very low in vitro activity
2	PH	α KG-dependent L-proline hydroxylase	in vitro activity
3	hT3H	α KG-dependent L-homotyrosine 3-hydroxylase	very low in vitro activity
4	GH	α KG-dependent putative L-glutamine hydroxylase	<i>Leotiomycetes</i> clusters and cluster PA
	OrnH	CYP, L-ornithine 4,5-hydroxylase	
	hT4H	CYP, putative L-homotyrosine 4-hydroxylase	absent in cluster CE_2 and CE_3
	ABH	putative thioesterase (α/β -hydrolase)	<i>Leotiomycetes</i> clusters and cluster PA
	PKS	polyketide synthase	<i>Leotiomycetes</i> clusters

B) Compounds and producer strains

Table S3: Echinocandins isolated from wildtype and mutant strains.

[a] Main products of wildtype strains are shown in bold. [*] Only known from mutant strain. [b] Differences from the archetype pneumocandin A₀ are indicated in bold. [c] Characterized only by LC-MS techniques. [d] proposed name. For an overview on “FR” compounds, see Hashimoto (2009); for “WF” classification see Hino et al. (2001). Revised and updated from (Hüttel 2017).

Amino acid abbreviations:

Position 1: *Orn*: L-ornithine; *dhOrn*: (4*R*,5*R*)-4,5-dihydroxy-L-ornithine; *4hOrn*: (*R*)-4-hydroxy-L-ornithine; *5hOrn*: (*R*)-5-hydroxy-L-ornithine.

Positions 3 and 6: *4-Hyp*: *trans*-4-hydroxy-L-proline, *3-Hyp*: *trans*-3-hydroxy-L-proline; *4Me3Hyp*: (3*S*,4*S*)-3-hydroxy-4-methylproline; *4hMe3Hyp*: (3*S*,4*R*)-3-hydroxy-4-hydroxymethyl-L-proline; *3,4dHyp*: (3*R*,4*S*)-3,4-dihydroxy-L-proline.

Position 4: *hTyr*: L-homotyrosine; *3,4dhTyr*: (3*S*,4*S*)-3,4-dihydroxyhomotyrosine; *3hhTyr*: (*R*)-3-hydroxy-L-homotyrosine; *4hhTyr*: (*R*)-4-hydroxy-L-homotyrosine; -3'SO₄: sulfate group at aromatic position 3' of the specified homotyrosine; -4-OH: the phenol group at 4' of the specified homotyrosine is sulfated; -3'OH,4'SO₄: the phenol is sulfated at 4' and hydroxylated at 3'.

Position 5: *hGln*: (*R*)-3-hydroxy-L-glutamine.

Abbr.	Compound ^[a] (Synonyms)	Fatty acid chain	Amino acid: ^[b] 1 ^l	2	3	4 ^l	5 ^l	6 ^l
P_{A0}	Pneumocandin A₀ (L-671,329)	dimethylmyristoyl	<i>dhOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>dhTyr</i>	<i>hGln</i>	<i>4Me3Hyp</i>
P_{A1}	Pneumocandin A ₁	dimethylmyristoyl	<i>dhOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>4hhTyr</i>	<i>hGln</i>	<i>4Me3Hyp</i>
P_{A2}	Pneumocandin A ₂	dimethylmyristoyl	<i>Orn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>dhTyr</i>	<i>hGln</i>	<i>4Me3Hyp</i>
P_{A3}	Pneumocandin A ₃	dimethylmyristoyl	<i>5hOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>hTyr</i>	<i>hGln</i>	<i>4Me3Hyp</i>
P_{A4}	Pneumocandin A ₄	dimethylmyristoyl	<i>Orn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>hTyr</i>	<i>hGln</i>	<i>4Me3Hyp</i>
P_{AG}	Pneumocandin G* (= Pneumocandin A _G ^[d])	dimethylmyristoyl	<i>dhOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>3hhTyr</i>	<i>hGln</i>	<i>4Me3Hyp</i>
P_{A9}	Compound 9* (= Pneumocandin A ₉ ^[d])	dimethylmyristoyl	<i>5hOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>hTyr</i>	<i>hGln</i>	<i>4Me3Hyp</i>
P_{A13}	Compound 13* (= Pneumocandin A ₁₃ ^[d])	dimethylmyristoyl	<i>4hOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>hTyr</i>	<i>hGln</i>	<i>4Me3Hyp</i>
P_{B0}	Pneumocandin B ₀	dimethylmyristoyl	<i>dhOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>dhTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B1}	Pneumocandin B ₁	dimethylmyristoyl	<i>dhOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>4hhTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B2}	Pneumocandin B ₂	dimethylmyristoyl	<i>Orn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>dhTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B5}	Pneumocandin B ₅	dimethylmyristoyl	<i>5hOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>dhTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B6}	Pneumocandin B ₆	dimethylmyristoyl	<i>4hOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>dhTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{BF}	Pneumocandin F* (Pneumocandin B _F)	dimethylmyristoyl	<i>dhOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>3hhTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B10}	Compound 10* (Pneumocandin B ₁₀ ^[d])	dimethylmyristoyl	<i>5hOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>hTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B11}	Compound 11* (Pneumocandin B ₁₁ ^[d])	dimethylmyristoyl	<i>4hOrn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>hTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B14}	Compound 14* (Pneumocandin B ₁₄ ^[d])	dimethylmyristoyl	<i>Orn</i>	<i>Thr</i>	<i>4Hyp</i>	<i>hTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B0-Ser}	Pneumocandin B _{0-Ser}	dimethylmyristoyl	<i>dhOrn</i>	<i>Ser</i>	<i>4Hyp</i>	<i>dhTyr</i>	<i>hGln</i>	<i>3Hyp</i>
P_{B5-Ser}	Pneumocandin B _{5-Ser}	dimethylmyristoyl	<i>5hOrn</i>	<i>Ser</i>	<i>4Hyp</i>	<i>dhTyr</i>	<i>hGln</i>	<i>3Hyp</i>

P_{C0}	Pneumocandin C ₀	dimethylmyristoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> 4Hyp
P_{D0}	Pneumocandin D ₀	dimethylmyristoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> 3,4dHyp
P_{D2}	Pneumocandin D ₂	dimethylmyristoyl	Orn	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> 3,4dHyp
P_{E0}	Pneumocandin E ₀	dimethylmyristoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> Pro
P_H	Pneumocandin H [*]	myristoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> 3Hyp
P_I	Pneumocandin I [*]	pentadecanoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> 4Me3Hyp
P_J	Pneumocandin J [*]	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> 3Hyp
P_K	Pneumocandin K [*]	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> 4Me3Hyp
A	Acrophiarin (Antibiotic 31794/F-1)	myristoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	h <i>Gln</i> 4Me3Hyp
S_A	Sporiofungin A (S 41062/F-1)	dimethylmyristoyl	dh <i>Orn</i>	Ser 4Hyp 3<i>h</i>hTyr	h <i>Gln</i> 4Me3Hyp
S_B	Sporiofungin B (S 41062/F-6)	dimethylmyristoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp 3<i>h</i>hTyr	h <i>Gln</i> 3Hyp
S_C	Sporiofungin C (S 41062/F-7)	dimethylmyristoyl	MedhOrn	Ser 4Hyp 3<i>h</i>hTyr	h <i>Gln</i> 4Me3Hyp
C	Cryptocandin	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	Gln 4hMe3Hyp
FR₉₀₁₃₇₉	FR901379 (WF11899A)	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i> -3'SO ₄	h <i>Gln</i> 4Me3Hyp
FR₉₀₁₃₈₁	FR901381 (WF11899B)	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp 3<i>h</i>hTyr -3'SO ₄	h <i>Gln</i> 4Me3Hyp
FR₉₀₁₃₈₂	FR901382 (WF11899C)	palmitoyl	5hOrn	<i>Thr</i> 4Hyp 3<i>h</i>hTyr -3'SO ₄	h <i>Gln</i> 4Me3Hyp
FR₂₂₀₈₉₇	FR220897 (WF14573B)	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp 3<i>h</i>hTyr -3'OH,4'SO ₄	h <i>Gln</i> 4Me3Hyp
FR₂₂₀₈₉₇	FR220899 (WF14573A)	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp 3<i>h</i>hTyr -3'OH,4'SO ₄	h <i>Gln</i> 3Hyp
FR₁₉₀₂₉₃	FR190293 (WF16616)	dimethylmyristoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i> -3'SO ₄	h <i>Gln</i> 4Me3Hyp
Fr₂₂₇₆₇₃	FR227673 (WF22210)	dimethylpalmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i> -3'SO ₄	h <i>Gln</i> 4Me3Hyp
FR₂₀₉₆₀₂	FR209602 (WF738A)	palmitoyl	dh <i>Orn</i>	Ser 4Hyp 3<i>h</i>hTyr -3'SO ₄	h <i>Gln</i> 4Me3Hyp
FR₂₀₉₆₀₃	FR209603 (WF738B)	palmitoyl	dh <i>Orn</i>	Ser 4Hyp 3<i>h</i>hTyr -3'SO ₄	h <i>Gln</i> 3Hyp
FR₂₀₉₆₀₄	FR209604 (WF738C)	palmitoyl	5hOrn	Ser 4Hyp 3<i>h</i>hTyr -3'SO ₄	h <i>Gln</i> 4Me3Hyp
E_B	Echinocandin B (A-30912 Factor A, Antibiotic A-22082, SL7810/F)	linoleoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	Thr 4Me3Hyp
E_C	Echinocandin C (A-30912 Factor B, SL 7810/F-II)	linoleoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp 3<i>h</i>hTyr	Thr 4Me3Hyp
E_D	Echinocandin D (A-30912 Factor D, SL 7810/F-III)	linoleoyl	Orn	<i>Thr</i> 4Hyp 3<i>h</i>hTyr	Thr 4Me3Hyp
E_{BPro}	Echinocandin B _{Pro} ^{*[c]}	linoleoyl	dh <i>Orn</i>	<i>Thr</i> Pro dh <i>hTyr</i>	Thr 4MePro
E_{CPro}	Echinocandin C _{Pro} ^{*[c]}	linoleoyl	dh <i>Orn</i>	<i>Thr</i> Pro 3<i>h</i>hTyr	Thr 4MePro
E_{De1}	Echinocandin B derivative 1 ^{*[d]}	linoleoyl	Orn	<i>Thr</i> 4Hyp dh <i>hTyr</i>	Thr 4Me3Hyp
E_{De2}	Echinocandin B derivative 2 ^{*[d]}	linoleoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp 4<i>h</i>hTyr	Thr 4Me3Hyp
E_{De3}	Echinocandin B derivative 3 ^{*[d]}	linoleoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp hTyr	Thr 4Me3Hyp
E_{De4}	Echinocandin B derivative 4 ^{*[d]}	linoleoyl	5hOrn	<i>Thr</i> 4Hyp hTyr	Thr 4Me3Hyp
E_{De5}	Echinocandin B derivative 5 ^{*[d]}	linoleoyl	Orn	<i>Thr</i> 4Hyp hTyr	Thr 4Me3Hyp
A_{30912H}	A-30912 Factor H	linoleoyl	MedhOrn	<i>Thr</i> 4Hyp dh <i>hTyr</i>	Thr 4Me3Hyp
A_{Ay}	Aculeacin A or A_y	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	Thr 4Me3Hyp
A_{Ag}	Aculeacin A _α	myristoyl	dh <i>Orn</i>	<i>Thr</i> 4Hyp dh <i>hTyr</i>	Thr 4Me3Hyp

A_{D_γ}	Aculeacin D _γ	palmitoyl	dh <i>Orn</i>	<i>Thr</i> 4 <i>Hyp</i> 3<i>hh</i>Tyr	<i>Thr</i> 4Me3 <i>Hyp</i>
A_{D_α}	Aculeacin D _α	myristoyl	dh <i>Orn</i>	<i>Thr</i> 4 <i>Hyp</i> 3<i>hh</i>Tyr	<i>Thr</i> 4Me3 <i>Hyp</i>
M	Mulundocandin	12-methylmyristoyl	dh <i>Orn</i>	<i>Thr</i> 4 <i>Hyp</i> dh <i>h</i> Tyr	<i>Ser</i> 4Me3 <i>Hyp</i>
dM	Deoxymulundocandin	12-methylmyristoyl	dh <i>Orn</i>	<i>Thr</i> 4 <i>Hyp</i> 3<i>hh</i>Tyr	<i>Ser</i> 4Me3 <i>Hyp</i>

Table S4: Fungal strains producing echinocandins. Revised and updated from Hüttel (2017).

Species	Metabolites	Strain (Comment)
a) Wild-type strains		
<i>Penicillium arenicola</i> (= <i>Acrophialophora limonisporea</i> nov. spec. ‘Dreyfuss + Muller’; suggested genus: <i>Phialomyces</i>)	A	NRRL 8095 (cluster Pa)(Dreyfuss 1986; Dreyfuss and Tschertter 1979; Lan et al. 2020), additional producer strains: NRRL 3392, NRRL 31507, NRRL 31509 (Lan et al. 2020)
<i>Aspergillus aculeatus</i>	A_{Ay} , A _{Ad} , A _{D7} , A _{D8}	M-4845, NRRL 11270 (Otani et al. 1978)
	A _{Ay} and others	M-4214, NRRL 8075 (Mizuno et al. 1977; Satoi et al. 1977)
<i>Aspergillus aculeatus</i> (= <i>A. japonicus</i> var. <i>aculeatus</i>)	A _{Ay}	ATCC 16872, NRRL 5094 (cluster: AA (lacks aminotransferase AT) genome available under GOLD seq. ID: Gp0010055) (Nordberg et al. 2014)
<i>Aspergillus mulundensis</i> (= <i>A. sydowii</i> Thorn and Church var. nov. <i>mulundensis</i> Roy)	M , dM	Cult. No. Y-30462, DSMZ 5745 (cluster: AM) (Bills et al. 2016; Mukhopadhyay et al. 1987; Roy et al. 1987; Wingfield et al. 2018; Yue et al. 2015)
<i>Aspergillus nidulans</i>	E _B	NRRL 8112, ATCC 58396 (cluster: <i>Ani</i>) (Higgins and Michel 1977)
	E _B	ZBJ-0817, CCTCC M 2010275 (Zou et al. 2015)
	E _B	F-109,962 (de la Cruz et al. 2012)
	E _B	F-167,724 (de la Cruz et al. 2012)
	E _B	CBS 240.9 (de la Cruz et al. 2012)
	E _B	CBS 542.83 (de la Cruz et al. 2012)
<i>Aspergillus pachycristatus</i> (= <i>Emericella rugulosa</i> , <i>A. nidulans</i> var. <i>roseus</i>)	E_B , E _C , E _D , A _{30912H}	NRRL 11440, ATCC 58397 (products: “A-42355 antibiotic mixture”; cluster: <i>Ecd/Hty</i> (Boeck and Kastner 1981; Lan et al. 2019; Yue et al. 2015)
<i>Aspergillus rugulosus</i>	E_B , E _C , E _D , an others	NRRL 8113 (Factors A–G) (Hoehn and Michel 1977)
	E_B , E _C , E _D ,	NRRL 8039 (Keller-Juslén et al. 1976; Traber et al. 1979), further strains are listed in Dreyfuss (1986)
<i>Aspergillus spinulosporus</i> NRRL 3860 (= <i>A. delacroixii</i> , <i>Emericella nidulans</i> var. <i>echinulata</i>)	E _B	A 32204, NRRL 3860 (stated cluster: <i>AE is identical with Ecd/Hty</i> (Benz et al. 1974)
<i>Chalara</i> sp. (= <i>Pochonia parasitica</i> , <i>Tolypocladium parasiticum</i>)	Fr ₂₂₇₆₇₃	FERM:BP-5553, No. 22210 (Hino et al. 2001; Kanasaki et al. 2006b)
<i>Coleophoma cylindrospora</i> (= <i>C. crateriformis</i>) (= <i>C. empetri</i>) (= <i>C. empetri</i>)	FR₂₀₉₆₀₂ , FR ₂₀₉₆₀₃ , FR ₂₀₉₆₀₄	FERM:BP-5796, No. 738, cluster: CC_1, <i>prfks1a</i> gene (Kanasaki et al. 2006c; Wingfield et al. 2018)
	FR₉₀₁₃₇₉ , FR ₉₀₁₃₈₁ , FR ₉₀₁₃₈₂	FERM:BP-2635, F-11899 (cluster: CC_2 ^{CE-1}) (Iwamoto et al. 1994)
	FR₂₂₀₈₉₇ , FR₂₂₀₈₉₉	FERM:BP-6252, No. 14573, cluster: CC_3 ^{CE-2} , <i>prfks1a</i> gene (Hino et al. 2001; Kanasaki et al. 2006a; Wingfield et al. 2018)
<i>Cryptosporiopsis</i> cf. <i>quercina</i>	C	(Strobel et al. 1999)
<i>Cryptosporiopsis</i> sp.	P _{A0}	“isolate P30A” (Noble et al. 1991)
<i>Emericella cleistominuta</i>	E _B	CBS 200.75 (de la Cruz et al. 2012)
<i>Emericella navahoensis</i>	E _B	CBS 351.81 (de la Cruz et al. 2012)
<i>Emericella parvathecica</i>	E _B	CBS 493.65 (de la Cruz et al. 2012)
<i>Emericella quadrilineata</i>	E _B	J. Guarro WD-007 (de la Cruz et al. 2012)
	E _B	CBS 114511 (de la Cruz et al. 2012)
	E _B	J. Guarro WH-042 (de la Cruz et al. 2012)
<i>Emericella rugulosa</i>	E _B	J. Guarro WO-021 (de la Cruz et al. 2012)
	E _B	J. Guarro WO-148 (de la Cruz et al. 2012)
	E _B	CBS 171.71 (de la Cruz et al. 2012)
	E _B	CBS 852.96 (de la Cruz et al. 2012)

	E _B	J. Guarro WP-050 (de la Cruz et al. 2012)
<i>Emericella</i> sp.	E _B	F-166,688 (de la Cruz et al. 2012)
<i>Glarea lozoyensis</i> (= <i>Zalerion arboricola</i>)	P _{A0} , P _{A1} , P _{A3} , P _{A4} , P _{B0} , P _{B1} , P _{B2} , P _{B5} , P _{B6} , P _{B0-Ser} , P _{B5-Ser} , P _{C0} , P _{D2} (wild-type), P _{E0}	ATCC 20868, F-160870 (pneumocandin A ₀ /B ₀ ≈ 7 : 1; cluster: <i>GL</i>) (Bills et al. 1999; Li et al. 2015; Masurekar et al. 1992; Morris et al. 1994a; Peláez et al. 2011; Schwartz et al. 1989; Schwartz et al. 1992)
	P _{A0} , P _{A1} , P _{B0}	F-226836 (Peláez et al. 2011)
	P _{A0} , P _{A1} , P _{B0}	F- 226838 (Peláez et al. 2011)
	P _{A0} , P _{A1} , P _{B0}	F- 239379 (Peláez et al. 2011)
<i>Pezicula</i> sp.	P _{A0}	(Noble et al. 1991)
<i>Pezicula radiculicola</i> (= <i>Cryptosporiopsis</i> sp.)	S _A , S _B , S _C	NRRL 12192, ATCC 20594, S 41 062/F cluster: <i>Pr</i> , <i>prfks1a</i> gene (Balkovec 1994; Dreyfuss 1986; Dreyfuss and Tschertner 1982; Yue et al. 2018)
<i>Venustampulla echinocandica</i> (= <i>Phialophora</i> cf. <i>hyaline</i> , <i>Tolypocladium parasiticum</i>)	Fr ₁₉₀₂₉₃	No. 16616, FERM:BP-5553, cluster: <i>Tpa</i> (Bills et al. 2014; Hino et al. 2001; Kanasaki et al. 2006b; Untereiner et al. 2019; Wingfield et al. 2018)
b) Mutant strains		
<i>Glarea lozoyensis</i>	P _{A0} , P _{B0} , P _{D0}	ATCC 20957 (pneumocandin A ₀ /B ₀ ≈1:10) (Masurekar et al. 1992), (Morris et al. 1994b)
	P _{A2}	ATCC 20958 (main product: pneumocandin A ₂) (Masurekar et al. 1992)
	P _{A2} , P _{A4}	ATCC 20988 (main products: pneumocandin A ₂ and A ₄) (Masurekar et al. 1992)
	P _{A0} , P _{B0}	ATCC 74030 (pneumocandin A ₀ /B ₀ ≈1:80, cluster: <i>Glo</i>) (Masurekar et al. 1992)
	P _{B0}	CGMCC 2933 (Developed from strain ATTC 20957 increased pneumocandin B ₀ production, cluster: <i>Glo</i>) (Xu et al. 2012)
	P _{A1} , P _{A3} , P _{A4} , P _{A9} , P _{A13} , P _{B1} , P _{B10} , P _{B11} , P _{B14}	ATCC 20868 ΔGLOXY1 (no hydroxylation at <i>hTyr</i> C-3) (Li et al. 2015)
	P _{B0}	ATCC 20868 ΔGLOXY4 (10GL0% B ₀) (Chen et al. 2015)
	P _F , P _G	ATCC 20868 ΔGLP450-1 (Li et al. 2015)
	P _{A2} , P _{B2} ,	ATCC 20868 ΔGLP450-2 (Li et al. 2015)
	A, P _{I-K}	ATCC 20868 ΔGLPKS4 (Chen et al. 2016)
<i>Aspergillus nidulans</i>	E _B	ULN-59 (Hu et al. 2016; Zou et al. 2015)
	E _B	ZBJ12037, CCTCC M 2015677 (Hu et al. 2016)
<i>Phialophora</i> cf. <i>hyalina</i> (= <i>Tolypocladium parasiticum</i>)	FR ₁₉₀₂₉₃	No. 16616 (increased production of WF16616) (Haifeng et al. 2013)
<i>Aspergillus pachycristatus</i>	E _D , E _{De1}	ATCC 58397 ΔecdH (ornithine hydroxylase disruption)
	E _{De2} , E _{De3} , E _{De4} , E _{De5} ,	ATCC 58397 ΔecdG (homotyrosine hydroxylase disruption)
	E _{BPro} , E _{CPro}	ATCC 58397 ΔhtyE (proline hydroxylation disruption)

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