

Supplementary Information

**The diversity and ecological roles of *Penicillium* in intertidal zones**

Myung Soo Park<sup>1</sup>, Seung-Yoon Oh<sup>1</sup>, Jonathan J. Fong<sup>2</sup>, Jos Houbraken<sup>3</sup>, Young Woon Lim<sup>1\*</sup>

<sup>1</sup>School of Biological Sciences and Institute of Microbiology, Seoul National University, Seoul 08826, South Korea

<sup>2</sup>Science Unit, Lingnan University, Tuen Mun, Hong Kong

<sup>3</sup>Westerdijk Fungal Biodiversity Centre, Uppsalalaan 8, 3584 CT Utrecht, Netherlands

Supplementary Table 1 Information, halo-tolerance, enzyme activity, gallic acid reaction, GenBank accession numbers for *Penicillium* species isolated from sand and mudflat along the west and south coast of South Korea

Species	Strain	Number of strain			Halo-tolerance <sup>a</sup>	Clear zone (mm) <sup>b</sup>			Gallic acid reaction	Accession No. ( <i>BenA</i> )
		DRBC	GYP	PDA		EA	GA	PA		
<i>P. allii</i>	SFC20151118-M09	2			T	4.5	1	9.5	-	MK682830
<i>P. allii-sativi</i>	SFC20151118-M13		8		T	2.5	0	6	-	MK682831
<i>P. antarcticum</i>	SFC20150915-M01	12	8	10	T	1.5	3.5	10.5	-	MK682832
<i>P. atramentosum</i>	SFC20150402-M34	10	2	4	T	2.5	2	3	-	MK682833
<i>P. aurantioviolaceum</i>	SFC20150303-M06	10		2	T	0	4	3	-	MK682834

<i>P. bialowiezense</i>	SFC20151014-M03	2			T	7	6.5	11	-	MK682835
<i>P. bissettii</i>	SFC100822			2	T	3.5	1	0	-	MK682836
<i>P. brasilianum</i>	SFC20150303-M10	12	8		T	2.5	1	1	-	MK682837
<i>P. brevicompactum</i>	SFC20151014-M11	20	4		T	5	6.5	12.5	-	MK682838
<i>P. caperatum</i>	SFC20151118-M06	2			T	0	2	3	+	MK682839
<i>P. charlesii</i>	SFC20150915-M13	4			T	0	1	0	-	MK682840
<i>P. chrysogenum</i>	SFC20151014-M02		6		T	1	6	5	-	MK682841
<i>P. citrinum</i>	SFC20151118-M02	10	6	16	T	5	9	8	-	MK682842
<i>P. commune</i>	SFC20151118-M04	10	2		T	1	6	4	+	MK682843
<i>P. coprophilum</i>	SFC20150303-M11	2			T	5	6	9	-	MK682844
<i>P. copticola</i>	SFC20150303-M12		2		T	3.5	6	9.5	+	MK682845
<i>P. cremeogriseum</i>	SFC20151014-M15	2	2	6	T	0	1	0	-	MK682846
<i>P. crustosum</i>	SFC20151118-M08	74	40	12	T	2.5	5.5	2	-	MK682847
<i>P. daejeonium</i>	SFC20151014-M05		2	4	T	3	3	12	-	MK682848
<i>P. decaturense</i>	SFC20150303-M14	6	4		T	3	2.5	5.5	+	MK682849
<i>P. digitatum</i>	SFC20151014-M04	4			T	2	0	0	+	MK682850
<i>P. echinulatum</i>	SFC20151014-M09	4			T	3	6	6.5	-	MK682851
<i>P. expansum</i>	SFC20150402-M38	24			T	3	4	8.5	-	MK682852
<i>Penicillium</i> sp. 05	SFC100716			2	T	1	6	13	-	MK682887
<i>P. frequentans</i>	SFC20150915-M09	2		2	T	1.5	2	5	-	MK682853
<i>P. glabrum</i>	SFC20150915-M02	10	4		T	2	5	12	-	MK682854
<i>P. griseofulvum</i>	SFC20151118-M01	12	6		T	3	6	2.5	-	MK682855

<i>P. guanacastense</i>	SFC100711		4		T	3.75	6	13	-	MK682856
<i>P. hetheringtonii</i>	SFC20151014-M08	4	2		T	6	5	8	+	MK682857
<i>P. infrapurpureum</i>	SFC20150915-M12	2		2	T	0	2	0	-	MK682858
<i>P. janczewskii</i>	SFC20151014-M10		2		T	5	5.5	10	+	MK682859
<i>P. janthinellum</i>	SFC20151118-M12	2			T	0	4	1	-	MK682860
<i>P. javanicum</i>	SFC20151118-M07	2		2	T	5.5	4	2	-	MK682861
<i>P. jejuense</i>	SFC20150402-M41	2			T	2	1.5	10	+	MK682862
<i>P. koreense</i>	SFC20151014-M13	20	6	8	T	0	0	0	-	MK682863
<i>P. limosum</i>	SFC20151118-M05	2			T	0	2	3.5	-	MK682864
<i>P. magnielliptisporum</i>	SFC20151118-M03		2		T	3	0	2	-	MK682865
<i>P. mallochii</i>	SFC20150915-M03	2			T	2.5	5	12	-	MK682866
<i>P. maximae</i>	SFC20151014-M14	6			T	1	5	10	-	MK682867
<i>P. menonorum</i>	SFC20150915-M07	6		4	T	4.5	5	1	+	MK682868
<i>P. mexicanum</i>	SFC20151014-M01		2		T	1	0	1	-	MK682869
<i>P. multicolor</i>	SFC20151118-M10	2			T	0	0	0	-	MK682870
<i>P. nalgiovense</i>	SFC20150402-M42			4	T	3	5	1	+	MK682871
<i>P. oxalicum</i>	SFC20150915-M10	66	24	12	T	2	2	12.5	-	MK682872
<i>P. paneum</i>	SFC20150915-M14	6		4	T	0	0	1	-	MK682873
<i>P. piscarium</i>	SFC20151014-M16	2	4		T	0	0	0	-	MK682874
<i>P. polonicum</i>	SFC20151014-M06	14	4		T	4	6	11.5	+	MK682875
<i>P. raperi</i>	SFC20150915-M08	36	32	24	T	1.5	8	2	-	MK682876
<i>P. rubens</i>	SFC20151014-M07		10		T	6	6	1	-	MK682877

<i>P. samsonianum</i>	SFC100899	2			T	4.5	5	4	-	MK682878
<i>P. solitum</i>	SFC100989		4		T	2	2	5	-	MK682879
<i>P. steckii</i>	SFC20150303-M17	4	2	2	T	4.5	0	10	-	MK682880
<i>P. sumatrense</i>	SFC20150915-M04	2	4	6	T	1	2	5.5	+	MK682881
<i>P. terrigenum</i>	SFC20150915-M06		4	4	T	4.5	7	6	+	MK682882
<i>P. velutinum</i>	SFC20150915-M11			2	T	1.5	4.5	2.5	-	MK682883
<i>P. viticola</i>	SFC20150915-M05	2			T	2	4	12.5	-	MK682884
<i>P. westlingii</i>	SFC20151118-M11	4			T	0	4	6	+	MK682885
<i>Penicillium</i> sp. 01	SFC20150303-M09	20	8		T	1	1	2.5	-	MK682886
<i>Penicillium</i> sp. 08	SFC100917	4	4		T	1	2	1	-	MK682888
<i>Penicillium</i> sp. 10	SFC100725			2	T	0	0	0	-	MK682889
<i>Penicillium</i> sp. 11	SFC101038	2			T	4	0	0	+	MK682890
<i>Penicillium</i> sp. 13	SFC100985	4			T	0	1	0	+	MK682891
<i>Penicillium</i> sp. 14	SFC100817	2			T	3	7	1.5	-	MK682892
<i>Penicillium</i> sp. 16	SFC100919	2	2		T	0	1	0	-	MK682893
<i>Penicillium</i> sp. 17	SFC100747	2			T	1	2	1	-	MK682894

<sup>A</sup>Species showed the best growth on MEA supplemented with artificial sea water (ASW) and without ASW (Corrected P < 0.05) are represented as “T”

<sup>b</sup>Endoglucanase (EA),  $\beta$ -glucosidase (GA), and protease (PA) activity

Supplementary Table 2 The number of strains or reads of *Penicillium* species detected from substrate (sand and mudflat), season (summer and winter), and seaside (west and south) using isolation (C), NGS using ITS (IN), and NGS using *benA* (BN)

Species	Seaside						Season						Substrate						Totals		
	West			South			Summer			Winter			Sand			Mudflat			C	IN	BN
	C	IN	BN	C	IN	BN	C	IN	BN	C	IN	BN	C	IN	BN	C	IN	BN			
<i>P. adametzii</i>		2	154			29		1			1	183		2	10			173		2	183
<i>P. allii</i>				2			2										2			2	
<i>P. allii-sativi</i>				8			8										8			8	
<i>P. antarcticum</i>	26	57	11151	4	9	70944	28	60	4897	2	6	77198	6	14	41925	24	52	40170	30	66	82095
<i>P. atramentosum</i>			10	16			2			14		10	4		10	12			16		10
<i>P. aurantioviolaceum</i>	8		1319	4		2	2			10		1321	2		109	10		1212	12		1321
<i>P. bialowiezense</i>		37	3078	2	25	8571		41	2827	2	21	8822		35	328	2	27	11321	2	62	11649
<i>P. bissetii</i>	2		127			15973	2		21			16079			1568	2		14532	2		16100
<i>P. brasilianum</i>	12	48	174	8	4	1057		47		20	5	1231	10	27	1018	10	25	213	20	52	1231
<i>P. brevicompactum</i>	4	8	5837	20	27	59258	2	18	50558	22	17	14537	2	4	33312	22	31	31783	24	35	65095
<i>P. cairnsense</i>			266						266									266			266
<i>P. caperatum</i>	2		110							2		110				2		110	2		110
<i>P. charlesii</i>			62	4						4		62			61	4		1	4		62
<i>P. chrysogenum</i>			2589	6		476	4			2		3065			2013	6		1052	6		3065
<i>P. citrinum</i>	18	3	3829	14	24	17473	6	21	15963	26	6	5339	2	26	11271	30	1	10031	32	27	21302
<i>P. commune</i>	2		296	10		101				12		397			332	12		65	12		397
<i>P. concentricum</i>			30920			17			30919			18			9924			21013			30937
<i>P. coprophilum</i>			38	2						2		38			38	2			2		38
<i>P. copticola</i>				2						2						2			2		
<i>P. corylophilum</i>			4027			3691			4027			3691			3800			3918			7718
<i>P. cremeogriseum</i>	8		3122	2		859	6		2886	4		1095	2		847	8		3134	10		3981

<i>P. crustosum</i>	22	220	44774	104	142	23213	20	208	25365	106	154	42622	18	206	29461	108	156	38526	126	362	67987
<i>P. daejeonium</i>	2	19	7023	4	1	7496	2	17	1250	4	3	13269	6	15	12769	5	1750	6	20	14519	
<i>P. daleae</i>			3403			676			1644			2435			16		4063			4079	
<i>P. decaturense</i>			605	10		499				10		1104	4		628	6		476	10		1104
<i>P. digitatum</i>		3	154	4	11	425		6	1	4	8	578	4	2	8		12	571	4	14	579
<i>P. echinulatum</i>				4				2			2					4				4	
<i>P. expansum</i>	10		29690	14		3848			25599	24		7939	4		24067	20		9471	24		33538
<i>P. exsudans</i>				2		4196	2		3929			267			4196	2			2		4196
<i>P. frequentans</i>	2		1073	2		681	4		1			1753	2		1708	2		46	4		1754
<i>P. georgiense</i>		10						9			1			7		3				10	
<i>P. glabrum</i>	8		560	6		13320	10		10045	4		3835	6		13686	8		194	14		13880
<i>P. griseofulvum</i>	16		828	2		3652				18		4480	8		2537	10		1943	18		4480
<i>P. griseopurpureum</i>			954			921						1875			921			954			1875
<i>P. guanacastense</i>				4				4								4			4		
<i>P. hetheringtonii</i>	2		6946	4		8393			3814	6		11525	4		4350	2		10989	6		15339
<i>P. infrapurpureum</i>	2		8	2			4					8	2			2		8	4		8
<i>P. janczewskii</i>				2		4				2		4				2		4	2		4
<i>P. janthinellum</i>				2				2								2				2	
<i>P. javanicum</i>	2		811	2		77	2			2		888			170	4		718	4		888
<i>P. jejuense</i>	2						2						2							2	
<i>P. koreense</i>	20		11373	14		62981	20		43778	14		30576	2		41294	32		33060	34		74354
<i>P. limosum</i>	2		904			713			1	2		1616			564	2		1053	2		1617
<i>P. magnielliptisporum</i>	2		3567			292			2	2		3857	2		11			3848	2		3859
<i>P. mallochii</i>	2							2												2	
<i>P. maximae</i>		3	1012	6	3	38	2	4		4	2	1050	2	3	2	4	3	1048	6	6	1050
<i>P. menororum</i>	10		25729			35903	4		6559	6		55073			45051	10		16581	10		61632

<i>P. mexicanum</i>			20090	2		799			20089	2		800			14714	2		6175	2		20889
<i>P. multicolor</i>		2		2	3	793	2			5	793		2	648	2	3	145	2	5		793
<i>P. nalgiovense</i>	4		283				4		283						4			283	4		283
<i>P. ochrochloron</i>						45						45			45						45
<i>P. olsonii</i>			6910			1			6906			5			2420			4491			6911
<i>P. ornatum</i>			31									31			31						31
<i>P. ovatum</i>			147						147									147			147
<i>P. oxalicum</i>	54	65	13429	48	32	4688	34	69	670	68	28	17447	16	53	12738	86	44	5379	102	97	18117
<i>P. paneum</i>			730	10		1128	6			4		1858	2		1250	8		608	10		1858
<i>P. paxilli</i>			825						824			1						825			825
<i>P. piscarium</i>	4			2		16	2			4		16	2			4		16	6		16
<i>P. polonicum</i>			12896	18		4579			11509	18		5966	2		13164	16		4311	18		17475
<i>P. radicicola</i>			8			1000						1008			1008						1008
<i>P. raperi</i>	92	7	17996		237	29299	84	239	8759	8	5	38536	12	110	20204	80	134	27091	92	244	47295
<i>P. rubefaciens</i>						54454			54116			338			22581			31873			54454
<i>P. rubens</i>	2			8		86	6			4		86	8		4	2		82	10		86
<i>P. samsonianum</i>			296	2						2		296	2		296				2		296
<i>P. sanguifluum</i>			1470						1470						1			1469			1470
<i>P. solitum</i>			1680	4		871				4		2551			1025	4		1526	4		2551
<i>P. steckii</i>			7251	8		16334	2		230	6		23355	2		6457	6		17128	8		23585
<i>P. sumatrense</i>	8	3	560	4	1	133	10	3		2	1	693	10	1	262	2	3	431	12	4	693
<i>P. terrigenum</i>	4	5	16584	4	5	45939	4	2	6	4	8	62517	6	5	34188	2	5	28335	8	10	62523
<i>P. ulaiense</i>						343						343			343						343
<i>P. velutinum</i>	2		7173			1476	2		1			8648	2		2734			5915	2		8649
<i>P. viticola</i>	2	23	2274		2		2	22	2274		3		2	21			4	2274	2	25	2274
<i>P. westlingii</i>			3	4		393	2		1	2		395	2		395	2		1	4		396

<i>P. yarmokense</i>		820		1		820		1		821		821		821								
<i>Penicillium</i> sp. 01	18	3509	10	15976	14	8047	14	11438	16	10737	12	8748	28	19485								
<i>Penicillium</i> sp. 08	4	2	404	4	12	2105	4	7	4	7	2509	4	3	1270	4	11	1239	8	14	2509		
<i>Penicillium</i> sp. 10				2																2		
<i>Penicillium</i> sp. 11	2		83					2		83		83	2							2	83	
<i>Penicillium</i> sp. 13	2		4558	2		4587			4		9145			3793	4		5352			4	9145	
<i>Penicillium</i> sp. 14	2		246			75	2				321			7	2		314			2	321	
<i>Penicillium</i> sp. 16			8	4		439			4		447	4		447						4	447	
<i>Penicillium</i> sp. 17	2						2														2	
<i>Penicillium</i> sp. 21						381					381			381							381	
<i>Penicillium</i> sp. 22			168			790					958						958				958	
<i>Penicillium</i> sp. 23			299								299			299							299	
<i>Penicillium</i> sp. 24			43								43						43				43	
<i>Penicillium</i> sp. 25			630			1					630			1			1				630	631
<i>Penicillium</i> sp. 26			45								45						28				17	45
<i>Penicillium</i> sp. 27			28								28						28				28	28
<i>Penicillium</i> sp. 28	12			4			10				6			8			8				16	
<i>Penicillium</i> sp. 29	13			9			16				6			6			16				22	
<i>Penicillium</i> sp. 33	18			40			33				25			36			22				58	
<i>Penicillium</i> sp. 34	19			12			14				17			20			11				31	
<i>Penicillium</i> sp. 36	8			94			79				23			94			8				102	
<i>Penicillium</i> sp. 38	3			10			8				5			4			9				13	
<i>Penicillium</i> sp. 39	12			9			7				14			8			13				21	



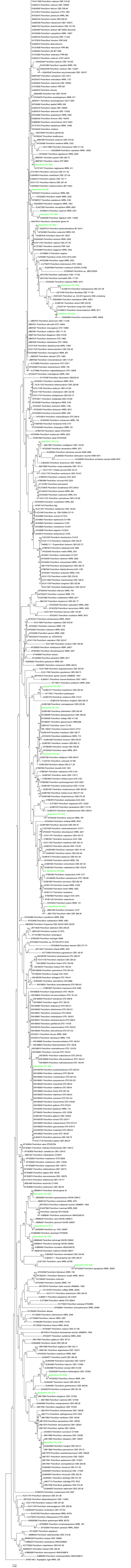
Supplementary Table 3 Growth rate of *Penicillium* species at different temperature on malt extract agar

Species	Strain	Growth rate (mm)				
		10°C	15°C	20°C	25°C	30°C
<i>P. allii</i>	SFC20151118-M09	10.3	23.0	32.0	39.0	16.3
<i>P. allii-sativi</i>	SFC20151118-M13	8.7	20.7	28.3	33.7	31.7
<i>P. antarcticum</i>	SFC20150915-M01	10.0	23.7	32.7	46.3	7.0
<i>P. atramentosum</i>	SFC20150402-M34	8.3	14.3	14.3	17.7	8.7
<i>P. aurantioviolaceum</i>	SFC20150303-M06	9.3	22.0	32.3	42.0	38.0
<i>P. bialowiezense</i>	SFC20151014-M03	11.0	17.3	22.7	24.3	0.0
<i>P. bissettii</i>	SFC100822	6.3	19.0	28.0	35.3	35.7
<i>P. brasilianum</i>	SFC20150303-M10	5.7	12.7	16.3	30.0	42.7
<i>P. brevicompactum</i>	SFC20151014-M11	7.0	16.0	22.0	22.0	3.0
<i>P. caperatum</i>	SFC20151118-M06	3.0	12.0	16.7	23.7	35.3
<i>P. charlesii</i>	SFC20150915-M13	3.0	8.0	15.3	18.0	9.0
<i>P. chrysogenum</i>	SFC20151014-M02	9.3	22.0	26.3	34.7	38.3
<i>P. citrinum</i>	SFC20151118-M02	3.0	9.0	17.0	26.0	30.3
<i>P. commune</i>	SFC20151118-M04	13.0	26.7	33.0	30.7	13.3
<i>P. coprophilum</i>	SFC20150303-M11	6.7	13.3	24.0	27.3	29.3
<i>P. copticola</i>	SFC20150303-M12	3.0	10.0	21.3	28.3	20.7
<i>P. cremeogriseum</i>	SFC20151014-M15	3.0	11.7	23.3	33.7	45.3
<i>P. crustosum</i>	SFC20151118-M08	12.0	24.0	31.7	34.3	28.0
<i>P. daejeonium</i>	SFC20151014-M05	5.3	14.0	22.0	28.3	12.7
<i>P. decaturense</i>	SFC20150303-M14	6.0	17.3	27.0	33.0	9.7
<i>P. digitatum</i>	SFC20151014-M04	4.7	16.0	24.3	25.0	6.0
<i>P. echinulatum</i>	SFC20151014-M09	11.3	23.7	30.3	35.0	13.0
<i>P. expansum</i>	SFC20150402-M38	11.0	19.7	27.7	34.7	3.3

<i>P. exsudans</i>	SFC100716	4.7	13.3	20.3	27.7	29.0
<i>P. frequentans</i>	SFC20150915-M09	7.7	19.7	27.0	35.0	24.7
<i>P. glabrum</i>	SFC20150915-M02	9.7	19.3	28.3	34.3	34.0
<i>P. griseofulvum</i>	SFC20151118-M01	7.7	17.3	24.0	26.3	24.7
<i>P. guanacastense</i>	SFC100711	5.3	10.0	16.7	25.0	31.3
<i>P. hetheringtonii</i>	SFC20151014-M08	3.3	12.0	17.7	31.0	32.0
<i>P. infrapurpureum</i>	SFC20150915-M12	4.0	8.3	13.3	16.0	7.7
<i>P. janczewskii</i>	SFC20151014-M10	4.3	11.3	18.0	26.0	19.3
<i>P. janthinellum</i>	SFC20151118-M12	3.3	12.7	20.7	29.3	35.0
<i>P. javanicum</i>	SFC20151118-M07	8.3	16.0	22.0	21.3	0.0
<i>P. jejuense</i>	SFC20150402-M41	7.3	17.7	29.7	39.7	14.0
<i>P. koreense</i>	SFC20151014-M13	3.0	9.0	20.3	28.7	33.3
<i>P. limosum</i>	SFC20151118-M05	3.0	13.0	26.3	38.0	47.0
<i>P. magnielliptisporum</i>	SFC20151118-M03	10.0	7.7	10.7	11.3	6.3
<i>P. mallochii</i>	SFC20150915-M03	4.0	11.3	20.0	29.0	23.0
<i>P. maximae</i>	SFC20151014-M14	3.0	12.0	21.0	30.0	32.7
<i>P. menonorum</i>	SFC20150915-M07	0.0	3.0	9.0	13.0	19.0
<i>P. mexicanum</i>	SFC20151014-M01	8.7	16.3	15.7	17.7	3.0
<i>P. multicolor</i>	SFC20151118-M10	3.0	7.7	12.3	17.0	13.0
<i>P. nalgiovense</i>	SFC20150402-M42	5.7	17.0	28.0	34.3	17.0
<i>P. oxalicum</i>	SFC20150915-M10	5.0	20.0	32.3	43.3	50.0
<i>P. paneum</i>	SFC20150915-M14	10.0	25.3	38.3	44.7	47.7
<i>P. piscarium</i>	SFC20151014-M16	5.0	16.0	26.3	37.3	44.7
<i>P. polonicum</i>	SFC20151014-M06	10.0	22.0	32.0	33.7	21.3
<i>P. raperi</i>	SFC20150915-M08	8.7	20.7	28.0	35.3	36.0
<i>P. rubens</i>	SFC20151014-M07	9.7	19.0	25.3	39.0	37.0
<i>P. samsonianum</i>	SFC100899	8.0	16.0	23.0	23.3	9.3

<i>P. solitum</i>	SFC100989	11.7	20.0	25.0	30.0	3.0
<i>P. steckii</i>	SFC20150303-M17	3.0	9.0	19.7	28.0	23.7
<i>P. sumatrense</i>	SFC20150915-M04	3.7	14.3	24.7	31.3	17.3
<i>P. terrigenum</i>	SFC20150915-M06	3.0	12.3	20.7	32.0	27.0
<i>P. velutinum</i>	SFC20150915-M11	6.0	19.0	31.3	45.0	50.0
<i>P. viticola</i>	SFC20150915-M05	6.7	14.7	24.0	29.3	9.0
<i>P. westlingii</i>	SFC20151118-M11	7.7	16.0	19.7	20.3	9.3
<i>Penicillium</i> sp. 01	SFC20150303-M09	5.3	13.0	25.0	33.0	31.7
<i>Penicillium</i> sp. 08	SFC100917	6.0	17.0	24.3	35.3	42.7
<i>Penicillium</i> sp. 10	SFC100725	0.0	8.3	18.7	19.3	11.0
<i>Penicillium</i> sp. 11	SFC101038	0.0	3.0	9.0	13.0	19.0
<i>Penicillium</i> sp. 13	SFC100985	4.7	13.7	20.3	32.7	40.7
<i>Penicillium</i> sp. 14	SFC100817	7.7	15.7	27.0	33.7	19.7
<i>Penicillium</i> sp. 16	SFC100919	3.0	13.7	21.7	36.7	43.0
<i>Penicillium</i> sp. 17	SFC100747	3.0	10.3	22.3	28.3	37.7

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Supplementary Figure 1 Neighbor joining tree inferred from the internal transcribed spacer (ITS) sequences of *Penicillium* species. The scale bar indicates the number of nucleotide substitutions per site. OTUs detected from ITS-NGS are indicated in green color.

