Review

Mycoviruses in Entomopathogenic Fungi

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Supplementary Materials

Table S1. Incidence of mycoviruses in entomopathogenic fungi.

Species	No. of isolates analysed	No. of isolates infected	Location	Reference
Beauveria amorpha	1	0	Spain	[38]
Beauveria bassiana	12	2	Canada	[34]
	13	2	Brazil (culture collections)	[35]
	73	40	Spain and Portugal	[25]
	8	6	New Zealand	[36]
	75	16	Brazil, Ecuador, Greece, Portugal, Russia, Spain, Syria, Uzbekistan	[37]
	43	12	Spain, France, and Denmark	[38]
	73	8	Korea	[41]
	28	8	China	[40]

Beauveria brongniartii	7	0	Korea	[41]
Beauveria caledonica	1	1	New Zealand	[36]
Beauveria pseudobassiana	5	0	Spain	[38]
	2	0	Korea	[41]
Beauveria varroae	3	0	Spain	[38]
Entomophthora muscae [a]	5	5	RNA-seq public databases[b]	[28]
	5	5	Denmark and Germany	[117]
	1	1	Denmark	[79]
	1	1	USA	[78]
Metarhizium anisopliae	41	2[c]	World[c]	[23]
	7	3	Brazil	[22]
	3	2	Oman and Trinidad	[34]
	73	28	Canada	[34]
	5	4	Brazil	[58]
	35	22	Brazil (ESALQ collection)	[59]
	7	0	Spain, Italy and Georgia	[38]
Metarhizium flavoviride	6	5	Australia, Benin, Chad, Mali	[34]
	7	5	Brazil, Tanzania, Nigeria and Australia	[133]
	1	0	Denmark	[38]
Metarhizium robertsii	1	0	Brazil (ESALQ collection)	[59]
	5	0	Spain and Denmark	[38]
Metarhizium brunneum	4	0	Spain and Denmark	[38]
Metarhizium guizhouense	2	0	Spain	[38]
Metarhizium majus	1	0	Denmark	[38]
Metarhizium pemphigi	7	2	Korea	[41]
Metarhizium pinghaense	2	2	Korea	[41]
Metarhizium rileyi	1	1	Korea	[41]
Trichoderma spp.	156	2	China	[163]
	307	32	Korea	[142]
Trichoderma harzianum	163	4[d]	China and Mongolia	[108]
	39	19	Italy	[164]

Trichoderma gamsii	29	7		
Trichoderma hamatum	9	6		
Trichoderma tomentosum	5	2		
Trichoderma samuelsii	4	1		
Trichoderma spirale	12	1		
Trichoderma velutinum	5	0		
Trichoderma virens	4	0		
Trichoderma koningii	2	0		
Trichoderma koningiopsis	2	0		
Trichoderma asperellum	1	0		
Cordyceps sp.	1	1	Brazil	[49]
Cordyceps amoene-rosea	2	1	Brazil	
Cordyceps farinosa	1	1	United States	
Cordyceps fumosorosea	6	3	Brazil, USA, France, and Nepal	
	12	3	Brazil, USA, Mexico and India	[165]
	2	1	Korea	[41]

a – For *Entomophthora muscae*, only RNA-seq and public transcriptome data are available; no population-based isolate studies have yet been reported.
b – Genomes assembled from public databases.
c – From Finland and Brazil.
d – *T. barbatum* and *T. harzianum* species.

Table S2. Mycoviruses characterised in *Beauveria* and their properties. The mycovirus name, the *Beauveria* spp. strain from which each virus was isolated, taxonomic classification (family and genus), and genome type are provided. For each viral RNA segment, the size in base pairs or nucleotides (bp or nt) with respective GenBank accession number, the encoded protein length in amino acids (aa), as well as its putative function, are listed. Reported effects of the mycovirus on the fungal host phenotype are summarised, alongside the detection methods used.

Mycovirus	Strain/Isolate	Taxonomy	Genome type	Segment size (bp or nt)	ORF product (aa)	Sequencing method	Effect on host phenotype	Reference
Beauveria bassiana RNA virus 1 (BbRV1)	EABb 06/02-Su	*Totiviridae*	dsRNA 1 segment	5,228; HE572591	CP (742); CCC42234 RdRP (834); CCC42235	Sanger	N.D.	[25]
Beauveria bassiana victorivirus 1 (BbVV1)	ICMP#6887	*Totiviridae Victorivirus*	dsRNA 1 segment	5,327; NC_024151	CP (759); YP_009032632 RdRP (843); YP_009032633	Sanger	N.D.	[36]
Beauveria bassiana non-segmented virus 1 (BbNV1)	EABb 92/11-Dm	"Unirnavirus"	dsRNA 1 segment	3,218; LN610699	HP (315); CEF90231 RdRP (585); CEF90232	Sanger	↑ Virulence ↑ Mycelial growth	[37,83]
Beauveria bassiana partitivirus 1 (BbPV1)	IMI 331273	*Partitiviridae Gammapartitivirus*	dsRNA 2 segments	1,771; LN896303 1,601; LN896304	RdRP (539); CUS18591 CP (440); CUS18592	Sanger	N.D.	[37]
Beauveria bassiana partitivirus 2 (BbPV2)	IMI 392612	*Partitiviridae Gammapartitivirus*	dsRNA 2 segments	1,801; LN896305 1,548; LN896304	RdRP (539); CUS18593 CP (432); CUS18594	Sanger	↑ Virulence ↑ UV-B resistance ↑ Drought tolerance ↑ Temperature tolerance ↑ Antagonistic activity	[37,136]
Beauveria bassiana small Narna-like virus (BbSNLV)	SP R 159	*Narnaviridae Narnavirus*	ssRNA 1 segment	1,689; LT627647	RdRP (509); SCW25778	Sanger	N.D.	[37]

Beauveria bassiana polymycovirus 1 (BbPmV1)	EABb 92/11-Dm	*Polymycoviridae* *Polymycovirus*	dsRNA 4 segments	2,425; LN896307	RdRP (775); CUS18595	Sanger	↑ Virulence ↑ Mycelial growth ↑ UV-B resistance ↑ Drought tolerance ↑ Temperature tolerance ↑ Antagonistic activity	[37,136]
				2,260; LN896308	HP (704); CUS18596			
				1,921; LN896309	MetT (610); CUS18597			
				1,373; LN896310	PASrp (306); CUS18598			
Beauveria bassiana chrysovirus 1 (BbCV1)	GXsk1011	*Chrysoviridae* *Alphachrysovirus*	dsRNA 4 segments	3,478; MK279433	RdRP (1,115); AZT88571	RNA-seq	N.D.	[102]
				3,143; MK279434	CP (976); AZT88572			
				3,069; MK279435	HP (964); AZT88573			
				2,770; MK279436	HP (851); AZT88574			
Beauveria bassiana non-segmented RNA virus 1 (BbRNV1)	ARSEF 8028	Unassignated	dsRNA 1 segment	3,170; MK279499	HP (315); AZT88648	RNA-seq	N.D.	[102]
					RdRP (590); AZT88649			
Beauveria bassiana partitivirus 3 (BbPV3)	RCEF5853	*Partitiviridae* *Epsilonpartitivirus*	dsRNA 2 segments	1,856; MN116721	RdRP (584); QFP40245	RNA-seq	N.D.	[166]
				1,719; MN116720	CP (500); QFP40246			
Beauveria bassiana polymycovirus 4 (BbPmV4)	BbOFJY	*Polymycoviridae* *Polymycovirus*	dsRNA 6 segments	2,427; MW385785	RdRP (768); QRF54813	RNA-seq	morphology ↓ sporulation ↑ virulence	[39,137,167]
				2,280; MW385786	Scaffold protein (699); QRF54814			
				2,015; MW385787	MetT (617); QRF54815			
				1,106; MW385788	PASrp (265); QRF54816			

				867; MW385789	Unknown (202); QRF54817			
				794; MW385790	PASrp (161); QRF54818			
Beauveria bassiana chrysovirus 2 (BbCV2)	BbOFZK152	*Chrysoviridae Betachrysovirus*	dsRNA 4 segments	3,441; MW314841	RdRP (1,114); QQZ01307	RNA-seq	morphology gene expression ↑ biomass ↓ virulence ↑ inhibition against phytopathogenic fungi	[103,135,139]
				2,779; MW314842	CP (805); QQZ01308			
				2,925; MW314843	HP (768); QQZ01309			
				2,688; MW314844	HP (777); QQZ01310			
Beauveria bassiana bipartite mycovirus 1 (BbBV1)	RCEF1446	Unassignated	dsRNA 2 segments	2,026; MW265927	RdRP (596); UDZ92910	RNA-seq	N.D.	[168]
				1,810; MW265928	CP (322); UDZ92911			
Beauveria bassiana polymycovirus 3 (BbPmV3)	ATHUM 4946	*Polymycoviridae Polymycovirus*	dsRNA 6 segments	2,401; LR991938	RdRP (767); CAD7829823	Sanger	Metabolism changes ↑ growth (dependent specific media)	[138]
				2,240; LR991939	Scaffold protein (697); CAD7829824			
				1,989; LR991940	MetT (615); CAD7829825			
				1,131; LR991941	PASrp (268); CAD7829826			
				937; LR991942	Unknown (170); CAD7829827			
				8,65; LR991943	Unknown (205); CAD7829828			
Beauveria bassiana victorivirus 2 (BbVV2)	RCEF6864	*Totiviridae Victorivirus*	dsRNA 1 segment	5,233; OR126353	CP (742); WMJ90927	RNA-seq	N.D.	[40]
					RdRP (834); WMJ90928			

Beauveria bassiana bipartite virus 2 (BbBV2)	RECF6899	Unassignated	dsRNA 2 segments	2,164; ON938188	RdRP (664); WEI52980	RNA-seq	N.D.	[40]
				1,760; ON938189	CP (317); WEI52981			
Beauveria bassiana negative-strand RNA virus 1 (BbNSV1)	GusB2	related to *Mymonaviridae*	ssRNA 1 segment	6,169; OR737625	RdRP (1,949); WPE03610	RNA-seq	N.D.	[99]
Beauveria bassiana orthocurvulavirus 1 (BbOCV1)	GusB2	related to *Curvulaviridae*	dsRNA 2 segments	2,164; OR737623	RdRP (664); WPE03609	RNA-seq	N.D.	[99]
				1,765; OR737624	CP (317); WPE03614			

N.D. = Not determined.

BbNV1 and BbPMV1 biological effects were determined in combination.

Table S3. Mycoviruses characterised in *Cordyceps* and their properties. The mycovirus name, the *Cordyceps* spp. strain from which each virus was isolated, taxonomic classification (family and genus), and genome type are provided. For each viral RNA segment, the size in base pairs or nucleotides (bp or nt) with respective GenBank accession number, the encoded protein length in amino acids (aa), as well as its putative function, are listed. Reported effects of the mycovirus on the fungal host phenotype are summarised, alongside the detection methods used.

Mycovirus	Strain/Isolate	Taxonomy	Genome type	Segment Size (bp or nt)	ORF product (aa)	Sequencing method	Effect on host phenotype	Reference
Isaria javanica chrysovirus 1 (IjCV1)*	NB IFR-19	*Chrysoviridae*	dsRNA 4 segments	3,593; KX898416	RdRP (1,117); APR73428	RNA-seq	N.D.	[26]
				3,175; KX898417	CP (974); APR73429			
				3,165; KX898418	Unknown (977); APR73430			
				2,874; KX898419	Put. Protease (843); APR73431			
Cordyceps chanhua alternavirus 1 (CcAV1)	RCEF6000	*Alternaviridae, Alternavirus*	dsRNA 3 segments	3,512; OK481552	RdRP (1127); UPH33984	RNA-seq	N.D.	[104]
				2,655; OK481553	HP1 (831); UPH33985			
				2,415; OK481554	HP2 (731); UPH33986			
Cordyceps chanhua partitivirus 1 (CchPV1)	RCEF5997	*Partitiviridae, Gammapartitivirus*	dsRNA 2 segments	1,784; OP727721	RdRP (540); WBW48344	RNA-seq	↓ Mycelial growth ↑ Conidiation ↑ Formation of fruiting bodies ↓ UV-B resistance ↓ Heat tolerance ↓ Salt tolerance ↓ Osmotic tolerance ↓ Antioxidant tolerance	[96]
				1,563; OP727722	CP (435); WBW48345			

Cordyceps militaris partitivirus 1 (CmPV1)	RCEF7506	*Partitiviridae, Betapartitivirus*	dsRNA 2 segments	2,206; PP155648	RdRP (670); WUV41264	RNA-seq	N.D.	[95]
				2,256; PP155647	CP (652); WUV41263			
Cordyceps javanica negative-strand RNA virus 1 (CjNRSV1)	NB7	*Phenuiviridae, Laulavirus*	dsRNA 3 segments	7,252; PP544309	RdRP (2,384); WYM67035	RNA-seq	N.D.	[113]
				2,401; PP544310	MP (692); WYM67036			
				1,117; PP544311	NC (254); WYM67037			

N.D. = Not determined

* Following recent reclassifications accommodating *Isaria* species to the *Cordyceps* genus (according to Kepler *et al*, 2017 [43]).

Table S4. Mycoviruses characterised in *Entomophthora* and their properties. The mycovirus name, the *Entomophthora* spp. strain from which each virus was isolated, taxonomic classification (family and genus), and genome type are provided. For each viral RNA segment, the size in base pairs or nucleotides (bp or nt) with respective GenBank accession number, the encoded protein length in amino acids (aa), as well as its putative function, are listed. Reported effects of the mycovirus on the fungal host phenotype are summarised, alongside the detection methods used.

Mycovirus	Strain/Isolate	Taxonomy	Genome type	Segment Size (bp or nt)	ORF product (aa)	Sequencing method	Effect on host phenotype	Reference
Entomophthora muscae mitovirus 1 (EnmuMV1)*	KVL-14-117	*Mitoviridae; Mitovirus*	(+)ssRNA 1 segments	2,804; MK682513.1	RdRP (757); QCF24445.1	RNA-seq	N.D.	[28]
Entomophthora muscae-Musca domestica iflavirus 1 (EmmdIV1)*	KVL21-40	*Iflaviridae; Iflavirus*	(+)ssRNA 1 segment	8,706; PQ468742	Polyprotein (2,901); XKQ11312.1	RNA-seq	N.D.	[117]
Entomophthora partitivirus D**	Won	*Partitiviridae; Partitivirus*	dsRNA 1 segment	2,106; MK231054.1	RdRP (555); QED42916.1	RNA-seq	N.D.	[77]
Entomophthora benyvirus E**	Cho	*Benyviridae; Benyvirus*	(+)ssRNA	6,325; MK231113.1	Put. RdRP (2,062); QED42962.1	RNA-seq	N.D.	[77]
Entomophthora rhabdovirus A**	Won	*Rhabdoviridae; Rhabdovirus*	(-)ssRNA 1 segment	6,934; MK231099.1	Put. RdRP (2,249); QED42948.1	RNA-seq	N.D.	[77]
Entomophthora narnavirus A**	Won	*Narnaviridae; Narnavirus*	(+)ssRNA 1 segment	2,838; MK940812.1	RdRP (914); QED43053.1	RNA-seq	N.D.	[77]
Entomophthora virgavirus A**	Won	*Virgaviridae; Virgavirus*	(+)ssRNA 1 segment	10,376; MK231110.1	Polyprotein (2,186); QED42956.1 HP (650); QED42957.1 HP (195); QED42958.1 HP (190); QED42959.1	RNA-seq	N.D.	[77]

N.D. = Not determined; Put. RdRP: Putative RdRP; *Complete CDS.; **Partial genome.

Table S5. Mycoviruses characterised in *Metarhizium* and their properties. The mycovirus name, the *Metarhizium* spp. strain from which each virus was isolated, taxonomic classification (family and genus), and genome type are provided. For each viral RNA segment, the size in base pairs or nucleotides (bp or nt) with respective GenBank accession number, the encoded protein length in amino acids (aa), as well as its putative function, are listed. Reported effects of the mycovirus on the fungal host phenotype are summarised, alongside the detection methods used.

Mycovirus	Strain/Isolate	Taxonomy	Genome type	Segment Size (bp or nt)	ORF product (aa)	Sequencing method	Effect on host phenotype	Reference
Metarhizium brunneum partitivirus 1 (MbPV1)	RCEF0736	*Partitiviridae*, "Epsilonpartitivirus"	dsRNA 2 segments	1,829; MN395473	RdRP (573); QHB49873	RNA-seq	N.D.	[29]
				1,720; MN395474	CP (496); QHB49874			
Metarhizium brunneum partitivirus 2 (MbPV2)	RCEF0736	*Partitiviridae*, *Gammapartitivirus*	dsRNA 2 segments	1,775; MT584790	RdRP (539); QTC11257	RNA-seq	N.D.	[97]
				4,568; MT584791	CP (430); QTC11258			
Metarhizium brunneum polymycovirus 1 (MbPmV1)	RCEF0736	*Polymycoviridae*; *Polymycovirus*	dsRNA 4 segments	2,421; OP524132	RdRP (767); WBL45227	RNA-seq	N.D.	[106]
				2,280; OP524133	Unknown (699); WBL45228			
				2,018; OP524134	MetT (615); WBL45229			
				1,153; OP524135	PASrp (180); WBL45230			
Metarhizium brunneum bipartite mycovirus 1 (MbBV1)	RCEF0766	Unassigned	dsRNA 2 segments	1,987; ON350778	RdRP (597); UPO93687	RNA-seq	N.D.	[169]
				1,642; ON350779	CP (308); UPO93688			
Metarhizium anisopliae	M5	*Totiviridae*, *Victorivirus*	dsRNA 1 segment	5,353; OP959068	CP (757); WCS16032	RNA-seq	N.D.	[81]

victorivirus 1 (MaVV1)					RdRP(839); WCS16033			
Metarhizium majus partitivirus 1 (MmPV1)	RCEF0578	*Partitiviridae, Gammapartitivirus*	dsRNA 2 segments	1,721; OL518956	RdRP (538); UPO93685	RNA-seq	↓ Conidiation ↓ Heat tolerance ↓ UV-B tolerance ↓ Virulence Changes in secondary metabolism	[140]
				1,407; OL518957	CP (415); UPO93686			
Metarhizium anisopliae polymycovirus 1 (MaPmV1)	RCEF3284	*Polymycoviridae, Polymycovirus*	dsRNA 4 segments	2,421; OP627094	RdRP (775); WGN91658	RNA-seq	↑ Mycelial growth ↑ Conidiation ↑ Expression of growth and conidiation-related genes ↓ UV-B tolerance	[107]
				2,259; OP627095	HP (704); WGN91659			
				1,917; OP627096	MetT (610); WGN91660			
				1,395; OP627097	PASrp (305); WGN91661			
Metarhizium flavoviride partitivirus 1 (MfPV1)	Mf_KF18	*Partitiviridae, Gammapartitivirus*	dsRNA 2 segments	1,775; MH143600	RdRP (538); AZU96334	RNA-seq	↑ Virulence ↑ Conidiation ↑ expression of virulence genes Changes in secondary metabolism	[141]
				1,575; MH143601	CP (440); AZU96335			
Metarhizium robertsii polymycovirus 1 (MrPmV1)	SDSET-20.42	*Polymycoviridae, Polymycovirus*	dsRNA 4 segments	2,342; PV166302	RdRP (758); XQD59753	RNA-seq	N.D.	[170]
				2,231; PV166303	Scaffold protein (716); XQD59754			
				1,885; PV166304	MetT (610); XQD59755			
				1,341; PV166305	PASrp (322); XQD59756			
Metarhizium acridum unirnavirus 1 (MaUV1)	CG423	*Amalgaviridae, Unirnavirus*	dsRNA 1 segment	2,907; PV797947.1	HP (317); XXJ30516.1	RNA-seq	N.D.	[84]
					RdRP (609); XXJ30517.1			

N.D. = Not determined.

Table S6. Mycoviruses characterized in *Trichoderma* and their properties. The mycovirus name, the *Trichoderma* spp. strain from which each virus was isolated, taxonomic classification (family and genus), and genome type are provided. For each viral RNA segment, the size in base pairs or nucleotides (bp or nt) with respective GenBank accession number, the encoded protein length in amino acids (aa), as well as its putative function, are listed. Reported effects of the mycovirus on the fungal host phenotype are summarised, alongside the detection methods used.

Mycovirus	Strain/Isolate	Taxonomy	Genome type	Segment Size (bp or nt)	ORF product (aa)	Sequencing method	Effect on host phenotype	Reference
Trichoderma atroviride mycovirus 1 (TaMV1)	NFCF028	*Fusagraviridae**	dsRNA; 1 segment	KX821737; 8,566	Put. Struct./gag (1,429); APU87539 RdRP (1,214); APU87540	Sanger	No changes	[27]
Trichoderma harzianum partitivirus 1 (ThPV1)	NFCF319	*Partitiviridae*, *Betapartitivirus*	dsRNA 2 segments	2,289; MG973751 2,245; MG973752	RdRP (722); AZL30773 CP (659); AZL30774	RNA-seq	↑ Enzyme activity ↑ Antagonistic activity	[94]
Trichoderma atroviride partitivirus 1 (TaPV1)	NFCF394	*Partitiviridae*, *Alphapartitivirus*	dsRNA 2 segments	2,023; MH921573 2,012; MH921574	RdRP (614); AYQ58321 CP (577); AYQ58322	RNA-seq	No changes	[98]
Trichoderma asperellum dsRNA Virus 1 (TaRV1)	JLM45-3	*Fusagraviridae**	dsRNA; 1 segment	9,838; MG897472	HP (1,502); AXR76116 RdRP (1,327); AXR76117	RNA-seq	N.D.	[171]
Trichoderma koningiopsis totivirus 1 (TkTV1)	Mg10	*Totiviridae*, *Totivirus*	dsRNA; 1 segment	4,712; MK993478	CP (687); QGA70770 RdRP (747); QGA70771	RNA-seq	N.D.	[82]
Trichoderma harzianum hypovirus 1 (ThHV1)	T-70*	*Hypoviridae*, *Betahypovirus*	(+)ssRNA 2 segments	11,214; MN172262	Polyprotein (443); QGA30968 Polyprotein (2,793); QGA30969	Sanger	↓ Mycelial growth ↓ Conidiation ↓ Mycoparasitic activity Changes in secondary metabolism	[116]

				9,816b; MN172263	Polyprotein (2,807); QGA30970			
Trichoderma harzianum mycovirus 1 (ThMV1)	HB40525	Unclassified	dsRNA; 1 segment	3,160; MH155602	RdRP (582); AYU71187 CP (379); AYU71188	RNA-seq	↑ Antagonistic activity ↓ Plant growth induction ↑ Biomass production	[85]
Trichoderma harzianum bipartite mycovirus 1 (ThBMV1)	137	Unclassified	dsRNA 2 segments	2,088; MH536648 1,634; MH536649	RdRP (631); AXU24203 HP (314); AXU24204	RNA-seq	N.D.	[172]
Trichoderma atroviride mycovirus 1 (TaMV1)	NFCF377	*Fusagraviridae**	dsRNA; 1 segment	9,584; MT450869	Struct./gag (1,429); QMU26426 RdRP (1,236); QMU26427	RNA-seq	↑ Antagonistic activity Changes in secondary metabolism	[90]
Trichoderma harzianum Partitivirus (ThPV2)	T673	*Partitiviridae*	dsRNA 2 segments	1,693; OL457022 1,458; OL457023	RdRP (524); UVB68789 CP (375); UVB68790	RNA-seq	↑ Antagonistic activity ↑ Conidiation and chlamydospore formation ↓ Plant growth induction	[144]
Trichoderma harzianum hypovirus 2 (ThHV2)	M6	*Hypoviridae, Alphahypovirus*	(+)ssRNA 1 segment	13,813; MW863664	Polyprotein (4,118); UDP60414	RNA-seq	N.D.	[173]
Trichoderma barbatum polymycovirus 1 (TbPMV1)	HB40111	*Polymycoviridae, Polymycovirus*	dsRNA 4 segments	2,420; OM307406 2,127; OM307407 1,909; OM307408	RdRP (766); WAA18813 HP (678); WAA18814 MetT (613); WAA18815	RNA-seq	N.D.	[108]

				1,041; OM307409	HP (260); WAA18816			

N.D. = Not determined

*Further studies were carried in *T. koningiopsis* T-51 strain and alterations in secondary metabolites production were observed [143].